ConAccount workshop
Ecologizing Societal Metabolism
Designing Scenarios for Sustainable Materials Management

November 21st 1998, Amsterdam, The Netherlands

René Kleijn
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CML report 148
Section Substances & Products

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Preface

ConAccount is the acronym for a concerted action entitled “Co-ordination of Regional and National Material Flow Accounting for Environmental Sustainability”. It started in May 1996 and was supported by the European Commission (DG XII) until December 1997. The established MFA-network will be sustained further.

ConAccount provides an international platform for information exchange on Material Flow Accounting (MFA). MFA refers to accounts in physical units (usually in terms of tons) comprising the extraction, production, transformation, consumption, recycling, and disposal of materials (e.g. substances, raw materials, base materials, products, manufactures, wastes, emissions to air or water). According to different subjects and various methods, MFA –and thus ConAccount – covers approaches such as substance flow analysis, product flow accounts, material balancing, and bulk material flow accounts. However ConAccount is generally restricted to studies of (supra)-national and regional scope. MFA projects for products and services (within Life Cycle Assessment (LCA) approaches) are not addressed in particular, although methodological overlaps have been discussed.

One of the activities of the Steering Committee of ConAccount is to organise yearly meetings for researchers/policy makers working on/with MFA. This volume documents the presentations of the first ConAccount meeting after the end of the concerted action. This workshop was organised by the Centre of Environmental Science of Leiden University and took place on November 21st at the *Vrije Universiteit* in Amsterdam.

The main topics of the workshop were:

1) dematerialization
2) problemshifting
3) monitoring
4) coupling MFA and societal developments
5) integral policy for materials management
6) combined economic and environmental accounting

During the workshop the presentations were organised in nine parallel sessions on the basis of the topics above. In this Volume the papers are organised on the basis of the six topics.

We would like to thank all participants of the workshop for their interest and their contributions.

The ConAccount Steering Committee:
Stefan Bringezu
Marina Fischer-Kowalski
René Kleijn
Viveka Palm

Plenary Lectures

Material Flow Analyses Supporting Technological Change and Integrated Resource Management

Stefan Bringezu

Wuppertal Institute, Wuppertal, Germany

Abstract
Recent developments are reported on the international consideration of MFA based policy targets. Empirical data on the change of energy carrier productivity in the German Ruhr district indicate that the targets set out in the German Draft Environmental Policy Programme are not unrealistic. Technological change depends on the proper consideration of alternatives. For the example of sewage sludge it is exemplified that the assessment of recycling routes critically depends on the scope of the analysis. Aspects of integrated resource management are discussed considering nitrogen fluxes to German rivers, the cleaning efficiency of municipal sewage treatment plants, the material intensity of waste water treatment and fresh water supply systems.

Policy and MFA: Recent Developments
As a result of a national debate on sustainability the German environmental ministry has drafted an Environmental Policy Plan which focuses on priority issues, defines a core set of indicators and describes targets and measures to overcome these problems (BMU 1998). The Draft comprises the following targets:

- Energy Productivity: increase by a factor 2 (1993 - 2020)
- Renewable Energy: increase to 25 % until 2030
- Raw Materials Productivity: increase by a factor 2.5
- Recycling of waste: increase to 40 % until 2010

The increase of resource productivity as a political aim has meanwhile caught wide attention under the heading of eco-efficiency. The factor 4-10 target has been adopted by the United Nations General Assembly Special Session in New York (UNGASS 1997). The UNCSD (1998) has proposed a set of indicators for sustainable production and consumption patterns which comprises the material flow based TMR indicator (Bringezu 1998). The OECD (1996) and other key economic players such as WBCSD (1998) have taken up the task to guide the increase of eco-efficiency, including resource efficiency. The factor 4-10 target has been adopted e.g. in the Austrian National Policy Plan (NUP 1995), by the Ecocyle Commission of the Swedish Government (1997), and by Finnish interagency activities (Ministry of Trade and Industry 1998).

One may expect the need for systems-wide MFA will increase in the further process of the operationalization and the measuring of eco-efficiency.

Technological Change in Practice
The above mentioned challenging targets provoke the question whether they are realistic and such a significant technological change may occur within the time frame envisaged. We studied the structural change in the old-industrialised region of the Ruhr. Analysing the sector aggregate of the mining and manufacturing industry its turnover was divided by the energy carrier consumption to indicate the energy carrier productivity (FIGURE 1).

From 1990 to 1996 this productivity increased on the average of all cities and districts by 11 % (including ecological rucksacks) or 8 % (excluding ecological rucksacks), resp.. In some communities the industry increased the resource productivity of energy by a factor of 1.8 to 2.8 within six years. This indicates that a technological change may occur rather quickly. In other cities the energy carrier productivity remained rather low, or even decreased, revealing a high variation between locations. Having in mind that this aspect of structural change did occur without special policy measures, one may conclude that the above mentioned political targets are not unrealistic, if policy measures are taken to increase resource productivity in the whole country.

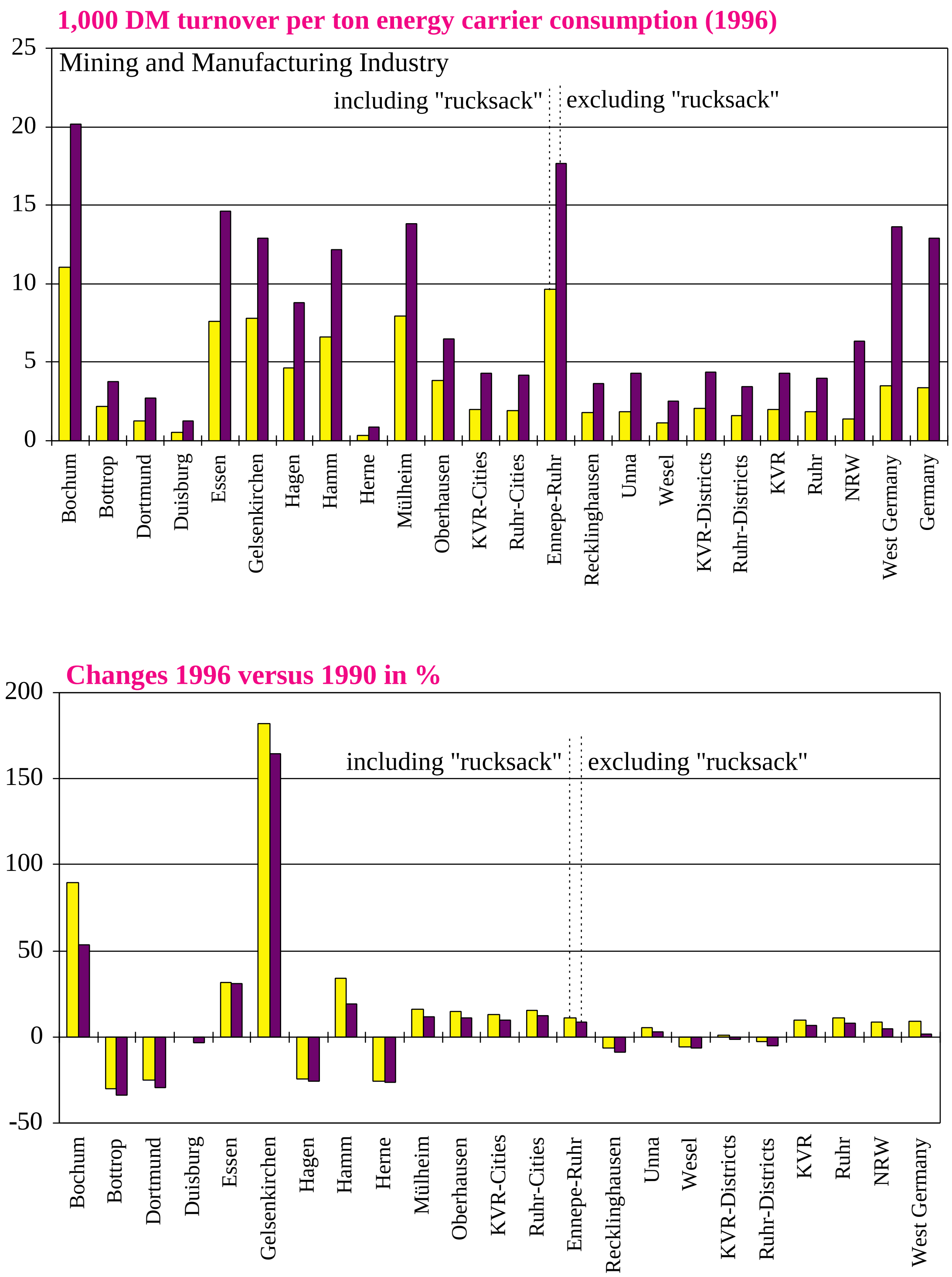


Figure 1: Monitoring aspects of technological change in the Ruhr area. See text.

MFA support: short-comings and „long-comings“

In order to support technological change towards sustainability, MFA based analyses can be used to assess different routes of processing, especially of recycling. Different options of recycling were studied for sewage sludge from municipal sewage treatment (Reckerzügl et al. 1999). Starting point was the question whether the sludge from a major treatment plant in Düsseldorf should be burned in a coal fired power plant (status quo) or used in agriculture. The main criterion for the assessment was the minimisation of carbon dioxide emission from fossil origin, because local administration was interested to contribute to climate protection.

A first comparison of the two alternatives indicates that the CO_2 emission is lower for the recycling in agriculture (mainly due to transport) than for the incineration (mainly due to the fossil energy consumption of the drying process) (FIGURE 2: top box).

But at second sight, it has to be considered that the burning of sewage sludge in the existing power plant substitutes the use of hard coal. Usually this is dealt with by accounting for a bonus (substracting the substituted emission). However, in order to evaluate both alternatives properly a bonus for one substitution is not sufficient because two substitutions have to be considered: (1) if the sewage sludge is used in agriculture for the production of biomass, the electricity of the power plant will have to be supplied from another energy carrier; (2) if the sewage sludge is burnt for electricity production, the nutrients for agriculture will be supplied by other means, usually mineral fertiliser (FIGURE 2: middle box). The result then clearly indicates that the co-burning of sewage sludge in a coal-fired power plant is associated with less CO_2 emission than the recycling to agriculture and contributes to climate protection.

However, at a third sight, the perspective has to be widened again, and the scope of the analysis should be extended further (FIGURE 2: bottom box). The special situation of the single power plant can be compared with the average situation in order to generalise the result. As the German electricity mix depends on coal to a large extent, the main conclusion for the time being remains valid. However, the current situation will probably change towards more sustainable ways of electricity supply. If, for instance, electricity is supplied from wind converters, this will be associated with much less CO_2 emission. In that case, the result of the analysis would again turn to the opposite.

The message for the decision-maker is therefore that the burning of sewage sludge in coal fired power plants may only be an interim solution. Otherwise an unsustainable use of fossil fuels would have the consequence to perpetuate an unsustainable use of nutrients (in sewage sludge) and non-renewable minerals (mineral fertiliser).

The message for the analyst of material flows is that alternatives of recycling always involve at least two different services to be fulfilled (in this case the production of biomass and the supply of electricity) (FIGURE 3). Both services and the associated routes have to be considered and evaluated according to the criteria which result from the target questions. At this point, the analysis is similar to a LCA approach. Thus, shortcomings could be overcome by widening the systems perspective and outlining a longer time horizon.

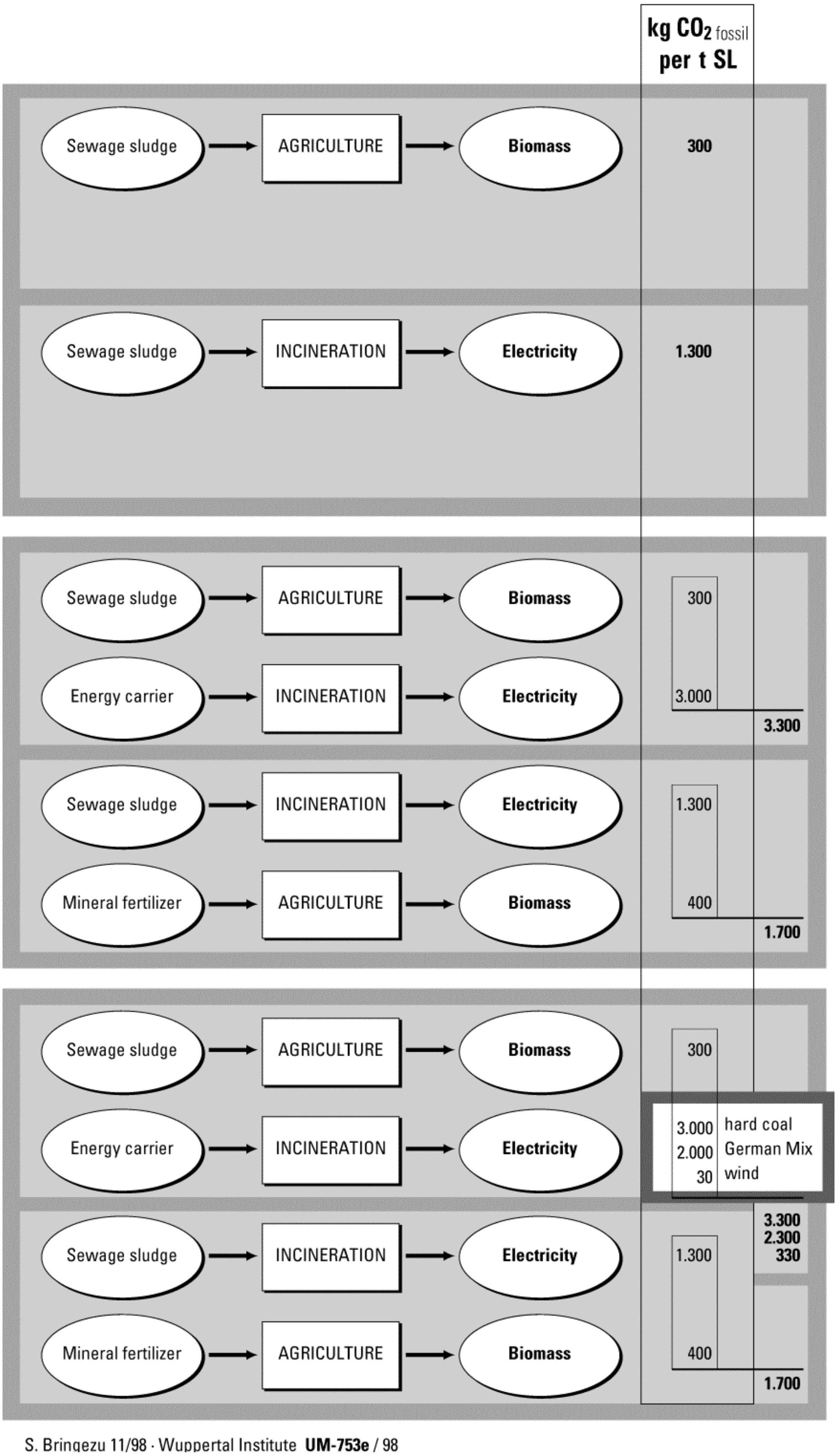


Figure 2: Fossil CO_2 emissions associated with different recycling routes of sewage sludge. Rounded values (source: Reckerzügl et al. 1999). See text.

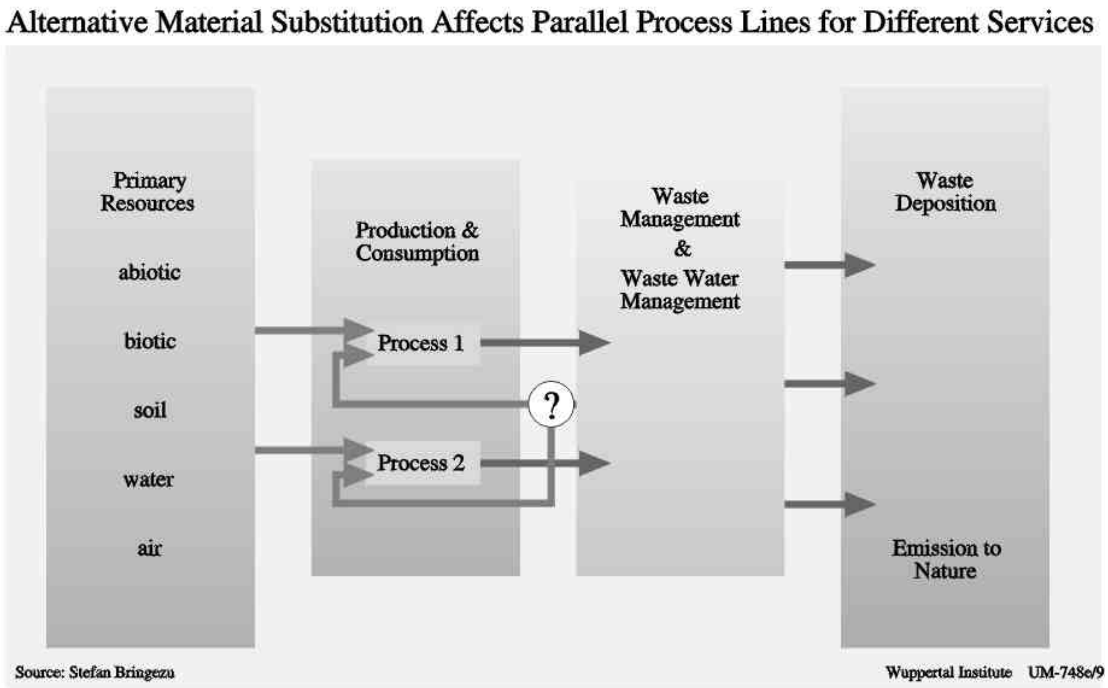


Figure 3: The analysis of recycling alternatives must consider all process combinations and services affected. See text.

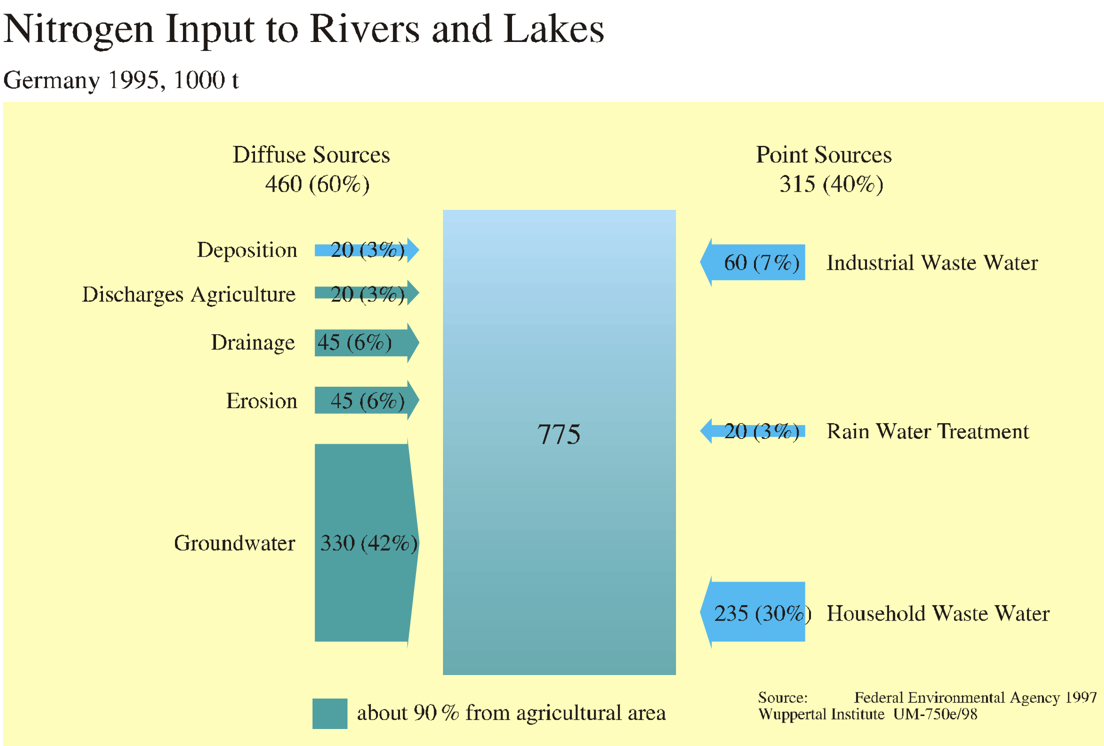


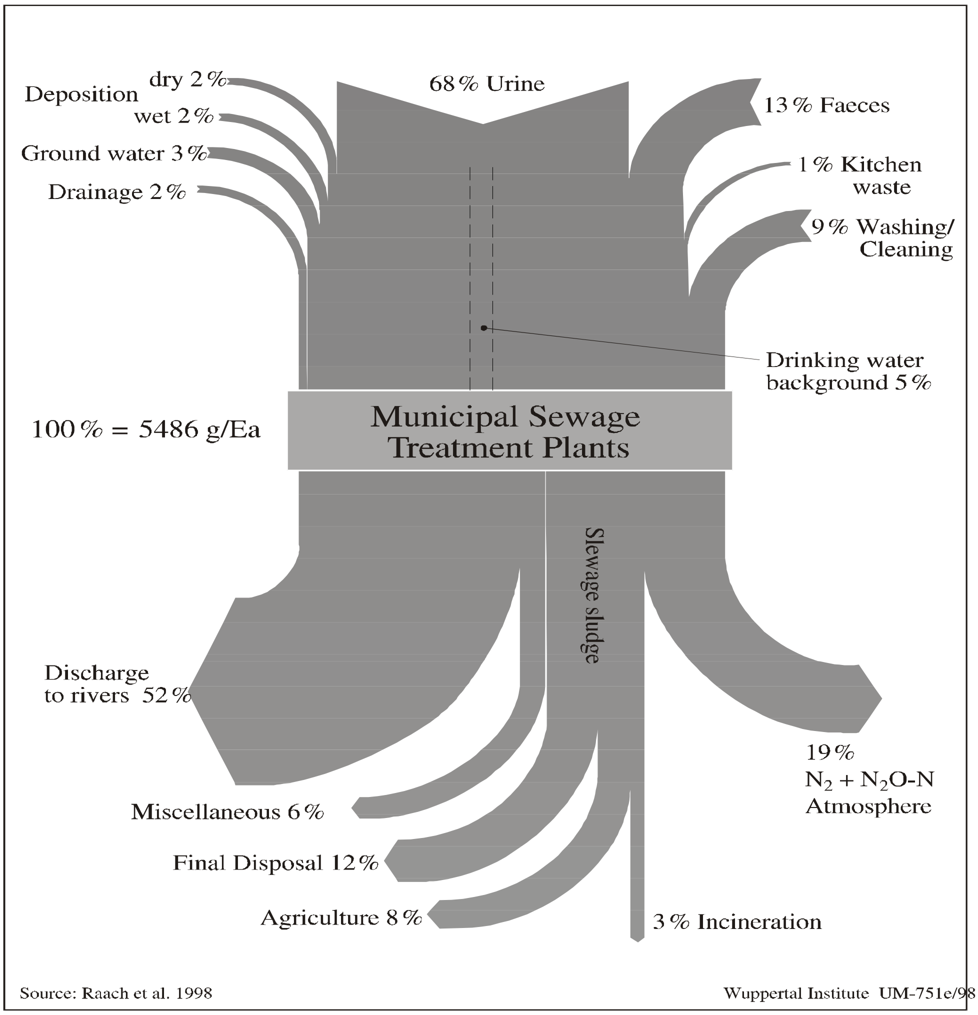
Figure 4: Major loads come from agriculture and households (Federal Environmental Agency 1997). See text.

Aspects of Integrated Resource Management

Progress towards sustainability will depend on the reduction of resource input on the one hand and the further reduction of pollutant output on the other hand. Material flows through the anthroposphere connect both of these ends, but the flows are handled by different actors and cross several sectors. For instance, mineral fertiliser may stem from mining and go to transport, agriculture, food industry, super markets, households, sewage treatment plants, in order to end up in rivers and finally the sea. On this way they are part of different products and their flow is intermingled with other flows of substances, bulk materials and water. Sustainable materials management will involve the different actors in an integrated manner. And before management, the analyst should consider the different processes and problems in a comprehensive way. In concrete terms, the substance flow related pollution problems should be reduced while at the same time the use of natural resources should be minimised.

In Germany the losses of nitrogen through agricultural sites and household waste water contribute significantly to the eutrophication of rivers and lakes and the increase of nitrogen in the North Sea and Baltic Sea (FIGURE 4). Several measures are ongoing to reduce the load from agriculture (BMU 1998). It is interesting to see that the release from households ranks second despite of the fact that most of them are connected to sewage treatment plants. The result becomes more obvious when looking closer to the inputs and outputs of those plants (Raach et al. 1999). In effect, the efficiency of water cleaning in municipal sewage treatment plants is rather low for a variety of different substances. In the period from 1990 to 1995, for instance, on the average about half of the nitrogen entering the plant leave it towards the river (FIGURE 5). Even with state of the art technology it will be still 25%.

Flow of Nitrogen through Municipal Sewage Treatment Plants
Germany 1990–95



%.

Figure 5: Municipal sewage treatment plants have a low water cleaning efficiency for nitrogen (Raach et al. 1999).

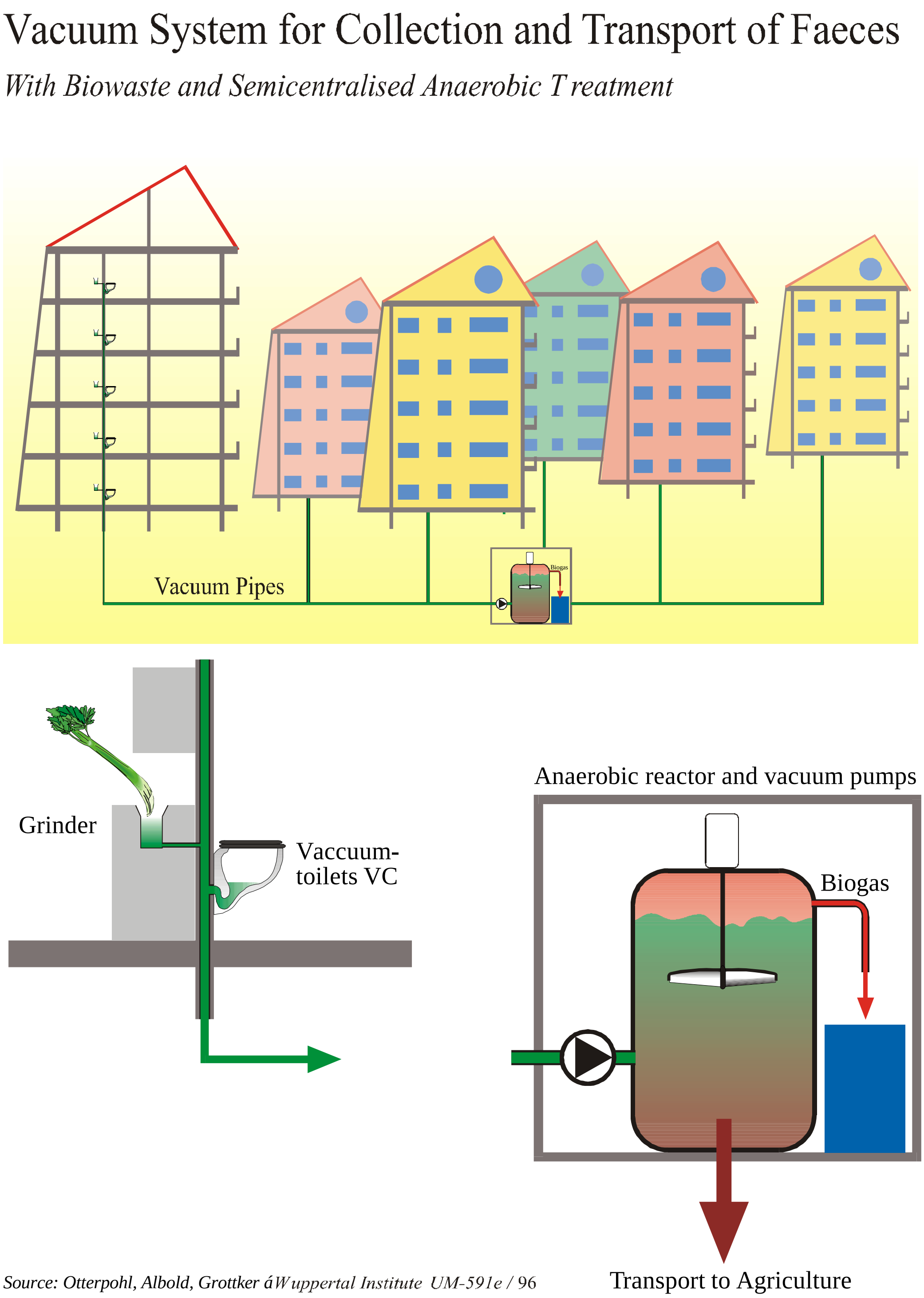


Figure 6: Scheme of the separate collection of faeces and urine („black water") with semi-centralised fermentation (See Otterpohl 1998)

This rather poor cleaning efficiency is associated not only with a significant input of financial and natural resources (energy and materials). The high losses of nitrogen are part of a linear throughput system that starts in chemical industry or mining for the production of mineral fertiliser and ends up in natural waters. How to generate a more cyclic situation with less losses to the environment? Alternative technologies do already exist. More than 80 % of the nitrogen delivered to sewage treatment plants stem from human urine and faeces (FIGURE 5). For phosphorus it is about 70 %. Instead of diluting these major nutrients with drinking water, they can be collected and recycled separately.

One option is semi-centralised systems where faeces are collected by vacuum pipes and treated in anearobic reactors together with biomass waste (FIGURE 6). Biogas can be produced to contribute to electricity supply. The nutrients can be transported to agriculture. The grey water from washing etc. may be treated in constructed wetlands, and the storm water may be drained locally.

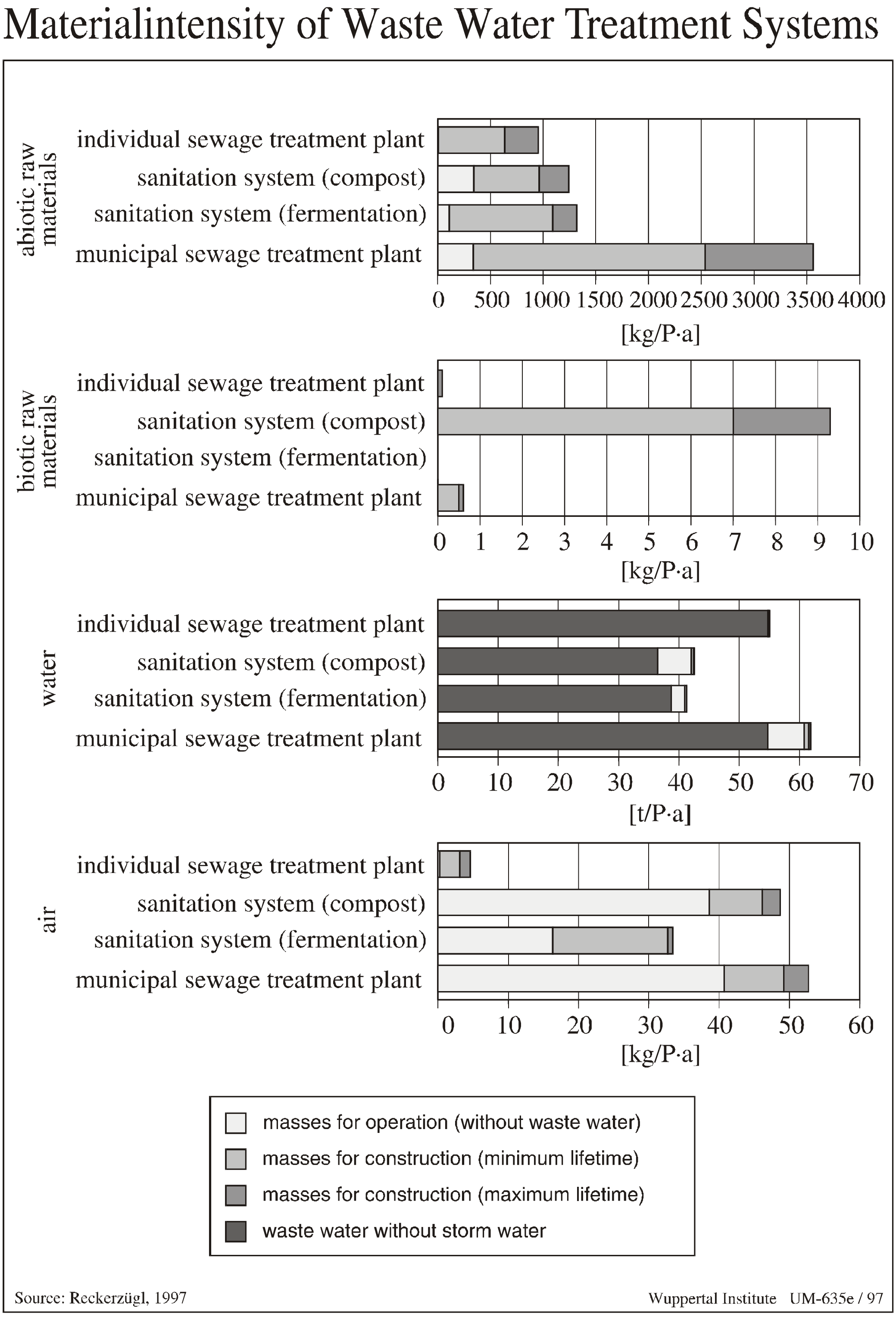
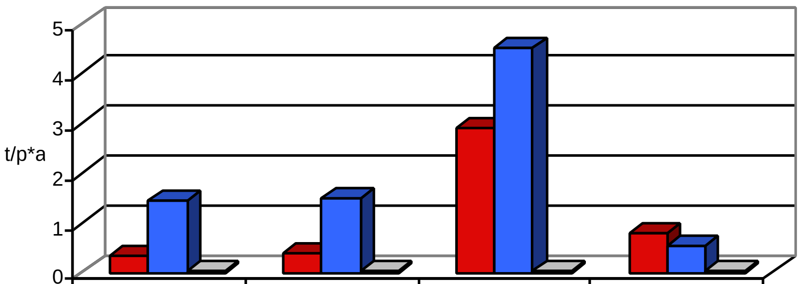


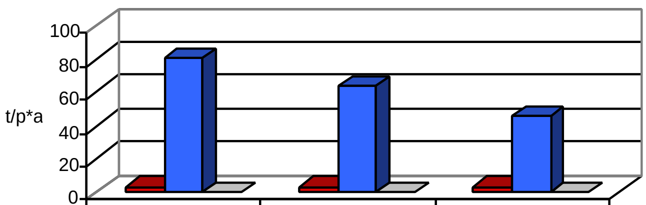
Figure 7: Life-cycle wide analysis of resource input flows (see Reckerzügl and Bringezu 1998)

MIPS of water supply and sewage treatment



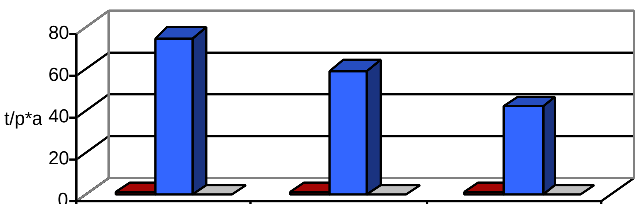
	use of rain water	drinking water supply	communal sewage treatment plant	small sewage treatment plant
abiot.	0,317	0,379	2,912	0,796
water	1,443	1,489	4,510	0,519
air	0,016	0,027	0,034	0,004

MIPS of water supply and sewage treatment
(communal sewage treatment plant)
including drinking water and drainage water



	conventional household	water efficient household	water efficient household, use of rain water
abiot.	3,509	3,410	3,608
water	80,469	64,110	45,922
air	0,088	0,076	0,077

MIPS of water supply and sewage treatment
(small sewage treatment plant)
including drinking water and drainage water



	conventional household	water efficient household	water saving household, use of rain water
abiot.	1,308	1,247	1,492
water	74,955	59,288	41,931
air	0,048	0,040	0,046

Figure 8: Material Intensity of different combinations of fresh water supply and waste water treatment in tons per person and year (Boermans-Schwarz 1998).

A life-cycle wide analysis revealed that the construction and use of such kind of alternative semi-centralised treatment systems may be associated with a lower material intensity and less CO_2 emissions[1] than the central municipal system (FIGURE 7: fermentation system). In addition, available data indicated that also the costs for those alternatives are lower or at least not higher than those for the usual+. municipal system (For detailed description of the analysed systems see Reckerzügl and Bringezu 1998).

Not only the waste water treatment but also the supply of fresh water is associated with resource requirements. In order to reduce drinking water consumption, rain water may be used for certain processes. However, based on life-cycle-wide analyses the efficient use of water through water spare technology within the households may be more effective for the reduction of abiotic (non-regrowing) resource inputs and CO_2 emissions[1] than the construction and use of rain water use facilities (FIGURE 8). However, the additional amount of abiotic inputs and CO_2 emissions may be tolerated in regions with water shortage because rain water use may reduce drinking water consumption significantly.

The message for the decision maker is that, for the planning of new settlements and the successive restoration of existing settlements, alternatives to traditional infrastructure systems do exist and should be considered which are associated with less financial and environmental burden through pollution and resource use. This relates to urban systems in middle Europe, but also to southern and eastern Europe as well as developing countries where infrastructure is going to be built.

The message for the analyst of material flows is that it is possible to combine a pollution reduction perspective with a resource minimisation strategy. The systems analysis approach allows not only to localise the predominant losses of substances to the environment but also to account for the bulk material flows that are associated with their control in order to minimise resource requirements (FIGURE 9). Thus, a major task for MFA is the provision of actor oriented information which reflect the interlinkage of different processes in order to facilitate an integrated resource management[2].

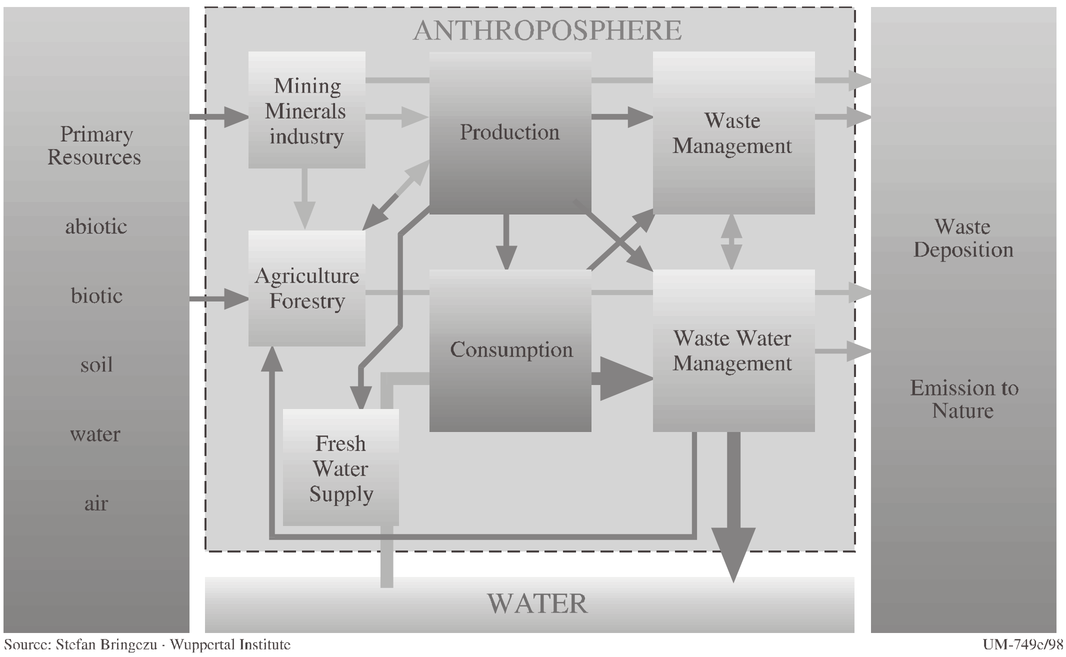


Figure 9: Based on a systems perspective can account for losses of the anthroposphere processes to the environment as well as for resource inputs required for the construction and maintenance of these processes.

[1] the input of air in the material intensity analysis corresponds to the output of CO_2

[2] which has been discussed here especially in terms of natural resources (on the input and output side), but in the end comprises also financial and social resources

Conclusions

- The implementation of sustainable materials management depends on policy goals. The rising number of targets for eco-efficiency on the national and international level will probably increase the need for MFA.

- Material flows and resource productivity should be monitored not only on the national level but also on the sectoral, regional and community level.

- The assessment of recycling routes demands for the comprehensive analysis of all major product lines affected through substitution. The results critically depend on the time horizon and scenarios for technological development.

- A system-oriented MFA is a pre-requisite for an integrated resource management. The combined analysis of pollutant flows and resource flows (materials, energy, water) can contribute to the further planning of infrastructures.

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Ecologizing Societal Metabolism in the US
Materials Flow Accounting and Industrial Ecology

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The tracking of the flow of materials and products through society and the environment is an activity of increasing prominence and consequence throughout the world. The pursuit of materials flow accounting (MFA)[1] has taken on somewhat different forms, emphases and especially institutional contexts internationally, with European activities generally more advanced than those in the US and Canada and the rest of the world. In North America, and especially in the US, MFA is embedded in the emerging field of industrial ecology. ConAccount's call to "ecologize societal metabolism" provides an opportunity to explain North American approaches to the global MFA community and to discuss trends in industrial ecology and their implications for MFA research.

First we must ask, however, what it means to "ecologize societal metabolism." If by societal metabolism, we mean "the whole of the materials and energy flows going through the industrial [and subsistence socio-economic] system[s]" (Fischer Kowalski and Hüttler 1999), then to ecologize could mean a variety of things:

- recognition by a variety of actors in society that choices in production and consumption have important environmental consequences, or
- a formal, and perhaps methodological, integration of environmental science with MFA.

The first interpretation does not require MFA, or even scholarly research, but clearly MFA clarifies and reinforces the appreciation of the environmental consequences of the flows of materials mobilised by production and consumption. The second interpretation points to important tensions in the MFA community about proper focus and boundaries of research.

Industrial Ecology

In the US, MFA is viewed as a component of the emerging, broader field of industrial ecology. Robert White as president of the US National Academy of Engineering, one of the institutional proponents of IE, defined it as

> …the study of the flows of materials and energy in industrial and consumer activities, of the effects of these flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use, and transformation of resources (White 1994).

The name industrial ecology is intended to be metaphorical—and hopefully evocative— in several ways. Industrial ecology is *industrial* in that it focuses on product design and manufacturing processes. It views firms as agents for environmental improvement because they are the locus of technological expertise which is critical to the successful execution of green design of products and processes. Industry, as the portion of society that produces goods and services, is an important but not exclusive source of environmental damages.

Industrial ecology is *ecological* in at least two senses. First, the field looks to non-human "natural" ecosystems for models for industrial ecology. This is what some have dubbed the "biological analogy" (Wernick and Ausubel 1997). Second, industrial ecology places human technological activity—industry in the widest sense—in the context of the larger ecosystems that support it, examining the sources of resources used in society and the sinks that may

[1] MFA is the investigation of the physical flows of materials, typically on a geographic basis. It includes (1) the accounting of bulk materials such as plastics, concrete or fibers, (2) groups of related substances such as chlorinated hydrocarbons or (3) individual elements such as cadmium or lead. The latter two types of analysis are typically labelled substance flow analysis (SFA) (Udo de Haes, van der Voet and Kleijn 1997).

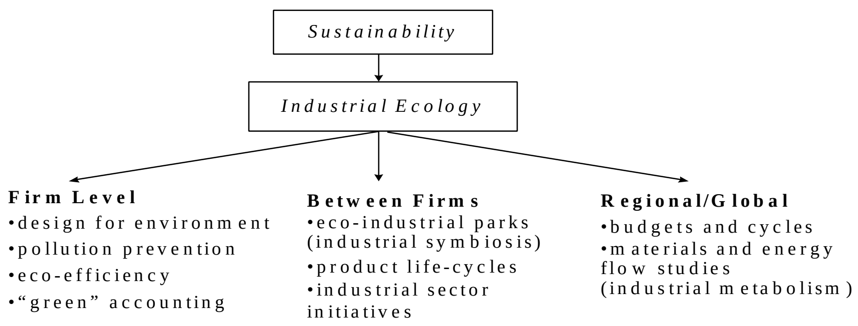
assimilate wastes. In this sense, industrial ecology explores questions that are sometimes framed in other fields in terms of carrying capacity.

Systems ecology has been the primary basis of the biological analogy to date. Systems ecology focuses on flows of energy, nutrients or pollutants and examines the critical processes determining the efficiency of energy transfers and productivity of material outputs. The components of the system are primarily of interest as processors of those flows (Levine 1999). Many (biological) ecosystems are seen as especially effective at recycling resources and thus are held out as exemplars for loop closing in industry (Graedel 1993, 1996). The most conspicuous example of industrial re-use and cycling of resources is the widely discussed industrial district in Kalundborg, Denmark. The district has a dense web of exchanges that include fuel gas, cooling and waste utility water, steam, waste heat, and scrubber and fermentation sludge. The network of exchanges has been dubbed "industrial symbiosis" as an explicit analogy to the mutually beneficial relationships found in nature and labelled as symbiotic by biologists (Ehrenfeld and Gertler 1997).

Because of the name chosen for this field, the biological analogy is perhaps industrial ecology's most conspicuous feature, but it is by no means the most important. Industrial ecology makes a self-conscious effort to take a comprehensive, systems view of environmental problems, seeking to avoid the kind of partial analyses that lead to mischaracterization of environmental and social phenomena. This effort to avoid the trap of partial analysis inclines the field toward analyses that are global in space and time. It also provides pressure for interdisciplinary approaches.

Typically, there are two bases for the systems-based work in industrial ecology: life cycle-oriented analyses and materials flow accounting. The life cycle-oriented analyses can take the form of formal life cycle assessments (LCAs), but just as often employ other methodologies but are informed by a life cycle perspective. MFA provides another basis for efforts at comprehensive analysis—and the obvious and important link to ConAccount. This is why industrial ecology has been described as having a resolute attention to materials flows. The effects of that kind of attention are "subversive" because industrial ecology "treats with indifference both what is easy to regulate and what is hard to regulate." (Socolow 1994, 12).

Industrial ecology embraces and builds on many antecedent concepts and tools in the environment field including design for environment (DfE), pollution prevention (P2, also known as cleaner production or CP), LCA, dematerialization and decarbonization, extended producer responsibility (EPR), product-oriented environmental policy and net energy analysis. These elements can be organised by thinking of the field as operating at several scales. At the micro-level, industrial ecology pays attention to unit processes, facility operations and to firm behaviour and organisation. At the meso level, it examines industrial symbiosis, municipal or regional materials flows and industry sectors. At the macro level, the field focuses on the grand cycles of nutrients (carbon, nitrogen, sulphur and phosphorus), international resource flows, national resource flows and flows within larger regions such as river basins. Figure 1 depicts this set of relationships.



From this capsule summary, it can be seen that industrial ecology includes materials flow accounting of the sort that is at the core of ConAccount's activities, but also include topics and tools that European and Asian researchers may group separately from MFA. To date, industrial ecology has relied more on LCA and life-cycle related analyses than on MFA in its attempts to take a systems view of environmental matters. This is more historical accident than theoretical or methodological preference.

CONNECTING INDUSTRIAL ECOLOGY AND ENVIRONMENTAL SCIENCE

As with any emerging field, industrial ecology struggles with questions of boundaries and focus. Recently, prominent members of the US industrial ecology community have called for a tighter connection between industrial ecology and environmental science (Socolow and Thomas 1997, Graedel 1997). There is tension between emphasising the analysis of materials flows with less attention to detailed considerations of risk—on the view that the variability in risk encountered is not significant in terms of the materials flows studied or on the view that risk is extensively studied in the established environmental community but materials flows are not— and an approach that relies more heavily on precise calculations of fate, transport, hazard or related matters. The way in which this tension has played out in industrial ecology is instructive and will be reviewed through the description of two examples.

Lead Acid Batteries and Electric Vehicles

In 1995, Lester Lave and colleagues from Carnegie Mellon University (CMU) published a controversial study in the prominent journal *Science* (Lave et al. 1995) in which they cast doubts on the environmental value of electric vehicles (EVs) by highlighting the amount of lead released into the environment because of increased use of lead-acid batteries. They argued that the total amount of lead discharged into the environment from all phases of the battery life cycle exceeded the amount that would be released if a comparable conventional (internal combustion engine) vehicle were to rely on leaded gasoline.[2] The lead releases arising from EVs came not from tailpipe emissions (as with leaded gasoline), but from the mining and smelting of lead and the manufacture and recycling of batteries.

This is characteristic of an industrial ecological perspective.[3] It looks at the life-cycle wide releases attributable to a product, not merely the releases in a specific life-cycle stage. The CMU analysis generated lively controversy (Letters 1995). It also generated a response from within the industrial ecology community that relied on notions at the core of industrial ecology—but not the same ones as those used by the CMU group.

Socolow and Thomas, researchers at Princeton University, responded to the CMU analysis by arguing that (1) it was oversimplified as a technology assessment, (2) as a risk assessment it was misleading and (3) it was incomplete as a guide to industry initiative and public policy (Socolow and Thomas 1997). The first and third criticisms revolved around how to forecast the evolution of technology and disputes over the role of government intervention in the economy to stimulate technological innovation. This tension between the CMU and Princeton researchers over the best approach to technological innovation reflects industrial ecology's fundamental interest in the potential for protecting the environment through technological innovation.[4] While both groups of researchers saw an important role for technological innovation in reducing the environmental impacts of automobile uses, the Princeton group was more sanguine about the potential for stimulating such innovation through public policy.

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[2] These claims were provocative for several reasons. First, the phase out of leaded gasoline in the United States is considered to be a very important improvement for public health and an environmental policy whose benefits substantially and unambiguously outweigh its costs (see Landy 1994). Second, to proponents of EVs, publication of a critical article in a prestigious journal such as *Science* was seen to be especially damaging at a time when the political fate of EV-related policies was in limbo. And finally, the findings of the CMU research team were publicised in a front-page story in the *New York Times* (Passell 1995), an event of political import in-and-of-itself.

[3] This is not surprising. Lave and his colleagues are leaders in industrial ecology. Indicative of this is the fact that they received an industrial ecology faculty fellowship from the Lucent Technologies Foundation (then the AT&T Foundation).

[4] See, for example, a recent collection of articles (Ausubel and Langford 1997) or the extended discussion of the "master equation" in the leading textbook in the field (Graedel and Allenby 1995, 5-8).

The Princeton researchers also emphasised the importance of disaggregating the lead discharges into those that are more problematic and those that are less so. They combined the concept of dissipative uses of materials—a concept that is characteristic, even emblematic of industrial ecology—with well known concepts from risk assessment of fate, exposure and dose-response. Dissipative uses of materials are those which result in a dispersion of the material throughout the environment so that recovery is technologically or economically infeasible. Airborne releases of lead from the combustion of leaded gasoline are a clear example of a dissipative materials use. Not only is such lead not recoverable, but it poses a well documented public health threat. In contrast, the potential for exposure of vulnerable populations to other releases of lead such as those in slag are more limited because the lead is more difficult to mobilise and less bioavailable. Further, such lead is, if not currently recoverable, at least hypothetically so.

The point is not to judge which point of view about lead-acid batteries and EVs is correct or more indicative of industrial ecology. Rather, the point is that concepts identified as indicative of industrial ecology—materials flow accounting, technological innovation, and dissipative uses of materials—enriched the discussion of the environmental character of EVs. The debate has also altered the policy and research agenda. Socolow and Thomas argued in their analysis that the absence of threat in some parts of the life cycle of lead-acid batteries should not blind society to those areas where important threats remain (i.e., occupational exposure, community exposure to releases from secondary smelters and export of batteries to processing with substandard controls facilities in developing countries). This has pressured the lead and battery industries to attend to these issues because they seek to counter the unwelcome criticism of a potentially large market for their products. In the research community, this debate has catalysed more detailed analysis of the parameters of clean recycling of a hazardous substance (Karlsson 1999).

Using Industrial Ecology to Clean Up the New York Harbor

The New York-New Jersey Harbor and its watersheds are an important mainstay of commerce and transportation in the eastern United States. To maintain the commercial viability of the harbor, shipping lanes must be dredged. The sediments, known as dredge spoils, require disposal or re-use. Because the sediments are contaminated and because U.S. regulations recently prohibited ocean dumping of the dredge spoils, disposal is a complicated and expensive problem.

Reducing the flow of contaminants to the Harbor can improve the prospects for management of the dredge spoils. It can also increase the opportunities for consumption of fish and shellfish and benefit the estuarine ecosystems in the watershed. As one official long involved in the Harbor's clean-up noted: "…reducing the human-dominated flow of toxicants to below levels which cause environmental or economic impacts…requires reliable quantification of these flows, particularly at locations in their cycles which can be influenced." (O'Connor 1998, 8).

Materials flow accounting has the potential to increase our knowledge of the sources of contamination in a variety of timeframes. Documentation of the *contemporary* flows of materials in the economy can reveal the source of some toxicants reaching the Harbor. A historical model holds out the possibility of also identifying stocks of materials from previous economic activities that may be the reservoirs from which contaminants are current leaching. Similarly, the contemporary creation of potentially problematic stocks may lead to *future* flows of contaminants. MFA can help us understand how changes in land use, industrialisation, consumption and population affect the cycles of chemicals of concern in this watershed. It provides a means of taking a comprehensive rather than an ad hoc view of the drivers and source of the toxic substances (Lifset 1999).

The use of industrial ecology to improve the environmental condition of the New York Harbor builds on important prior research efforts. The study of the heavy metal flows in the Rhine River Basin by researchers at the International Institute for Applied Systems Analysis is an important precedent and source of lessons for this effort (Stigliani and Anderberg 1994). The efforts to bring a historical perspective to investigations of sources of pollution of New York

Harbor build on pioneering research in the 1980s by Robert Ayres and colleagues on the reconstruction of flows in the Hudson-Raritan Basin (Ayres et al. 1985).

The use of MFA in the clean-up of the New York Harbor is of interest not only because of its practical implications. It is suggests a linking of industrial ecology with hydrology and environmental chemistry—ecologizing the field through the coupling of MFA with existing bodies of environmental expertise. This effort also represents an interesting test of the efficacy of MFA: can it provide leverage over an important and difficult problem where other approaches have failed?

Other Efforts to Ecologize MFA

The American effort to link industrial ecology more tightly to environmental science is neither isolated nor without precedent. To take but one example, the Metals Programme sponsored by the Dutch government formally integrates economic, MFA and environmental fate modelling.[5] The strength of the American impulse to link industrial ecology tightly to environmental science probably reflects the institutional and cultural emphasis in the U.S. on risk assessment and science-based environmental policy. Whether that emphasis represents the future of environmental policymaking internationally is difficult to predict.

Just as MFA does not exhaust the extent of industrial ecology, neither is the coupling of the study of materials or product flows with environmental science the only notable trend in the field. There are, for example, innumerable efforts to ecologize in the first and more practical sense described at the beginning of this paper: there is much effort to create tools and metrics for managers, engineers, designers and policymakers that can help them in decisionmaking without consuming all their time and money or forcing them to become environmental experts (Goedkoop 1997, NAE 1999).

Other trends are more subtle. There is an increasing use of decision analytical tools to bring rigor to industrial ecological concerns. Several examples are notable. Chang and Allen (1997) model the use of chlorinated substances in chemical manufacturing using linear programs (LPs) well known to chemical engineers for use in optimising production. The authors add an additional objective to the LPs, the reduction of chlorine use, and calculate the impact on the cost to the industry of maintaining output while reducing throughput of substances argued by some to be environmentally problematic. This analysis takes a sector level perspective and combines materials flow accounting with mathematical models well known to industry. This approach allows analytical discussion of costs in a debate known for its polarisation.

Allen and Keckler (1999) use linear programming to examine how wastewater might be re-used in industrial parks through blending and careful attention to varying quality requirements by different users. Here the cost advantages and impacts on quality of inputs from cycling of resources are assessed mathematically in the context of industrial ecology's ecological emblem—the eco-industrial park. Carnahan and Thurston (1998) use decision analysis at the facility level to integrate process design for the environment and concurrent engineering. Statistical manufacturing process control combined with multi-objective optimisation provides a mathematical characterisation of tradeoffs among environmental goals and between those goals and cost. These examples represent a maturing of industrial ecology beyond the "checklist" types of characterisation of environmental impacts to the use of sophisticated tools from the managerial and social sciences.

Final Comments

The examples of current research in industrial ecology touch on only some of the themes that are receiving energetic attention in the field. Two themes seem ubiquitous: (1) the grounding of the study of materials flows in concrete end points of concern, typically, although not exclusively, environmental science and (2) increasing sophistication and rigor in the character of the analyses, often through the borrowing and integration of mathematical and scientific approaches and tools from allied fields.

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[5] For additional information on this project, see the homepage for the project <http://www.leidenuniv.nl/interfac/cml/metals/index.html>

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Dematerialisation

Are Industrial Economies on the Path of Dematerialization? Material Flow Accounts for Austria 1960-1996: Indicators and International Comparison

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Introduction

Material flow accounting (MFA) is typically regarded as a tool to inform sustainability strategies. However, at the moment this is rather a claim than a proven fact, and much clarification has yet to be done. Among the various attempts to operationalize material flow accounting at the national level the discussion about dematerialization is one of the most noticeable. The argument is that irrespective of the further specific effects socio-economic metabolism may have upon the environment, it is the sheer size of turnover that presents a burden. Moreover, if a societal metabolism of industrial dimension serves as a development model for the rest of the world, resources and sinks for residuals will be hopelessly overburdened within a short period of time (Schmidt-Bleek 1994, Weizsäcker et al. 1995, Spangenberg 1995). A path towards sustainability, then, would be feasible if economic welfare (typically measured in terms of GDP) could be delinked from environmental burden (typically measured in terms of resource use).

The "dematerialization" hypothesis developed in the 1970s argues that highly industrialized countries already delinked their resource intensity from economic growth (Malenbaum 1978, Jänicke et al. 1989, World Bank 1992). With the growing number of empirical data on the physical scale of economies critical reconsideration of the dematerialization hypothesis emerged (de Bruyn and Opschoor 1997, Berkhout 1998). One of the key problems which has been recognised widely, concerns the kind and quality of the empirical data. In our opinion, the availability of methodologically sound and internationally comparable macro indicators for the resource use of economies are a major prerequisite for a further re-examination of the dematerialization hypothesis.

In 1997 the World Resources Institute for the first time provided time series data for the resource use of four industrialized countries, Germany, Japan, the Netherlands and the USA which attracted much attention (Adriaanse et al. 1997). This publication definitely accelerated the whole field through initiating intensive discussions but also gave rise to criticism (see e.g. Berkhout 1998).

In this paper we will present a preliminary time series for material inputs into the Austrian economy. We then will discuss the results within the context of the previously published data on the material basis of industralized economies (Adriaanse et al. 1997) and finally we will draw some conclusions for the hypothesis of dematerialization using the Environmental Kuznets Curves as framework. Clearly this is an ambitious program which we cannot fully redeem. What we are trying to do here is merely a first step, leaving a more elaborated analyses to further publications.

Material flow trends for Austria – methodological framework and empirical results

Based on the preparatory work of Steurer (1992, 1994), Hüttler et al. (1996) and Schandl (1998) the physical input into the Austrian economy was calculated for the period 1960 to 1996.[6] We use two core indicators, the Direct Material Input (DMI)[7] as an indicator for a

[6] In 1998 a co-operation project of the Austrian Central Statistical Office and the IFF-Social Ecology led to the implementation of national MFA into public statistics (Wolf et al. 1998; see also the 1998 edition of „Facts & Figures" provided by the Austrian Central Statistical Office).

[7] The Direct Material Input consists of domestic extraction of materials plus imports.

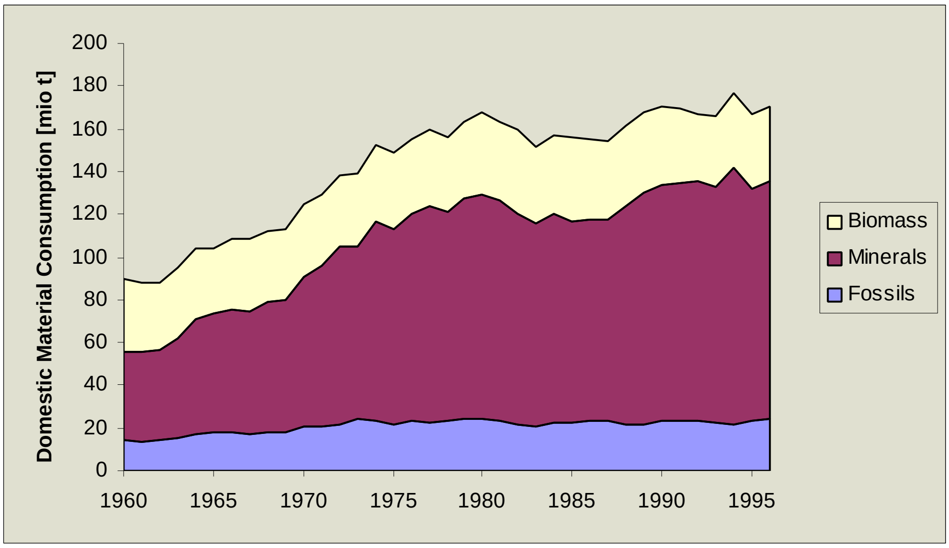
specific way of production, and the Domestic Material Consumption (DMC)[8] as an indicator for the characteristic metabolic profile of the industrial way of life. Both are high aggregated and rough background indicators for the material basis of an economy – comparable to the GDP in economic terms.

The time series we present in this paper (see figure 1) still reflect the preliminary state of this project. Using this the above mentioned works as empirical and methodological starting point we applied the idea of the OMEN calculation (see Weisz et al. in this volume) to gain methodological clarifications. Whereas data for fossiles are checked within an input-output calculation model (OMEN), mineral inputs, especially construction minerals and biomass inputs have to be checked up in a next step. In our analysis of the input side of the Austrian metabolism we differentiate between the categories biomass, minerals and fossils with regard to the domestic extraction of materials. For imports and exports, which consist not only of raw materials but also of half finished and finished products, we use two additional categories: namely chemical products and other products. This decision reflects a standard problem of material flow accounting, which is connected to the common way of disaggregating materials along groups of raw materials (for a more detailed discussion see Weisz et al. in this volume). Our estimation is based on specific conceptual and methodological assumptions, which elsewhere are discussed in detail (Fischer-Kowaslki and Hüttler 1998).

Most of the primary data incorporated in the calculation are periodically reported within the official statistics. For some aggregates, like for example sand, gravel and crushed stone or animal grazing we had to rely on estimations. In contrast to Adriaanse et al. (1997) we did not calculate hidden (material) flows like overburden in mining and soil erosion.

Table 1 shows the material flow accounts for Austria. Between 1960 and 1996 the material input into the Austrian economy (DMI) has more than doubled, mainly driven by an increase of domestic extraction of minerals and by an increase of imports which are now three times as high as in the early 1960s. At the same time the extraction of fossils shows a constant decrease. Biomass remained more or less constant over the whole period of time.

Figure 1: Domestic Material Consumption in Austria 1960 - 1996



Source: own calculations

The metabolic profile for Austria – indicated by the domestic material consumption – has changed significantly: Total domestic consumption increased from 90 million tons to 170 million tons, thus raising per capita amounts from 13 to 21 tons per year. This period of rapid material growth took place in the 1960s and 1970s and was more or less finished at the beginning of the 1980s. Minerals predominantly account for this increase, while growing rates for biomass and fossils are considerably lower.

8 The Domestic Material Consumption sums up domestic extraction plus imports minus exports.

Table 1: Material Flow Accounts for Austria 1960 - 1996

IFF-Social Ecology 1998, own calculations

million tons

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Domestic Extraction																			
Fossils																			
Lignite	6.0	5.7	5.7	6.1	5.8	5.5	5.3	4.6	4.2	3.8	3.7	3.8	3.8	3.6	3.6	3.4	3.2	3.1	3.1
Hard Coal	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crde Oil	2.4	2.4	2.4	2.6	2.7	2.9	2.8	2.7	2.7	2.8	2.8	2.5	2.5	2.6	2.2	2.0	1.9	1.8	1.8
Natural Gas	1.1	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.2	1.1	1.4	1.4	1.5	1.7	1.7	1.8	1.6	1.8	1.8
Dom. Extr. Fossils	9.7	9.3	9.4	10.1	9.9	9.7	9.5	8.7	8.1	7.7	7.9	7.7	7.7	7.9	7.5	7.2	6.8	6.7	6.7
Minerals																			
Salt	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Iron Ore	3.9	4.1	4.1	4.1	3.9	3.9	3.8	3.8	3.9	4.4	4.3	4.8	4.7	4.8	4.8	4.4	4.5	4.2	3.6
Industrial Minerals	2.7	2.9	2.7	2.3	2.7	2.8	2.8	2.7	2.7	2.7	2.6	2.7	2.7	2.8	2.8	2.5	2.2	2.3	2.2
Clay	2.3	2.3	2.4	2.6	3.1	3.3	3.3	3.5	3.6	3.6	4.1	4.0	4.3	4.3	4.1	4.2	3.8	3.7	3.6
Sand and Gravel	14.7	15.2	15.9	19.2	24.9	28.0	27.4	27.5	30.7	30.5	33.5	37.9	43.7	42.9	51.6	52.3	56.4	58.6	56.2
Crushed Stone	17.0	16.6	16.4	16.5	18.0	17.0	18.2	19.7	18.8	18.6	22.0	23.9	25.1	24.1	26.8	25.6	26.7	28.8	28.8
Dom. Extr. Minerals	40.9	41.4	41.8	45.1	52.8	55.3	56.0	57.5	60.0	60.1	66.8	73.4	80.7	79.2	90.5	89.2	93.9	97.8	94.7
Biomass																			
Agricultural Products	24.4	22.8	22.3	23.8	24.4	22.1	25.5	25.4	26.0	26.1	25.8	25.2	25.3	26.2	26.6	27.7	26.2	27.3	26.9
Wood	7.3	7.4	7.0	7.1	7.3	7.6	7.3	7.8	7.0	7.6	8.1	7.7	7.4	7.1	7.3	7.0	8.6	7.8	7.7
Grazing	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9
Dom. Extr. Biomass	32.7	31.1	30.3	31.8	32.7	30.7	33.7	34.2	34.0	34.7	34.9	33.9	33.6	34.2	34.8	35.7	35.7	36.0	35.6
Total Domestic Extraction	83.3	81.8	81.5	87.0	95.4	95.7	99.2	100.4	102.2	102.6	109.5	115.0	122.1	121.3	132.8	132.2	136.4	140.5	136.9
Import																			
Biomass	2.2	1.8	2.2	2.1	2.4	2.6	2.3	2.1	2.2	2.2	2.9	2.9	2.9	3.9	4.3	3.4	3.9	4.0	4.0
Minerals	4.7	5.0	5.1	5.8	4.7	3.7	3.9	3.6	4.3	4.6	5.4	5.5	6.0	5.7	6.9	5.9	6.5	7.0	7.4
Fossils	5.2	4.8	5.1	5.7	6.9	8.0	8.5	8.1	9.7	10.4	12.6	12.7	13.4	15.8	15.6	14.3	16.5	15.4	16.5
Chemical Products	0.0	0.0	0.0	0.0	1.2	1.2	1.2	1.3	1.4	1.5	1.6	1.7	2.0	1.8	2.0	1.6	1.8	2.2	2.2
Other Products	1.3	1.4	1.4	1.5	1.1	0.8	0.9	0.9	0.9	1.0	1.2	1.4	1.6	1.6	1.6	1.6	1.9	2.1	1.9
Total Import	13.5	13.0	13.7	15.1	16.3	16.4	16.8	16.0	18.6	19.7	23.7	24.1	25.9	28.8	30.4	26.9	30.7	30.6	32.1
Export																			
Biomass	0.1	0.2	0.2	0.2	1.4	2.6	2.6	2.7	3.0	3.5	3.5	3.3	3.5	3.8	3.8	3.5	4.7	4.5	4.9
Minerals	4.1	3.6	3.4	3.3	3.6	3.8	3.6	3.6	3.6	3.8	3.1	4.1	4.3	4.4	4.6	4.1	4.1	4.1	4.5
Fossils	0.0	0.0	0.0	0.0	0.2	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.3
Chemical Products	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.9	1.1	1.0	1.0	1.1	1.2	1.5	1.6	1.7	1.8	1.8	2.1
Other Products	3.0	3.1	3.2	3.3	2.1	0.8	0.9	0.4	0.4	0.5	0.6	0.7	0.7	0.8	0.9	0.9	1.1	1.0	1.1
Total Export	7.2	7.0	6.9	6.8	7.3	7.7	7.6	7.9	8.3	9.0	8.4	9.5	10.0	10.7	11.2	10.4	12.0	11.7	12.8
Direct Material Input	96.8	94.8	95.2	102.1	111.7	112.0	116.0	116.4	120.7	122.2	133.3	139.1	148.0	150.1	163.2	159.0	167.1	171.2	169.0
Domestic Consumption	89.5	87.8	88.3	95.3	104.4	104.3	108.4	108.5	112.4	113.2	124.9	129.6	138.0	139.4	152.1	148.6	155.1	159.5	156.2
Fossils	14.4	13.6	13.9	15.2	16.8	17.9	18.2	16.8	17.9	18.3	20.8	20.6	21.5	23.9	23.3	21.5	23.3	22.4	23.3
Minerals	40.9	42.1	42.8	47.0	54.3	55.7	56.7	57.9	61.1	61.4	69.6	75.3	83.1	81.0	93.2	91.3	96.6	101.2	97.9
Biomass	34.2	32.1	31.6	33.2	33.3	30.7	33.4	33.8	33.4	33.6	34.5	33.7	33.3	34.6	35.5	35.8	35.2	35.9	34.9
Population [mio]	7.0	7.1	7.1	7.2	7.2	7.3	7.3	7.4	7.4	7.4	7.5	7.5	7.5	7.6	7.6	7.6	7.6	7.6	7.6
DMI/Capita [t/c]	13.7	13.4	13.4	14.2	15.5	15.4	15.8	15.8	16.3	16.4	17.8	18.6	19.6	19.8	21.5	21.0	22.1	22.6	22.3
DMC/Capita [t/c]	12.7	12.4	12.4	13.3	14.5	14.3	14.8	14.7	15.2	15.2	16.7	17.3	18.3	18.4	20.0	19.6	20.5	21.1	20.7
GDP (real 1983) [bio ATS]	516	560	590	604	628	666	686	722	742	772	815	867	912	968	1015	1055	1052	1100	1096
Material Intensity [kg/10 /	1.9	1.7	1.6	1.7	1.8	1.7	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.5

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Domestic Extraction																		
Fossils																		
Lignite	2.7	2.9	3.1	3.3	3.0	2.9	3.1	3.0	2.8	2.1	2.1	2.4	2.1	1.8	1.7	1.4	1.3	1.1
Hard Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crde Oil	1.7	1.5	1.3	1.3	1.3	1.2	1.1	1.1	1.1	1.2	1.2	1.1	1.3	1.2	1.2	1.1	1.0	1.0
Natural Gas	1.8	1.4	1.1	1.0	0.9	1.0	0.9	0.8	0.9	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.1	1.1
Dom. Extr. Fossils	6.2	5.8	5.5	5.6	5.2	5.1	5.1	4.9	4.7	4.3	4.2	4.6	4.4	4.0	4.0	3.5	3.4	3.2
Minerals																		
Salt	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.5	0.5	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5
Iron Ore	4.1	4.4	4.2	4.6	4.8	5.0	4.5	4.0	3.7	3.0	3.1	2.9	2.7	2.2	1.7	1.7	2.3	2.2
Industrial Minerals	2.4	2.7	2.5	2.3	2.4	2.6	2.6	2.4	2.4	2.7	2.8	2.7	2.1	2.3	2.0	2.3	2.3	2.0
Clay	3.4	3.4	3.5	3.4	3.2	3.1	3.3	3.1	3.0	3.1	3.5	3.4	3.7	3.7	3.3	3.2	3.4	2.9
Sand and Gravel	57.3	58.3	58.6	52.5	53.2	53.5	50.2	50.4	49.8	50.7	55.1	58.2	59.0	60.5	59.1	64.8	55.8	56.9
Crushed Stone	31.2	32.4	30.6	32.1	30.1	30.0	30.0	31.4	32.4	38.3	39.7	38.8	39.0	38.6	39.9	42.4	39.8	41.3
Dom. Extr. Minerals	98.8	101.6	99.9	95.4	94.0	94.6	91.0	91.8	91.9	98.2	104.6	106.4	107.0	107.8	106.4	115.0	104.2	105.9
Biomass																		
Agricultural Products	26.2	28.1	27.5	30.8	27.0	28.5	29.4	27.4	27.5	27.9	27.5	25.7	24.4	20.7	22.6	23.0	23.9	23.0
Wood	9.3	9.3	8.9	8.1	8.5	8.8	8.5	8.9	8.6	9.3	10.1	11.5	8.4	8.9	9.0	10.5	10.1	11.0
Grazing	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.9	0.9
Dom. Extr. Biomass	36.4	38.3	37.3	39.8	36.3	38.2	38.7	37.1	37.0	38.1	38.4	38.0	33.6	30.5	32.3	34.3	34.9	34.8
Total Domestic Extraction	141.4	145.7	142.7	140.8	135.6	137.8	134.9	133.9	133.6	140.6	147.2	149.0	145.0	142.3	142.7	152.7	142.6	144.0
Import																		
Biomass	4.8	5.5	5.2	5.4	5.6	5.7	6.6	6.7	7.0	7.5	7.4	7.9	9.5	9.3	9.2	10.1	10.2	10.2
Minerals	8.7	8.2	8.0	7.8	7.0	9.0	8.6	8.2	8.2	9.5	10.0	9.9	10.4	11.2	10.8	12.6	14.1	14.5
Fossils	18.0	18.2	17.8	16.0	15.1	17.7	18.2	18.1	18.4	17.3	17.6	18.8	19.4	19.1	18.6	18.7	20.1	21.5
Chemical Products	2.5	2.7	2.8	2.8	3.0	3.1	3.4	3.3	3.4	3.9	3.8	3.8	3.7	3.7	3.6	4.0	4.2	4.8
Other Products	2.1	2.3	2.1	2.2	2.3	2.3	2.4	2.5	2.7	2.8	3.0	3.3	3.5	3.5	3.4	3.8	4.0	4.5
Total Import	36.1	36.8	35.8	34.2	32.9	37.7	39.2	38.9	39.7	41.0	41.8	43.7	46.4	46.7	45.7	49.2	52.6	55.4
Export																		
Biomass	5.7	5.8	5.8	5.6	6.2	6.6	6.5	6.9	7.0	7.9	8.4	9.0	8.2	8.6	8.4	9.6	10.2	10.1
Minerals	5.2	5.3	5.5	5.5	5.7	6.4	6.2	5.9	6.3	6.2	6.4	6.9	7.0	7.1	7.3	7.9	9.7	9.5
Fossils	0.2	0.2	0.2	0.2	0.2	0.5	0.9	0.6	0.5	0.4	0.4	0.5	0.4	0.6	0.7	1.1	1.0	1.3
Chemical Products	2.3	2.4	2.5	2.6	2.9	3.1	2.9	2.9	3.3	3.6	3.6	3.4	3.5	3.4	3.5	3.9	3.9	4.2
Other Products	1.2	1.4	1.4	1.5	1.5	1.6	1.7	1.7	1.7	1.9	2.1	2.4	2.6	2.6	2.8	2.8	3.4	3.7
Total Export	14.6	15.1	15.3	15.3	16.5	18.2	18.3	18.0	18.7	20.0	21.0	22.3	21.8	22.2	22.6	25.3	28.1	28.7
Direct Material Input	177.5	182.6	178.5	175.0	168.5	175.5	174.1	172.8	173.3	181.5	189.1	192.7	191.4	189.0	188.4	202.0	195.1	199.4
Domestic Consumption	163.0	167.5	163.2	159.7	152.0	157.3	155.9	154.7	154.5	161.5	168.1	170.4	169.6	166.8	165.8	176.7	167.0	170.6
Fossils	24.4	24.2	23.4	21.8	20.4	22.5	22.9	23.0	23.1	21.6	21.8	23.4	23.7	23.0	22.1	21.5	22.9	24.0
Minerals	102.7	105.0	102.8	98.1	95.6	97.4	93.9	94.5	94.1	101.8	108.5	109.9	110.8	112.3	110.2	120.0	109.0	111.5
Biomass	35.8	38.2	37.0	39.9	35.9	37.4	39.1	37.2	37.3	38.0	37.8	37.1	35.1	31.5	33.4	35.2	35.2	35.1
Population [mio]	7.5	7.5	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.7	7.8	7.9	8.0	8.0	8.0	8.1
DMI/Capita [t/c]	23.5	24.2	23.6	23.1	22.3	23.2	23.0	22.8	22.9	23.9	24.8	25.0	24.5	23.9	23.6	25.2	24.3	24.7
DMC/Capita [t/c]	21.6	22.2	21.6	21.1	20.1	20.8	20.6	20.5	20.4	21.3	22.0	22.1	21.8	21.1	20.7	22.0	20.8	21.2
GDP (real 1983) [bio ATS]	1156	1182	1181	1204	1237	1241	1269	1299	1321	1363	1420	1485	1536	1557	1564	1604	1637	1664
Material Intensity [kg/10 /	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.3	1.2	1.2

The metabolic profile of industrial economies

Table 2 presents the Domestic Material Consumption for five industrial countries. While some methodological inconsistencies still seem to exist hampering international comparability, the numbers and distributions are similar enough to support the concept of a „characteristic metabolic profile“ (Fischer-Kowalski and Haberl 1998) of the industrial way of life. It amounts to a resource consumption of about 19 metric tons per inhabitant and year. This is equivalent to a daily resource consumption of about 50 kg/cap.yr.

Table 2: The metabolic profile of industrial countries 1991 (tons per capita)

	Austria	Germany	Japan	Netherlands	U.S.A.	unweighed arithmetic mean
biomass	4,5	2,6	1,5	4,3	3,0	3,2
oil, coal, gas	3,0	6,2	3,3	6,4	7,7	5,3
metals, minerals, others	14,2	10,7	11,8	5,9	8,0	10,1
total domestic material consumption (DMC)	21,7	19,5	16,6	16,6	18,7	18,6
(population in millions)	(7,8)	(80,0)	(124,0)	(15,0)	(252,8)	(5 countries)

Sources: Data on Germany, Japan, Netherlands and USA: Adriaanse et al. (1997, 1998), Data on Austria: own calculation.

The Domestic Material Consumption was calculated from above sources (i.e. domestic extraction plus imports minus exports). The table only includes used materials, excludes air, water and "hidden flows“ (overburden, erosion) and excavation materials.

The overall figures of the material flows still show remarkable differences. These differences reflect both different methodological assumptions and/or the different economic structures of the economies compared. Austria appears to have a remarkable high consumption of biomass due to high proportion of domestic meat and wood production, whereas Japans economy largely depends on imported meat or fish. Since they do not raise cattle their biomass input is much lower than those of other industrialized countries[9]. Consumption of fossils is similarly low in Japan and in Austria, which is due to a relatively high share of non-fossil based energy supply in both countries (nuclear energy in the case of Japan and hydropower in the case of Austria; OECD 1998). The high consumption of minerals in Austria appears to be a runaway. This is mainly a result of the attempt to account for underestimations within the official statistical data. There are also indications that the high consumption of minerals reflects a higher building intensity (see Hüttler et al. 1997).

Delinking

Environmental Kuznets Curves (EKC) provide a framework for the analysis of the linkage between the economy in monetary terms (i.e. as measured by economic indicators as for example GDP and GNP) and the associated physical flows. EKCs are constructed by explicitly relating per capita income (GDP or GNP per capita) to environmental indicators in the broadest sense (World Bank 1992, Selden and Song 1994, Shafik 1994, de Bruyn and Opschoor 1997).[10] EKCs thus allow a conceptual separation of "economic growth" in monetary terms from "physical growth" in terms of tons and joules and to empirically assess how these two dimensions of the economy are related. The underlying idea, or hope, expressed in EKCs is that it could be possible to achieve an environmentally sustainable economic growth by fostering monetary growth while at the same time reducing the physical flows associated to it.

EKC may have an „inverted U shape“ or a „N shape“. The inverted U shape indicates a delinking of environmental pressures and per capita income, while the N shape hints at the

9 Biomass consumption of the Netherlands is in the same order of magnitude than for Austria. Due to a lack of disaggregated data in the corrected data sheets of the German publication of „Resource flows“ (Adriaanse et al. 1998) an interpretation is not possible yet.

10 A comprehensive picture of the current discussion concerning the Environmental Kuznets Curves can be found in a special issue of Ecological Economics (Vol. 25, No. 2, 1998).

possibility that a period of delinking may be followed by a phase of „relinking“ of physical flows and economic growth. Delinking may be envisaged as a result of technological change and/or changes in prevailing production patterns due to various reasons, and/or changes in environmental policy. However, delinking may not be a stable or persistent process. Efficiency gains might be of short duration and in the long run a relinking of GDP and material input may take place. In this case the EKC will be shaped like a "N" instead like an inverted "U".

Early empirical work within the EKC framework, mainly conducted by economists, tended to relate all environmental data at hand with GDP values, regardless whether they indicated pressures, natural states, or feedbacks of environmental change on society. These included among others indicators for lack of safe drinking water, lack of urban sanitation, annual deforestation, dissolved oxygen in rivers, faecal coliforms in rivers, ambient SO_2 levels, municipal waste per capita, and carbon emissions per capita (e.g. Shafik 1994). Not surprisingly, indicators for problems which may be overcome by technical solutions or end of pipe technologies could be quite easily delinked from GDP growth, whereas overall resource use indicators, e.g. carbon emissions, tended to be linked much more closely to economic activity. On the basis of the considerations put forward in section 2 of this paper, we argue in favour of a more systematic approach, i.e. an approach which only links indicators for driving forces with indicators for pressures, but not directly with indicators for natural states or effects of environmental change on society. This appears necessary for constructing theoretically plausible models.

Recent empirical EKC case studies offer a more stringent approach by using indicators for total material throughput, energy use, or large material flows as for example CO_2 emissions. De Bruyn and Opschoor (1997) suggested to examine the hypothesis of delinking effects in industrialized societies using data for total material throughput. As there were only limited data available on this, they use data of Jänicke et al. (1989) who provide four types of proxies for total material throughput: energy consumption, steel consumption, cement production and weight of freight transport on rail and road. Following a concept of indicators rather than total flows, de Bruyn and Opschoor consider these proxies as a reliable set of data, that captures to a large extent the environmental relevant part of industrial metabolism. Taking into account latest empirical works the EKC discussion could refer to complete MFA data for five industrial economies, Germany, Japan, Netherlands, U.S.A. (Adriaanse et al. 1997) and Austria for the last decades.

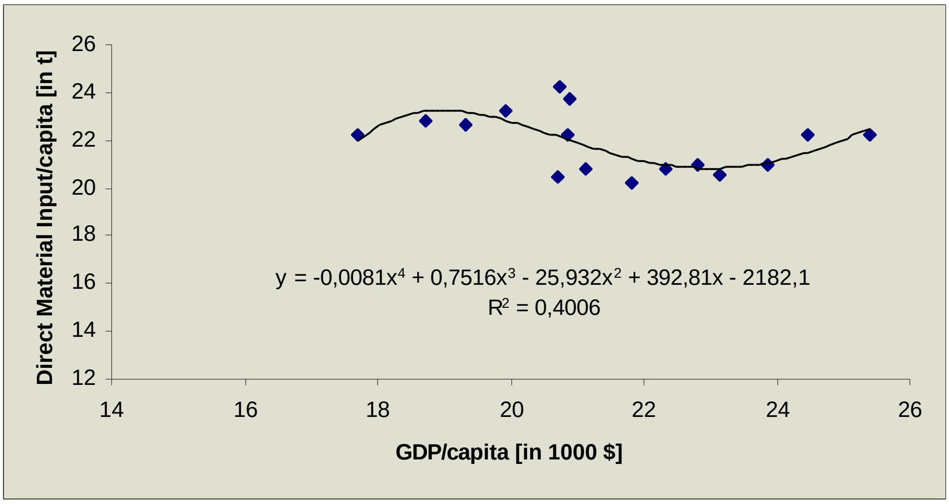
Using these data we will discuss the idea of a dematerialization of industrialized economies. Figure 9 provides data for Japan, Germany, and Austria about delinking and relinking effects in these national economies during the period of 1975 to 1995.

Basically EKC do not represent a time series. Due to the fact, however, that all three countries had growing GDP rates almost throughout the time period, the GDP scale implicitly covers the time scale [11]. For this reason we may in these particular cases interpret the EKC also according to the time dimension.

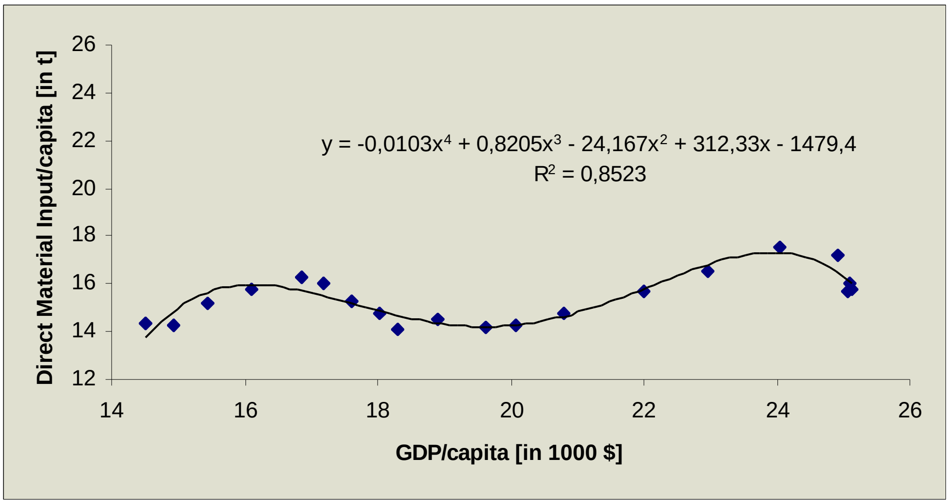
[11] Exeptions from the overall trend of a continuously growing GDP since 1975 are for Germany the years 1981 and 1982 (without considering the years after the reunion i.e. the years after 1990), for Japan 1993 and for Austria 1981.

Figure 3: Environmental Kuznets Curves on the basis of Direct Material Input and GDP data for Germany, Japan and Austria

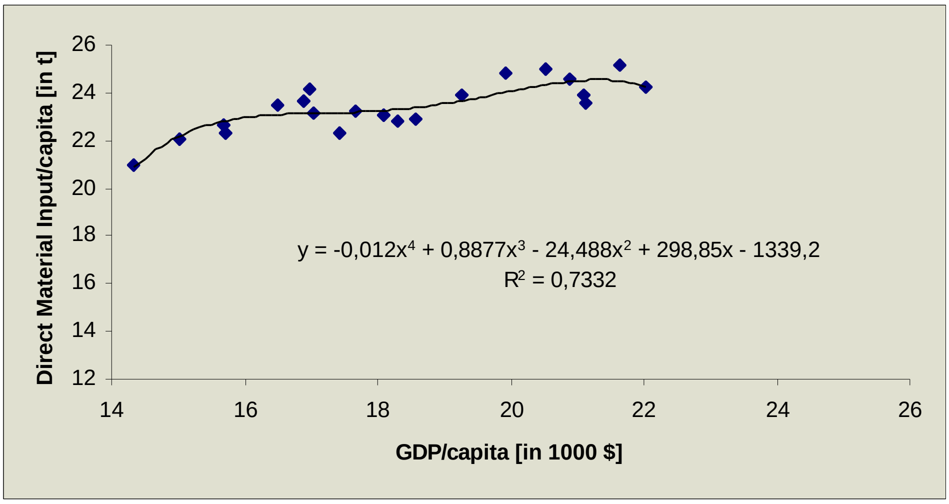
Germany 1975 – 1990



Japan 1975 – 1994



Austria 1975 – 1995



Source: Adriaanse et al (1997), own calculations

Data for Germany show an uncommon trend at a midrange GDP of about 21.000 $ per capita and year [12]. Within a short period of time (1979 to 1982) GDP more or less stagnated, whereas material inputs continuously decreased. This suggests that the resulting delinking effect during this period of time originated as a side effect of the economic development rather than as a result of environmental policy. Probably material intensive industrial units were most affected by the economic stagnation. As they increased again, from 1982 on, the material inputs accordingly increased, but not as fast as in the previous period. This suggests that the phase of economic stagnation eventually led to an irreversible structural change, characterized by a shift towards less material intensive industrial units.

The Japanese data show that delinking and relinking can be a wave-like process. Despite the curve neglects the time dimension, we can imagine the effects of strong environmental policy in the 1980s in Japan. Before 1980 there was a parallel development of economic growth and material input. While GDP growth went on without any restraints, the use of materials went down in absolute numbers. This may best be explained by effective efforts of environmental policy in Japan in the late 1970s and early 1980s. Yet in the subsequent years delinking did not prevail, but was followed by a relinking phase. At the highest income rates at the right end of the GDP scale we can again observe delinking effects. This effect corresponds to a phase of economic stagnation since 1991, with one year of recession (1993). This second delinking therefore may best be explained as a consequence of the economic development, analogously to the period between 1979 and 1982 in Germany.
Data for Austria do not show a significant trend at all, although we might observe the Japanese pattern in a much weaker form. Continuing the arguments above we could now argue that in Austria neither considerable structural change caused by economic stagnation, nor strong effects of environmental policy took place. However, GDP is growing faster than material input, which leads to a "relative" delinking effect. A dematerialization, i.e. shrinking material throughputs, is out of sight.

Conclusions

Societies in general, but also specific subsystems like politics or science need instruments for assessing societies impact on ecological systems. MFA based indicators seem to be fruitful to provide a first picture of the impacts a society has on its natural environment. Therefore these indicators may serve as a rough estimation of the success of sustainability policies. MFA based indicators are simple enough to be communicable among various potential users, thus serving as a „good simplification“. Material flow analyses provides an empirical framework, from which numerous environmental indicators can be derived and calculated in a consistent and comprehensive manner.
Although the comparability of existing national MFA data is in some respects still weak (especially for biomass) we can draw a first picture of a characteristic metabolic profile of the industrial way of life.
We have shown that metabolism may be linked to socio-economic driving forces in a quite straightforward manner. This can be done for example within the concept of Environmental Kuznets Curves (EKC). This approach yields interesting insights into the relation between economic development, and environmental pressures. The analyses show that "relative" delinking”, i.e. GDP growing faster than overall material input, may be a common phenomenon. However, there are no convincing examples for an "absolute" delinking between economic activity and resource use, i.e. a reduction of material flows combined with continued economic growth in monetary terms.
Apart from the advantages MFA based indicators may provide there are still some open ends within the discussion: The process of standardisation and harmonisation of both the concepts and the rules of accounting has to be carried on to guarantee the relevance of the indicators for decision making processes. National MFA should profit from taking into account the idea of input-output balancing. Nevertheless, the advantages environmental policy can draw from such a broad indicator, must be elaborated especially with respect to the appropriate level of dissaggregation. Above all this needs closer relation to the experience of the stakeholders and to the experience of those who are engaged in every day environmental policy.

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[12] Valid data for Germany end in 1990, the year before the re-union. Data from 1991 on (Adriaanse et al. 1997) is based on domestic requirements for re-united Germany whereas Import data is only considered for former Western Germany. Comprehensive foreign trade flow data are provided by the Federal Statistical Office Germany (1998).

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Material Flow Analysis of the Italian economy. Preliminary results.

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The estimation of the material flows through the economy of a country for a given period, for example one year, provides a better comprehension of all the activity that concerns the pulling out of natural resources, their transformation in goods and services, and the production of waste and residual products that are generated during the production and usage of such goods.

Some economists now agree that the GDP is inadequate to describe completely the economical activity of a country. In fact, the GDP does not include the movement or the processing of large quantities of materials that have a null or negative value.

Since the early '70s researchers of the Commodity Science of the University of Bari have shown their interest in these topics, and promoted researches on material and energy balance of product chain of some types of goods, and on the material flows of the Italian and US economies, expressed in physical units (Nebbia 1971, 1975a, 1975b, 1996; Pizzoli 1975, De Marco 1975, 1979, 1980, Nebbia-Notarnicola 1979, Notarnicola 1979, 1983, Spada et al. 1984).

Since then, their interest in this research field had continued (Pizzoli 1989, 1994, Costantino and Nebbia 1994, De Marco 1994, De Marco and Lagioia 1997, Pizzoli and Camaggio 1997, Spada and Tricase 1998), and produced several papers, including a few recent ones that were published during the current year (De Marco and Lagioia 1998a, 1998b, Lagioia and De Marco 1998, Notarnicola and Lagioia 1998).

In this work, similarly to what foreign researchers (Adriaanse et al. 1997, Bringezu et al. 1997, 1998a, 1988b) have done in other countries, we have tried to evaluate also the hidden flow that concerns materials leaving the ecosphere and entering the technosphere. Here they are processed, used, and partly stocked. Finally waste products go back into the ecosphere. In other words this is the so-called TMR (Total Material Requirement) of the Italian economy in 1994.

Some previous researches have been done about four different classes of materials: non-metals, metals, mineral fuels, and no food organic substances (De Marco and Lagioia 1998a, 1998b, Lagioia and De Marco 1998). This research also concerns a fifth class, food organic materials.

The DMI (Direct Material Inputs) of Italian economy in 1994 was about 685 Mt (Million metric tons) (table 1), the 80% of which was produced in the country (about 530 Mt), and the remaining 20% was imported from abroad (about 200 Mt). The amount of exported materials were more than 41 Mt.

The domestic production consists essentially of non-metal group, with over 265 Mt, and of the organic substances – both food and no food – which amounts to about 182 Mt. Steel represents the most significant contribution in the group of metals.
Among the imported materials, the most important substances are mineral fuels, with about 150 Mt. Among the exported non-renewable materials, there is a predominance of steels. Paper, paperboard, and food organic substances prevail among renewable materials.

Even though the information presented here comes from official sources, it can be somewhat confusing, and could be deemed not to be very precise, because of the way data have been originated, as declared by statistical offices themselves.

The estimation of the hidden flow (e.g. the flows of materials, associated with extracted or harvested primary natural resources, that are part of a country's economic activity, but most never enter the monetary economy as commodities) is affected by the original lack of precision. It also depends on errors in calculations based on literature data, which cannot be valid in any cases, and on direct information from various industrial sectors, that can always include errors.

Therefore, this work is intended to be the contribution of Italian researchers to the work of foreign researchers. This work has been done with the same or similar methodology as in the other countries.

The chart in figure 1, which is similar to that one published in Germany by the Wuppertal Institute, is an attempt to evaluate the total material flows in Italy during 1994.

Materials have been grouped in non-renewable and renewable ones, and also subdivided between domestic and imported materials.

The import hidden flows (table 2, figure 1), which is about 550 Mt, are associated with 173 Mt of non-renewable material, plus 24 Mt of renewable material, and is placed on the left of the border line.

From the border line domestic production materials – over 340 Mt of non-renewable materials and about 188 Mt of renewable ones – together with their hidden flows (some 350 Mt), with imported materials (about 173 Mt of non-renewable materials and about 24 Mt of renewable) and with the oxygen (about 314 Mt) used in combustion reactions, enter the technosphere (e.g. the yearly economical activity, expressed as physical units).

A fraction of the materials that enters the technosphere (about 500 Mt or about 9 t per capita) remains there in the form of durable goods (roads, buildings, devices, etc.), while another portion is exported (about 33 Mt of non-renewable material plus about 9 Mt of renewable material). The hidden flows of exported (about 148 Mt) and domestic (some 202 Mt) materials with disposal waste (over 55 Mt) leave the technosphere but remain within Italian country.

Also the erosion associated with domestic materials – which has been estimated to be around 200 Mt - remains within Italian country. Gas emissions (about 440 Mt) - that by nature do not have well-defined environmental boundaries - move from the technosphere to the ecosphere.

Water has been excluded from these calculations. Water is a resource that is present in every production chain, and moves from the ecosphere to the technosphere, and then goes back to the ecosphere, usually in a degraded form. It is difficult to define water border lines.

Conclusions

Even with a few limitations deriving from incomplete data, the evaluation of the total material flows (TMR) is a useful indicator that complements the GPN when performing a correct economic account. This analysis has been carried following the methodology indicated in Resources Flows (Adriaanse et al. 1997), essentially in order to compare the TMR of the Italian economy with those of other countries (USA, Japan, Germany and Netherland). In 1994, Italy had a DMI of about 685 Mt, and an estimated hidden flow of 750-770 Mt. Therefore Italy had a TMR of over 1,450 Mt. In the same year Germany had a TMR of 6,764 Mt (TMR per capita 86 t), USA had a TMR of 21,237 Mt (TMR per capita 84 t), Japan had a TMR of 5,716 Mt (TMR per capita 46 t) and Netherlands had a TMR of 1,275 Mt (TMR per capita 84 t) (Adriaanse et al. 1997).

The annual material flows leave behind itself (and after itself) a damage whose intensity and repairability degree is difficult to evaluate. For a correct planning, a good economy administration should therefore consider the actual cost of the production of one physical unit of any commodity, in terms of resources directly and indirectly used.

The previous data prove that every Italian inhabitant "consumed" in 1994 about 25 tons of materials (TMR), and about 12 tons of direct materials used (DMI). Comparing the TMR within GDP, it is possible to deduce that in 1994 about 890 tons of materials had been "consumed" to produce 1 billion liras of wealth. To produce the same result in 1975 about 1,700 tons were necessary (about twice as much). In the same year, the per-person TMR was a little more than 22 tons, and the DMI was a little more than 12 tons.

Appendix

Renewables
In 1994 the domestic production of renewables amounted to 188 Mt, thus representing 27% of DMI. Imports were 24 Mt and exports were about 10 Mt.
The plant and animal biomass hidden flows (production + import – export) were estimated by applying a parameter specific to each plant and animal biomass. When possible, parameters have been taken from literature and through personal communications.

As to timbers and semi-manufactured timber products (plywood, wood chips, wood coal, etc.) it has been assumed that for each traded ton of timber, it is necessary to cut about 1.5 tons of trees (Adriaanse et al. 1997).
Hidden flows of agricultural products (fruit, vegetables, etc.) have been roughly estimated by applying a factor that depends on the type of product and generally it is in the range 0.2 to 1.5 tons per ton of product (Macchia 1998).
Hidden flows of livestock and meat have been estimated as follows: by assuming 4.5 tons of fodder per ton of meat, and considering that one ton of living cattle gives – on average – 0.5 tons of meat. It results a hidden flow of 2.5 tons of fodder per ton of living cattle (Adriaanse et al. 1997, our calculations). According to the literature, hidden flows of fish are 30 tons per ton of fish (Vitousek et al. 1986).

Erosion
There is no formal national inventory of soil erosion over agriculture areas. Domestic erosion was estimated by using international literature soil erosion rate and Italian estimate of muddy runoff. Erosion associated with imported materials was not estimated.

	1994 1,000 ha	%	erosion rate t/ha*year	erosion kt
Agricultural areas	13,500	45	10	135,000
Forest	7,000	23	10	70,000
Pastureland	3,500	12	5	17,500
Not cultivated land	4,000	13	7	28,000
Others (City, road, river, lake)	2,000	7	0	0
Total ITALY	30,000	100		250,500
Total muddy runoff estimate				150-180,000

Sources: Gentile F., *Rivista di Ingegneria Agraria*, (1) 48-53 (1995); Palmieri E. L., Il problema della valutazione dell'entità dell'erosione nei bacini fluviali, *Atti del XXIII Congresso Geografico Italiano, Catania, 9-13 maggio 1983*, vol. II - tomo I, Catania, 1983; Graziani C.A., Erosione dei suoli agricoli nella CEE, *Ambiente Risorse Salute*, aprile 1988; Boardman J., An average soil erosion rate for Europe: Myth or reality?, *Journal of soil and water conservation*, *53*, (1) 46-50 (1998); Poesen J.W. et al., Water erosion monitoring and experimentation for global change studies, *Journal of soil and water conservation*, *51*, (5) 386-390 (1996); Pimentel D. et al., Environmental and economic costs of soil erosion and conservation benefits, *Science*, *267*, 1117-1123 (24 February 1995); Pimentel D. et al., World agriculture and soil erosion. Erosion threatens world food production, *BioScience*, *37*, (4), 277-283 (April 1987).

Fossil fuels
Crude oil. The hidden flows (8% of oil weight) of imported and domestic crude oil and its derivatives were calculated on the database of the Wuppertal Institute (Adriaanse et al. 1997) and on confidential information of Italian manufacture (SAPIEM-AGIP-ENI 1998).
Coal. Overburden of imported and exported coal was estimated 6 tons per ton of coal production and overburden of domestic production was calculated to be 8 tons per ton of coal production considering data from literature (Smidt-Bleek 1994, Adriaanse et al. 1997, Bringezu et al. 1997).
Natural gas. The domestic hidden flows of natural gas have been calculated on the base of 2% of production (SAPIEM-AGIP-ENI 1998). The hidden flows of imported natural gas were calculated on the data of Annual Energy Review 1995 (EIA 1995).

Metals

Iron and steel. The hidden flows (1.5 tons per ton of iron ore) have been calculated by accounting the imported mineral ores (Fe content 60%) and considering the average data of Germany, USA, Japan and literature data (Adriaanse et al. 1997, Ayres-Ayres 1998).

Aluminium. Overburden of domestic, imported and exported aluminium has been calculated considering a world-wide weighted average of 0.48 tons of overburden per ton of bauxite (Adriaanse et al. 1997, Ayres-Ayres 1998) and accounting that 4 tons of bauxite yields, on average, 1 tons of aluminium.

Others. Overburden of metals has been calculated considering parameters reported in literature (Smidt-Bleek 1994, Adriaanse et al. 1997, Ayres-Ayres 1998).

Non metals (or Construction materials)

Sand and gravel. The domestic production was about 118 Mt (40% of total production of non-metals). The overburden is 2% of production according to statistical data of local authority of Trento (Servizio Minerario 1998) and according to literature (Smidt-Bleek 1994).

Clay. Domestic production of clay was 40 Mt (14 % of total production of non-metals). Domestic hidden flow factor (3 tons/ton of clay production) was derived from personal communication of ANDIL and ASSOPIASTRELLE (Italian association of brick and tile manufacturers).

Marble. In 1994 domestic production of marble and granite was 8 Mt (3% of total non-metals). The overburden has been estimated to be 1.5 tons per ton of products (Baldassare 1979, Spada 1990, Atti 1985, Co.Ge.Ser. 1998).

Lava. The domestic production of lava (volcanic origin) was about 3 Mt. The overburden has been calculated as 0.5 tons/ton of products (Servizio Minerario 1998).

Tuff. The domestic production of tuff was nearly 10 Mt (about 3.5 % of total domestic non-metals production). The hidden flows have been estimated 20-30% of the production (Baldassare 1979).

Other non-metals. Overburden of other non-metals has been calculated considering factors from literature (Smidt-Bleek 1994, Adriaanse et al. 1997).

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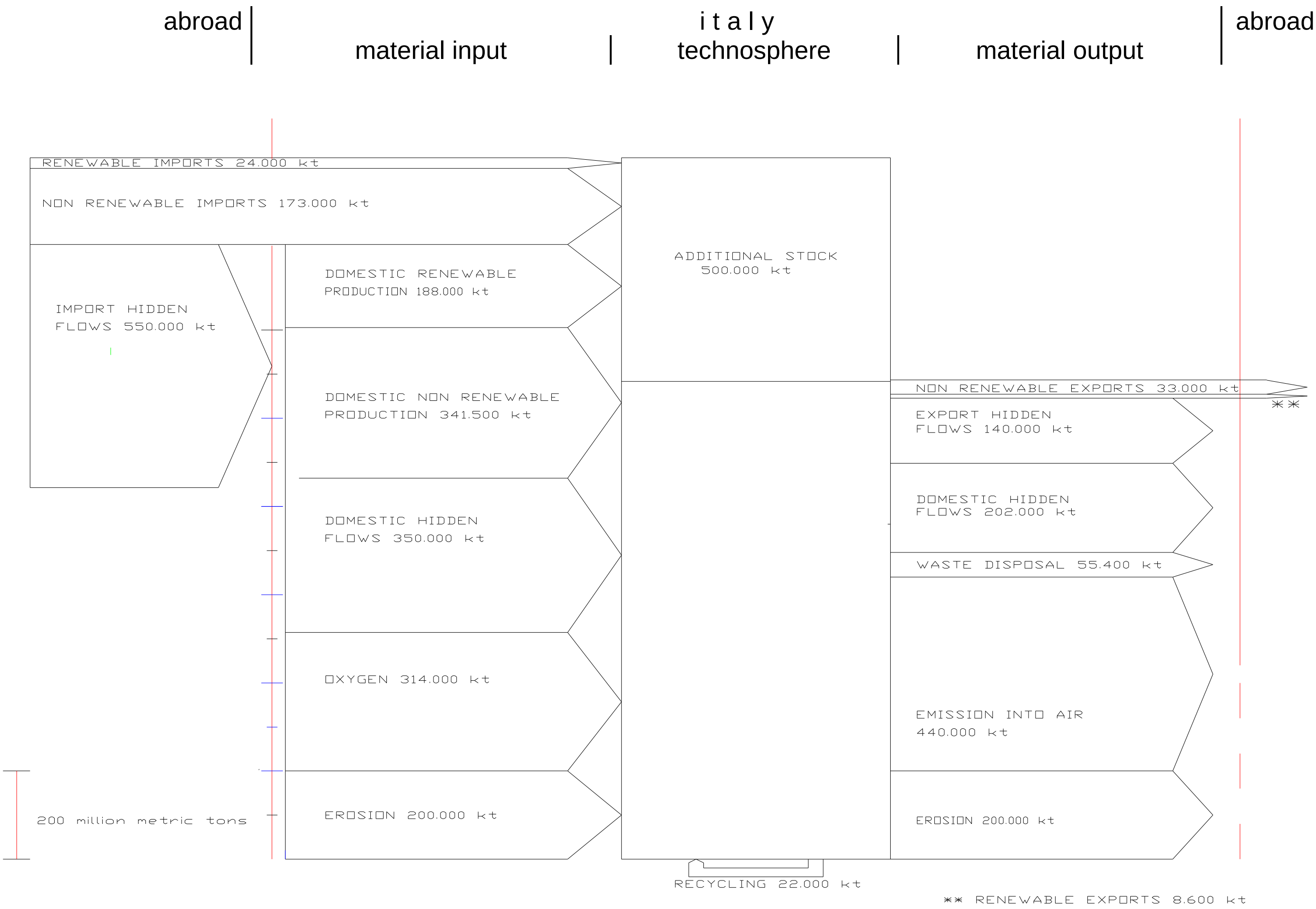
Table 1- Direct Material Inputs (DMI) of Italian Economy in 1994 and 1975.

Materials	1994 kt	%	% of total	kg/ab	1975 kt	%	% of total	kg/ab
Stone	93,086	31	14	1,625	107,630	33	15	1,928
Sand and Gravel	118,317	39	17	2,066	137,058	43	20	2,455
Cement	34,488	11	5	602	33,951	10	5	608
Clays and pozzolan	41,818	14	6	259	32,615	10	5	584
Other non metals	8,448	3	1	148	10,383	3	1	186
Salt	4,240	1	1	74	4,151	1	1	74
Total non Metals	**300,397**	**100**	**44**	**4,774**	**325,788**	**100**	**47**	**5,835**
Petroleum	95,420	63	14	1,666	88,496	73	12	1,585
Carbon	16,685	12	2	291	14,344	12	2	257
Natural Gas	38,274	25	6	668	18,141	15	3	325
Total Fossil Fuels	**150,379**	**100**	**22**	**2,625**	**120,981**	**100**	**17**	**2,167**
Iron and steel	28,299	92	4	494	21,544	95	3	386
Aluminium	1,109	4	0.16	19	404	2	0.06	7
Copper	630	2	0.09	11	326	1	0.05	6
Other metals	717	2	0.10	13	504	2	0.07	9
Total Metals	**30,755**	**100**	**4**	**537**	**22,778**	**100**	**3**	**408**
Industrial Wood	5,882	41	1	103	4333	51	0.6	78
Fuelwood	3,192	22	0.5	56	2686	32	0.3	48
Natural Textile Fibre	665	5	0.10	12	392	5	0.06	7
Natural Rubber	126	1	0.02	2	122	2	0.02	2
Paper and Pulp	4,391	31	0.6	77	884	10	0.1	16
Total No Food Organic Substances	**14,256**	**100**	**2**	**250**	**8,417**	**100**	**1**	**151**
Plant biomass (cereals, vegetables)	155,351	82	23	2,713	192,371	87	27	3,446
Plant biomass (fruit)	19,235	10	3	336	19,461	9	3	349
Fish, Livestock and derivatives	14,083	8	2	246	10,042	4	2	180
Total Food Organic Substances	**188,669**	**100**	**28**	**3,295**	**221,874**	**100**	**32**	**3,975**
TOTAL	**684,456**		**100**	**11,481**	**699,838**		**100**	**12,536**

The population in the 1994 was 57.268.578, in the 1975 it was 55.827.000.

Table 2 - ***Renewable and Non Renewable Direct Material Inputs and Hidden Flows***

	1994 production kt	1994 hidden flows kt	1975 production kt	1975 hidden flows kt
Domestic Non Renewable	341.419	278-294.000	360.132	228.000
Domestic Renewable	187.548	66.000	220.723	57.000
Total Domestic	**528.967**	**344-360.000**	**580.855**	**285.000**
Non Renewable Import	172.811	520.000	135.411	294.000
Renewable Import	23.962	34.000	14.767	23.000
Total Import	**196.773**	**554.000**	**150.178**	**317.000**
Non Renewable Export	-32.699	-137.000	-25.996	-48.000
Renewable Export	-8.585	-11.000	-5.199	-5.500
Total Export	**-41.284**	**-148.000**	**-31.195**	**-53.500**
TOTAL	**684.456**	**750-770.000**	**699.838**	**655.500**



Material demand of the Brazilian economy: a first approach

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Abstract

The present work gives a general overview of the material demand of the Brazilian economy, considering the main natural resources, relating them to their specific kind of use in the different economic sectors.

The material demand of each sector is then correlated to monetarian values of the national accounting system actually used in Brazil, and compared to the results recently published in other countries, like USA, Japan and EU.

The methodological approach is based on the Material Flow Account studies developed mainly in Austria, The Netherlands and Germany. The database used to obtain the primary information is extracted from the official agency for national statistics (IBGE) and important sectorial organisations.

The main goal of the study is to create the basic conditions to develop a consistent view of the social-economic metabolism of Brazil to produce an indicator system, able to measure the qualitative and quantitative importance of the natural resources used in the Brazilian economy.

A full paper was not available.

An Input-Output Approach to Analyse the Total Material Requirement (TMR) of National Economies

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Introduction

Sustainable Development requires de-linking of "welfare" and "use of nature"
Humans striving for more "*welfare*" seem to be unlimited. Sooner or later, the resource and waste flows ("*use of nature*") fuelling humans welfare will exceed carrying capacities of the earth. Sustainable Development calls for a de-linking of "*welfare*" and "*use of nature*". In particular, industrialised economies are challenged to reduce their "*use of nature*". The concept of eco-efficiency is standing at the core of a progress towards achieving "more welfare with less nature".

Indicators for "welfare"
The gross domestic product (GDP) measuring all economic activities within a national economy is the most accepted indicator to express "*welfare*". The calculation is based on the U.N. System of National Accounts (SNA).
However, GDP as a measure of welfare or well-being has often been criticised. Several indicators like the *Index of Sustainable Economic Welfare* (ISEW) or the U.N. *Human Development Index* have been developed in order to measure more accurately "*welfare*".

Possible Indicators for "use of nature"
There is as yet no such comprehensive and well accepted indicator like GDP for the "*use of nature*".
The environmental performance of industrial economies resolves itself widely as a metabolism between technosphere and eco-sphere (Ayres/Simonis 1993, Baccini/Brunner 1991, Fischer-Kowalski et al. 1997). Resources are taken from nature and transformed to products and services in order to satisfy mankind's needs. Due to the law of conservation of matter all material inputs into the technosphere will leave it sooner or later as solid or liquid wastes or air emissions.
Although, some interesting proposals to formalise the environmental performance of human activities have been made (Georgescu-Roegen 1971, Ayres 1994, Lawn 1998 etc.) there is still no general accepted theory of "*use of nature*". Beside others, this might be one reason for the lack of well accepted indicators for the "*use of nature*" on a comparable information hierarchy as socio-economic indicators like GDP, unemployment rate or inflation rate.
Recently, movements towards core-sets of 5-20 environmental "headline" indicators can be observed[14].

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14 Germany: "Umweltbarometer"; UK: "Sustainability Counts"; Sweden: "Gröna Nyckeltal"

As sufficient is known about some negative impacts from the *use of nature*, such as acidification, ozone depletion, climate change and some toxicities/eco-toxicities, any 'core' set could include 'impact' or output indicators, as well as resource input indicators (Gee/Moll 1998):

Inputs (resource use):	Outputs (impact/pollutants):
- material input	- greenhouse effect
- energy	- acidification
- land-use	- ozone depletion
- water	- (hazardous) waste
	- chemicals

Formalising de-linking: basic equations & absolute and relative de-linking
There are two simple possibilities to combine "*welfare*" and "*use of nature*" in terms of a tautology (see Box). The absolute amount of "*welfare*" is the product of the *resource productivity* and the absolute amount of "*use of nature*". *Resource productivity* expresses how much "*welfare*" is achieved from one unit of "*use of nature*". It is, hence, perceivable as an expression of technology. Vice versa, the total amount of "*use of nature*" is the product of the *eco-intensity* and the absolute "*welfare*". *Eco-intensity* expresses how much "*use of nature*" is required to achieve one unit of "*welfare*". Again, *eco-intensity* can be interpreted as a notion of technology. Recently, the re-introduction of natural resources as a primary production factor has been advocated (see Bleischwitz 1998).

$$\text{welfare} = \frac{\text{welfare}}{\text{use of nature}} * \text{use of nature}$$

↗ *resource productivity*

$$\text{use of nature} = \frac{\text{use of nature}}{\text{welfare}} * \text{welfare}$$

↗ *eco-intensity*

While observing the development of "*welfare*" and "*use of nature*" over the time it is useful to distinguish *relative* and *absolute de-linking*. As long as the growth rate of "*welfare*" is higher than the growth rate of *resource productivity*, a relative de-linking occurs, i.e. "*use of nature*" has a positive growth rate, i.e. is increasing in absolute terms:

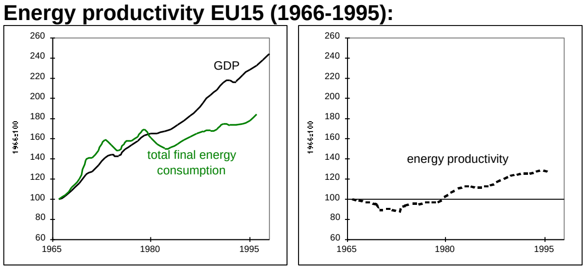
relative de-linking: $$\Delta Y > \Delta \frac{Y}{R}$$

Absolute de-linking occurs if the growth rate of *resource productivity* is higher than that of "*welfare*":

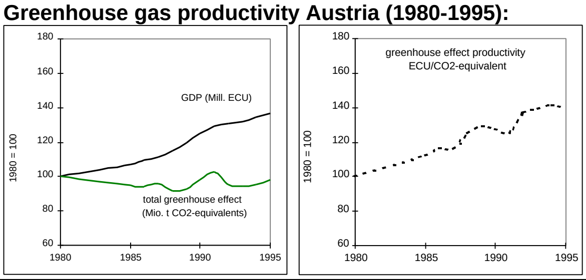
absolute de-linking: $$\Delta Y < \Delta \frac{Y}{R}$$

Examples for de-linking
Using more than one indicator for the "*use of nature*" (see section 1.3) implies that de-linking analyses have to differentiate several developments.
As regards prominent air emissions (SOx, NOx) an absolute de-linking can be observed. This is clearly a success stemming from the command & control oriented environmental policies of the recent decades.
As regards CO_2 (and other greenhouse gas emissions) a relative de-linking can be observed and an absolute de-linking is envisaged according to the Kyoto protocol.
The resource use (energy, materials) has de-linked relatively since the oil crisis. However, looking at the more recent data, a re-linking seems to be expectable.

Energy productivity EU15 (1966-1995):

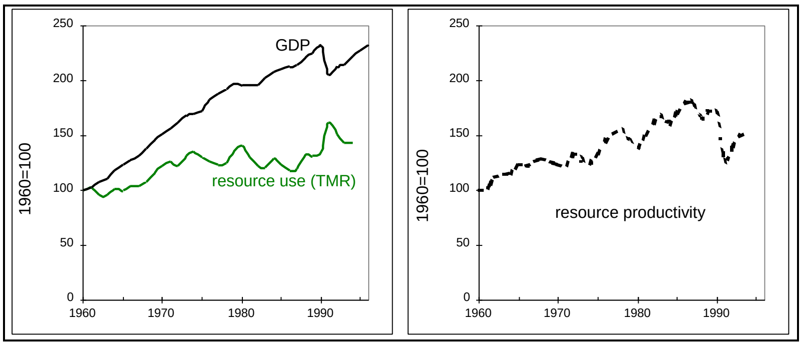


Greenhouse gas productivity Austria (1980-1995):



For wastes and water consumption no de-linking at all has been observed so far. In addition, data availability for those indicators is rather weak.

The target question for the following study
The following graph shows the development of resource productivity in Germany for the period 1960-1996. The resource use of Germany (operationalised by the indicator *Total Material Requirement*, TMR, see Adriaanse et al. 1997, Bringezu/Schütz 1996) de-linked from GDP at the end of the seventies until the reunification of Germany. The TMR increased by 0.8% between 1980-1990, whereas the GDP grew 24.9%. The objective of this study is to analyse the economic determinants of this de-linking using an input-output model approach extended by resource inputs combined with decomposition techniques. The method introduced can also be used to investigate the de-linking of other environmental indicators as mentioned in section 1.3.



Method[15]

The input-output framework
The input-output framework according to the system of national account provides a highly dis-aggregated picture of the national economy. Through linking the material flows to the particular economic activities, the contribution of each economic activity to the total de-linking can be identified. Knowing how much a certain economic activity is responsible for the resource use might be a useful information for policy as regards setting priorities for policy measures.
One main feature of the system of national accounts which is conceptually based on the *economic cycle* is the distinction of two main complementary elements: production and consumption. This means, production and consumption cannot be separated hence all production outputs are produced to be consumed. In the end, all material flows between economy and nature - be it resource inputs or pollutants outputs - can be attributed to the so-called final demand (comprising consumption of private households and state, investments, and exports).
This is reflected by the basic input-output model developed by Leontief. The basic model re-attributes the total production output (**q**) to the final demand (**y**). Depending on how differentiated final demand is considered, three equations can be derived:

$$\mathbf{q} = (\mathbf{I} - \mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}\mathbf{y}_{\mathbf{inl}} \quad (1a)$$

$$\mathbf{Q}^{*}_{\mathbf{Y}}(\mathbf{inl}) = (\mathbf{I} - \mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}\mathbf{Y}_{\mathbf{inl}} \quad (1b)$$

$$\mathbf{Q}^{*}_{\mathbf{y}}(\mathbf{inl}) = (\mathbf{I} - \mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1} < \mathbf{y}_{\mathbf{inl}} > \quad (1c)$$

The basic model can be extended by any primary input (**r**), e.g. material flows. Those primary inputs are also re-attributable to final demand (**y**). The extended input-output scheme comprises the following matrices and vectors:

[15] For a comprehensive description of the method in German see Moll et al. 1998. The method is influenced and motivated by several studies: see e.g. Stahmer 1992, Femia 1996, Proops/Faber/Wagenhals 1993, Femia/Hinterberger/Renn 1998, Behrensmeier/Bringezu 1995.

$\mathbf{X_{inl}}$, $\mathbf{X_{imp}}$: intermediate goods (from domestic production and imports)
$\mathbf{q}$: total of domestic production
$\mathbf{Y_{inl}}$, $\mathbf{Y_{imp}}$: final demand of goods (from domestic production and imports)
$\mathbf{p}$: total of imports
$\mathbf{r_{Xinl}}$, $\mathbf{r_{Ximp}}$: resource inputs to production sectors (domestic and via imports)
$\mathbf{r_{Yinl}}$, $\mathbf{r_{Yimp}}$: resource inputs to categories of final demand (domestic and via imports)

Decomposing the change of TMR between 1980 - 1990
In order to investigate the change of TMR use between 1980 and 1990 the method of decomposition is used. Thereby the change of total TMR can be decomposed in several effects like *intra* and *inter* structural change and changes in final demand.

A model to analyse the total resource requirement (model 0)
The following model shows the total *vertical integrated* resource use (TMR_y^*) in terms of a scalar. The model comprises four parts:

$$\begin{aligned} TMR_y^* &= R_y^*(inl) + \mathbf{r'}_{\mathbf{Y_{inl}}}\,\mathbf{e} + R_y^*(imp) + \mathbf{r'}_{\mathbf{Y_{imp}}}\,\mathbf{e} \\ &= \mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{inl}}}(\mathbf{I}-\mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}\mathbf{y}_{\mathbf{inl}} \\ &\quad + \mathbf{r'}_{\mathbf{Y_{inl}}}\,\mathbf{e} \\ &\quad + \mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{imp}}}(\mathbf{I}-\mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}\mathbf{y}_{\mathbf{inl}} \\ &\quad + \mathbf{r'}_{\mathbf{Y_{imp}}}\,\mathbf{e} \end{aligned} \tag{2a}$$

Decomposing this model (using the "central difference assumption", i.e. weighting with the mean) leads to the following equation:

$$\begin{aligned} \Delta TMR_y^* &= \Delta\mathbf{r'}_{\mathbf{Y_{inl}}} \\ &+ \Delta\mathbf{r'}_{\mathbf{Y_{imp}}} \\ &+ \Delta\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{inl}}}\,\overline{(\mathbf{I}-\mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}}\cdot\overline{\mathbf{y}_{\mathbf{inl}}} \\ &+ \Delta\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{imp}}}\,\overline{(\mathbf{I}-\mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}}\cdot\overline{\mathbf{y}_{\mathbf{inl}}} \\ &+ (\overline{\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{inl}}}} + \overline{\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{imp}}}})\cdot\Delta(\mathbf{I}-\mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}\cdot\overline{\mathbf{y}_{\mathbf{inl}}} \\ &+ (\overline{\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{inl}}}} + \overline{\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{imp}}}})\cdot\overline{(\mathbf{I}-\mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}}\cdot\Delta\mathbf{y}_{\mathbf{inl}} \\ &+ \text{Rest} \end{aligned} \tag{2b}$$

The particular effects which can be distinguished within this model and the results are given in the following table:

Model 0	Effect	Contribution to changes compared to 19980
$\Delta \mathbf{r'}_{\mathbf{Y_{inl}}}$	**domestic production - direct final demand effect**	**0.0%**
$\Delta \mathbf{r'}_{\mathbf{Y_{imp}}}$	**imports - direct final demand effect**	**2.3%**
$\Delta \mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{inl}}}$	**domestic production - direct resource productivity technology effect**	**8.0%**
$\Delta \mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{imp}}}$	**imported intermediate goods effect**	**-1.0%**
$\Delta(\mathbf{I}-\mathbf{X}^{\mathbf{q}}_{\mathbf{X_{inl}}})^{-1}$	**indirect resource productivity effect (Leontief effect)**	**-22.0%**
$\Delta \mathbf{y}_{\mathbf{inl}}$	**final demand effect**	**13.1%**
Rest		**0.4%**

The main results of model 0 are:

- Ceteris paribus (i.e. if the structure of production system have remained the same) the increase of final demand between 1980-1990 would have caused an increase of TMR by 13%.
- The most significant effect for the relative de-linking was the improvement of the indirect resource productivity of domestic production sectors (*inter* structural change).

A model to analyse TMR by categories of final demand (model 1)

Model 0 re-attributed the TMR (scalar) to the aggregated final demand. The following model 1 re-attributes the TMR to the six categories of final demand. This time, a vector with the dimension 1,6 is standing on the left hand side of the equation:

$$\begin{aligned}\mathbf{r'}^*_{\mathbf{Y}} &= \mathbf{r'}^*_{\mathbf{Y}}\,(\mathbf{inl}) + \mathbf{r'}_{\mathbf{Y_{inl}}} + \mathbf{r'}^*_{\mathbf{Y}}\,(\mathbf{imp}) + \mathbf{r'}_{\mathbf{Y_{imp}}} \\ &= \mathbf{r'}^*_{\mathbf{X_{inl}}}(\mathbf{I}-\mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}\mathbf{Y_{inl}} \\ &\quad + \mathbf{r'}_{\mathbf{Y_{inl}}} \\ &\quad + \mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{imp}}}(\mathbf{I}-\mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}\mathbf{Y_{inl}} \\ &\quad + \mathbf{r'}_{\mathbf{Y_{imp}}}\end{aligned} \qquad (3a)$$

The decomposition of equation (3a) leads to:

$$\begin{aligned}\Delta\mathbf{r'}^*_{\mathbf{y}} &= \Delta\mathbf{r'}_{\mathbf{Y_{inl}}} \\ &+ \Delta\mathbf{r'}_{\mathbf{Y_{imp}}} \\ &+ \Delta\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{inl}}}\,\overline{(\mathbf{I}-\mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}}\cdot\overline{\mathbf{Y_{inl}}} \\ &+ \Delta\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{imp}}}\,\overline{(\mathbf{I}-\mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}}\cdot\overline{\mathbf{Y_{inl}}} \\ &+ (\overline{\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{inl}}}} + \overline{\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{imp}}}})\cdot\Delta(\mathbf{I}-\mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}\cdot\overline{\mathbf{Y_{inl}}} \\ &+ (\overline{\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{inl}}}} + \overline{\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{imp}}}})\cdot\overline{(\mathbf{I}-\mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}}\cdot\Delta\mathbf{Y_{inl}} \\ &+ \text{Rest}\end{aligned} \qquad (3b)$$

The effects distinguished in model 1 and the results for the decomposition are listed in the following table:

Effect	Private consumption	State consumption	Machinery, equipment	Buildings	Stock-changes	Exports	Total
	changes of the components in % compared to 1980						
$\Delta \mathbf{r'}^{*}_{\mathbf{Y}}$, to explain	8,0%	-9,6%	5,2%	-14,3%	-22,9%	3,5%	0,8%
$\Delta \mathbf{r'}_{\mathbf{Y_{inl}}}$	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
$\Delta \mathbf{r'}_{\mathbf{Y_{imp}}}$	5,4%	0,0%	2,8%	0,1%	15,2%	1,2%	2,3%
$\Delta \mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{inl}}}$	12,7%	11,4%	5,7%	1,2%	-25,1%	8,8%	8,0%
$\Delta \mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{imp}}}$	-3,3%	-2,4%	1,2%	2,1%	20,3%	-1,5%	-1,0%
$\Delta (\mathbf{I} - \mathbf{X}^{\mathbf{q}}_{\mathbf{X_{inl}}})^{-1}$	-19,5%	-27,8%	-30,5%	-17,4%	-13,1%	-23,5%	-22,0%
$\Delta \mathbf{Y_{inl}}$	12,4%	8,8%	25,0%	-0,2%	-19,7%	18,0%	13,1%
Rest	0,3%	0,3%	1,0%	0,1%	-0,4%	0,5%	0,4%
in absolute terms: $\Delta \mathbf{r'}^{*}_{\mathbf{Y}}$ '80-'90	120.352	-21.430	21.717	-155.131	-9.534	92.597	48.571

The main results of model 1 are:

- Changes in consumption of private households and exports would have caused (ceteris paribus) a significant increase of TMR between 1980-1990 mainly due to increased demand.
- Changes in final demand of buildings would have caused (ceteris paribus) a significant decrease of TMR, mainly due to constant level of final demand and increased indirect resource productivity (Leontief effect).
- Resource productivity has indirectly increased in the production of machinery and equipment.

A model to analyse TMR by categories of goods (model 2)

In order to investigate the relative de-linking of TMR and economic growth between 1980-1990 in a more differentiated way, the following model 2 re-attributes the total TMR to the final demand differentiated by 55 goods. In this model (which comprises only 3 parts), a vector (1,55) is standing on the left hand side of the equation:

$$\begin{aligned} \mathbf{r'}^{*}_{\mathbf{y}} &= \mathbf{r'}^{*}_{\mathbf{y}}\,(\mathbf{inl}) + \mathbf{r'}^{*}_{\mathbf{y}}\,(\mathbf{imp}) + \mathbf{r'}_{\mathbf{y_{imp}}} \\ &= \mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{inl}}}\,(\mathbf{I} - \mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1} < \mathbf{y_{inl}} > \\ &\quad + \mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{imp}}}\,(\mathbf{I} - \mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1} < \mathbf{y_{inl}} > \\ &\quad + \mathbf{r'}_{\mathbf{Y_{imp}}} \end{aligned} \tag{4a}$$

The decomposition of this model leads to:

$$\begin{aligned} \Delta \mathbf{r'}^{*}_{\mathbf{y}} &= \Delta \mathbf{r'}_{\mathbf{Y_{imp}}} \\ &+ \Delta \mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{inl}}}\,\overline{(\mathbf{I} - \mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}} \cdot \overline{< \mathbf{y_{inl}} >} \\ &+ \Delta \mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{imp}}}\,\overline{(\mathbf{I} - \mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}} \cdot \overline{< \mathbf{y_{inl}} >} \\ &+ (\overline{\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{inl}}}} + \overline{\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{imp}}}}) \cdot \Delta (\mathbf{I} - \mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1} \cdot \overline{< \mathbf{y_{inl}} >} \\ &+ (\overline{\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{inl}}}} + \overline{\mathbf{r'}^{\mathbf{q}}_{\mathbf{X_{imp}}}}) \cdot \overline{(\mathbf{I} - \mathbf{X}^{\mathbf{q}}_{\mathbf{inl}})^{-1}} \cdot \Delta < \mathbf{y_{inl}} > \\ &+ \mathrm{Rest} \end{aligned} \tag{4b}$$

This models helps to identify those final demands of goods which have contributed to an increase or decrease of total TMR respectively. The increased final demand of non-ferro metals, road vehicles, and electricity has significantly contributed to an increase of total TMR. On the other hand, the decrease of final demand of coal, iron and steel, and construction has contributed towards a decrease of total TMR.

Conclusions

The method introduced allows the investigation of delinking processes in a highly disaggregated way (considering all economic activities in a consistent way). The method can be used for any kind of primary inputs (use of nature, emissions, wastes, water use, labour, value added). The decomposition method in combination with input-output approach provides a high heuristic potentials, i.e. wide range of questions can be tackled.

The following limitations of the method should be mentioned:

- rather ambiguous data requirements (input-output tables)
- high time lag of publication of input-output tables
- interpretation requires a certain level of expertise
- transport, as one of the main environmental policy fields, is not considered in an appropriate way due to SNA conventions
- re-attributation is based on monetary flows (and not on real, i.e. physical, flows)

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Industry's Demand for Dematerialization: a discussion of the point of view of Industrial firms in France

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INTRODUCTION

Dematerialization, Industrial Ecology, Resource Productivity, Industrial Metabolism or Eco-efficiency are terms that are today more and more widely accepted in international research on environmental problems and sustainable development. Events like the ConAccount meeting underline the recent expansion of the idea that reducing material flows in our societies will contribute essentially to environmental improvement via the prevention of emissions, wastes, soil movements and so on.

In spite of several attempts of applying these concepts on the microeconomic level, the main part of research is still focussed on the macroeconomic level. Material flow analyses are more and more regularly realised on the national level for different countries and deduced policies are most often national or supranational policies. Without criticising this fact at all, we think that the microeconomic level is crucial because it is here that basic economic decisions are taken; consumers and firms form the basis of overall human economic activity. We therefore propose that in order to implement Dematerialization[17] more efficiently, attention should be paid to firm performance and consumption patterns.

In our work we concentrate on the role of industrial firms for Dematerialization. Several other research groups focus on this subject, often however following a more technical approach, applying for example tools as life cycle analysis or MIPS in firms or analysing the functioning of eco-industrial parks like the Symbiosis project in Kalundborg, Denmark.[18] Our approach is a more socio-economic one, trying to discover reasons behind certain behaviour patterns and certain firm strategies concerning the environment. The fundamental question is thus not how a firm can contribute to Dematerialization, but why it might or might not do so. This kind of question leads to a more broad view on the possible acceptance of the metabolism ideas outside the research circles accustomed to the idea and its recent evolutions. We are therefore providing important results fur further implementations of the metabolism ideas in the real world.

The argumentation of this paper is based on a qualitative survey realised in May and June 1998 among eleven French industrial firms of different size, sector and origin, having as a common property the existence of an environmental management system.[19] In each one of these companies, we talked to persons in charge of environmental management. These semi-directive interviews were divided into two parts: one on the environmental management of the company and its consequences on competitiveness; another on Dematerialization, based on a short presentation of the concept and its possible application on the firm level. Our survey aimed at the induction of an "*industrial point of view on the Dematerialization concept* ", summarising the perceived consequences of dematerialising firm performances on environmental management, on competitiveness, and for industry in total. The first part of our interview helped us to better understand the "French way" of taking nature into account in industrial firms and serves as a basis for reflections on Dematerialization.

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17 Among the several related terms mentioned in the beginning, we use "Dematerialization" for designing the idea to reduce material flows and improve resource productivity.

18 See for example Liedtke et al. (1994), Schmidt-Bleek (1994), Marstrander (1994), or (for information on Kalundborg) the website: http://tbe.mit.edu/kalundborg.htm.

19 We are grateful for the willingness to receive us and to participate in our study to the following firms: Louis Vuitton-Moët-Hennessy, Hélio Corbeil, 3M France, Gaz de France, L'Oréal, Saint Gobain Emballages, Elf Aquitaine, Soplaril, Procter & Gamble, Elopak, Renault. Of course, the results of our study do not necessarily represent the view of each one of these firms. We have aggregated and interpreted the data from our personal point of view.

Environmental management and dematerialization: the French case

Framework of analysis: environmental management in France

Before presenting the results of our analysis, some words should be said about methodology. We have realised a qualitative analysis and our interviews were based on a semi-directive guideline. Since the analysis of qualitative data does not follow mathematical rules, but careful interpretation and intuition, we can not make statistically rooted statements about French industry in general. [20] We will rather propose a certain number of hypotheses on the signification of a concept as Dematerialization for industrial firms and vice versa. The nature of our sample adds to this form of results: since the aim of our study was not to draw a representative picture, we have chosen firms that had already institutionalised a system of environmental management. This fact makes them some sort of an ideal in French industry: industrial (as well as public) environmental consciousness is slightly lower in France in comparison to its Northern European neighbours.[21] The chosen firms can thus be characterised as "leaders" in the French context. And since leaders are supposed to make others follow, our sample <u>potentially</u> represents French industrial firms, in case the others decide to follow them. The hypotheses we propose are therefore valid for French industry in case it might develop according to the principle of taking nature into account.

In the first part of our interview, we questioned the firm representatives on the reasons for adopting environmental management, the applied instruments, personal factors concerning the environmental managers, and obstacles they see for an efficient environmental performance. We further talked about competitiveness and environmental performance: financial aspects, innovation, regulation and public perception of the firms' environmental concern. We finally identified, with the help of our interview partners, the most important actors that play a role in the firm's environmental performance. These elements allowed us to draw a picture of environmentally conscious firms and especially the French particularities that might distinguish French industry from other countries. What we learned is the following:

- The different **systems of environmental management** have been established following external pressure, like environmental legislation, market pressure (for example the energy crises in the 1970s), new customs in industry spilling over from more environmentally conscious countries, or influence from parent companies (for some of the multinational companies in our sample). The methods and procedures they apply are "modern" in the sense of being holistic, implying decision making tools like measures of emission flows, energy input etc…, being firmly established, including top management as well as more operational levels. However, some tendencies towards end-of-the-pipe measures were still clearly visible and the "traditional" industrial objective of cost minimisation and profit maximisation is obviously dominant in comparison to ecological and ethical considerations.
- The **firms' competitiveness** is both positively and negatively influenced by the fact of taking nature into account. Positive aspects are the possibilities to improve the company's image, to attract new customers, to decrease costs, and to anticipate new legislation. Negative effects on competitiveness are the necessity of high investments often not profitable in the short run, as well as unreasonable actions imposed by legislation.[22] In sum, the most influential factor seems to be environmental legislation, perceived as a constraint because it imposes higher costs and investments. On the other hand, legislation has contributed largely to the expansion of environmental management systems in France and the companies are increasingly trying to be ahead of new legislation. A certain dynamics has thus been created through legislation, which would otherwise probably have appeared much more slowly.

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[20] On the methodology of qualitative analysis see for example Freyssinet-Dominjon (1997) or Miles / Huberman (1984).

[21] An example demonstrates this fact: in France, only 177 firm sites were certified ISO 14.000 on November 3rd, 1998, and 21 were certified EMAS on July 21st, 1998. Information obtained from the website: http://www.oree.com/gestion/normes.htm.

[22] We elsewhere intensified our research focus on factors influencing the competitiveness of French industrial firms in the environmental context, and also identified the outstanding importance of environmental legislation. The examined case was petroleum refining, which we analysed in the framework of a European research project: see Allal et al. (1998).

- Concerning the **actors influencing the environmental performance** of industrial firms in France identified in our interviews, the most important are industrial associations (traditional sector associations as well as business organisations for the environment): the firms seem to prefer to act as a group signifying higher negotiation and lobbying force but also more efficient exchanges of information and experiences. However, the exchange between firms remains a critical point – environmental management is considered as a competitive factor, because sensitive data are handled and some kind of "environmental competition" seems to be developing due to which the firms are cautious with information on their environmental performance. Other essential actors are governments and ministries. This corresponds to what we have mentioned about legislation; the dialogue with ministries and legislators is crucial for a firm to be able to anticipate new legislations and to influence the process of creation of new laws, norms and standards. Insurance companies insuring pollution damages are third group of actors: firms aim at determining their optimal rate of insurance. Even if insuring oneself against the risk of pollution is nowadays a "normal" procedure within industry, we still have to remark that the fact that insurance companies are underlined as one of the most important external actors in environmental management hints at a spirit not corresponding to pollution prevention, but focussing on pollution already caused. Finally, consumers are considered as significant for environmental management. Their positive or negative reaction to a firm's image or to its products is crucial for competitiveness. To give an example: one of the reasons mentioned for not effectuating environmental innovation is the lack of environmentally oriented demand. French consumers seem less interested in environmental characteristics of products or in the environmental performance of firms. Environmentally orientated demand is a phenomenon only recently developing in France and might play a more important role for environmental management in the future.

The sum of these broadly outlined elements forms an important starting point for our analysis of the opinion of French environmental managers towards Dematerialization: a strong focus on legislation, a relatively weak public environmental demand, but an eagerness to efficiently integrate the environment into day-to-day management.

Dematerialization in the eyes of French industry

Keeping the presented general framework in mind, we analysed the reactions of our interview partners to the presentation of the Dematerialization concept, its basic idea and ways of how to implement it in industrial firms. Most of the eleven interviewed persons did not know the concept before the interview, although some of them were familiar with notions such as Eco-efficiency or Factor 4 or 10. Their reactions were mixed and they brought forward a large set of arguments for and against the concept. It is worth mentioning that one argument was prevalent in most of the interviews: the interviewees more or less all stated that the concept corresponds to what they are doing, anyway. In other words, the idea to reduce material flows and thus to reduce costs corresponds to the traditional economic principle saying that a given objective should be reached with minimal input or that a given input should be used for reaching a maximum output.

Among the mentioned disadvantages was, above all, the problem of materials quality, a problem widely discussed in research on Dematerialization and material flow analysis: how can different levels of environmental impact of materials such as toxicity, biodegradability, radioactivity etc… be embraced in these quantitative concepts? Several interview partners underlined this aspect because decisions on the choice and substitution of materials often seem to be based on such characteristics.

Another disadvantage mentioned in the interviews is the risk of harming industry in general if Dematerialization aims at a general reduction of material consumption in our societies. Indeed, one of the goals covered by the idea of dematerialising society is to reach the satisfaction of needs and wants with the help of less material input. Studies such as "Sustainable Germany" (BUND / MISEREOR, 1996) request that consumers undergo a change in their habits and demand structures towards less material demand: people should try to live in a "good" way instead of "having a lot". Focus is thus laid on "well-being" instead of "well-having". Without wanting to discuss these arguments in further detail, it is clear that

from an industrial point of view, this represents a threat because the general need for industry in its present form and significance is questioned; and even if there will most probably always be some kind of production of material goods in our societies, the mentioned requests must sound alarming to an industrialist (although we did not present these aspects of Dematerialization in our interviews – the conclusion was drawn by the persons themselves).
A third critical point was the fact that the potential adoption of a new way of managing the environment would necessarily require internal changes in management. Some of the interview partners regarded their own management structures as equally efficient and some feared the costs involved with refocusing their environmental objectives. This corresponds to the general phenomenon of firms' aversion against innovation and change.

Even if the mentioned critical aspects are important and some of the interviewed persons were sceptical about the idea of Dematerialization, most of them were rather open-minded toward this concept and saw quite a potential of advantages for a firm implementing it. This open-mindedness was surely due to the mentioned impression that the concept harmonises with what firms do in general, that is reduce costs and avoid wastefulness and losses. Dematerialization thus seems to correspond in a certain way to the traditional functioning principle of industrial firms. Most of the interviewees gave several examples of how their firms contributed to Dematerialization. They mentioned lighter products, longer living products, condensed products, recycled materials, less wasteful processes, closing of material loops (especially water), reuse of excess materials of production processes and so on… This shows that, even if the origin of these examples is not a Dematerialization goal and even if the concept is not even known in most of the firms we met, it does play some kind of a role in industrial management. To find out more about this phenomenon, we took a closer look at the reasons behind the implementation of the underlying changes for the sum of the examples given by the firms. Once again, it were mostly costs that were at the basis of these examples. Products and processes were made lighter, smaller or more efficient in order to reduce production costs, materials were recycled because it was financially more efficient to do so and wastes were reduced because it allows to avoid additional costs. Environmental reasons were, on the other hand, mentioned much less often as a reason for the “Dematerialization” measures.

To conclude on the industrial point of view on the Dematerialization concept, we would like to stress two aspects: firstly, we learned from our interviews concerning industry's need of environmental protection systems and measures. They need to harmonise with a firm's main activities and goals, and they need to be cost-efficient. Decision making tools should be easily applicable, based on easily available data and should include considerations on materials substitution. This makes clear that tools as MIPS are efficient and potentially applicable but not necessarily sufficient from a firm perspective. Additional tools or weighing procedures should be considered. Secondly, industry seems to be rather open-minded towards Dematerialization. It seems to fit into their considerations of reducing costs, avoiding wastefulness and improving efficiency. A critical point remains however the fact that the firms seem to focus merely on their own activities, the firms' physical limits seem to be those of their environmental considerations. Life cycle considerations transcending the firm's activities are not as frequent as can be considered as optimal from a holistic environmental perspective. We will discuss this point in more detail in the following paragraph.

Dematerialization in French industry? identification of obstacles and capacities

We will now take a closer look at the results presented above from a "Dematerialization perspective", that is we will analyse them concerning the potential to implement Dematerialization in industry respecting the basic principles of the concept. In order to do so, we have established a series of criteria that a firm should ideally comply with. These criteria are based, one the one hand, on what we have learnt so far from our analysis, and on the other hand on more theoretical considerations on the role of firms for Dematerialization as we have discussed elsewhere (see for example Haake, 1998, or Haake et al., 1999). We will compare the results of our study to these criteria and discuss if or if not (French) industry is apt to "really" dematerialise according to the principles pronounced in research and how possible obstacles can be overcome.

Criteria for the implementation of Dematerialization in industrial firms

Two sets of criteria that a firm should satisfy for an adequate implementation in industry of the Dematerialization to be guaranteed seem important from our point of view. The first one corresponds rather to a certain open-mindedness of the firm and its managers, which makes it a facilitating but not a necessary condition. The criteria included in this category are: an efficient and working environmental management system, the estimation that taking nature into account can help to reduce costs, and a general openness towards change and innovation. The first of these three aspects can facilitate the comprehension of the basic idea of Dematerialization and of the instruments needed to implement it on the firm level (this was also the reason for the choice of our sample). The second point represents an advantage for the promotion of Dematerialization in industry and thus facilitates the acceptance of the concept. The third criterion helps to avoid the aversion against risk, uncertainty and change - difficulties a new management concept necessarily meets when presented to a firm, which already disposes of an alternative system. It is clear that these three points represent possibilities to soothe the path towards the application of Dematerialization to environmental management inside a firm. They are preliminary conditions that ease the implementation, but in case they are not met, the obstacles (risk aversion, scepticism, inefficient or not existing environmental management) would not necessarily block the process of implementation.

More fundamental obstacles reside in the second set of criteria. One of them is the fact that even if environmental management is efficient and even if some of the measures taken tend towards the idea of Dematerialization, the entire life cycle of a product is not taken into account. Our survey shows that a clear message from the firms is missing showing their intention to assume total responsibility for their products, showing a clear interest in the origin of their raw materials and in the reduction of their transports, to give just some examples concerning life cycle wide thinking. Separate dematerialising measures can always be taken without accepting the concept as a general principle that covers the entire field of the firm’s activity. It even represents a risk to praise a firm taking such singular measures and to state that Dematerialization is actually taking place – the concept could easily become a possibility of advertising for something, which does not correspond to reality. This might then cause chain reactions within industry, with other firms realising that a concept is becoming popular that is easy to accomplish, even without implementing any kind of change, but simply by renaming already existing measures.

Another related obstacle is the focus on cost efficiency in environmental management. The idea of Dematerialization includes not only efficiency considerations, but also environmental concerns that might, in some cases, be more costly than would be considered as acceptable by a firm’s management. This includes not only process or product innovation, but also possible organisational changes towards more holistic management structures, including the upstream and downstream, inside and outside the company. It becomes clear that we are dealing with a difficult situation. While we discovered certain aspects facilitating the acceptance of the Dematerialization concept in the industrial world, it is exactly these factors that represent a certain risk. While it is a good sign that managers accept the possibility to reduce costs with the means of Dematerialization, the mere focus on costs is dangerous because environmental and ethical questions are likely to be left aside. In order to actually realise Dematerialization, it might be necessary for a firm to take certain measures exceeding the factual boarders of a firm’s activity, or traverse the limits of profitability. Of course, we can ask ourselves if it is absolutely necessary that all actors comply at 100% to the principles of Dematerialization, or if we accept singular actions leading at least in the right direction… We tend towards the "perfectionist" solution, given the risks of deteriorating the quality of total environmental industrial performance and of mere publicity action without actually doing something.

The sum of the proposed criteria is:

Favourable conditions in a firm for the acceptance and application of Dematerialization:

- an existing and efficient environmental management system,
- the conviction that environmental firm performance can help to reduce costs,
- an openness towards change.

Necessary conditions to ensure the correctness of the application of Dematerialization in a firm:

- life cycle wide thinking and actions,
- fundamental environmental conscience leading to the inclusion of precaution and prevention measures.

A check of our sample concerning the criteria

The first criterion seems to be satisfied by most of the firms in our sample: they nearly all practice what we identified as a consequent, holistic and efficient environmental management system. Consequently, this criterion does not disguise a major obstacle for the implementation of Dematerialization if we consider our sample to be potentially representing French firms. The same holds for the second criterion, the opinion on possible financial advantages of environmental firm performance. Most of the firms in our sample had made positive experiences, even if the financial advantage was often rather referred to as a long run phenomenon. The only obstacle we might see in this first set of criteria is the risk aversion and the short run orientation, which we identified in several of the firms we met. Implementing a new guideline in environmental management was not necessarily seen as an option that the firms were likely to choose. At this moment we could ask the question if a company not yet disposing of an established environmental management would more easily accept the Dematerialization concept (material flow analysis – deduced actions and instruments – product, process and marketing policy…) since it would not mean to change an existing concept. This consideration underlines the fact that this first set of criteria can not be considered as a necessary condition for the implementation of Dematerialization in a firms.

When comparing the second set of criteria to our sample, it is clear that we are facing a more complex question. Firstly, we have already stated that the environmental performance and interest of the firms were limited by their proper activity. Life cycle considerations were perhaps mentioned but did not necessarily lead to actions focussing on the upstream or downstream stages of the firms' product life cycles. Product take back, environmental requirements of raw materials, upgrading of used products or other examples of the kind did not count among the actions of environmental management. Neither do the firms seem to impose their environmental considerations on their sub-contractors, as does for example the French cosmetics company Yves Rocher (Lombard, 1998). Another related argument is the fact that the firms tend to look at the environment from a technological perspective. Marketing measures or "immaterial" actions focussing more on services (alternative sales forms, repairing services, promotion of the durability of products through use forms…) were not very often part of the discourse. With our second criterion we demanded that a firm should, apart from cost and efficiency calculations, also have an "environmental conscience". This is the case in our sample – most of the environmental managers we met were personally interested in environmental questions, a fact that we consider to be crucial because the person in charge with environmental management shapes to an important degree the ways of which this management is designed and carried out. Environmental considerations were however often not focussed on prevention and precaution and thus not able to outbalance the simple cost calculations limiting the possibility to implement Dematerialization effectively.[23] This reflection shows us that we deal with a difficulty and an important potential obstacle.

Following our analysis, the main potential obstacles in a company for the implementation of Dematerialization as well as the advantages that seem to favour the Dematerialization concept in the eyes of an industrial firm are:

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[23] A related argument is brought forward by Day (1998) stating that eco-efficiency might not be a concept strong enough to launch a "real" sustainable development.

<u>Advantages</u>

- The idea to reduce costs through material input reduction fits into the "traditional" framework of industrial firm performance,
- the conception of "modern" environmental management systems and connected knowledge levels of environmental managers facilitates the acceptance of the Dematerialization concept.

<u>Obstacles</u>

- The short term orientation and hostility against change, innovation and risk inside many companies,
- a lack of life cycle wide considerations and actions,
- a lack of prevention and precaution principles as basis of environmental management.

Is a synthesis possible?
We have learnt so far that Dematerialization represents a concept potentially furnishing advantages to a firm, and the reactions of the firm representatives we met were relatively positive. We thus dispose of a confirmed set of arguments speaking for Dematerialization with an industry-oriented reasoning. But, as we already mentioned, the mere promotion of the concept on this basis bears problems that might threaten sustainable development itself. The obstacles we observed and deduced are however not due to single viewpoints of the one or the other person we met, or linked to one or another firm in particular, but we can identify them as inherent to industry in general. The problems to overcome seem thus to be more deeply rooted in the functioning of our society. The conception itself of a firm and of industrial functioning represents a certain obstacle to dematerialization and sustainable development. When thinking about possibilities of how to conquer these obstacles, we find it difficult to say if solutions should come from inside a firm or if external influence might be more efficient.
Let's have a look at our analysis of French firms concerning the environment-competitiveness relationship. Some of the identified points might help us to think about possible solutions. Concerning external influence on industry, we have detected the importance of environmental legislation in France and the resulting orientation of environmental management. The functioning of French politics and economy has for a long time been shaped in a centralist manner. This could in fact mean that within the French context command & control instruments are likely to be more efficient in its influence on firms, at least in the short run, than market instruments. It would be important to find out how the mentioned obstacles can be attacked by legislation, that is how from an environmentalist's point of view, life cycle, prevention, and precaution aspects can be more effectively taken into account by firms. On the other hand, legislation bears the danger that firms merely comply with the norms and laws but do not exceed them – the risk is that firm action is reduced to reaction. Other identified external actors of importance in the French context are insurances, industrial associations, ministries and consumers. Information diffusion among these actors on Dematerialization might create an indirect influence, more incentive orientated that command & control methods. A possibility to foster action from the inside of the firm would be to emphasise the possibility to improve a company's image through Dematerialization. We have identified this factor as a crucial point in the positive relation between environmental management and competitiveness. By making the concept more known in the business world, but also among consumers, insurances, or politics, the business dynamics towards pro-active environmental orientation and innovation-friendliness could be improved. Further research will be necessary to investigate the mentioned possibilities.

Conclusion

The conclusion we draw from this paper particularly concerns its interest for future research and we want to insist on two points. The first is a direct conclusion that we reach from the results of our analysis. We identified an inconsistency between industrial firm performance including environmental management and the possibility of implementing Dematerialization. This inconsistency represents an important aspect that should be kept in mind when talking to firms about Dematerialization and related concepts. A thorough and careful application of the concept is necessary in order to avoid freerider behaviour of firms who would sell some of their activities under a notion *à la mode* although the environmental gain of the entire firm activity does not comply with the goals of sustainable development. We propose to go more into detail in future research than we did in this paper on the ways of how to overcome the mentioned inconsistencies.

The second point we would like to underline concerns our research method. We proposed a framework of analysis for research on the possibility to implement Dematerialization on the firm level: qualitative analysis focussing on a limited number of leaders in environmental management and leading to the identification of (a) the socio-economic external framework of the firms' environmental performance and (b) the opinions of environmental managers on the concept on Dematerialization (or whatever you might call it – Eco-restructuring, Eco-efficiency, Industrial Ecology…). This framework of analysis allowed us to induce a certain amount of hypotheses that then lead to the identification of areas of further research. An application of the same kind of research in other countries or in a particular sectoral case study would allow comparisons or even a generalisation of the stated case.

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Radical improvements in resource productivity: a review of the evidence

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Abstract

In this paper claims that radical reductions can be made in resource use in industrialised countries (dematerialisation) are tested using empirical evidence on historical materials throughput for the United States, Germany, Japan and the Netherlands. Much of this data is contained in the 1997 publication *Resource Flows: The Material Basis of Industrial Economies*, but this is supplemented where possible with data from other European countries. This paper presents a systematic reassessment of this data using a more restrictive definition of materials throughput in the economy. 'Direct resource inputs' (dry mass) are used, rather than the more ambiguous 'total material requirement' which includes materials displacements at the periphery of economic activity.

While there is evidence of improvements in relative resource productivity, patterns of improvement appear to be long-term, country-specific, and not rapid enough to enable current normative targets to be met (Factor 4, Factor 10). There is little evidence of a de-coupling between economic growth and materials throughput in economies. Even in relative terms, rates of improvement in materials intensity of economic activity appear to have slowed since the early 1980s. In absolute terms, industrial economies continue to expand in mass terms at a rate of 1-2 percent per year. In seeking to reduce these flows, the 'bulkies' (energy carriers and construction materials) would be the first target. The structure of energy systems changes only very slowly, while flows of construction materials appears to be cyclical (being closely related to business cycles). Industrial materials flows are much less important in terms of scale, but even in relative terms, materials efficiency improvements in industry appear to have slowed dramatically over the past decade. This may be related to low commodity prices and a lack of consistent policy signals encouraging efficiency.

A full paper was not available.

Coupling MFA and societal developments

Acting as a Cameleon: Material Flows of a Subsistence Economy in Northeast Thailand

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This paper presents a case study, in which we looked for indicators of sustainable development in rapidly changing societies[1]. Considering the vast amount of rapidly developing countries, especially in East and Southeast Asia, sustainability problems can be expected to arise in the near future. The research for this study was done in a small village in northeastern Thailand, a region that is unusually dry in the context of tropical Southeast Asia. The research is designed as a case study, but similar processes can be expected for the whole cultural area of Northeast Thailand, which is about 4 times the size of the Netherlands. The people we investigated are ethnic Lao, their main source of subsistence being rice farming. As Thailand's Northeast has a dry season of 5 to 6 months when agriculture is impossible, they also engage in hunting and gathering and, more recently, in off-farm hired labour (Fukui 1993; Klausner 1993).

The overall aim of the research was to look for alternative paths of sustainable economic development, concentrating on societies in transition from an agricultural to an industrial production system. In asking how to define the somewhat muddy concept of sustainability, we decided that we would look for indicators that let us know, how man's relationship to nature is constructed in a particular area. In this process we developed several indicators of sustainability, Material Flow Analysis (MFA) helping to provide several of these indicators (Fischer-Kowalski et al. 1997)

It has to be made clear, that - due to the difficult field situation and a limited budget - a concise, fully balanced Material Flow Analysis could not be achieved. For example, the output side of materials and energy in the production system has not been accounted for. Rather, we looked for indicators by which sustainability limits can be identified. In particular, we accounted for consumption of water, food, consumer goods, buildings, and energy.

SangSaeng, the name of the studied village, has a maximum of 191 inhabitants, although the actual population fluctuates strongly at any given time. We find a large number of migrants who, at least temporarily, work outside of the village. Migration forms an important part of *SangSaeng*'s economic activities, and it certainly represents an important factor when looking at societies in transition. Migrants are socially, but not geographically, members of the village community (Porpora; Lim 1987). However, their activities show totally different characteristics of material and energy consumption. Most of the time they are part of the global modern economy, but their activities also have major effects on the village structure. A large part of the influx of new materials can be traced back to migrants, whether these imports are caused by money or by goods sent back home. Together with modern consumer goods, village society is exposed to alien values and new world views. Migration is therefore a crucial factor influencing sustainability of the village economy in many ways.

Migrants are a part of the village community, and they confirm this by maintaining a tight network of exchanges between villagers and migrants. Nevertheless, in measuring material and energy flows, we used the figure of the actual population size at the time of the research for accounting, which was 155 inhabitants.

[1] The data in this paper was collected during fieldwork in 1998. Members of the IFF-Dept. of Social Ecology carried out the research project. An in-depth description of the project's aims, methods, and results is provided by Grünbühel, C.M.; Schandl, H.; Winiwarter, V. 1998

Water

A total of almost 9 million litres are used in one year. This amounts to 55.700 litres per capita. Household water use amounts to about $^{2}/_{3}$ of total water use. This includes water used for cooking, drinking, washing, and the irrigation of small kitchen gardens. Household water is rainwater, either directly collected from the roof in jars, or ground water from manually dug wells.

Additionally, we have irrigation water for rice growing at 2.676.000l/annum. We find here a recent innovation in the agricultural system. The water is generated by diesel-fuelled water pumps and used for the irrigation of rice seedbeds, which are critical for the farming process. Traditional agriculture was exclusively rain-fed, meaning that the producers had to wait for the rainy season to bring enough water (Fukui 1993). With the use of the water pump, preparations can start earlier in the year and risk of water shortage is reduced. Not all households in *SangSaeng* use water pumps, some fields not being located near any water source.

***Table 1: Water use in* SangSaeng**

	litres per year	utilised for
water use in households	6,193,000	cooking, drinking, washing, gardening
agricultural water use	2,676,000	watering of seedbeds
total	**8,869,000**	
per capita water use	55,700	

Source: Data collection in *SangSaeng*, NE-Thailand (1998)

Total water consumption in *SangSaeng* is about 159 l/capita/diem. In comparison, an average Austrian - representing consumption in an industrial society - needs 1500 l/capita/diem, including water used for agricultural and industrial production. Household water consumption lies only little below the calculated personal water consumption of an average Austrian (109 vs. 130 litres/diem; cf. Hüttler et al. 1996).

Food

The average nutritional intake in *SangSaeng* ranges between 2.600 and 3400 kcal. Amount of consumed calories does not seem to relate to the wealth or status within the village community. Rather, the kind of food consumed seems to characterise wealthy and poor households. While better-off households eat meat, which they buy on the market, the others catch fish to supplement their diet. The staple food remains rice - of the glutinous variety - in all cases.

***Table 2: Food consumption in* SangSaeng**

household's social characteristics	wealthy	inter-mediate	inter-mediate	low income	low income
adults	6	2	3	6	2
children	2	1		3	3
household members	7.5	2.75	3	8.25	4.25
total calorie intake [kcal]	24,826	8,331	9,637	27,734	11,215
kcal per person	**3,310**	**3,030**	**3,212**	**3,362**	**2,639**
kJ per person	**13,856**	**12,684**	**13,445**	**14,073**	**11,047**
meat consumption [g]	1,650	500	550	300	

Source: Data collection in *SangSaeng*, NE-Thailand (1998)

Consumer goods

As indicated, the recent most important technical innovation in agriculture has been the introduction of the water pump. Though not many in number (6), water pumps are shared, and therefore can be used by a larger amount of households. Motorised ploughs have not or not yet replaced the buffalo as the source of traction labour.

***Table 3: Consumer goods in* SangSaeng**

	[quantity]	[per household]
manual ploughs	44	1.10
bicycles	44	1.10
fans	38	0.95
TVs	31	0.78
radios	23	0.58
motorcycles	20	0.50
refrigerators	19	0.48
electric rice cookers	18	0.45
electric irons	15	0.38
electric pans	10	0.25
motor vehicles	10	0.25
other electric appliances	8	0.20
water pumps	6	0.15
motorised ploughs	2	0.05

Source: Data collection in *SangSaeng*, NE-Thailand (1998)

In the household, a bicycle and a ventilator are parts of the standard equipment. The bicycle has replaced the horse, while the ventilator has become a necessity since the introduction of corrugated iron roofs (Klausner 1993). Three out of four households have a TV set, and very second household has a refrigerator and a motorcycle. The refrigerator is used almost exclusively to cool water and to produce ice cubes, while the motorcycle seems to represent a technical improvement to the bicycle. On the whole, it seems that consumer goods in the household are favoured, if they enable an extension to the world outside the village or if they symbolise modernisation.

Buildings

Of 51 houses in *SangSaeng*, 19 are traditional wood constructions (Pornchai 1989). A further 25 houses have recently been adapted, using concrete to create additional living space. These represent a semi-traditional type of construction. Modern buildings are made of concrete exclusively, of which there are 7. All houses are roofed with corrugated iron.

Regarding weight of building materials, concrete as well as sand and gravel overshadow by far all other materials. Sand and Gravel are needed for the construction of modern concrete buildings. All other materials have been used traditionally, wood being the most frequent. Other materials are still in use for constructions other than houses, such as field huts, rice granaries, and secondary buildings.

***Table 4: Building materials in* SangSaeng**

	[in tons]	[percentage of total]
sand and gravel	1,743.9	52.10%
concrete	1,277.2	38.16%
wood	303.9	9.08%
other building materials	23.2	0.69%
total	**3,347.3**	

Source: Data collection in *SangSaeng*, NE-Thailand (1998)

The modern building materials concrete and sand and gravel are still a minority, but seem to constitute a new trend in *SangSaeng* architecture. The concrete buildings in the village are not older than 5 years. Due to widespread deforestation of the region and restrictive logging laws enforced by the central government, wood has become a very expensive material (ESCAP 1986).

In addition to the total amount of building materials, we have estimated that the material increase accounts to about 8,5 tons per year. Four new houses were built between 1996 and 1998, three of which being the concrete type and one a mixed materials construction.

Energy

Main sources of energy are wood and charcoal, which account for more than half of the energy consumed in *SangSaeng*. Wood, charcoal, and gas are used for cooking, although gas is only used by wealthy households, since that includes purchasing a stove and fuel tanks. Another large energy provider is gasoline and diesel, used as fuel for motorcycles, cars, and water pumps. The total consumption of energy sources amounts to 8.165 MJ/capita (Austria: 110.434 MJ/cap; Hüttler et al. 1996).

***Table 5: Energy consumption in* SangSaeng**

	used energy [in MJ]	used energy per capita [in MJ]	utilised for
wood	252,042	1,585	cooking
charcoal	407,726	2,564	cooking
gas	39,494	248	additional cooking
fossil fuels	541,487	3,406	motor vehicles, water pumps
electricity	57,499	362	lightening, household appliances
total	**1,298,248**	**8,165**	

Source: Data collection in *SangSaeng*, NE-Thailand (1998)

To what extent can we use the presented material when looking at the dynamics of social change and paths towards sustainability? Three issues come to mind that seem to be major themes in the MFA of this case study.

1. New materials can be identified to be imported into the village. As showed, concrete, fossil fuels, and modern consumer goods are all non-traditional. The implication of this is that these materials are costly, energy-inefficient, and non-recyclable. Also, several cycles of energy increases can be identified. Concrete structures require the building to be constructed on higher ground. This causes massive movements of sand and gravel, the transportation of this leading to even higher intensities of energy. Likewise, new fuels, such as propane gas, gasoline, and benzine are used. They already range second to the traditional sources of energy, and it is most probable that the proportion of these will continue to rise.

2. Recent jumps in material flows can be identified. The increase of water use by over 2 million litres per year is caused by the introduction of water pumps in the agricultural system. Although these represent an improvement in labour efficiency and a decrease of economic risk, water pumps will further increase fossil fuel consumption in *SangSaeng*. Fossil fuels as well as electricity are not only new sources of energy, but they also account for a major jump in energy consumption. Together, they account for a doubling in energy consumption as opposed to the traditional fuel materials. The major influx of concrete as a new building material in recent times has already been mentioned.

3. Material flows have to be interpreted in the context of the studied society's culture. Regarding consumer goods the major influx of TV's as opposed to, say, washing machines has to be explained. Likewise there have to be reasons for the import of water pumps in agriculture versus the absence of other motorised/mechanised tools. Regarding the even distribution of calories intake among the village population, we could pose the hypothesis of *SangSaeng* being a society with little social stratification. Caste-structured agricultural societies, like that of Northwest India have been identified to have a similar average calorie intake as in *SangSaeng* , however the range between high and low-caste calorie intake varies a lot more than it does in the present sudy's case (cf. Mehta; Winiwarter 1997).

One important issue has been left out by the present study. As indicated, migrants are the main force behind change and modernisation of the village society (see also Fukui 1993). As part of the village society they nevertheless produce their own characteristic material and energy flows, which is rather different from those identified in the village itself. It is therefore necessary that we include the aspect of migration in future research.

The indicators of sustainability certainly do not lie exclusively in MFA, but we can ascertain this method to be useful for several of these. Especially when looking into qualitative and quantitative changes of material inflow, many processes can be understood early on and prospects for future developments envisioned. Comparisons with other cases will provide further information, so that eventually we will be able to understand the major issue of societies on their way to modernisation.

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The Ecological Footprint and Biocapacity of Sweden, a South Swedish Region and a Catchment Area

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Abstract
The appropriation of bioproductive space by human consumption ("the ecological footprint") and available biocapacity were calculated for Sweden, its southernmost county and a catchment area within that county. The principles used were developed by Rees and Wackernagel at the University of British Columbia with applications including the calculation of the ecological footprints of 52 nations using UN statistics.

Here national statistics were used with slightly different results for Sweden. In addition, government statistics on settlement and land use in catchment areas and on regional yields in areal production were used to calculate local bioproductivities. The study of a catchment area also aims at combining data on consumption, material flows, and land use with data on water flow and water quality. To make the study comparable internationally, all results are expressed in world average productive space.

Sweden has both a large ecological footprint and a high biocapacity per capita compared to other nations, but present land use does not correspond to the present consumption patterns. The calculations show that Sweden would have sufficient biocapacity for absorption of e.g. agriculturally based water pollution. Insufficient biocapacity is, however, designated for reduction of pollution from leaching plant nutrients. Thus the Baltic Sea is threatened and groundwater quality is at risk.

Introduction
In this Con-Account workshop, there is a heavy emphasis on material flows and possibilities of dematerialisation. For this to occur, information and control of stocks and flows of different materials are important. Models for estimation of effects on material use from the introduction of new technologies and other measures in industry and society are needed. Such stock and flow accounting studies are in general performed in nations, municipalities or equivalent administrative units.

In our study we have used the ecological footprint concept as an aggregated measure of human area-based consumption including built-up areas, energy and space for absorption of waste. The ecological footprint is expressed in world average bioproductive space and thus allows international comparisons (Wackernagel & Rees, 1996). Based on national statistics, it can be calculated per person or for the population of a certain area. The ecological footprint of any defined population is essentially the total area of biologically productive land and sea occupied to produce the resources and services consumed and to assimilate the wastes generated by that population using prevailing technology. As people use goods and services from all over the world and affect far away places by their waste, footprints sum up these biologically productive areas wherever on the planet land or water may be located. By using the same categories of space combined with statistics on local productivity, the biocapacity of a region or country can be calculated in world average space and compared to the ecological footprint, that is, appropriation of bioproductive space by the consumption of its population.

The method for calculating ecological footprints and biocapacities and their use is still being further developed. The concepts are nevertheless effective for providing an overview of the human impact on nature and what consumption nature can support. Here we discuss footprints and biocapacities calculated for Sweden, its southernmost county and a catchment area in that county, as reported elsewhere (Wackernagel, Lewan, Borgström-Hansson 1998). Catchment areas are generally not used for administrative purposes, but they are the base for natural flows. A catchment area is indeed the meeting place between society and the physical reality, and thus more appropriate for administrative purposes than the present municipalities. Water districts with responsibility for the quality of groundwater including that of rivers and lakes are being considered in the EU (Com 97/49). In Sweden, governmental statistics are available on population and land use of major catchment areas and some subcatchment areas.

Although ecological footprints and biocapacities are based on scientific calculations, the concepts are easy to understand even for politicians and the general public. In this workshop, ecological footprint analyses are of relevance because they transform the use of energy for services, manufacturing, eco-cycling, clean technology, etc. into appropriation of productive areas to be added to other areas used to support the consumption of a population. There are limited amounts of global productive space, it is already overused, and development must proceed towards smaller footprints in total. Material flows must always be seen in relation to the use of energy/exergy.

Method of calculation

Consumption in Sweden was calculated by adding imports and subtracting exports from the national production of different consumer goods. Eight categories of consumer goods were analysed: plant-based food, animal-based food, non-plant-based fibres, chemical products, metallic products, timber products, etc. The consumption per capita of each specific good divided by the yield on world average space (arable, pasture, forest) shows the footprint component of the areal production. Manufacturing gives additionally an embodied energy footprint component, and for many consumer goods, such as chemical products and metallic products, there is only the manufacturing energy footprint component. The net import of areal production shows the appropriation of productive space abroad. The net import of embodied energy (fossil oil) is added to the energy consumption which is specified in an energy budget (fossil gas, oil, and coal, waterpower, nuclear power, biofuels, etc.). The calculation of the energy footprint components is based on the amount of energy generated per area, i.e. dams, stations and cables for waterpower (built-up area), the area of young growing forest necessary for absorption of the carbon dioxide generated by combustion (energy land). Nuclear power is transformed into equivalents of fossil oil. Energy land can also be seen as an area for replacement of fossil fuels and nuclear power, but the absorption of carbon dioxide from fossil fuels and the production of biofuels must be served by different areas. Thus the ecological footprint is made up of different kinds of world average productive space, as shown in Table 1. For summing up they are multiplied by equivalence factors in relation to their biological productivity. Thus the different components can be amalgamated into an ecological footprint expressed in hectares of world average space (equivalence factor 1).

Table 1. The ecological footprint per capita in Sweden and footprint components

Category of world average space area	Category demand by consumption ha/cap world average	Equivalence factor	Demand of equival.world average space ha/cap
Arable	0.4	2.8	1.2
Pasture	1.6	0.5	0.9
Forest	1.4	1.1	1.6
Coastal waters	1,5	0.2	0.3
Energy land	2.3	1.1	2.6
Built-up area	0.2	2.8	0.7
World average productive space		*1*	
		TOTAL USE	**7.2 ha/cap world average space**

Arable is the most fertile category of space. Pasture is unimproved agricultural areas. Forest areas are used for timber, pulp and biofuel, etc. Coastal waters correspond to productive coastal areas. Energy land differs from forest in that it is used for absorption of carbon dioxide from fossil fuels during a growth period of around 70 years. After these 70 years, it must be left for spontaneous renewal in order not to release sequestered carbon dioxide. Cities and roads are considered to be built on arable land.

The above-mentioned categories of bioproductive space used for footprint calculations are also used for calculation of biocapacity. The biocapacity of a state or a region is the actual area of each category of space expressed in world average space. The areas are transformed into world average space by multiplication by their specific equivalence factors, Table 1, and a yield factor characteristic for the state/region (Swedish Statistics) as shown in Table 2. Although built-up areas are no longer productive, they are included in the biocapacity in order to show the full potential of a region or a country. On the other hand, 12% of the biocapacity is set off to provide space for wildlife flora and fauna and thus deducted from human use.

Table 2. Land use and biocapacity per capita in Sweden

Category of productive space	Area in Sweden **ha/cap**	Equivalence factor	Yield factor	Yield adjusted world av. space **ha/cap**
Arable used for crops	0.27	2.8	1.6	1.2
Arable used for pasture	0.12	0.5	7.7	0.5
Pasture	0.06	0.5	7.7	0.3
Forest	2.76	1.1	2.1	6.5
Coastal waters	0.58	0.2	1,0	0.1
Energy land	0.0	1.1	2.1	0.0
Built-up area (used)	0.15	2.8	1.6	0.7
	3.9 ha/cap	TOTAL existing biocapacity 9.3 ha/cap		
	Biodiversity	(-12%) - 1.1 ha/cap		
	TOTAL AVAILABLE	**8.2 ha/cap world av. space**		

Results

Based on the calculations in Table 1, the requirements of bioproductive space for consumption among people in Sweden, or the ecological footprint, was found to be 7.2 ha world average space per capita. This demand was compared to the total biocapacity in Sweden. Although there are big individual differences in consumption in Sweden, regional differences in lifestyles and mean standard of living are small. Thus the national footprint of 7.2 ha/cap was also used for comparisons with the regional biocapacities in the county and the catchment area studied.

The biocapacity in a state/region is based on the actual areas of productive space categories, the use of these areas and applied technology. The available biocapacity in Sweden is bigger than the demands of consumption as indicated by the footprint, Table 1 and 2. It must be considered, however, that more that 9% of the available biocapacity is already used for built-up areas, and that no energy land is designated for absorption of carbon dioxide from fossil fuels.

Table 3. Swedish footprint and biocapacity components, percentage of total

Category of	**Footprint demand of consumption**	**Biocapacity productive space available**
Total in world average land	7.1 ha/cap	8.2 ha/cap
Arable	17%	15%
Pasture	13%	10%
Forest (fiber, timber, biofuel)	20%	80%
Sea	4%	1%
Energy land, CO_2 absorption	36%	0%
Built-up area	10%	(9%, already used)

The footprint calculation shows that areas for such absorption amount to one third of the total demand, Tables 1 and 3, Fig 1. The demand for agricultural biocapacity (arable & pasture) roughly corresponds to the available biocapacity, but little attention has been paid to pollution.

Comparisons between the footprint and biocapacity components as a percentage of the total areas show that there is much more forest than required by consumption, Table 3, Fig. 1. On the other hand, there is hardly any energy land set aside. Some forest biocapacity can be used for more biofuel production, and newly planted forest areas can serve as CO_2 absorption land. But the surplus forest is now used for export of timber and other forestry products and is the base of the Swedish economy.

The biocapacity of the southernmost county in Sweden [Malmöhus County, since 1998 amalgamated with Kristianstad County to make Skåne County (Scania)] and one of its major catchment areas is much higher per hectare than in other parts of Sweden, and this results in high yield factors, cf. Table 2. Because of the high density of population (160/square km), however, there is insufficient biocapacity, or 3 ha world average space per capita, for support of the population's consumption, Fig 1. The footprint is 7 ha as for the average Swede, Table 1. In the more rural and sparsely populated catchment area there is better balance with a biocapacity of 7.0 ha per capita, which is slightly less than the footprint.

Figure 1

Discussion
An ecological footprint of 7.2 ha world average space per capita in Sweden and a biocapacity of 8.2 ha available for human use, as calculated in this study using national statistics, differs slightly from previous calculations based on UN statistics which indicated a footprint of 5.9 ha and a biocapacity of 7.0 hectares of world average space, Table 5. Deviations between national and international statistics have been confirmed and may explain some of the differences in the footprint and biocapacity results for Sweden. The size relation between the two measured areas, however, remained the same.

The deficit in biocapacity in the south should not be a problem in Sweden with its total high biocapacity, and it can be supplemented by biocapacity in less densely populated regions. Considering the need for energy land all over the country there is, however, no surplus of productive space with present lifestyles and technologies in Sweden. On the contrary, the problem is where to fit in energyland or how to reduce the use of energy (exergy). There are also needs for protective zones for water. The ecological scarcity in other countries, however, is more severe, as shown below.

Table 5. Ecological footprints and biocapacities of some nations (from Wackernagel et al. 1998)

Nation	**Ecological footprint** ha world average space per capita	**Biocapacity** ha world average space per capita
Sweden	5.9	7.0
Canada	7.7	9.6
Belgium	5.0	3.1
Austria	4.1	3.1
Chile	2.5	3.2
USA	10.3	6.7
Bangladesh	0.5	0.3
World	2.8	2.1

Differences in calculation show the importance of using results from the same series of analyses for international comparisons. Moreover, it should be stated that ecological footprints and biocapacity values are no exact measures but rather guidelines for sustainable development including fairer distribution of resources. They offer a good overview of the global situation regarding demands for consumption and available biocapacity, as shown in Table 5. It is quite obvious that there is insufficient biocapacity compared to demands as illustrated by footprints in developed as well as developing countries and by the figures for the world as a whole.

In most nations, as for Sweden, land use is not compatible with the requirements of consumption. Bioproductive space is not designated for absorption of CO_2 from fossil fuels, and the need for space for protection of water and production of tapwater in many countries is much more severe than in Sweden.

The biocapacity in a region changes with the technologies used in areal production. These technologies are often both resource-demanding and polluting. Calculation of the biocapacity in a catchment area offers the possibility to consider effects of land use on water flows and water quality. In Sweden, it is well known that land use must be adjusted for better retention of plant nutrients to protect groundwater and reduce the load on the Baltic Sea. Thus protective zones must be introduced which lower the available biocapacity. They may, however, function as small CO_2 sinks and may also improve biodiversity. Plans are in progress for the catchment area studied, but they are not sufficient. The biocapacity may also be reduced because of exploitation for further building and for new areas for waste deposits and treatment of sewage and solid waste, etc.

The footprints show the demands for biocapacity for consumption. They can be reduced by more efficient and cleaner technologies in farming, forestry, manufacturing industries and services, by reduced material consumption per capita and by curbing population growth.

Footprint and biocapacity analyses are essential for adjustment of the total consumption to the available resources. Networking for the integration of knowledge about the global situation and regional differences is most important and can start on the scale of a catchment area, as described elsewhere (Lewan 1998).

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Environment and Resource Account of Forest/Timber In Southeast Asian Countries

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The Purpose and Background

The aim of this paper is to give a brief outline of our environment and resource account of forest and timber resources in Southeast Asian countries. IDE., a semi governmental, a daughter organisation of the Ministry of Industry, has planned to know the relation between the environment and economy in Southeast Asian countries.

This is a joint program between four countries, Japan, Thailand, Indonesia and the Philippines. From Thailand and Indonesia, statistical agencies have participated, i.e. National Economic and Social Developing Board of Thailand (NESDB) and Central Bureau of Statistics(CBS) of Indonesia. From the Philippines, privates research company, Resource Environment and Economics Center for Studies (REECS) has joined in co-operation with National Statistical Coordination Board and National Statistical Office. In the background of this joint program, there has been long research co-operation on I/O table compilation between IDE and statistical offices of Southeast Asian countries.

In 1992, IDE has started the program, with surveying on theoretical framework and data availability in south East Asian countries. Along the conclusion of those surveys, we have decided to compile physical account of forest and timber sectors following Norwegian and Finnish experience.

When compared with monetary account, physical account can cover more comprehensively the environmental degradation in developing countries. Material flow can include transfer of materials outside the market, which is still substantial in the metabolism of such societies. 1)

The structure of Forest resource accounts

The basic structure comes from Norwegian and Finish scheme.
Forest balance is a stock account like a Balance sheet in managerial accounting. The stock of the beginning, added or subtracted natural and man made variations, becomes stock of the end of the period of time. Stock account consists of Area, volume , and in French case, number of standing trees. In the future, those will be disaggregated into species. Material balance describes the production process and the environment. According to the law of conservation, in these case conservation of mass materials, total input into processing facilities have to be identical with total output. output divided into main product, by product and many types of emissions.

Sector Commodity Table is the essential table of those 3 tables, because Sector Commodity Table links Material Balance and Forest Mass Balance with the economy. Economic activity is now indicated by SNA, and SNA include Input/Output table now. So we can convert I/O table into physical term, and slightly modify sector definition, we can get Sector Commodity Table, In other word Sector Commodity Table is a kind of physical input/output table concerning the relation between tables.

There are two important linkages. One is 'removal' in Sector Commodity Table, it must be identical with removal, or man made extraction in Forest Balance. The other, Material Balance is a converted form of Sector Commodity Table, volume converted into weight, and added columns for emissions and final use. In many cases, discrepancy might take place in these linkages.

These two figures are topologically identical. Researchers has already pointed that which relation exist between "environment 1 " and "environment 2". We have to integrate conceptually the environment as a whole. Actually, so many institutes try to clarify these linkages, especially carbon and ash cycle. (Fig. 1 ,2)

Actual step to make up tables

At first, we begin with tracing the process of I/O compilation, to get information in physical term, for paper, weight and for timber, volume.

For cells, which we cannot fill up with in physical term, we have to conduct field surveys. In order to estimate Material Balance table, we have to know the specific gravity of tree species. Because, usually statistics on timber production and consumption is reported not in weight term but in volume term. In many cases, wood product statistics use other units than weight. For example, plywood producers usually use area term instead of weight. Therefore, we have to estimate conversion factor to convert commonly used unit into weight.

About the additional part of Material Balance, for political and bureaucratical reason, we can use very little information about emission to the environment. We have to also conduct field surveys to fill up unknown cells.

Bureaucratical bodies, in these case “Forestry department”, usually do not want to admit what is illegal. Then ‘removal’ from forest has a firm tendency of under estimation.
As for the case of fuelwood including charcoal, NESDB, a member of our joint program, conduct socio-economic survey in every 2 years. In this statistics, we can know household expenditure for fuels. According to that statistics, except for the Bangkok metropolitan Area, Households spent about 50% for ‘fuel wood and charcoal’.

Using price index to calculate physical weight, we can estimate the removal from forest for fuel use. Never the less this figure is still underestimated because, consumption data does not include self-consumption, fuels not purchased in the market.

We tried to investigate these discrepancies further, first, area of the forest has continued to increase, but the rate of change becomes small, this is too small to explain the removal. Then we have analysed sample plot survey in the permanent plots by the Forestry department. These sample plots data shows ‘fatal decrease of standing volume or biomass in the forest. Northern region is relatively mountainous area, still some forest left. Northwest region is the most developed area in 60’s; we can see only little forest. Pine forest is artificial forest and well maintained.

After all, forest has been decreased not so much in area, but significant in volume. People still heavily depend on forest resource.

As for the Material Balance, in case of the pulp sector, the ratio of fuel use to emissions varies remarkably by countries.(Fig.3-6, Tab.1,2) 2)

Some problems encountered in practice

There must be reorganisation of nomenclature. Statistical agencies have to extend the coverage of ‘removal’. Include timber resource not from forest, i.e. para rubber and legalised smuggling of logs.

In case of consolidated sector, - Charcoal and firewood, - pulp and paper, these sectors have to be divided into individual sectors.

Appropriate agencies have to make official report on charcoal sector, for now no information is available. The departments responsible to forest and forest product have to estimate classified charcoal productions.

Future development

Data coverage is not sufficient for environment and natural resources. More co-operation with statistical department is necessary. This scheme will work as effective stimulation for governmental sector but for mass communication sector and various forms of NGO's. Now, we are examining to extend to other resources, land and so on.

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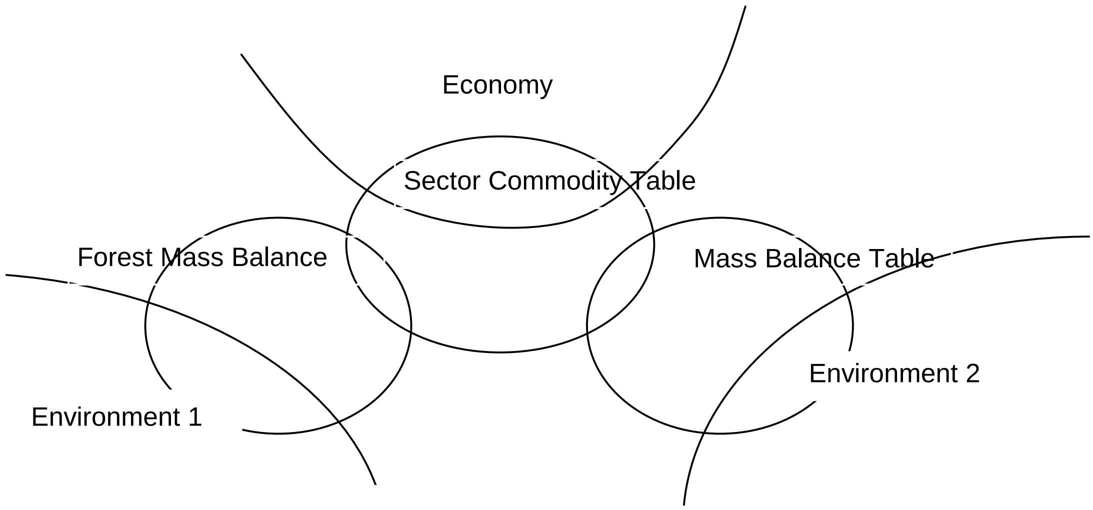
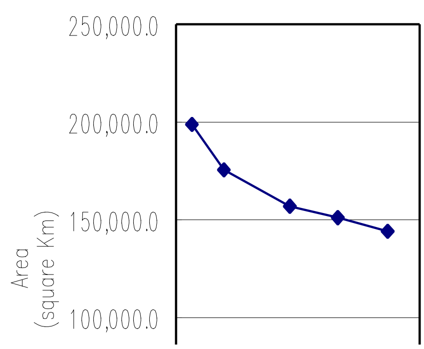


Fig3. Change in Forest Area(Thai)



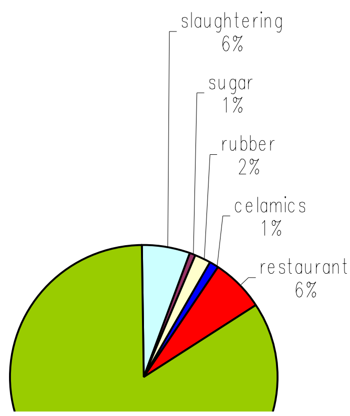


Fig.5 Rate of Change "Density (M3/ha)"

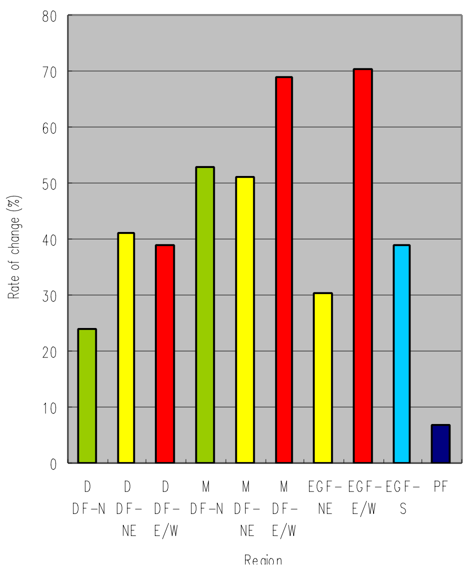


Fig.6 Output from Pulp Sector

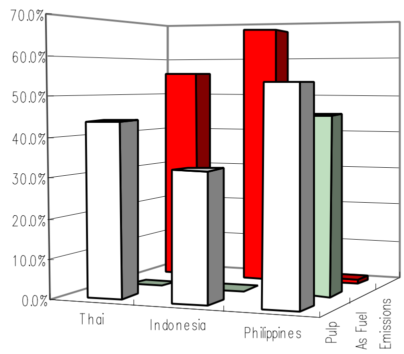


Table 1 : Sector Commodity Table for the Forestry Sector, Philippines, 1990

		Log	Sawn wood	Veneer/	Residue	Fuelwood	Charcoal	Pulp	Paper	Paperboard	Waste Paper
				Plywood							
Removal		8154840				28984294					102332
Import		381178	3741	3632				67000	26000	228653	264000
Export		51031	77000	223031		6	716	10000	4000	6305	
Inventory		388987	58000	95000		34000	2000	-9000	-30000	-34000	-8453
Primary Supply		8874004	-15259	124399		29018288	1284	48000	-8000	188348	357879
Wood processing Sectors											
Sawmill	input	6815569			821966	1150746					
	output		4210050		793332	2468551					
Veneer/Plywood	input	1123269			16072	206307					
	output				143436	206730					
Pulp	input	531282			98730	275289		24342			356238
	output					275289		446739			
Paper	input							186045			
	output								194000		
Paperboard	input							260694			
	output									271840	
Fuelwood	input					26485126					
	output					26485126					
Charcoal	input					3581390					
	output						1925695				
Total		403884	4194791	471227	0	26485126	1926979	23658	186000	460188	1641
Final demand for Wood											
Agriculture			91442	5594					1950	9820	
Food			3296	3		105000	96285		19565	156453	
Mining		375612	1653449	183636					2751	13854	
Trade, transport		12	101280	88892					15723	55879	
Printing			105						100113	88953	
Other manufacturing		80	29193	2992		2047834			19782	70308	
Furniture & fixture			599583	58227							
Millworks			1462469	63541							
Service & commerce		28271	160435	8410		1406502	288854		9504	47850	985
Government			3650	821					15269	13567	656
Household			89889	59111		22925790	1549556		2123	3504	
Final Demand		403975	4194791	471227		26485126	1925695		186780	460188	1641
Statistical discrepancies		-91	0	0		0	1284		-780	0	0

Table 2: Mass Balance for the Forestry Sector, Philippines, 1990

		Log	Sawn wood	Veneer/ Plywood	Residue	Fuelwood	Charcoal	Pulp	Paper
Sawmill	input	3,196,502			13,429	1,150,746			
	output		1,974,513		26,001	404,121	38,530		
Veneer/Plywood	input	478,513							
	output			334,818	54,257	606			
Pulp	input	172,493			33,806				
	output							110,477	
Paper	input							55,046	
	output								194,000
Paperboard	input							55,431	
	output								
Fuelwood	input					12,421,524			
	output					12,421,524			
Charcoal	input					1,806,302			
	output						966,699		

(continued)

		Paperboard	Waste Paper	Fuel Used	Emissions	Transfer	Bads
Sawmill	input						
	output			539,699	46,865	175,387	4,815
Veneer/Plywood	input						
	output			87,887		945	
Pulp	input						
	output			93,479	2,343		
Paper	input						
	output						
Paperboard	input						
	output	271,840					
Fuelwood	input						
	output						
Charcoal	input						
	output				839,603		

Inflow and Accumulation of Heavy Metals in Stockholm, Sweden[24]

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Abstract
The inflow and accumulation of seven metals (Hg, Cd, Ni, Cr, Zn, Pb, Cu) in the anthroposphere of Stockholm is presented. The accumulation was estimated for the 20th century, the inflow for the mid 1990th. Estimations were based on: Official statistics broken down to Stockholm level using different factors such as, inhabitants, households, cars; life-length multiplied with the average consumption each year; metal content per product multiplied with the volume in use etc.

The results show that the inflow varies between 2-8% of the stock. For Cu, with a dominating use of electrical cables, other electrical equipment and roofs, i.e. goods with a long life expectancy, the inflow is only about 2% of the accumulated amount. For Cd, the corresponding part is 8%, reflecting the expanding use of NiCd - batteries in the mid 1990th. Further, the stock is dominated by Cu (170 kg/capita) followed by Pb (73), Zn (40), Cr (8), Ni (4), Cd (0.2) and Hg (0.01 kg/capita).

The focus on both inflow and accumulated amount will make it possible to understand and predict future problems that may arise from metal containing goods.

Introduction
The research for this paper was done as a case study covering the flows and accumulation of heavy metals in the anthroposphere of the Swedish capital Stockholm from year 1900 to 1995. Thus, the work covers part of a substance flow analysis (SFA). Outflow in form of emissions due to e.g. corrosion is presented in Sörme *et al*. (1999) and a complete SFA can be found in Bergbäck (1999). The administrative border of Stockholm City was chosen as the spatial system border. The study focused on the urban metabolism of cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn). The metal flows and stocks in various goods for different time periods was calculated.

Official statistics on a national, regional and local level were used. Contacts were established with industrial/sector representatives from production - construction - authorities in order to calculate the flows and stocks of the different metals. More information about the use of mercury in Stockholm can be found in Svidén and Jonson (1999).

The aim of the present study was to quantify the inflow and stock of heavy metals (Cd, Cr, Cu, Pb, Hg, Ni, and Zn) in goods in the anthroposphere of Stockholm, Sweden.

Results
The total amount of heavy metal in the inflow/yr, stock and waste/yr is presented in Table 1. The inflow of the different heavy metals varies considerably. Cu has the numerical largest inflow. Cu and Pb both have a very low inflow in comparison with the stock, 2-3%. All other metals have double that amount, between 6-8%. This indicates the importance of the stock.

The amount of metal per capita has been calculated. For example, the use of Cu is 170 kg per capita and the use of Pb is 73 kg per capita. Total amount of metals in waste has been calculated in Bergbäck and Svensson (1999). The amount of metal in household waste dominates to a large extent compared to the amount of waste from industry. The largest proportions of metal in industrial waste are for Cu and Zn, 20% respectively 13% of the total.

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[24] The full version of this paper will be published in *Water, Air and Soil Pollution*.

For all other metals, waste from industry accounts for less than 8% of the total. Between 13% and 37% (Cd and Hg not included as they are currently phased out) of the corresponding annual amount in inflow is found in waste (Table 1). This is an indication that recycling is far from complete.

The data is also presented in a model, for more information of the model, see Hedbrant (1999).

Table 1: The inflow/yr, stock and waste/yr, inflow/capita, stock/capita of metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn) in Stockholm, Sweden 1995. The yearly amount of heavy metals in waste is compared to the amount in inflow.

Metal	Inflow (ton/yr)	Stock (ton)	Waste (ton/yr)	Inflow/capita (kg and yr)	Stock/capita (kg)	Waste/Inflow (%)
Cd	8.8	120	4	0.01	0.2	45
Cr	360	5600	100	0.5	8	29
Cu	2300	123000	300	3	170	13
Hg	0.46	7	1	0.0007	0.01	>100
Ni	190	2500	30	0.3	4	16
Pb	1600	52000	300	2	73	20
Zn	1900	28000	700	3	40	37

Conclusion

This study has shown the importance of the stock, and even if the range of calculated amounts is large some general conclusions can be made.

First, the metal stocks are large and the accumulation probably still continues, Hg excepted. The accumulation rates have not been calculated due to lack of reliable recycling data. However, the inflow is larger than the metal flow in waste and even if high recycling rates are assumed there will be a net accumulation in the anthroposphere of Stockholm. Thus, for the three metals with national restrictions, Cd, Hg and Pb, one can conclude that the stock is decreasing only for Hg. Pb accumulation continues although there is an overall national goal to phase out the Pb use in the long term. In the case of Cd, there has been a decrease in the inflow after the data was collected, due to the partial replacement of NiCd batteries which was the main type of goods for the inflow. This makes it difficult to estimate if Cd accumulation still continues.

Further more, large amounts of the heavy metals reach waste. Approximately 15-40% of the amount of the heavy metals in the inflow is found in the waste. This indicates that recycling is far from complete and potential future resource problems. The risk of leakage from landfills also increases. Thus, to implement a more sustainable use of metals will be a major challenge for the future.

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Differences in Resource Consumption and Lifestyles- what are the implications for greening the North?

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Abstract
As a result of differences in travelling patterns and food consumption, energy consumption differ substantially between different socio-economic groups in Sweden. Men with high incomes and middle-aged men have travelling patterns resulting in energy consumption almost ten times higher than elderly women or persons with low-income. High-income earners, and men, consume more meat than people with low incomes, or women do, something that entails a higher resource consumption and more pollution. The differences demonstrated are as large as between average citizens in the North and South but hardly discussed in the current debate about greening the North. However, when compared to a sustainable level for energy consumption, almost all population groups in Sweden are in excess. Explanations for and implications of the results are discussed. While differences in occupation rate and age can explain some differences, gender based inequalities are the cause of others. It is argued that lifestyle related differences in resource consumption should be given proper attention otherwise efforts to promote sustainability may be inefficient. A broad societal discussion is advocated in order to gain consensus about how the property rights to ecosystems services shall be allocated in a fair manner within societies.

Introduction
The transition of societies and lifestyles during the age of consumerism, which has occurred after the second world war, has undoubtedly permitted large numbers of people to enjoy levels of material consumption unparalleled in history. However, the natural state of the ecosystems, together with their ability to provide the resources and the ecological services needed to
demands (e.g. Loh et al, 1998). Patterns of consumption common in the developed countries are largely responsible for this deterioration (e.g. Parikh and Painuly, 1994). Awareness of this has resulted in numerous recommendations for changing such patterns, one of which is Agenda 21, adopted at the Earth Summit in Rio de Janeiro 1992 (United Nations, 1993). However, up to now, only marginal progress has been made to this end (United Nations, 1997).

It becomes more and more apparent that the biosphere's capacity for regulating the global climate is perturbed (IPCC, 1996a). During the past decade, weather-related ecological disasters have been abundant. Human induced climate change cannot be ruled out as a major cause. [25] The debate about property rights to ecological services is heating up. Developed countries will eventually have to curtail unsustainable consumption patterns. This will most certainly involve completely new approaches for understanding and monitoring the environmental implications of lifestyles among populations seemingly all belonging to the same wealthy class.

[25] Examples are the extensive death of corals caused by unusually high sea-temperatures as well as the disaster caused by hurricane Mitch in Honduras and Nicaragua during 1998. Both are examples of extreme weather conditions which the IPCC (1996a) considers as one of the consequences of human induced climate change.

It is in this context which this paper is written. Here, results from studies of the energy consumption from different kinds of travel and food consumption patterns currently adopted in Sweden are presented. The following issues are addressed:

- How large can differences in energy consumption be among different population groups within a nation, and why?
- How far from what can tentatively be defined as a sustainable consumption level are current levels of energy consumption among different population groups?
- How can findings about differences in resources consumption among population groups be used in policy making?

Consumption patterns, energy and sustainability

Sustainable development (WCED, 1987) means that the effect of human activities should be limited to what nature can bear in a long-term perspective, that resources should be preserved also for the needs of future generations, and that all people should have a fair share of the use of global resources.

Emissions of greenhouse gases can be sharply reduced if energy systems would be based on renewable energy instead of fossil fuel (IPCC, 1996b). An estimation of global potential for renewable energy supply is 360 EJ per year of fuels and electricity (Steen et al, 1997). This level is used as guideline for sustainable energy consumption. The fair share of energy available for travelling and food consumption is calculated in the following manner:

- The global potential for renewable energy supply (360 EJ per year) is divided equally among the global population for 1996. With a population of about 5.8 billion people, this puts the renewable energy supply available for each individual to 62 000 MJ per year.

- The renewable energy available for each individual is supposed to cover a broad range of personal and other needs. The assumption is that 30% is set aside for common purposes, such as defence, education, health care, and so on. Even today, about 30% of income is commonly set aside for such purposes in Sweden and other countries. Of the remaining renewable energy available for each individual, travel and food are assumed to account for 25% each. This is a reasonable assumption, as several studies have indicated that transportation accounts for 13 to 33% of the total energy consumed in a household and that the corresponding figure for food consumption may be 17 % to 30 % (Biesot & Moll, 1995, Vringer & Blok, 1995; Forbrugerstyrelsen, 1996; Wackernagel & Rees, 1996).

The resulting sustainable levels of energy consumption per person for travel and food consumption would be 11 000 MJ respectively during 1996. These levels are used as targets for comparing today's levels of energy consumption for travelling and eating. Note that these targets stem from a purely theoretical approach. So far, Swedish authorities have not adopted any such goals.

Travel patterns, energy consumption and sustainability among different population groups in Sweden

The study of energy consumption for different travel patterns is based on a database developed as part of the Swedish National Travel Survey, NTS (Statistics Sweden, 1997). This survey covers a sample of 50 000 persons, interviewed about their daily travels. The results from NTS were sorted according to age and gender and according to income and gender. The energy consumption for different travel patterns was calculated by combining information about number of kilometres travelled by different means of transportation with estimates of the energy consumption for travel by different vehicles, expressed as MJ per personkm. The energy consumption for travelling with different vehicles differs a lot. Aeroplanes and cars have high energy consumption per personkm when compared to public transport such as trains and buses. A complete account of the methods and results are available in Lindén and Carlsson-Kanyama (1998) and in Carlsson-Kanyama and Lindén (1998).

The results show that the most energy for travelling is used by men with high incomes, 94 000 MJ during 1996. This is contrasted by the consumption of 23 000 MJ during 1996 which was the consumption for travel among men with low incomes (Figure 1). Men with high incomes travelled longer for work and leisure purposes than any other of the analysed groups. If all Swedes had the same travelling patterns as men with high incomes, Sweden could only have one million inhabitants if the calculated goal for sustainability should be adhered to.

Energy consumption for travelling differs a lot among different age groups and among the two genders, see Figure 2. Elderly women (75-84 years) were the only ones who came close to the goal for sustainability as they only consumed 12 000 MJ per year. Men aged 45-54 years consumed most energy of all people defined by age and gender as their travelling patterns required 68 000 MJ. But young children's energy consumption was also much higher than the goal for sustainability. Gender differences are apparent in our study as women almost throughout use less energy than men in the same age group or with the same income.

The differences in energy consumption for travelling have several explanations. Some of these are:

Stages in people's life cycles necessarily will have consequences for the amount of travelling needed. People who work most often commute for that purpose daily, as opposed to children and pensioners.

- Men and women take on different kinds of responsibilities in the households. Women more often than men rear young children, and thus during part of their life may abstain from working outside the home. When they do work outside home, they may choose to work in places close to home and to avoid extensive in-service travelling.
- Men have been shown to have different preferences during leisure time than women. Women more often spend their leisure time in the neighbourhood while men may travel to sport arenas at some distance from their home. The way men and women spend their leisure is more or less a matter of differing lifestyles.
- High-income earners more often live in low-density areas with detached houses. Such areas are almost always located further away from bus-terminals and subway stations than high -rise buildings where many low-income earners live. The consequences are that it may be difficult for high-income earners to commute to work or to do the daily shopping by foot or by bicycle.
- High-income earners travel longer for leisure purposes as they can well afford holiday trips abroad. Travelling for long distance often means that aeroplanes are chosen in order to save time.
- Men and women have different attitudes towards cars. Even when they have the same income, men more often own a car than women do.

Food consumption, energy consumption and sustainability among different population groups in Sweden

No complete estimates of the energy consumption for food consumption in different populations groups have yet been made. This is because time-consuming life-cycle assessments of a large number of different foods would have to be available to this end. Such estimates have not yet been made for all the types of food consumed in Sweden. However, during recent years, several studies of the environmental impacts of food production, delivery and consumption have been presented (e.g. Andersson, 1998, Carlsson-Kanyama, 1998 a, Carlsson-Kanyama 1998 b, Cederberg, 1998, Hogaas Eide, 1998, Stadig, 1997). Therefore, prospects for achieving results of similar types as presented in part 2 of this paper seem promising.

I will use levels of meat consumption among different population groups to draw tentative conclusions about the ecological consequences of different food consumption patterns. This is because meat is well documented for being more resource demanding than many other foods (Carlsson-Kanyama, 1998b and Swedish Environmental Protection Agency, 1997).

Meat consumption was compared among the two genders and among households with different incomes. Meat consumption differs according to gender. Men eat more meat than women do (Table 1) and these differences are consistent in all age groups.

Table 1: Consumption of meat, poultry and dishes according to age and gender in Sweden, 1989 (Becker, 1994, Appendix E).

Age and gender	Consumption of meat, poultry incl. dishes, g per day
Boys, 1-6 years old	59
Boys, 7-14 years old	87
Men 15-74 years old	100
All men	95
Girls, 1-6 years old	56
Girls, 7-14 years old	71
Women, 15-74 years old	73
All women	71

The amounts of meat purchased may also differ according to income. When different types of households were compared, those with high incomes often appear to buy more meat than those with low income (Table 2).

Table 2: Amount of meat and meat products purchased among households with different incomes during 1989 (Statistics Sweden, 1992, p. 139, Table 18).

	Kg of meat purchased in 1989
Singles, low income	35.9
Singles, high income	38.4
Two grown-ups, one child, low-income	110
Two grown-ups, one child, high income	140.6
Two grown-ups, two children, high income	142.7
Two grown-ups, two children, low income	133.8
Two grown-ups, three children, high income	180.0
Two grown-ups, three children, low income	192.8

A tentative conclusion about environmental impacts from food consumption within different population groups is that impacts differ according to the same patterns as were found for transportation (Figure 1 and 2). The most energy consuming, resource demanding or polluting food consumption patterns are likely to be found among men with high incomes, while women with low incomes are more likely to have consumption patterns with lesser environmental impacts.

The reasons for why men eat more meat than women are but briefly explored here. Interesting clues for understanding this phenomenon are given by Fiddes (1991). Fiddes argues that meat is a symbol by which Western societies - like many other societies - expresses its relationship to the world with its inhabitants. Meat eating is a way of expressing control over the natural environment and during history it is primarily men who have been, and are, in the positions like controllers, hunters and providers. Women in many Western societies may be referred to as game, or animals [26] and they are portrayed as Man the Hunter's willing prey (Fiddes, 1991). Thus, explanations for meat consumption may well be others than commonly recorded variables such as income or nutritional needs. The reasons

[26] For example, in Sweden young women may be referred to as lamb meat.

for why meat consumption is related to income could perhaps also be explained partly along with Fiddes (1991) arguments. Persons with high incomes are more likely to be men than women (Carlsson-Kanyama, Lindén and Thelander, 1999).

The energy consumption recorded for food most likely exceeds the goal for sustainability set here among many population groups. The total energy consumption within the whole food chain in Sweden has been estimated at 360 PJ per year (Uhlin, 1997), or 17 % of the total energy consumption in Sweden. This puts the individual energy consumption for food to 40 000 MJ per year as Sweden has 8.9 million inhabitants. The goal for sustainable energy consumption for food was 11 000 MJ during 1996 (section 2 of this paper).

Implications for policy making

Energy consumption for travelling, and likely for eating as well, differs substantially depending on age, gender and income. Today some population groups in Sweden have sustainable consumption patterns, while many others are very far from reaching that goal. In this context, it is relevant to discuss whether targets for reduction in resource consumption should be the same for all, or if efforts to address unsustainable consumption patterns should be directed towards population groups where changes are most critically needed. For example, it may not be very important, or even worthwhile, to convince old ladies to reduce their resource consumption by a factor of four or ten. Persons with high-incomes, and men, should rather hear this message.

When setting targets for sustainability, it is important to remember that goals that are seen as unrealistic or unachievable are demoralising. Such goals may not be actively pursued and they may be completely neglected (Lindén and Carlsson-Kanyama, 1998). Goals for sustainability should be set with regards to the possibilities and obstacles experienced by the different targets groups. Goals may be different if there are proper motivations for this. However, to determine what can be accepted as proper motivations is likely to be a controversial issue. For example, is it acceptable that persons with high incomes use more energy than persons with low-incomes because the former group perceive that they need to travel to more exotic places during leisure time to relax from a demanding professional life? Is it acceptable that families with children use more energy for travelling than families without children because the former group perceives that living in a detached house in the suburbs is necessary for bringing up their children in a good environment? Is it acceptable that men use more energy for food consumption than women do because men need to confirm their positions as controllers and providers by eating more meat?

The discussion about goal setting mentioned above may not be as far-flung as it first may seem. Currently, work within the ISO-14000 system is underway to determine criteria for the environmental declaration of products (Ryding, 1998). With such information available to the consumer, it will be possible to monitor the environmental impacts from whole consumption patterns. Smart cards could probably be used for continuos monitoring of energy consumption or other environmental impacts over time. This opens the door for personal environmental declarations, for policy discussions about goal setting for individuals and for a market where environmental property rights can be traded. Science should be prepared for such a development and should further contribute to the understanding of environmental implications from consumption patterns. In this endeavour, perspectives from both the natural, social and human sciences are equally important. In the broad societal discussion about sustainability and consumption that will be needed in the years to come, the understanding of their causes and consequences will be dearly sought for.

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Translating a Factor X into Praxis

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Prologue - Setting the Factor X Target

With respect to the use of resources in our society today senior governmental, non-governmental, industry and academic leader argue the following: the total resource productivity of a nation should be increased by a Factor of 2 globally a Factor of 10 in industrialised countries within one generation (The Factor Ten Club, 1997) and by a Factor of 4 within the next decade (Weiszäcker et al., 1997) in order to redirect our course towards a sustainable economy. To achieve these factors every individual actor within the economy has to optimise its use of resources from the national (macro) level, over sector, regional (meso) levels on to the single firm and the household (micro level). The long time span is needed to allow the technical, social and economic dynamics to adapt and adjust without major conflicts with the requirements of economic sustainability. This is all the more necessary if, alongside technology improvements and the resulting efficiency gains, a culture of sufficiency is to emerge among the populations of industrial countries, accustomed to levels and - more important and problematic - forms and dynamics of well-being which clearly cannot be maintained for a very long time.

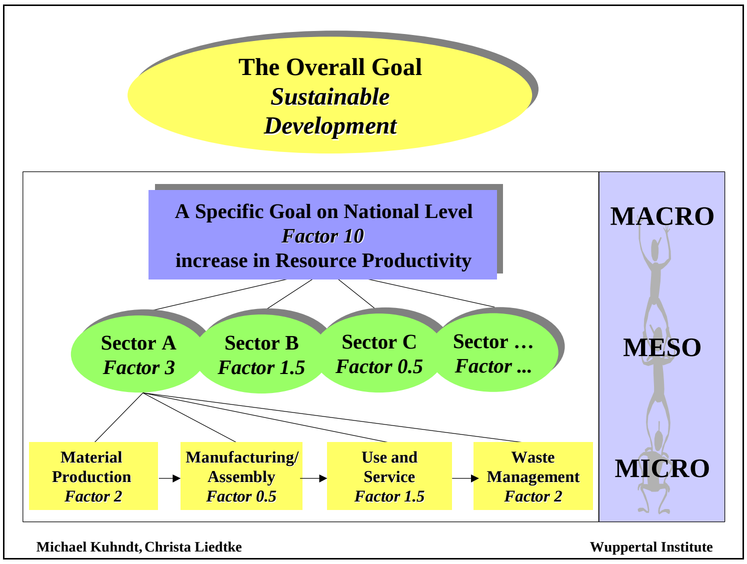

Figure 1: The setting of Factor X goals on different levels

The Factor of 10 refers to total material flows (that include also material flows for energy production) within the economy and can be set e.g. in the national policy plan as quantitative goal[27]. For the industrial production of goods and services within this national economy, this

27 Die „Ecocycle“ – Commission from the Swedish Government is driving for a Factor 10 within the next 25-50 years (Kretsloppsdelegationens Rapport 1997/13: Hallbrat Sa Klart – en Kretsloppstrategi“, Stockholm), The Netherlands formulated a Factor 4 goal in their national environmental plan in 1996 (Ministry of Housing, Spatial Planing and the Environment. 1996: National Environmental Policy Plan, The Netherlands), Austria wrote a factor 10 goal into their national environmental plan in 1995. (Austrian Government. 1995: National Environmental Action Plan, Vienna, Austria.) The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety suggested a 2,5-fold increased raw material productivity by 2020 compared to 1993 and a 2-fold increased energy productivity by 2020 compared to 1990. (The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. 1998: Sustainable Development in Germany - Draft Programme for Priority Areas in Environmental Policy, Bonn, Germany.)

does not mean that the resource productivity of every single process or every individual phase of the life cycle must be drastically increased. Rather those whole industry sectors contribute with different factors to the Factor 10 goal according to their life cycle wide potential to reduce resource consumption (Figure 1).

In the big picture, it may turn out to be ecologically preferable to ‘invest’ more resources in a particular sector (e.g. according to the figure in sector C) or at a specific stages in the life of a product (e.g. according to the figure in the manufacturing/assembly phase), in order to increase the overall resource productivity.

Is the "factor goal" for optimisation chosen, it is even more important to benchmark the current resource productivity and to develop possible implementation measures to improve the material flow. We will, in the following, present such possibilities, which focuses on the industry sector and enterprise as the relevant actor.

Our general framework:
1. Set the Factor X target.
2. Analyse/measure the distance to target.
3. Improve the material flow.
4. Communicate & market your achievement.

The Performance Assessment - Measuring the Distance to Target

Only what is measured gets done is also the underlying principle of the Factor X discussion. What we prefer to measure resource productivity are methods which can be chosen according to the information extend (unit) desired: Should the information be based on mass units we prefer MIPS (Material Input per Service Unit), should it be based on combined mass and monetary units we prefer REA (Resource Efficiency Accounting) and on combined mass and monetary units with social considerations COMPASS (companies' and sectors' path to sustainability). In the following the different methods are explained briefly.

MIPS - A monitoring tool for the material flow

MIPS is a methodology to measure the material input at the level of products including all their "ecological rucksacks", i.e. the total mass of material flows activated by an item of consumption in the course of its life-cycle. (Schmidt-Bleek, 1994)

The material input (including primary materials for energy production, infrastructure, transportation) thus reflects all the material displaced in nature during the product life-cycle measured in tons, and can be related to a service provided by the product in question. The total material input of the analysed product minus its actual weight is the so-called "ecological rucksack". Since the different phases (production, usage, disposal, recycling) are analysed separately it is possible to specify phase-related "ecological rucksacks". The concept distinguishes the following categories of material inputs:

1. abiotic (non-renewable) raw material,
2. biotic (renewable) raw material,
3. moved soil (in agriculture and forestry),
4. water (any volume removed from natural water ways or reservoirs),
5. air (if it is chemically or physically transformed).

Consequently, energy carriers are also accounted in tons because a quantitative comparison of energy carriers and other materials is only possible on the basis of non-energetic units. As will be described below the MIPS indicator can not only be applied for a life-cycle wide analysis but can also be included in resource management systems and auditing schemes in enterprises (see below). In this manner, the environmental impact (associated with the resource use) of functionally equivalent goods or production sites can be compared directly. Whatever knowledge available about the toxicity of materials involved is to be included in all decision-making processes - which is generally already required by law.

Resource-Efficiency Accounting - Linking the Economic and Ecological Information
As companies suffer from a lack of information tools which simultaneously assess economic and environmental aspects of decisions and activities throughout the whole life-cycle the Wuppertal Institute has developed the Resource-Efficiency Accounting (REA) tool. (Orback et al, 1998)

The ecological assessment of REA is based on the MIPS-concept. Whereas the economic dimension of REA may be depicted by various cost accounting systems the objective of REA is to reveal (hidden) environmental costs and to explore the potential for environmentally sound cost reduction.

REA links the economic and ecological dimension by so-called Resource-Efficiency Portfolios at process, product and company level (the latter to compare companies within a sector). All relevant material flows and costs of a company are allocated to the processes and products which are classified in different Resource-Efficiency Portfolios. At product level it is interesting to show the contribution margin or other economic figures in addition to cost figures. The Resource-Efficiency Portfolios enable to identify "economic and ecological cost drivers" at process and product level. Data at company level can easily be derived from the Portfolio data by simple accumulation.

COMPASS - companies' and sectors' path to sustainability
For companies and sectors it is important to know what kind of targets and actions they will bring on a path to sustainability. Within this resource productivity is one important path for companies and sectors. However in the broader context of sustainable development there are also numerous other economic (e.g. high profit, high competitiveness, low investment pay back), ecological (e.g. low toxicity, high biodiversity, low erosion) and social targets (from employee satisfaction over a low unemployment rate to overall stability in society) which have to be addressed. In order to handle the enormous amount of economic, environmental and social criteria measurable quantities have to be derived, and an integrated analysis and decision support tool for manager, politicians, associations and local authorities is needed.

COMPASS (companies' and sectors' path to sustainability) (Kuhndt & Liedtke 1999) has been developed to provide decision-maker in a company or sector with sufficient information. COMPASS includes a methodological framework, instruments and measures to operationalise the normative concept of sustainable development at micro level. It helps step by step supporting the understanding of what sustainable development means for an enterprise or sector - from a life-cycle wide perspective of a product or service - and shows to what extent a development in the direction of a sustainable economy is achieved. It gives combined ecological, economic and social information on the status quo and on consequences of decisions. It helps to evaluate the actual company's impacts and to explore improvement strategies concerning the ecological, economic and social situation of the company.

An overriding priority of companies and sectors attempting to promote sustainability on the company level is translating the broad indices and indicators of sustainability on national and regional level into measurable indices and indicators for the company to reflect in its business decisions. How does the company decide whether one product line or technology is more sustainable than another? How does the company design products and services for sustainability? COMPASS includes an assessment part which combines selected performance indicators with overall (reduction) targets to present a holistic picture of the decision situation. Furthermore, COMPASS benchmarks the performance (e.g. the material throughput) of a product/service/company in a sector/on the market and evaluates the impact (e.g. CO_2 emissions) the product/service/company is responsible for compared to the overall national impact (Kuhndt & Liedtke 1999).

The integration, implementation and communication of new business strategies in itself constitute a process and require further tools to take action. Currently, within different industry case studies COMPASS is developed further in order to provide guidance for different business units and stakeholders within the different industry sectors.

The Improvement Management - Optimising the Material Flow

All three methods provide the data for an improvement management, specifying in which processes resource consumption is particularly high. In this way businesses receive information on where optimising potential is greatest (both „in-house" and from „cradle to grave"). Simultaneously businesses receive information about which purchased inputs are particularly resource intensive. The Resource Management (RM) program is designed to improve the life-cycle wide cost and material flows with the overall goal to increase the resource productivity by a factor of 10. It includes three different components (figure 3) which complement one another and which are interlinked: material flow management, product management and eco-design.

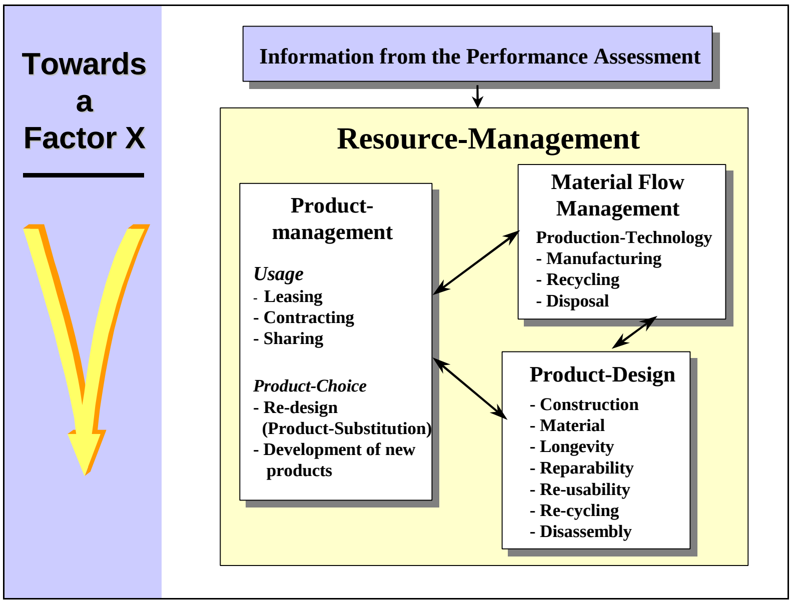

Figure 2: The three key areas of the Resource Management Concept and possible areas of action.

Material flow management focuses on the life cycle phases of manufacturing, recycling and disposal of the materials used to produce a product, and the final product itself. Product management has the goal of improving the environmental performance of the product during use, that is, designing a resource efficient use phase. The eco-design component aides in product development through specific resource efficiency criteria (Schmidt-Bleek & Tischner, 1995). Depending on the situation (re-design or new design of a product) the following RM will be implemented.

Case one - re-design of an existing product: The product is on the market, the production site is already installed, consumers (enterprises and final consumers) are in tune with their behaviour in relation to the product. Steps for RM include:

- Material flow management: Different processes will be analysed concerning their cost and resource efficiency potential. Plans for improvement will be developed.
- Product management: The consumer will get advice how far their behaviour influences the resources efficiency of the product. A channel of communication will be opened so that new ways of product usage can be conveyed.
- Eco design: The product's weaknesses will be analysed with a resource efficiency criteria list. It will be examined how far a resource efficient product design is possible with the existing production infrastructure.

Case two - design of a new product: Because the product is new, consumers (enterprises and final consumers) are not in tune with their behaviour in relation to the product. Steps for RM include:

- Product management: The needed service the product has to deliver will be closely defined with the final consumer, paying special attention to the resource efficiency, e.g. to provide fresh foodstuff (to provide the cooling function) in a household with reduced energy and material consumption.

- Eco design: Using the resource efficiency criteria list a new consumer-oriented product will be developed. Designing a product that needs fewer resources throughout the life cycle also means altering how the consumer uses the product. In the following, the action of new design will be explained taking the cooling chamber "FRIA" (Weizsäcker et al., 1997) as an example: FRIA is in a sense a multichamber refrigerator with certain design principles borrowed from a larder concept. The larder has always been a fixed non-moving element in architecture, well insulated against cooking and typically facing in the north face of the dwelling. In countries like Germany, the larder is as cool as a typical refrigerator for 3 to 5 months of the year. FRIA uses high-tech cooling techniques and better insulation than conventional refrigerators. It has an extremely long service life and the chambers can be repaired or exchanged separately. The cooling system is separated from the cooling chamber and thus can also be exchanged separately. Because FRIA can outlive perhaps five to ten generation of traditional refrigerators, as well as being at least two to four times more energy-efficient, a factor between four and eight in total resource efficiency compared with the conventional refrigerator is achievable.

Figure 1: FRIA, the cooling chamber

- Material flow management: For the new product, new production technologies are needed. Often it will be necessary to include new and different companies in manufacturing and operating the product (e.g. for maintenance, repair, and recycling). For the new cooling concept, the architects, construction companies, heating and electronic engineers have to work together and share their knowledge to allow the modular construction of the cooling chamber. The transition between "old" and "new" product concepts is not easy as it needs numerous structural changes; therefore it should be made in small steps, considering the profit and organisational structure of the company.

An increasing number of businesses have used the resource management approach to increase their resource productivity and to saves cost, examples are: Hess Natur, the largest mail order house for eco-textiles in Germany, Austria and Switzerland, which is driving for eco-efficient textile products that have an increased resource productivity by at least a factor of 4; Kambium Furniture Workshop, a medium-sized furniture enterprise, uses it as a prerequisite for a cost- and eco-efficient environmental management system (Liedtke et al., 1998); businesses in the chemical industry use it as an element for product development (Hoechst AG 1997), and a builder of promotional stands at trade fairs uses it in his concepts (Internal Working Paper, 1998).

Communication - Show the Improvements

To translate resource efficiency as a strategic management goal into praxis and to achieve system wide improvements towards the goal of Factor X networking and the exchange of knowledge is important. Therefore two new platforms has been launched in 1998: Together the Word Business Council for Sustainable Development the Wuppertal Institute has organised an international conferences to discuss ideas towards increased resources productivity. Similar conferences are planed for 1999. Jointly with the Factor 4+ association the institute provides a yearly platform - the Factor 4+ trade fair - where all stakeholders and especially industry are invited to show their concept and practical achievements towards the goal of Factor X.

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Monitoring material flows

Characterising Material Flows: The Case of Sustainability

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Introduction

An account, of the physical material input and output balances, of an economy is not an end in itself – except as a first approximation of the weight of human activity on the environment. Instead, it is a tool that allows us to ask questions of human activities related to materials and resources. Through this analysis we can better estimate the specific environmental consequences of human economic activity and thus construct indicators of material flows that allow us to understand and balance the environmental impacts and the economic costs and benefits of our actions.

This is directly analogous to purely economic analysis. Our system of National Accounts is a database which allows us to ask questions about the state of the economy. One macro measure, the Gross Domestic Product (GDP), is just a first look at the size and trends in the economy. To ask more detailed questions of the financial accounts requires us to look more closely as those aspects of the database that are relevant to the specific questions we ask. What is the balance of trade? What is the inflation rate? How much public debt is generated each year? Specific analysis requires giving weight only to those data that are relevant.

To ask questions of a database of the physical accounts of an economy requires us to look at each material or commodity in terms of the questions we ask. If we want to ask questions of the impact of materials extraction and use on the ozone layer, we must characterise each material by its ozone depletion potential. If we want to ask questions of effects on freshwater biota we might want to weight each material by whether it enters water and by its effect on aquatic life (toxicity for example). If we want to answer questions related to sectoral or spatially distributed effects we would have to characterise each commodity as well by the economic sector that uses it, or the area where it extracted or re-enters the environment. In any case, the analysis of the database must be tailored specifically to the questions being asked of it.

Choosing the weights to use in these analyses must be done with care, transparency, and an understanding of the purpose and audience for the results. It follows that the question must be answerable in the first place and that the answer have consequences for the management of those materials or their place in the economy.

By accounting for all material flows mobilised by our economy and qualifying them by their impact on the environment, we gain a tool enhancing our ability to improve environmental quality. This paper introduces a methodology developed by the World Resources Institute to characterise disaggregated flows based on quantity, mobilisation, quality, and velocity.

Background

Sustainable development is a stewardship concept. It is the idea that we bear a responsibility for the legacy which we leave to future generations. This legacy can, in broad terms, be thought of as having environmental, economic and social components. This paper considers specifically the environmental component of sustainable development. Changes in our environmental legacy arise from the movement or transformation of physical material. Movements and transformations can be driven by solar energy and geologic processes which are part of the natural environment. They can also result from the activity of humans and other living organisms. In this paper, all transformations or movements of physical material are denoted by the term “material flow”.

In the early 1970’s Daly (1), Ayres (2), and others, recognised that material flows resulting from human activity were increasingly impacting the environment. Daly pointed out that the human industrial economy was a subsystem within the total environment and there are no infinite sources of resources, excepting the sun, and no infinite sinks where we could dispose of our wastes. The system was shown as bounded and fundamentally incompatible with continuous physical growth. Ayres examined a number of material balances for the US industrial economy and showed the magnitude of the outputs (residuals) which were accumulating in the environment.

In 1994 Ayres (3) pointed out that material flows which are part of a closed system are sustainable as long as there is energy available from an external source. This is the case for flows in the natural (non human) environment where flows exist in a state of dynamic equilibrium, constantly occurring but self sustaining. In contrast to closed systems, Ayres showed that open systems are inherently unsustainable and unstable, since there are build-ups and decreases in stocks in various parts of the system. Most industrial economies are almost totally open systems

To begin to understand how we impact the environmental component of sustainability, we must have information on human induced material flows. In an industrial economy these flows vary significantly in type and magnitude and their effect on the surrounding environment varies accordingly. Individual flows can be examined to assess their impact, but it is exceedingly difficult to arrive at a coherent understanding of the whole. Additionally, the relative importance of various flows differs between people and groups. This paper introduces a method of characterising flows for use in the current World Resources Institute (WRI) study of the total physical outputs of the United States industrial economy for the period 1975-96. In accordance with recommendations in the literature on sustainability, the characterisation methodology can be used to address a wide range of questions of interest to the public and policy makers.

A tree falls in the forest and decomposes with the aid of organisms for which it provides nourishment. Its components return to the soil to feed other trees and growing vegetation which nourish the many creatures in the forest who in turn die, and yield up their nutrients back to the growing vegetation which supported them. This is a closed system, a system in nature. Life goes on in a continuous cycle and the system is, and will stay, in dynamic equilibrium unless disturbed by some geologic or atmospheric event.

Take the tree or the animal from the forest, use the wood for shelter, the meat and fur for food and clothing, and deposit what is left in a site far from the forest, and you have an open system. Take metals and other minerals from the ground and distribute them on the surface of the land and you have an open system. Up until about 10,000 years ago, humans were part of a closed, natural system. With the rise of agriculture and the creation of concentrated settlements (cities), we began to live in open systems, separate at first but increasingly interconnected.

The material flows associated with our emerging open systems, while sometimes deleterious, were small at first. They grew slowly until the advent of the industrial revolution about 300 years ago, at which time they began an exponential increase to the point where they are today. In the United States the degree of openness of our current system exceeds 20 billion metric tons per year. This means that each year we physically move or transform more than 80 tons of material for every person in the country. And we are not alone. Recent studies of material flows in Germany, Japan, and the Netherlands showed that these nations had open flows of equal magnitude. Indeed we are busy creatures, and we are changing our environment. Of course our environment is, and has always been, changing. As mentioned previously geologic process are constantly reforming the landscape, sometimes in disastrous ways, and life forms are evolving constantly. However, there is an important difference between changes which are beyond our control and those which are the result of our actions. To begin to assess if the flows we cause are compatible with an environment acceptable to current and future generations we must examine the overall dimensions of the flows associated with our industrial economy

Arriving at definitive conclusions with respect to monetary flows is easier than for physical material flows. Monetary flows are measured by economists using the agreed upon proxy of monetary units. Sum up all the monetary flows and decide whether things are good or bad. Considerations which cannot be assigned a monetary value might be mentioned but, for the most part, are ignored in the calculations. There is little mystery why economics has played such a powerful role in our lives. We all think we know something about economics. Having ten dollars is better than only five. It's the bottom line of a profit or loss statement that we can understand and relate to. Material flows are a different matter. A pound of lead taken from deep in the ground and disposed of in a river or stream is quite different from the same thing done with a pound of sand. Similarly the release of CO2 to the atmosphere is different than the release of chlorine gas. Unfortunately just summing up the pounds as if they were dollars doesn't tell us very much about potential impacts on the environmental legacy, and examining every material flow separately obscures information on important trends in a ocean of data.

Review of Literature on material flows and sustainability

The issue of deciding which material flows are important to sustainability and extracting useful information from the mass of data on material flows has been examined by a number of authors. Various methods of aggregation have been suggested based on considerations that some flows are more important than others, and criteria for assessing which flows might affect sustainability have been developed.

Goodland (4) formalised a model of a stable system and provided a definition of sustainability which required that 1) waste emissions should be within the assimilative capacity of the environment and, 2) harvest rates for renewables must be within regenerative capacity, and depletion of nonrenewables should not exceed the development rate of substitutes. These general principles are shared in a modified form by Karl-Henrik et al (5) and by Azar et al (6) who expand them to include considerations of efficient use with respect to human needs. Azar develops a set of about sixteen indicators to assess movement towards or away from sustainability. A logical method of aggregating flows is suggested, and a social equity dimension is introduced. This is an important issue in the overall consideration of sustainability. However, no apparent distinction is made with respect to the importance of individual indicators.

Toman (7), examining sustainability from the perspective of economics, concludes that some of the effects (impacts on the environment) of human activity should be left to the free play of individual incentives and resource tradeoffs. As potential impact and cost of damage increase, there is a moral imperative for resource and ecosystem protection. Toman admits that the line between these two categories is not sharp. While operationally vague, this notion is conceptually important since it identifies that some things are more critical than others and they belong in different domains.

This theme is echoed by Norton (8) who suggests that hierarchy theory is useful in the formulation of meta criterion to sort decisions into those which have mainly individual impacts over limited periods and those which have intergenerational impacts. He proposes that time and spatial scale are important elements in decision making, and hierarchy theory is a way of organising information regarding complex systems into multiple scales. Norton's consideration that the degree of reversibility- time of reversibility- and degree of substitution are important, leads him to conclude like Toman, that small scale reversible changes are the domain of economic theory, and large scale irreversible changes should be governed by moral considerations. His suggestion that a temporal horizon of 0-5 years be the domain of human economics might however be more limiting to this sphere than Toman would prefer.

Fischer-Kowalski (9) agrees with the notion of different categories but suggests that the spatial dimension should distinguish between outputs distributed on national territory and the international media of air and water. Since countries are vastly different in size, this introduces some complexity but politics are real and important. Fischer -Kowalski also introduces the operationally useful idea that we should distinguish between fast throughput, such as fossil fuels, and long lived consumer durables.

Sharpe (10)reminds us that useful measures must relate to where peoples' attention is, and that current close by issues are what people are most concerned about. In this she provides a useful quote by David Hume, the Scottish philosopher that humans are "principally concerned about those objects which are not much removed either in space or time, enjoying the present and leaving what is afar to the care of chance and fortune. Talk to a man of his condition thirty years hence, and he will not regard you. Speak of what is to happen tomorrow, and he will lend you his attention. The breaking of a mirror gives us more concern when at home, than the burning of house when abroad, and some hundred leagues distant.

Friend and Rapport (11) propose a system of Natural Resource Accounts which track stocks and flows of natural resources and indicate that "While there is an expressed desire for a common denominator to evaluate economic benefits and environmental costs, we believe, that a pluralistic approach is preferable to the procrustean bed implied by forcing an artificial value structure on decision making. Intelligent multi-variable analysis of bio-physical and economic data on conditions and trends are probably more enlightening than a single trade-off balance sheet". They propose a conceptual framework which tracks stocks and flows of natural resources, agreeing in principle with Samuel Johnson that " Particulars are not to be examined till the whole has been surveyed".

Aggregating material flows

Traditionally a specific environmental question has preceded the gathering of data on the material flows causing the impacts under consideration. Based on the question being asked, individual flows having similar properties are combined to provide useful information. The combination may be a simple aggregation of a selected set of individual flows or it may involve a weighting scheme of some kind. The questions addressed may be global, regional, or local in scope, and the data set selected changes accordingly. In most cases a time series is constructed to provide a view of the trends, sometimes in relation to perceived or desired limits

Adriaanse (12) considered a number of themes (environmental issues) of Dutch environmental policy for which indicators were developed. The indicators devised had as their purpose the conveyance of information on complex processes to policy makers in a format that could be easily understood. In order to accomplish this he proposed a pressure-state-response model with appropriate indicators for each category. Environmental pressure, created by human activities such as agriculture, impacts the state of air, water, and other environmental resources, and responses must be undertaken to reduce the negative impacts which occur. For each environmental theme the constituent contributing factors were defined and weighted to arrive at a single indicator for each theme. The weighting of constituents was done on either a technical basis, (the warming potential of various greenhouse gasses), or a subjective basis, (the contribution of noise and odours to disturbance of local environments). A time series display of each theme indicator was then compared with a target, and individual themes were combined to create a total environmental pressure based on the relationship of the individual theme to its target. Decision makers then had available information on the aggregate measure and the individual themes.

Jesinghaus (13) recommends using a somewhat similar approach but proposed that experts be used to assign weights. The Expert Topic Assessment System, EXTASY, uses a two level weighting scheme. Experts assign weights to the constituent parts of each individual environmental theme and then a second weighting scheme is used to aggregate the components into an overall "Index of Total Environmental Pressure". Jesinghaus recommended that weightings be performed by appropriate experts and the weighting rules be transparent. It was also recommended that the higher level aggregation be done by experts with a much broader view than those doing the first level aggregation.

Both of the above approaches attempt to arrive at an some overall assessment of environmental pressure, or potential impact. Similar schemes have been constructed with different questions in mind. Questions concerning the regional effects of acid rain have examined the emissions of SOx and NOx from various sources, and global warming has been addressed using a weighted aggregation of greenhouse gasses. Similarly, concerns about local and regional health have focused on flows of toxic compounds.

All of these approaches share two things in common. First, the material flows which are investigated derive from the environmental impact under consideration, or the question being asked. Second, some weighting scheme is normally required to aggregate the contribution of individual material flows included in the investigation. In the first condition means there is no ability to address questions other than those for which the system was devised. The second condition imposes a requirement that the weighting scheme be both transparent and acceptable to all users of the analysis. Additionally, while the aggregation methods discussed above are useful for addressing specific questions they fall short of satisfying a number of the recommendations in the literature.

Categorising flows based on spatial, quality, and velocity characteristics

As mentioned earlier the industrial economy of the US and the rest of the world, is essentially an open system. Matter is preserved and output flows accumulate rather than assimilate The impacts of accumulating output flows may be local, and fairly easily and quickly reversible by us, albeit with a necessary input of energy and additional material flows, or they may be global and irreversible for all practical purposes. A local waste dump is an example of the former, global warming arising from emissions of CO2, the latter. These two examples differ in terms of the spatial domain affected, our ability to undo the impacts that our material flows have caused, and the institutional mechanism (local, national, or international polity) which can effect a change in the current state of affairs. From a personal perspective they may also differ in terms of importance. The creation of a waste dump close by today is different than one in another district next year. What we care about depends to a large degree on where we stand.

Historically some of the environmental changes that we have caused have been deemed by society to be unacceptable. In the 1970's the pollution of air, land and water became a national issue in the US, and action was taken to correct the worst of the ills that existed. Considerable progress was made in correcting the perceived problem, but little in the way of fundamental change was made in the degree to which the industrial system is open. What did occur was a change in the form of certain flows and where they went. We took particulate matter out of flows to air and water and contained it on the land We changed concentrated local waste streams to more dilute ones and distributed them over larger areas, possibly expending more energy and/or increasing other flows in the process. While the fundamental openness of the industrial system was not markedly altered that the changes made were useful and beneficial. Containing an output flow in a controlled impoundment or landfill is certainly better than distributing it to the water or air.

As can be seen from the above, a coherent method of examining material flows should track not only the quantities of output flows, but also give us some information on how the form and ultimate fate of the flow changes with time. The literature review showed that the degree of difficulty in reversing the impacts of a flow should be considered as one measure of how critical a flow is. For instance, the impacts of material in a controlled landfill can probably be reversed more easily than if the material had been deposited in a river. Reversibility is a useful notion, and even though there is considerable methodological difficulty in directly operationalizing this concept, we feel that an understanding of reversibility is to a large degree derivative from information on the spatial distribution of a flow in combination with some information on the quality of the flow.

The importance of an additional characteristic of material flows was identified by Fischer-Kowalski, who suggested that the speed with which a flow travels from the environment, through the industrial economy, and back to the environment was useful to know. Recycling and increased product life, are intervention strategies which work by slowing the velocity of material flows. The following sections of this paper consider methods for defining the spatial, quality, and velocity characteristics of material flows which are outputs from an industrial economy. The methodology has been created for use in conjunction with a system of national material flow accounts under development at WRI. for the time period 1975-96.

As part of this study, approximately fifty separate commodity and activity material flows are being examined. For each commodity flow individual input and output streams are being compiled for separate uses of the commodity. As an example, time series data on arsenic outputs will show yearly losses in process, and use as a wood preservative, an agricultural chemical, in glass, and as an alloy. Spatial, quality, and velocity category assignments are then made based on the use of the commodity, or form of process loss. In some cases use data are quite fine grained and complete, for others this is not the case. Activity categories include highway building, general construction, agriculture, and dredging. For some of these, data are directly available; for others, estimation methods are used. It is our intent that this methodology will allow users to obtain information in response to a wide variety of questions.

Spatial characterisation of flows

The spatial dimension, or extent over which a flow can impact the environment, is related to its dispersion and freedom of movement in the environment. We feel that a first approximation of what we term mobilisation, can be inferred from the physical state of the output flow (gaseous, liquid, solid), and the degree to which the flow is controlled in the industrial system. This approach is similar to that taken by the Environmental Protection Agency (EPA), which compiles data on the physical form, medium of release, and degree of containment for flows it keeps track of.

It is fortunate that the available information on the material life cycles for most major flows allows a reasonable judgement to be made about these two factors, at least at the point where the flow first enters the environment. Changes in form and mobility clearly do occur subsequent to first entry. Flows dispersed as solids on land may later be dissolved and report to water systems, those released to air may end up on the land. Identifying all the possible pathways subsequent to first release is necessary for a complete assessment of potential impacts. However, this is an extremely complicated, site dependent analysis much beyond the first level characterisation being proposed in this paper. It should also be noted that no attempt was made to provide information on the specific sites of output flows.

We considered two aspects important in the creation of categories describing the mobilisation of material flows. The first: Is the distinction useful as a first step in understanding the spatial impact of the flow? The second: Does the available data permit a reasonable decision to be made about which category a flow should be assigned to? In our current work the following mobilisation categories are proposed:

> M1) Flows contained, controlled, on land as solids (landfills, overburden, highway earth moving…).
>
> M2) Flows contained on land as a liquids or partial solids (tailings ponds, impoundment's…).

Since both M1 and M2 are controlled in essentially the same manner, it may be possible to combine them.

> M3) Flows dispersed directly onto land in a solid, partial solid, or liquid form (fertilisers, pesticides, fungicides…).
>
> M4) Flows discharged into water systems in a solid, partial solid or liquid form (dredge spoil, soil erosion, sewage effluent, deep well injection…). While it could be argued that deep well injection is a controlled release more appropriate to category M1, the degree of containment in the geologic structure can be uncertain.

M5) Flows discharged into air from point sources in a gaseous or particulate form (power plant and industrial source stack emissions…).

M6) Flows discharged into air from diffuse sources in a gaseous or particulate form (auto emissions, household heating plants, spray paints….).

M7) Flows that take many, or no clearly defined path, or which are not classifiable.

While it is felt useful to differentiate between point and diffuse sources, it is acknowledged that the spatial domain affected by multiple point sources may be the same as that from diffuse sources.

Quality characterisation of flows

A specification of the quality of a flow should provide some information on how easily the flow can be assimilated by the environment. As stated previously, assimilation is quite different from accumulation. Only flows which are biodegradable, or are a consequence of our human physiology, can potentially be assimilated in anything short of thousands of years, or longer. This is geologic time, the time it took to form the coal and oil deposits which we are now transforming into gaseous emissions to the atmosphere. There are however some geologic processes which operate over shorter time frames. Erosion, beach formation and removal, and siltation of rivers are continuous natural processes which physically transform and move material, observable in a human time frame. Some flows in our economy are similar to these.

Assigning flows to quality categories is more difficult, and potentially more contentious, than mobilisation categories, but it is necessary if we are to begin sorting out flows in a useful way. Treating every flow individually leads to information overload and simple aggregation has little utility. While recognising that a many of quality measures, useful for addressing specific questions, might be constructed, we propose initially to use the following categories in our work:

Q1) Flows which are biodegradable (agriculture, forest, and fishery products,…).

Q2) Flows which replicate rapid continuous geologic processes (particle size reduction and movement only)

Q3) Flows which have not been chemically processed but are chemically active (salt.), or biologically hazardous (asbestos).

Q4**)** Flows which have undergone chemical processing. These may or may not be chemically active (fuel emissions, fertilisers, industrial chemicals, certain mineral processing wastes….).

Q5) Flows which are heavy metals, synthetic and persistent chemical compounds, or radioactive.

It should be noted that flows in the Q1 category cannot automatically be considered to be innocuous. As an example, while manure can be a useful soil supplement, too much in one place can be a significant problem as recently witnessed at some large scale pig and poultry farms. Similarly, just because a flow replicates a geologic process, category Q2, does not mean it is benign. The filling of a wetland, or the building of a road through a critical ecosystem can have major impacts. The assignment of individual output flows to quality categories is to be done by the WRI project staff based on professional judgement. Alternative assignments can be made by subsequent users.

Velocity characterisation of flows

The velocity of a flow, or its converse, the residence time in the human economy, is an important variable which can be related to potential impacts on the environment. Some flows, such as overburden removal, enter and exit almost simultaneously. Others such as the aluminium used in a beverage container which is not recycled, may have a service life of weeks. Concrete and steel used in construction may remain in the economy for one hundred years. While the impact a flow has on the environment is not, on a per unit basis, directly related to its velocity, the quantity released, or disposed of in a given period of time certainly is. Recycling increases residence time and reduces the quantity released per unit of service obtained. In theory, as velocity approaches zero the system approaches a closed and sustainable configuration. Energy is, of course, required to sustain the service providing physical flows within the economy, and it would be necessary for this energy to be from renewable sources.

Available information allows the velocity of a flow to be reasonably estimated according to three broad categories as shown below:

> V1) Flows which exit within two years after entry (food, fertiliser, packaging, petroleum used as fuel,...)
>
> V2) Flows which exit after from (3) to (20) years in the economy (durable consumer goods, automobiles,…). It would be useful if V2 could be further divided into 3-10, and 10-20 year categories, but it is not clear that the available data permits this distinction to be made.
>
> V3) Flows which stay in the economy for more than 20 years and are additions to the stock of built infrastructure (highways, buildings,…)

Material flows and sustainability

As noted earlier, the 1970's saw the US undertake a prevention and cleanup of the pollution of water, air, and land that was occurring. Pollution was identified as being the result of uncontrolled flows of certain materials to the environment. The flows which were identified as pollutants included toxic, radioactive, and hazardous material. These flows were curtailed or redirected and significant environmental benefits resulted. However, the early consideration of what was a pollutant did not include CO_2 and CFC's which cause global warming and ozone depletion, fertilisers which raise nutrient levels in waterways and cause eutrophication, roadway building and earth moving activities which destroy and reorder ecosystems, and manure from animal farms to name a few. The early definition of what was a pollutant turned out not to be very useful notion, and it may in fact have created the false impression that industrial societies had only a limited set of material flow issues to confront.

Today there is a greater awareness of the point we have stressed, that all material flows cause environmental change. Particular flows can be good or bad depending on their magnitude and dispersion. Flows can be critically important or trivial depending on proximity in time and space, and a contained flow is different from one which is dispersed. The consideration of material flows in relation to environmental impacts and sustainability therefore, requires a systematic characterisation of all the flows in the industrial economy. A complete disaggregated accounting of all national material flows, characterised on the basis of quantity, mobilisation, quality, and velocity can provide this. Accounts of this kind are essential for policy makers since they provide an overall national picture within which individual flows can be assessed. It is also useful to individuals who seek information on flows of particular concern to them.

Discussions of sustainability are often difficult and confusing because individuals are not always talking about the same thing. Figure 1 illustrates this by using a log-log representation of the spatial domain impacted by a material flow, and the time or cost to remediate the impacts of the human induced environmental change. Superimposed on these axes is a graphical representation of how the spatial temporal dimensions of concern might vary in a discussion of sustainability with individuals, large corporations, medium sized cities. and the US government. In this illustration there is a commonality of concern at the origin of the illustration, a somewhat formal way of saying that local, short term issues are important to everyone However, a considerable divergence is suggested on where the outer boundaries might be in a discussion on sustainability. Is it useful for a national discussion of sustainability to include every local short term environmental and health issue, or should it be restricted to the longer term global and national issues-the long term legacy we leave our children? Similarly, should discussions at the community level focus attention on global warming or local problems. Certainly all are related and important, but a confused focus makes discussion difficult.

National accounts which characterise flows on the basis of quantity, quality, mobility, and velocity can provide a way of facilitating discussions on sustainability. Consider that most large quantity flows, with the exception of gaseous products from fossil fuels, are controlled and primarily of local interest. Flows which are of regional and national interest are mostly those which are highly mobilised in gaseous form. However, releases of heavy metals and synthetic chemicals can also cause concern to extend to the national or global level. The effect of each of these flows is different, but each is important. Compiling and characterising national material flow accounts is an important first step towards understanding how our activities change the environment, and defining a path to sustainability.

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A PRODUCT COMPOSITION DATABASE FOR MATERIAL MANAGEMENT: APPLICATION FOR PRIORITY SETTING AND SUBSTANCE FLOW ANALYSIS OF ALUMINIUM IN DENMARK

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Summary
A product composition database has been developed for the Danish Environmental Protection Agency. In the database, all industrial end products traded in Denmark are arranged into 966 commodity groups based on the commodity statistics compiled by Statistics Denmark. For each commodity group the average material composition, the loss of resources and the energy consumption on a life cycle basis are determined. Figures of production and consumption can for each year be retrieved from the national statistics. The database was developed with the purpose of ranking industrial products according to the total resource loss and energy consumption connected with the use of the products. The product composition was differentiated on 150 materials, e.g. metals and plastics, and consequently the database can be used for a broad compilation of the total Danish consumption of each material. The database has been used for substance flow analyses of a number of metals. In this paper the application of the database for a substance flow analysis of aluminium at the national level is shown.

Introduction
Knowledge of material composition of industrial products is often an important prerequisite for successful substance or mass flow analyses at the national level. In Denmark the efforts in this field have in the recent years benefited from the Danish EPA's Product Composition Database developed in 1993. This database was developed in order to prioritise the efforts invested by the Danish EPA in improving the environmental characteristics of different types of industrial products. However, the database has also proven to be extremely useful in SFA's/MFA's and in particular for analyses covering substances like copper, nickel and aluminium, that is used widespread in many industrial products. In this paper the database and its potential use are briefly presented.

Environmental ranking of industrial products
With the purpose of identifying the groups of industrial products that over their entire life cycle (from raw material extraction to their final disposal) have the highest total environmental impact, all industrial end products sold in Denmark were ranked according to the total loss of resources and energy consumption that was connected with the use of these products (Hansen, 1995). Loss of resources and energy consumption were used as indicator parameters for the total environmental impact of the industrial products through their life cycle. These indicators were chosen because they represent an essential part of the total environmental impact of industrial products. Additionally it was relatively easy to estimate these parameters of all industrial products.

The material composition database
All industrial manufactured goods sold in Denmark were arranged into commodity groups. The grouping was based on the commodity manufacturing and trade statistics compiled by Statistics Denmark. Of a total of 10,376 commodity numbers in the trade statistics, 3,729 were considered to cover raw materials, semi-manufactured goods or handicraft, and were consequently sorted out. The remaining 6,647 commodity numbers were arranged into a total of 966 commodity groups.

The average material composition differentiated on 150 materials was determined for each commodity group. The materials included metals, minerals, chemicals, rubbers, plastics and agricultural products among others. The commodity groups were described including packaging as well as spare parts and working means that are needed during the whole in-service life-span of the products of the group. For instance the group washing machines included the total use of soap, softener and water.

The average material composition of a commodity group was determined based on information of typical products within the group. The determination was based on information from the leading producers and suppliers of the products in Denmark. These data were compiled in 1993. The content of materials was only determined for materials that made up more than 1% of the commodity group. Materials that were present at a percentage below this threshold were included in the database without content specifications. For illustration by example the material composition of the commodity group 'Vacuum cleaners' is shown in table 1. As shown paper used for the bags during service made up a third of the total material content of the group. The ratio of the total material consumption of the commodity group including working means, etc. to the consumption figures from the statistics was expressed by a weight correction factor. In the example in table 1 the weight correction factor was 1.81.
For each material, the average loss of resources (the amount that was not recycled) was estimated. This average was used as a default value. The loss of resources connected with each commodity group was subsequently determined as the sum of the total loss of the constituent materials. The loss of constituent materials was calculated from the average loss figures. For commodity groups where the recycling rate differed significantly from the default value, however, commodity specific values for loss of resources were determined. For the vacuum cleaners shown in table 1 specific values were determined for paper, low alloy steel, copper and aluminium.

The energy needed to extract, produce and manufacture each material was determined along with the inherent energy content of the material. For each commodity group the energy consumption was determined from the energy consumption for production of the constituent materials. Beside this, the total energy consumption by use during the total in-service life-span of the product was estimated. The energy consumption of the manufacturing of the end products as well as the energy consumption of distribution, recycling and disposal of the discarded were not included. It was estimated that this energy consumption for most commodity groups would account for 10-30% of the total energy consumption.
Information of the content of a limited number of environmental adverse substances was determined qualitatively, in such a way that the database could be used for a broad survey of products containing these substances.

Figures of production and supply (production + import - export) were retrieved from the commodity statistics of Statistics Denmark. The information was retrieved as average figures for the years 1990 to 1992. In the cases where the production figures were confidential, an estimate was made of the probable size of the production and the supply.

Table 1: Data sheet for commodity group "Vacuum cleaners"

Commodity group : 85014 Vacuum cleaners

Includes commodity no.:	85091 01 00		
	85091 01 90	Environmental adverse substances:	
		No.	Substance
Production	1695 t/year	1531	Lead (Pb)
Consumption	2217 t/year	1546	Cadmium (Cd)
Energy consumption	12.7 E0 GJ/piece	2061	Copper (Cu)
Average weight	7 E-3 t/piece	2101	Nickel (Ni)
Weight correction factor	1.81	9840	Phthalates (PHT)

No.	Material name	Content %	Loss of resources %	Manufacture suppl.
x605	Paper	32	100	N
p362	Polystyrene	12		N
x600	Cast iron/construction steel (low alloy)	11	50	N
p350	ABS	9		N
p361	Polypropylene	9		N
p365	PVC (soft)	9		N
x604	Cardboard	5		N
m050	Aluminium	4	50	N
p356	Polyamide	4		N
m053	Copper	3	50	N
d500	"Others"	2		N
j012	High alloy construction steel	0		N
k452	Petrochem. liq	0		N
m059	Brass	0		N
p355	Thermoplastic polyester	0		N
p359	Polyethylene	0		N
p366	PVC (rigid)	0		N
u305	Nitrile rubber	0		N

Al data were entered into a database, and a software was made to carry out the calculations of loss of resources, energy consumption, and the rank according to these parameters.

Ranking results

All commodity groups were ranked according to the total loss of resources and the energy consumption respectively, and a joint ranking was performed from the average rank of each commodity group.

The result of the joint ranking showed that the commodity groups that ranked high were typically characterised by one or more of the following properties:

- The products have an active energy consumption during use (e.g. cars)
- The products have a large consumption of working means (e.g. a washing machine that uses soap and water)
- The products are traded in very large quantities and consist primarily of non-renewable materials (e.g. cement and asphalt)

A considerable number of products among the 50 highest ranked commodity groups were used within the sectors of energy production, transportation, agriculture or construction. For the energy sector this regards coal, oil, natural gas, gasoline, kerosene and coke. In the transportation sector ships, automobiles, trucks and trains ranked high. In the agricultural sector the high ranked products were fertiliser, feed, meat and cheese. Although these products (fertiliser excepted) consist primarily of renewable materials, they represent a considerable energy content. Construction products that ranked high included cement, concrete, asphalt, gypsum, mineral wool and steel reinforcement.

Also a number of household appliances were among the 50 highest ranked commodity groups including refrigerators, freezers, washing machines and televisions. All these products are characterised by a large energy consumption during use. Washing machines are in addition characterised by a large consumption of working means such as soap, softener etc. Measured over the total life-span of a washing machine the soap consumption constituted 86% of the total material weight exclusive of water.

Newspapers and magazines - although they consist primarily of renewable materials - ranked high due to the fact that these products were sold in such large quantities that even a small content of non-renewable materials gave a considerable loss of resources. The high rank of the newspapers and magazines has been reflected in the initiation of several Danish projects concerning analyses of graphic products in a life cycle perspective.
It should be noted that the ranking did not take the social utility value of the industrial products into consideration.

It should also be emphasised that the ranking contains elements of uncertainty, as all data included in the calculations can only be determined with a certain uncertainty. The uncertainty of the ranking results was indicated from estimates of the uncertainty of input data by the use of computer simulation (Monte Carlo modelling). These simulations indicated that differences between two commodity groups separated by a factor of ten in the rank was in general significant, whereas the differences between e.g. number 30 and 35 were insignificant.

Use of the database for substance flow analyses

The database was set up on the Danish Environmental Protection Agency’s computer system and has among other analyses been used for substance flow analyses of copper, nickel, tin and aluminium.

As an example the database was used for a substance flow analysis of aluminium for Denmark (Lassen et al.). The year of reference was 1994. Figures of production, import and export of commodities were retrieved from the 1994 commodity statistics of Statistics Denmark. These figures replaced the 1990-1992 figures that were used for the environmental ranking project. In the period from 1992 to 1994 several commodity numbers had been combined or divided up, and a minor update of the database was necessary.
In total 119 commodity groups contained aluminium, and the database provided a comprehensive view of the consumption of aluminium in Denmark. Products that made up a substantial part of the total aluminium consumption were further investigated in order to improve the estimated aluminium content. Additionally the uncertainty of the data concerning aluminium in the database was estimated.

The Danish consumption of aluminium metal with manufactured goods is shown in table 2.

Table 2: Aluminium metal consumption with final products in Denmark; 1994.

Product	Consumption Tonnes Al	% of Al metal consumption
Packaging	7,300-11,200	10
Building materials	19,100-25,800	25
Electric and electronic appliances	14,200-20,700	20
Transportation	19,000-26,400	26
Other uses as metal	12,700-20,400	25
Total (round)	72,000-105,000	100

The information in the database of resource consumption (loss of resources) was used for an initial survey of the loss of aluminium to waste disposal, but the more general information in the database concerning loss of aluminium could only be used for providing a preliminary, broad idea of the losses. As the losses are highly product specific, a further detailed investigation of all losses had to be carried out, but the database survey was useful in information retrieval. As shown in figure 3 aluminium packaging accounted for nearly 50% of the total loss of aluminium metal in Denmark. In the environmental ranking of industrial end products based on supply figures, aluminium packaging ranked as no. 26, whereas aluminium profiles, sheets, tubes etc. ranked as no. 22. The ranking shows that the energy and the resource consumption connected with the use of aluminium is of high significance.

Table 3: Loss of aluminium metal to the environment and landfills in Denmark, 1994.

Source	Tonnes Al/year	% of total loss
Packaging	7,300-11,200	48
Electronics	370-1,300	4
Electric appliances	410-1,540	5
Building materials	40-210	0.6
Cables left in the ground	20-100	0.3
Other products	910-4,000	13
Wastes from manufacturing processes	960-2,000	8
Wastes from shredders	50-300	0.9
Wastes from secondary aluminium production	880-1,200	5
Iron and steel scrap	500-700	3
Deoxidiser for steel production	1,100	6
Anodes for harbours and ships	1,100-1,400	6
Total (round)	14,000-25,000	100

The experience with the product composition database has shown that the database is a strong tool for substance flow analyses and similar analyses of material management. The drawback of the database, however, is that the fast development in product composition requires a continuous updating of the information in the database. Such updates are quite labour-intensive, as data of product composition is not open information. The solution could be a common European product composition database. As most industrial end products are intensively traded regionally or globally, the material composition of most products will only show a limited country specific variation within Western Europe. A common European product composition database that can be multiprogrammed with the national statistics would provide a very useful tool in material management in Europe.

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MONITOR - an integrated environmental information system

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Abstract
MONITOR is a joint research effort between a number of academic institutions and the city of Stockholm. It has three basic foundations:

- the hypothesis that the state of the environment in a certain place is a function of previous and prevailing flows of materials, energy and information through that place;
- the fact that environmental goals mainly are expressed by state and impact parameters for the environment (air and water quality, land use, flora and fauna, biological diversity, health etc);

a conviction that an improved approach to environmental monitoring necessarily has to cope with both *flows of materials and energy (environmental pressure)* as well as describing the *state of the environment* and the *environmental impact* in an integrated way. For this, elaborated *environmental information systems* will be needed.

In the programme, existing environmental monitoring in Stockholm will be integrated with new information on material flows in society. Existing static and dynamic models will be further developed and connections between fluxes of materials and environmental state and impact parameters will be sought. Material and Substance Flow Analyses will be an important part of the work as well as scenario constructions and evaluation. From these, environmental indicators and indices will be developed. A long term goal is to develop a tool for an improved economising of materials and energy in the Stockholm region. In the paper, the MONITOR programme is presented as well as initial practical approaches to the work.

Introduction
The further development of greater Stockholm in harmony with requirements for a sustainable development is a formidable and important task. Greater Stockholm will presumably grow in population during the next few decades. This necessitates that new ground and water areas will be used for urbanisation. At the same time, the gradual adaptation of the current greater Stockholm life and service functions to a more sustainable route needs much effort. All this will require improved methods for forecasting and surveying Stockholm's development including the assessment and evaluation of various alternatives for action and development.

Several cities and municipalities are already using surveillance systems to measure emissions to air, ground, lakes, rivers and other water environments, noise impacts, waste flows, etc. Stockholm and some of the regional townships are no exceptions. Contacts with Swedish municipalities have shown, however, that their environmental monitoring procedures have little influence on the decision-making process (Brandt and Frostell, 1995; Brandt *et al.*, 1998). This seems to be the case both for setting environmental goals and for the environmental management work as such.

The approach to local environmental monitoring thus needs to be changed. The qualitative and quantitative knowledge of different natural and anthropogenic material flows needs to be improved. A much more system-oriented approach needs to be taken. For a comprehensive understanding, the entire metabolism of society and nature would have to be considered from a systems point of view (cf. Ayres & Simonis, 1994). In the sustainable city, thereafter, the material flows will have to be kept within limits set by the overall assimilating capacity of the local, regional and global eco-systems.

There is thus a need to develop integrated and comprehensive environmental information systems, that also are able to describe how possible solutions to one environmental problem will affect other areas in a negative way, i.e. avoiding suboptimal solutions. The main problem for decision making is to optimise solutions to minimise the total environmental impact, e.g. by obtaining support from relevant computer programmes to be developed.

The City of Stockholm has increased its efforts to enter a route of improved environmental management and ultimately a sustainable development. One aspect of this is an increased co-operation with academia in the Stockholm region on systems approaches to environmental management. Specific results from this co-operation have been reported at the 1997 Wuppertal ConAccount Conference on Analysis for Action (cf. Björklund and Bjuggren, 1997; Burström *et al.*, 1997).

Objectives

The main aim of the programme is to develop methods and tools for an integrated and systematic local and regional environmental information management in order to facilitate (i) the formulation of environmental goals, (ii) improve strategic planning procedures, (iii) establish relevant strategies for environmental management measures and (iv) follow up implemented measures.

A subgoal of the programme is to identify and characterise sources, sinks and stocks for various material- and energy flows in order to facilitate the implementation of more efficient land use practices and other development strategies. Activities in the programme also aim at identifying and improving analytical, mapping and presentation tools for environmental monitoring. A requirement on the system is the ability to compare various measurements of the state of the environment to temporal changes in fluxes through the system and to secure good data quality through long measurement series.

MONITOR - A vision of a future environmental information system

The present research initiative has three basic foundations:

- the hypothesis that the state of the environment in a certain time is a function of previous and prevailing flows of materials, energy and information through that environment (cf. Cohen, 1986; *Costanza et al*., 1993);
- the fact that environmental goals mainly are expressed by state and impact parameters for the environment (air and water quality, land use, flora and fauna, biological diversity, health etc; cf. SEPA, 1993);
- a conviction that an improved approach to environmental monitoring necessarily has to cope with both *flows of materials and energy* as well as describing the *state of the environment* in an integrated way. For this, elaborated *environmental information systems* will be needed (cf. Draggan *et al*., 1987; Fenham *et al*., 1990).

In Figure 1, our comprehension of the relations between material and energy flows, the state of the environment and environmental impact/risks has been schematically outlined. If the state of the environment and/or environmental impact/risks are undesirable , actions to change the flows need to be taken as indicated in the Figure.

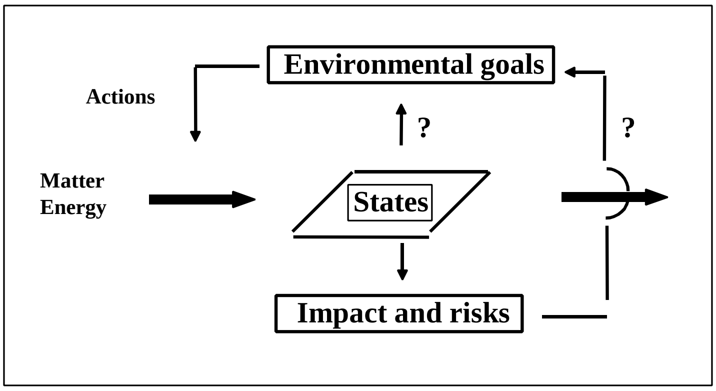

Figure 1: Schematic diagram of assumed relations between material and energy flows, the state of the environment and environmental impact/risks.

The approach used in the MONITOR programme fits very well into the PSR (cf. OECD, 1993) and the DPSIR (Drivers, Pressure, State, Impact, Response; cf. EEA, 1998) models for environmental management. Both the PSR and the extended DPSIR models are based on the fact that different societal activities (drivers) cause a pressure on the environment, causing quantitative and qualitative changes of it (changing state and impact). Society has to react (respond) to these changes in order to achieve a sustainable development. By use of the PSR (DPSIR) model, different indicators of sustainability may be established, covering all aspects of the model (drivers, pressure, state, impact and response). A revised DPSIR model is schematically shown in Figure 2.

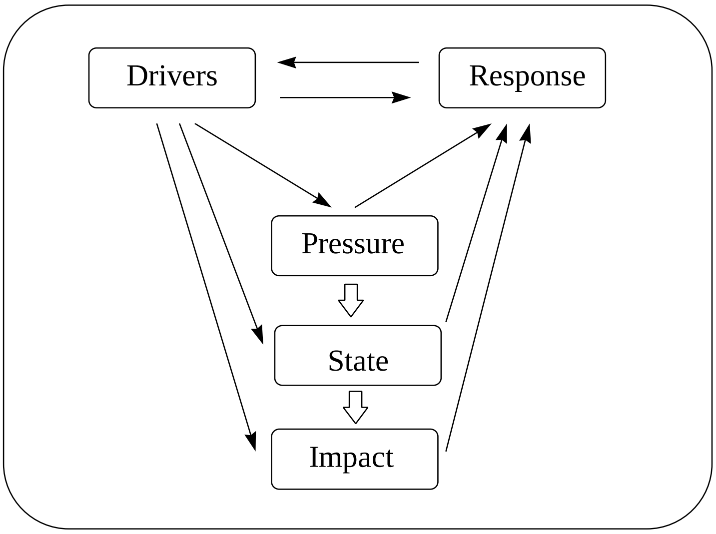

Figure 2: A revised schematic drawing of the DPSIR model for environmental management

The MONITOR programme aims at finding means of collecting, processing and presentation of pressure, state and impact information according to the conceptual model shown in Figure 2. Another important aim is to try to find casual links between material and energy flows on the one hand and the state of the environment as well as the environmental impact on the other. Information technology is therefore a very important and integrated part of the research efforts.

"The ComBox" model (Kommunlådan), is a conceptual model for a more system-oriented environmental monitoring at the local governmental level, based on the concept of material flow accounting (Frostell *et al.,* 1994; Brandt *et al*., 1995; Frostell et al., 1998). In the model, periodic (e.g. annual) material flow balances are established for a certain geographical area, which is limited by the geographical boundaries of the local community as well as fictive boundaries in the atmosphere and in the ground. In principle, the model covers all elements and substances in all the three states of aggregation, i.e. solid, liquid and gaseous material flows are simultaneously considered. The material flow accountings are made through data collection from (i) continuously operating environmental monitoring stations, (ii) discrete sampling and analysis and (iii) model estimates. Geographical Information Systems (GIS) has been proposed for conveniently handling the geographical aspect of data as well as for visualising modelling results.

The ComBox model deals with material flows (environmental pressure) in the local community. In the present initiative, the proposed second and third important levels of monitoring are the state of the environment and environmental impact. These three levels (pressure, state, impact) will principally be used as the regular control measures in the tentative overall MONITOR -Integrated Environmental Information System.

The combined conceptual system is illustrated in Figure 3, showing the monitoring of material- and energy flows as a horizontal flux in three media (air, water and society) and the surveillance of the state of the environment within four different areas (air, water, soil and sediment) and the impact in two areas (biota and health).

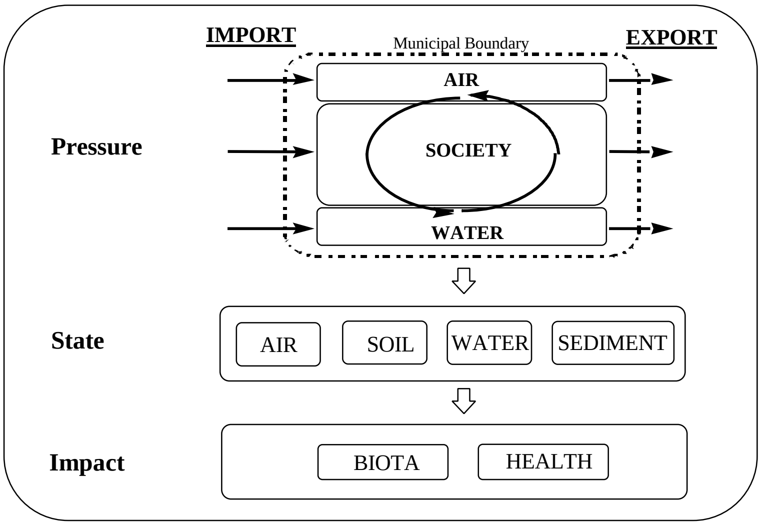

Figure 3. The conceptual MONITOR model for collection, processing and presentation of pressure, state and impact environmental information.

Practical approach

To start with, the vision of the MONITOR programme may be partly realised by a more systematic compilation, evaluation and presentation of already existing environmental information. In a longer perspective as the long-term goal of the programme, various models will be developed to describe the flows of material and energy through the surveyed system (the local and regional areas). The principal composition of this future model system is illustrated in Figure 4. Transport of various substances and substance groups are modelled together with chemical and biochemical reactions. The transfer of substances between the three studied media will need to be taken into account as well. Connected to these transports, reaction and exchange models are models describing the state of the environment. For water and air, the state will be directly obtained from integrated flow and state models. For impacts on biota and man, other model relations will need to be built as well as models describing risks to the environment and man.

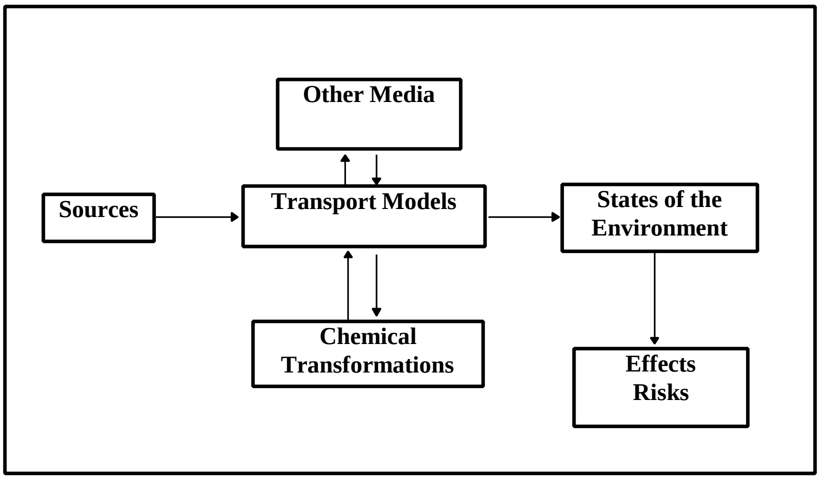

Figure 4. Schematic diagram showing principal approach to practical modelling in the MONITOR programme.

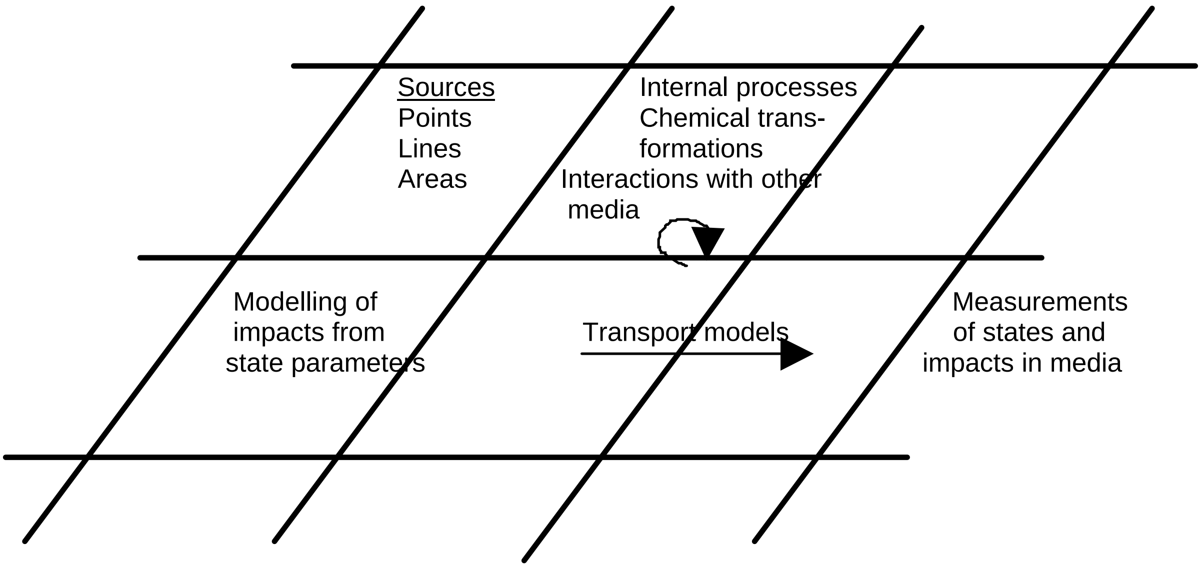

Figure 5. Illustration of foreseen necessary capabilities of models schematically shown in Figure 3. The models will be constructed in a grid system with a space resolution of app. 100 x 100 m

A common basis for all areas of state and impact monitoring in the MONITOR programme (cf. Figure 3) is a grid system in GIS (Geographical Information System). Various other tools (models etc.) used will be linked to this common resource. Some simpler models may be implemented directly into GIS, while other more complicated ones will have to be implemented by means of special programmes, connected to the general GIS tool. The principles have been illustrated in Figure 5.

The requirements of the system from a functional stand-point are that it shall be able to:

- store data
- visualise data
- exchange data
- prognosticate
- perform simulations

The programme will be divided into three main sub-areas with a strong interconnection, (i) flows of materials and energy, (ii) state and impact monitoring of the environment and (iii) environmental informatics.

In a first step, involving five sub-projects with participation from the Stockholm university, the Royal Institute of Technology, the Swedish Environmental Research Institute and the Environment and Health Protection Administration of Stockholm (EHPAS), the sources sinks and fluxes of PAH in Stockholm will be investigated. Later other substances and elements will be covered as well.

Examples of potential practical case studies are:

- Implementation of new municipal environmental management strategies
- Establishment of new city areas, such as the Hammarby sjöstad (Fyrhake et al. 1998).
- Reallocation of routes for ferry traffic through the Stockholm archipelago
- Establishment of a new airport in the Stockholm area

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Integral policy for Materials management

Environmental aspects of material use in the infrastructure - a manager's perspective

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Abstract
The infrastructure contains huge amounts of material. For several metals it is actually the main area of use. There is a need for an integrated environmental analysis using the perspective of the manager or user of infrastructure systems in order to reach an environmentally sustainable material strategy. A functionally defined material flow analysis (MFA) based on areas of responsibility could possibly serve this purpose. In this paper we discuss the characteristics of material use in infrastructure in relation to consumer products and conclude that the preconditions for a sustainable material economy of the infrastructure are good.

Case studies on managing zinc in the road environment and copper in the railway environment illustrate the usefulness of MFA for the material manager. Furthermore, some important components for the evaluation of the MFA are briefly discussed.

Consumer or manager?
Most studies using material and substance flow analysis (MFA/SFA) are based on a spatial scale, such as a nation, a region or a river basin. This makes their results mainly useful for administrative bodies governing these areas. However, commercial companies or authorities responsible for functional sectors of society, like the road administration, are not likely to benefit so much from these studies. Since their area of responsibility does not have such a spatially defined distribution, this calls for MFA/SFA- studies applying the perspective of the manager or owner.

The owners of infrastructure systems do not have to be seen as materials consumers. Instead, their preconditions for a responsible and sustainable material management are good, and they could be termed material managers. An important basic concept in this context is that companies and organisations are responsible for the material flows which their activities induce. This is definitely in accordance with the ambitions of environmental management systems (EMS), such as the ISO 14000-series and EMAS, which are now spreading and gaining importance. For the environmental work within a company or an organisation in the form of EMS in particular and environmentally strategic work in general, it is a necessary prerequisite to have a good picture of the relevant stocks and flows of material managed by the company or organisation.
In this paper, the characteristics and preconditions of material management of infrastructure is compared to the use of materials in individual consumers products. The discussion deals mainly with metals but is probably possible to apply to other substances as well. Furthermore, the use of material flow analysis in the inventory phase of two infrastructural systems is briefly discussed.

Metals in infrastructure
The infrastructure constitutes an important and often long-lasting part of society's total use of metals. For copper, infrastructure and buildings constitute more than 80% of the total stock in Stockholm, Sweden (Lohm et al., 1997). For lead and zinc, the corresponding figures exceed 50%. The use of iron/steel is also dominated by the areas of infrastructure and buildings and probably exceeds 70% of the total use. Despite this, in relation to metals in consumer products, not much attention is given to the infrastructure in environmental

research and debate. The infrastructure and consumer products are two areas of use for metals which display important differences in relation to their preconditions for sustainable material management (Table 1). In contrast to metals in individual consumer products, metals in the infrastructure generally occur in large stocks with a limited spatial distribution, managed by a single owner. As a consequence, important advantages are gained in at least two areas. First, the risk of pollution by "technotoxic" substances (Norrthon, 1996), that deteriorate the quality of the material and restrict the technical flexibility of uses for the recycled materials, decreases. Secondly, the collection of material taken out of use for metal recycling is much easier than for consumer products. Since material recycling is generally labour intensive and thereby expensive, the easy accessibility to material is crucial for the economic evaluation of increased material recycling. From this perspective, metals in the infrastructure would be an ideal area. It is thus much easier to reach a sustainable material economy in the infrastructure than in many other areas. Perhaps, further features of such an economy can be identified by studying the infrastructure from a material flow perspective. It is however not likely that the closing of material cycles in this sector at present is optimised since no communication takes place between the producer and the end-user of infrastructure products. The material interactions between companies are generally not well developed despite the introduction of the theoretical concept ”industrial ecology” which could emphasise the importance of optimising material flows through the economy.

Table 1: Characteristics of metal use in consumers and infrastructure products from a material management perspective

	Consumers products	**Infrastructure products**
Size of individual supplies	small	large
Number of owners	many	few
Degree of small-scale dispersion	large	small
Geographical distribution	mainly urban	national
Product longevity	short	long
Product complexity	heterogeneous	homogeneous
Common and uncommon* metals	large volume of uncommon metals	large volume of common metals
Material hibernation**	significant	occurs
Diffuse emissions	common	significant
Dissipative uses	common	uncommon
Potential for increased recycling	low	high
Potential for sustainable material management	low	high

*Common and uncommon refers to their occurrence in the environment .
**Hibernation refers to products no longer in use, but not yet considered as waste (Bergbäck and Johansson, 1996)

Cases

In our research programme on the infrastructure and environment, projects have been initiated on managing zinc in the road environment and copper in the railway environment. The aim of these projects is to illustrate how the material flow analysis can be useful for managers in optimising their material economy from an environmental point of view. Many studies have earlier been made into the individual components of infrastructure systems, for instance in the road environment. However, there are not many studies with holistic ambitions of trying to synthesise data producing a picture of stocks and flows of substances in the infrastructure environment. Here are presented two tentative inventories of zinc in the road environment and copper in the railway environment.

Managing zinc in the road environment

The national road network in Sweden is managed by the Swedish National Road Administration (Vägverket). They are responsible for planning, constructing, handling, maintaining and taking out of use national roads. They are also commissioned by the Swedish government to be responsible for the total road transport sector and its environmental impact, traffic safety, accessibility and efficiency. This means that it will be

important for the Swedish National Road Administration to get a comprehensive view over material use in the road transport sector. The choice of material will be crucial because it effects almost all activities in the lifetime of a road such as construction, maintenance and taking out of use.
Zinc will be taken as an example of material use in the road environment because it is present in several applications. We have invented one kilometre highway with two separated carriageways (Figure 1). It is newly constructed and therefore the area closest to the road is not as polluted as it will be after several years of traffic.

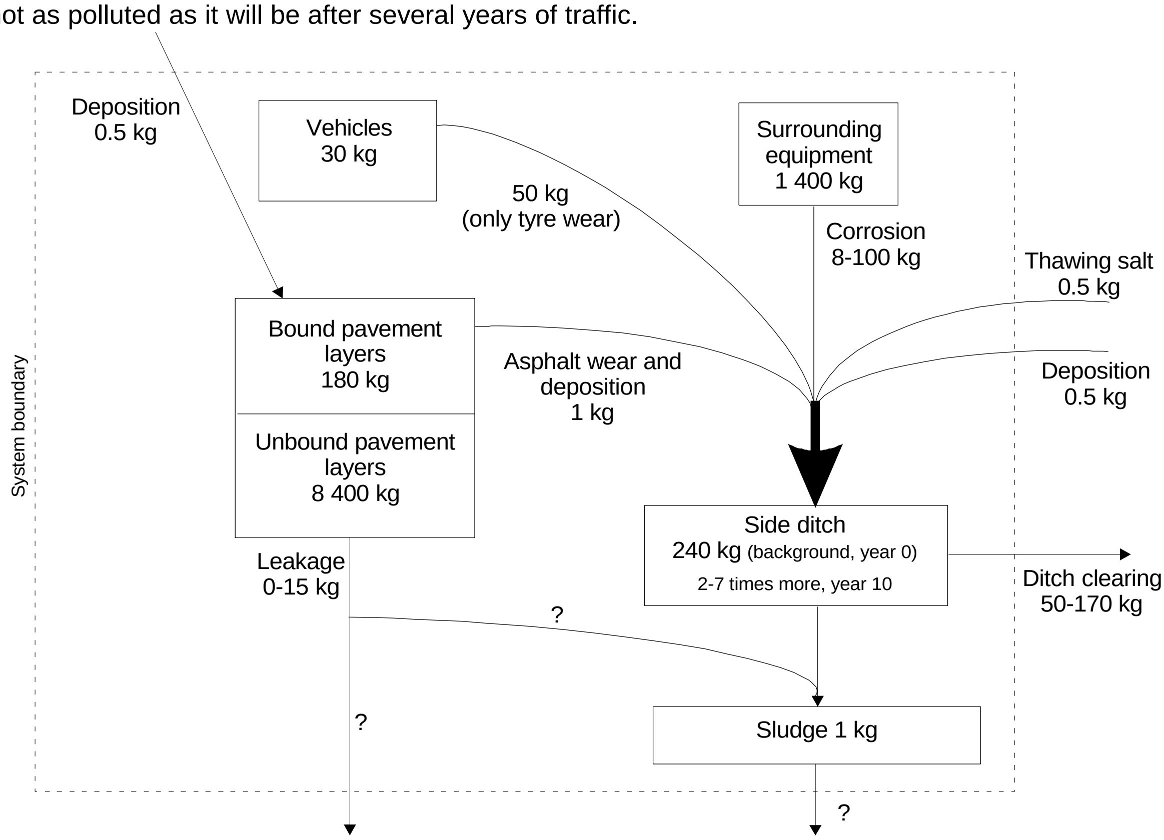

Figure 1: Material flows of zinc in a one kilometre highway. The flows, illustrated as arrows, are accounted for one year. The amounts of zinc in stocks, presented in boxes, are the total amount accumulated in a newly built highway.

The highway consists of bound and unbound layers. The bound layers are constructed of stone material (95 %), where zinc is naturally common, and bituminous material (5 %) (Swedish National Road Administration, 1994). Based on figures from Kälvesten (1996) it can be concluded that these layers contain about 180 kg of zinc. Since the road is newly built, the bound layers are considered impermeable (Lindgren, 1998) and there is no leakage to the unbound layers. Unbound layers are constructed of stone material and constitute the largest stock of zinc in the road environment, about 8 400 kg, based on Kälvesten (1996). However, leakage will commence and according to the leakage tests by Kälvesten (1996) this flow probably could reach an annual amount of about 15 kg.

There are 9 900 vehicles passing the highway per day, about 20 % of that is heavy traffic. These vehicles cannot represent the total stock of vehicles. Each moment there are 3.75 vehicles present on the road and we have allocated the amount of zinc in these 3.75 vehicles to the stock of vehicles in the flow chart. Data presented in Lohm et al. (1997) imply that there are about 30 kg of zinc in this stock. Zinc is also used in tyres and therefore zinc will be dispersed with tyre wear. The annual amount calculated from figures presented in a report written by Bjelkås and Lindmark (1994) is about 50 kg, a relatively important component of the zinc metabolism of the highway. Not yet included in this study, are zinc in motor oil and other chemicals used in a vehicle.

The stock of surrounding equipment includes concrete constructions, such as bridge structures and the drainage system, where zinc occurs naturally in the ballast material. Also included in this stock are steel constructions such as lamp-posts and safety fences, where zinc is used for protection against corrosion. Based on figures from Norrthon (1996) and Kälvesten (1996) these applications altogether contribute to a stock of zinc that reaches a total amount of 1 400 kg. The flow from this stock is mostly caused by corrosion and figures originating from Nilsson (1996) indicate that about 8 - 100 kg of zinc could be dispersed to the environment.

Flows of zinc from asphalt wear, tyre wear and corrosion will end up in the side ditch. Since the highway is newly built we have only considered the total amount of zinc based on the background concentrations. About every tenth year the side ditch is cleared and then it can contain from two to seven times more zinc than the background level (Swedish National Road Administration, 1998).

Its is remarkable, however not surprising, that the largest flows of zinc in the road environment are not connected to the largest stocks. Instead the largest flows are connected to the dissipative use of zinc in applications such as corrosion protection and tyres. Flows that are exposed to organisms are more important to control than others. One example of such a flow is particles in tyre wear and asphalt wear that will come out in the air. It is very important to consider these aspects and to analyse the flows in more detail. This information is crucial when the manager decides which measures are to be taken in maintenance or the construction process.

Stocks of zinc in the road environment are thus important from a manager's perspective. The continuing changes of the environment and long-term effects of accumulated material make it important to control stocks since they represent potential problems.

Copper in the railway environment

The main use of copper in infrastructure is related to electrical applications. The railway system uses a lot of electricity and thus constitutes a large manager of copper stocks. Most of copper can be found in the electrification system but significant amounts are also found in cables in the telecommunication and signalling system. Copper can also be found as traces in the crushed natural rock used in concrete railway ties and as ballast in the railway embankment. Dispersion of copper to the environment is primarily caused by mechanical wear of the contact wire when transferring electricity to the trains, but there are also contributions of copper to the environment by corrosion of equipment. To illustrate the magnitudes of the stocks and flows of copper in the railway environment, an outline of the material flows for copper in a one kilometre railway is depicted in figure 2.

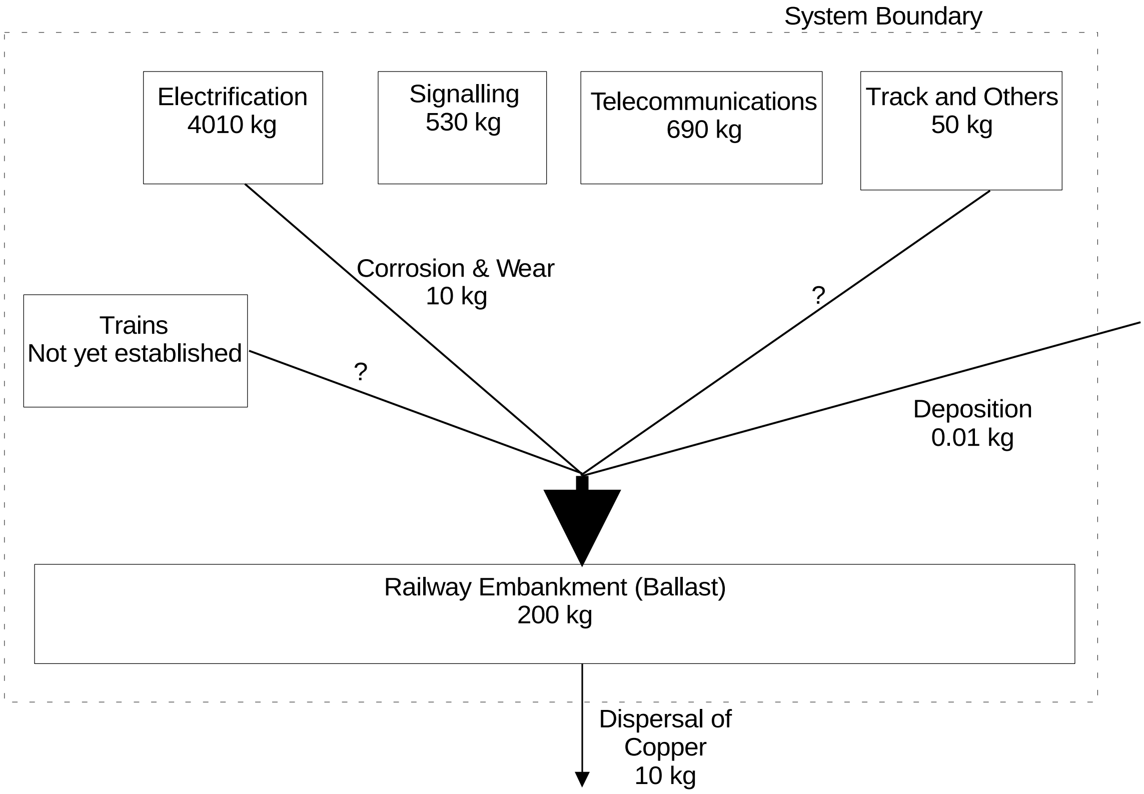

Figure 2: Material flows of copper in a one kilometre double track railway. The stock figures are from a newly built Swedish double-track railway. The figures for the dispersal of copper are annual means.

The dispersal of copper to the environment, related to a one kilometre railway, may seem minor. However, since the railway infrastructure on a national level manages large stocks of copper, the amount is far from insignificant. Assuming that 15 000 km contact wire is used for the electrified railway in Sweden (Berggrund, 1998) the annual dispersal of copper reaches 75 tonnes. This is approximately the amount of copper dispersed from other buildings and constructions together with emissions from road traffic (Norrthon, 1996).

The treatment of used cables and wires in the railway environment is currently not sustainable. The percentage of cables and wires left in the ground after use is estimated to 90% (Johansson, 1998) As long as it is not economically feasible to dig them up, the cables and wires will be left in the ground. This problem raises an interesting question; should this be seen as a special form of landfill or as a future resource? The way of looking at it may be crucial to the assessment of environmental impacts in a study? Cables and wires above ground are recycled. The concrete ties and ballast are, if possible, reused.

Trains are not yet accounted for in the inventory, which might suggest that the amount of copper that is dispersed is underestimated. Most of the copper in trains is not exposed to dissipative use, but there are indications of copper content in brakes which might result in emissions to the railway environment.

A strategy for environmentally sustainable material management

MFA can play an important role in the development of a strategy for sustainable material management in the infrastructure. With a broad evaluation of the MFA, a comprehensive material strategy aiming at environmental sustainability can be outlined (Figure 3). MFA can be useful for identifying crucial areas of substance losses to the environment. In this context, it can also clarify the degree of exposure of substances to organisms. From a manager's perspective this makes it possible to give priority to the "right" issues where cost-efficient measures can be taken. Furthermore, the material manager can make use of MFA in the processes of building and maintaining the infrastructure systems. Examples of such areas where MFA can contribute to a sustainable material management are choice of products and maintenance practices.

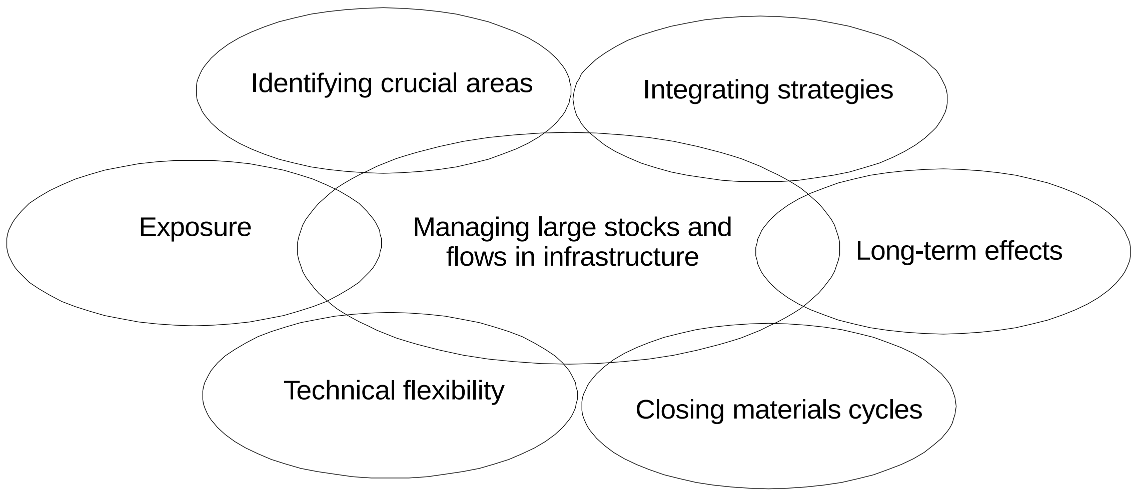

Figure 3: A tentative outline describing some components of a comprehensive strategy for material management in infrastructure.

The evaluation of an MFA cannot be restricted to the size of stocks and flows. They are of course important aspects, representing the potential size of the environmental impact and the mobility in and change to the system, respectively. Other aspects that need to be covered in the evaluation are the degree of exposure to organisms and the maintenance of technical flexibility. The issue of the function of the material in a certain application needs attention since it can vary from the important contribution of longevity to a material to unwanted pollution of materials.

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Technique for Visualisation of Flows and Accumulation of Metals in Stockholm, Sweden.

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Abstract
The inflow and accumulation of seven heavy metals (Cd, Cr, Cu, Hg, Ni, Pb and Zn) during the 20th century were studied in the Swedish "Stock-home" project.

A spreadsheet model was used to visualise the heavy metal consumption process. The model showed historical time courses during the 20th century. It also indicated the present profiles of areas of use, exposure for corrosion and responsibilities. Since data were more or less vague, a comprehensive presentation of the uncertainties of different product categories was available. A simulation feature allowed the user to study future trends based on a few simple assumptions.

Flexible data management software that supports the discussion of different MFA issues would be of interest for most monitoring activities.

Introduction
Heavy metals have been used in society for centuries. The inflow and accumulation has increased markedly after the Second World War. In 1994, the Swedish EPA initiated a research program in which one part was the study of the urban consumptive use of the heavy metals Cd, Cr, Cu, Hg, Ni, Pb and Zn. The Swedish capital Stockholm was used a research object.

The research resulted in the database "Stockhome" [1]. Data included the inflow and accumulation of heavy metal containing goods during the 20th century. Each heavy metal was discussed separately and presented with areas of use, sources of emissions and availability of information about the metals.

With all this information, need soon arose for presenting it in a way that made professionals from different fields formulate questions around the society's use of goods: Where were heavy metals used? Did they cause emissions? Who were responsible for the different goods?

The Stockhome model structure
The Stockhome data was fed into a spreadsheet model of the heavy metal consumption process [1, 2]. We denoted the steps of the process "Inflow", "In use", "Hibernation", "Re-use", "Incineration" and "Landfill". See the flow diagram in figure 1.

Most of the steps would be possible to understand intuitively, but "hibernation" may need a comment. "In use" meant that the goods regularly produced the services they were designed for. But sometimes goods were replaced while they still worked; e.g. a black-and-white TV replaced by a colour TV. The old TV was kept as a spare TV, put in the attic and was more or less forgotten. This TV was then said to be "hibernating", since it no longer produced the service it was designed for. Hibernation also included e.g. out-phased power cables left in the ground, or metal waste in filling material used for construction purposes. In our model, all metal that was no longer in use but was not collected was considered to be hibernating.

After we estimated also lifetimes and emission coefficients of goods, we achieved a model that could be a first step towards a monitoring tool for e.g. an EPA office in a community.

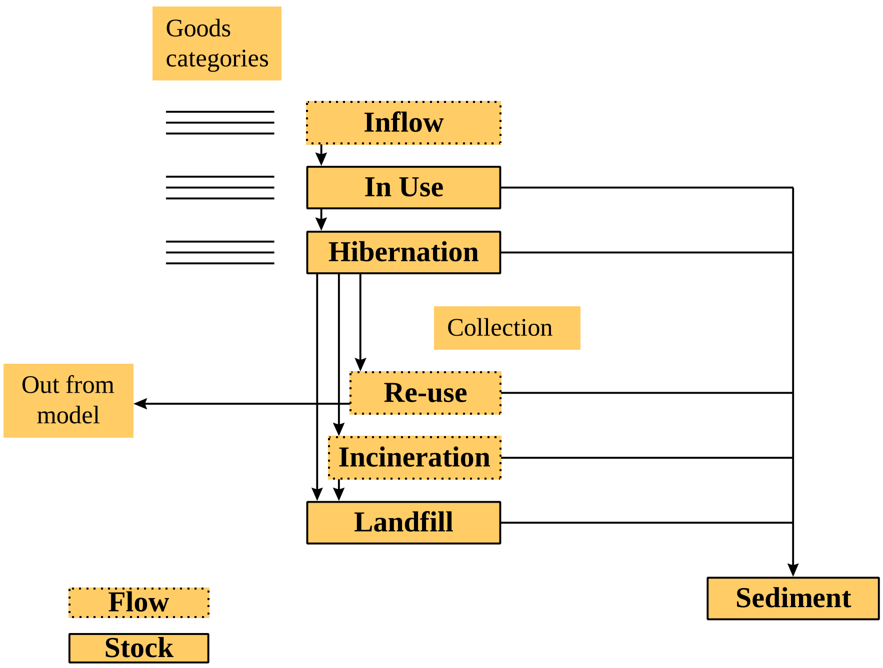

Figure 1. Flow diagram of the heavy metal consumption process.

Historical time courses

The model visualised the historical time courses during the 20th century. Plotting historical use over time for different goods categories may inspire discussions about the societal processes and contexts where metals were utilised. See figure 2, where the use of Cd is displayed.

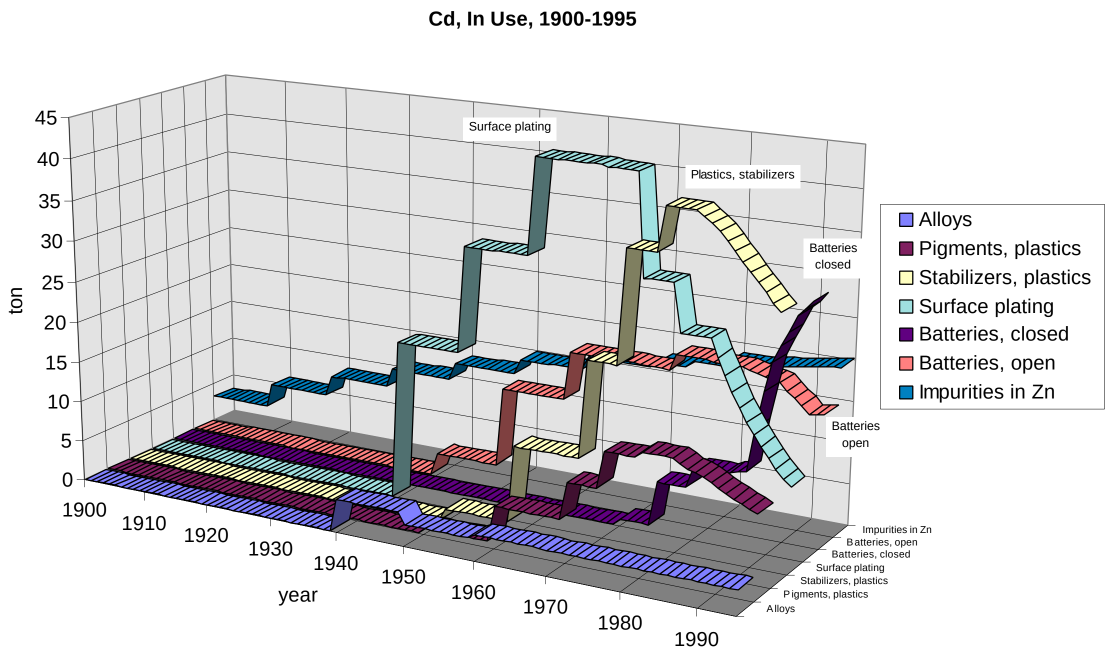

Figure 2. Historical use of Cd.

Looking at the time courses of figure 2 from a bit distance, other patterns of social development may emerge. The "surface plating decades" was dominated by e.g. industrial expansion, infrastructure investments, building of apartment houses and increased use of cars in households. The ”plastic decades” included e.g. building of small-houses and increased use of disposable goods in society. The ”closed batteries decades” are still progressing, characterised of battery powered hand-tools, toys and information related equipment, e.g. mobile phones and computers.

The use of heavy metal containing goods is linked to significant parts of our societal history. Looking at the contexts, in which the metals were used, may give ideas of how to replace goods or reformulate needs so that societal benefits may be gained from less heavy metal.

Uncertainties

Some data in the database were more or less vague. It turned out that for some goods, data should be regarded rather as a magnitude instead of a number. When many samples are available it is possible to calculate a standard deviation and use intervals to indicate the range of uncertainty for each good. If very few samples are available, traditional statistical methods cannot be used to determinate the uncertainty intervals. We therefore used subjectively estimated intervals, within which the true values almost certainly would be [3].

We found it convenient to use asymmetrical intervals. Data was then described by a probable value and a factor to be multiplied or divided with to decide the upper or lower limit of the interval. We used the notation X */Y for this (compare with X ±Y for traditional intervals notation). An uncertainty factor may be used for both ”numbers” and ”magnitudes”. When the factor was near 1, the interval was close to symmetrical. When the factor was large, the interval was asymmetrical. This gave a continuous progress from ”numbers” to ”magnitudes” in data management.

We categorised the data sources into levels with respect to the uncertainty [3]. See table 1.

Table 1. Uncertainties of some data sources.

<u>Uncertainties of some data sources:</u>

***/1.1**	**Official statistics on local level.** No of households, cars, small-houses, apartments etc. Copper in electrical grounding.
***/1.33**	**Official statistics on local, regional and national level.** Share of leather shoes. Lead stabilisers in PVC cables. Amount of Pb and Cu in power cables.
***/2**	**Official statistics on national level.** Impregnated wood. Share of Volvo-cars among all cars. Use of stainless steel on roofs and fronts in Stockholm.
***/4**	**Information from production/construction/authorities.** Weight catalytic converters. Amount of brass in Stockholm.
***/10**	**Cd content in Zn.**

In the model, a comprehensive presentation of the uncertainties of different goods categories was available. An example for Pb [4] is seen in figure 3.

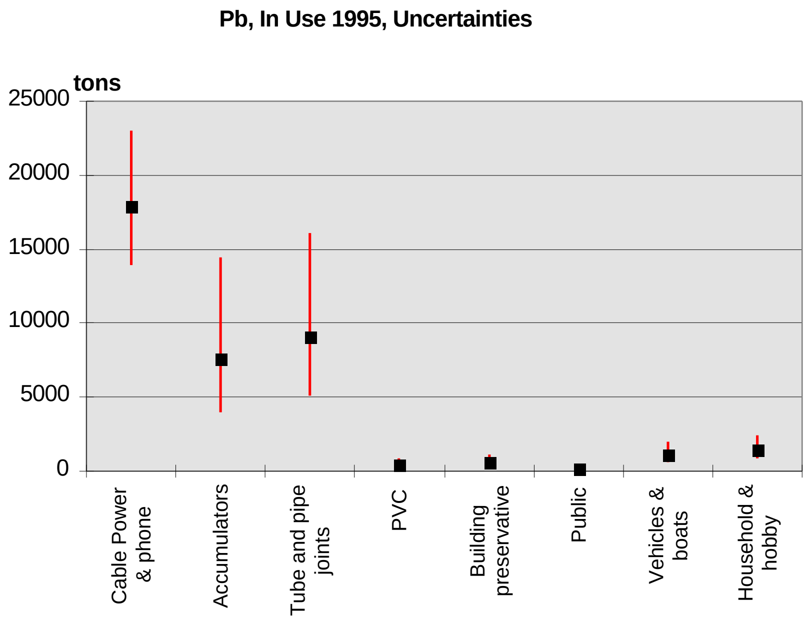

Figure 3. Uncertainties of Pb goods categories.

Categorisations

The model also illustrated the present areas of use, exposure for corrosion and responsibilities. This was done by distributing each of the goods among the available categories. For instance, areas of use may be [infrastructure, buildings, household, enterprises, vehicles] (see figure 4). The 21250 tons of Pb in Power cable were distributed as [100%, 0%, 0%, 0%, 0%], the 29 tons of Pb in light bulbs and fluorescent tubes were distributed as [21%, 3%, 31%, 31%, 14%] and so on. The total amounts of Pb for all categories were summed together and may be used for discussions of where in the technosphere heavy metals were used.

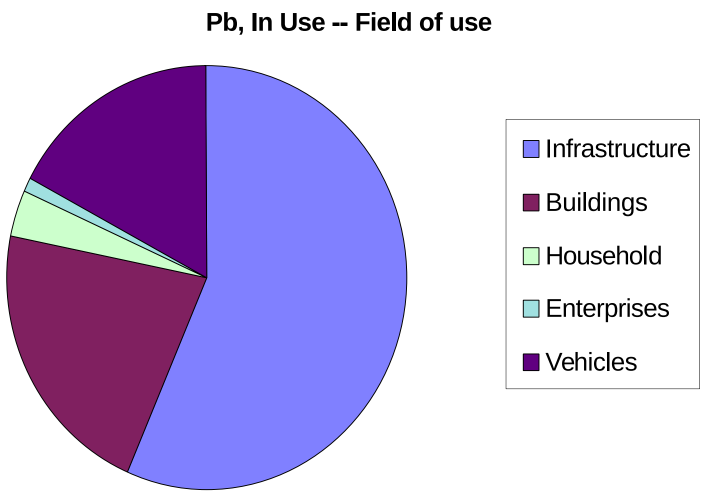

Figure 4. Categorisations of Pb goods.

Scenarios

The model included inflow, usage and lifetime of goods. It was hence possible to simulate the future development of the heavy metals in technosphere by assuming future inflow of goods. Figure 5 illustrates the hypothetical case that the inflow of all Pb goods were frozen at the 1995 values and then reduced with 5% per year.

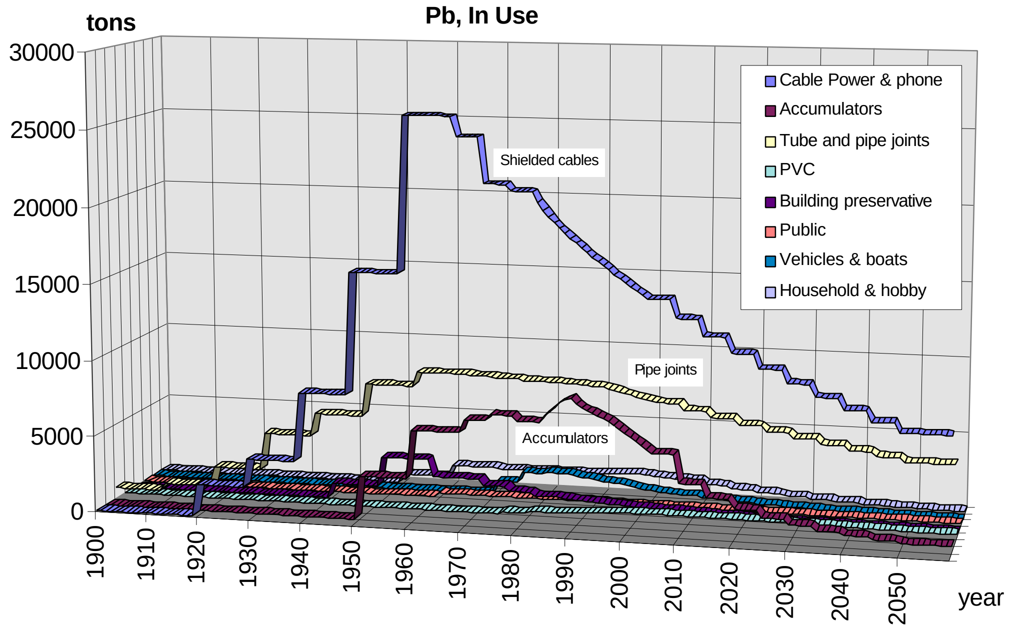

Figure 5. Scenario simulation. Inflow of all Pb goods reduced with 5% per year after 1995.

It may be noted that goods with a short lifetime, e.g. Pb accumulators in figure 5, would soon be phased out. Durable goods with large stocks, e.g. shielded cables and pipe joints in buildings and infrastructure, would be present in the technosphere for long time.

Discussion

Using a spreadsheet model may have its drawbacks. It easily gets messy, complicated, and computationally slow. However, if the model is based on a widely spread software platform, users generally have the experience to maintain the model by themselves. In most universities, mobility of research personnel is encouraged to cross-fertilise and multiply knowledge. This requires transparency and flexibility of the computer tools used.

In future it would be a challenge to further develop the model concept with professionals implementing long-term environmental strategies for a major city.

Conclusions

Flexible data management software that stimulates discussions of different MFA issues would be of interest for most monitoring activities. Simple models for data management and presentation would be useful for analysis and decision support in environmental issues.

Acknowledgements

The model described in this text is based on data, information, discussions and other materials from the research group submitting the report [1].

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Problemshifting: ecological rucksacks, indicators, footprints

Problems associated with establishing reliable estimates of materials flows linked to extractive industries

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Abstract
The environmental "rucksack" linked to extractive industries is computed or estimated by accounting for the amounts of overburden removal and waste products associated with each type of mining, mineral production and topographic extractive site location. Such quantities are seldom recorded accurately for individual mines or enterprises, so the usual technique is to develop a multiplier which can be applied to national production figures. While national production figures and multipliers may be readily obtained for such commodities as copper and large-scale mining of coal, they are much less readily obtained for all forms of aggregates used in construction and for most forms of small and unofficial, or illegal mining. In computing national, continental or global materials flows, aggregate production may be estimated from economic indicators, the most appropriate of which is energy consumption. Such calculations suggest that in excess of 57 x 10^9 t of material are dug up from the earth's surface every year, 19.7 x 10^9 t of which are minerals which are used and 37.5 x 10^9 t of which are general waste, overburden or spoil. However, such estimates fail to take account of the undocumented, informal mining, widespread in many countries, which may involve several million people and which could increase the annual mass of materials moved by 1 - 5%. Such problems have to be overcome to convince sceptics of the value and accuracy of materials flows assessments.

Introduction
Earth scientists concerned about the human dimensions of geological processes have established a programme, Earth Surface Processes, Materials Use and Urban Development (ESPROMUD) as part of the work of the Scientific Committee on Problems of the Environment (SCOPE) to determine the effects of extractive and urbanisation activities on geomorphic processes (Cendrero & Douglas, 1996; Douglas and Lawson, 1997a). A first step in the project is to quantify the total mass of material moved by extractive industries, both the production tonnage and the "ecological rucksack" (Adriaanse et al, 1997) of mining and quarrying overburden, waste, and by-products.

The ESPROMUD project builds on an earlier SCOPE project (Wolman and Fournier, 1987) which examined the impact of agriculture on landscape stability by considering the materials flows involved in mining and quarrying and involved in the consumption, accumulation and waste production of cities (the urban metabolism of Abel Wolman, 1965). It employs a combination of the principles of Life Cycle Assessment (LCA) and Materials Flow Accounting (MFA) to:

- establish reliable estimates of the magnitudes of the direct and indirect people-driven changes that result from urbanisation and mining,
- assess the environmental consequences of these people driven changes and means of conducting such activities in a more sustainable manner.

LCA measures the environmental impact of individual mineral resources, or products, over their entire life cycle from cradle to grave. MFA can be used to trace the physical flows of all these natural resources, including their rucksack, from extraction to final disposal. Although international and national agencies, such as the United Nations, the United States Bureau of Mines and the British Geological Survey, collate reliable mineral production figures, few statistics of waste and overburden exist. We have derived the total mass of material moved by each individual mineral product by applying a multiplier (Table 1) to the net production figures to estimate the overburden and waste materials moved during the extraction process for each major mineral. We derived the multipliers from published data and case studies and then discussed them with specialists to obtain maximum and minimum multipliers of each individual commodity listed in the industrial commodity statistics of the United Nations (Douglas and Lawson, 1997b).

Table 1 Examples and sources of proposed multipliers for major commodities (from Douglas and Lawson, 1997b).

COMMODITY (General notes)	**Minimum Multiplier** (Source)	**Maximum Multiplier** (Source)	**PROPOSED MULTIPLIER** (Applicable to UN data)	**Remarks**
Coal, Hard 61.5% = underground 38.5% = opencast (Countries which = 40% of world production in 1989 quoted in UN Annual Bulletin of Coal Statistics for Europe and North America)	Underground: Developed. World: 35% Third. World: 25% (RJB-verbal communication) 50% in UK (Sherlock 1922) x 5.65 in US (Ayres & Ayres quoting anon. from the US Dept. of Energy) (US prod. is 90% hard coal and is 18% of world prod.).	61.5% underground = x 1.30 and 38.5% opencast = x 18 then total = x 7.73 (multipliers for UK per RJB) World opencast x 12.5 underground x 1.5 therefore x 5.9 (Hymans) China = 28% of world prod.	**x 4.87**	Ayres USA figure equates to x 1.35 under-ground and x 8.83 re opencast. Underground = 61.5% @ x 1.35 and opencast = 38.5% @ x 8.83, therefore x 4.23 av. Accepts this formula for 61.5% of prod. accepts Hymans for 38.5 % of prod
Coal , Brown, including lignite 11.5% = underground 88.5% = opencast (Countries which = 39% of world prod. quoted in UN Annual Bulletin of Coal Statistics for Europe and N. America)	95% opencast 8:1 stripping ratio (Hymans) Polish lignite x 6.24 overburden/coal assuming overburden = 1.9 ton/m³ (Chadwick 1996)	Opencast: 1:18-19 Coal/Overburden, which is re-placed (RJB) German production in 1995 = 1: 9.89 coal/overburden assuming overburden = 1.9 ton/m³. (Klatt et al)	**x 9.9**	Accepts Klatt et al (NB German production = 33.4% of global in 1988)
Iron-bearing ores (Fe content of iron ores and concentrates and all other iron-bearing ores and concentrates intended for the treatment of iron recovery)	Iron ore =50% waste (Sherlock 1922) 50% iron content in Australia	25% concentration (Blackburn & Dennen) Fe x2 iron ore, and ore x3 for total removed, i.e. x6 (Highley) US iron ore is taconite with 25% iron content (Masini & Ayres)	**x 5.2**	Accepts US Bureau of Mines 1994
Copper-bearing ores Cu content of copper ores and concentrates and all other copper bearing ores and concentrates intended for treatment of copper recovery)	Copper ore =1000% waste (Sherlock 1922) 1.23% = av. of 6 mines (Mining Annual Review 1996) Bougainville quoted 1 ton waste to 1 ton ore (Winslow) Freeport ore =2.5% copper (Mitton) Copper content of ores hardly 1%, 165 material to 1 refined metal (Masini & Ayres)	1% copper in ore and need to move 5 tons per 1 ton ore. i.e. x 500 (Highley) Bingham Canyon 0.7% copper in ore (Gilluly et al) x 337 - x550 (Tilton in Eggert quoting US Bureau of Mines) 0.49% av. for US prod. in 1990-1994. (US Bureau of mines) 0.77 % concentration (Blackburn & Dennen) x 603 in US (Ayres & Ayres)	**x450**	Highley = x 500 accept Tilton and Highley average

Zinc bearing ores (Zn content of Zinc ores and concentrates and all other zinc bearing ores intended for treatment for zinc recovery)	1,500% waste (Sherlock 1922) 9% Zn = av. 4 mines (Mining Annual Review 1996)	2.45% concentration (Blackburn & Denning) 6% Zn at Pine Point (Rhodes et al) x 49 in US (Ayres & Ayres) Same as Lead (Manning)	**x 32**	average, (assumes deep mined) Accepts Manning
Limestone flux and calcareous stone (commonly used for making cement, excluding building or monumental stone. Powdered soil improvement mate-rials included. Dolomite and chalk are excluded)	15% waste (Sherlock)	20% (Highley) 30% (CAMAS)	**x 1.2**	Accepts Redland and Rivas, and = average of other sources
Sand, silica and quartz (Commercially-extracted sand used in building, in glass industry,...etc.)	5% silt discarded (ARC) Quartz 15% (Rivas)	Sand & Gravel: 33% overburden + 5-10% production waste re land produced sand only (Redland) x2 (Highley)	**x 1.75**	Average
Gold-bearing ores (Au content of gold ores and concentrates and all other gold-bearing ores and concentrates intended for gold recovery)	8 grammes per ton of ore (Blackburn & Dennen) less than 1/3 oz. per ton (Gilluly et al) Bougainville 0.56 gr. per ton of ore and ore = half of mined material (Gilles in Winslow)	0.9 - 4.0 gr. Gold per ton of ore, but 1:9.5 ore to waste, in the Andes (Fox) 5.4 gr. per ton in 4 mines in Canada 0.99 gr. per ton in 3 mines in Australia (Mining Annual Review 1996) x 2,680,730 in US (Ayres & Ayres)	**x 950,000**	Av. Australia, Canada & South America linked to production =2.61 gr. per ton and assumes x 2.5 overburden/ore

Estimating aggregate production and the resulting overburden

Aggregates and building stone production accounts for over 52% of the net weight of all mined or quarried material. Published UN data only covering 22 countries who produce about 50% the aggregates and building stones used. There are few figures covering the developing world. The only available global estimates of aggregates and building materials production have been made by correlating US production figures with GDP (Evans, 1993; Hooke, 1994). AS GDP includes exports, it is going to be variable predictor. Alternatively, an extrapolation could be based on population or energy consumption. As development involves building roads, housing and industrial facilities which use both aggregates and energy, data on energy consumption may be a good predictor of aggregate use. Absence of efficiency considerations in energy figures may compensated for by the additional labour use. Available national UN aggregate and building stone production data the production figures correlate better with energy consumption than with GDP or population.

Aggregates - Energy	80% of results range	9% +/- the median
Aggregates - GDP	80% of results range	43% +/- the median
Aggregates - Population	80% of results range	>100% +/- the median

Global materials flows associated with minerals extraction

The total mineral production recorded in published data for 1995 was 19.7 billion tons, but the actual total amount of material mined or quarried from the earth's surface was of the order of 57.5 billion tons as some 37.8 billion tons of waste, overburden or spoil were also moved (Table 2).

Table 2 Global mineral production and associated earth materials movement 1995

Commodity 1995	Production Net Weight 1000 Tons	% World	Multiplier	Production Gross weight 1000 Tons	% World	Remarks
Coal, Hard	3787216.00	19.190070	4.87	18443741.92	32.048941	
Coal, Brown + lignite	929742.00	4.711063	9.9	9204445.80	15.994192	
Petroleum, crude	3065313.00	15.532140	1.016	3489358.01	6.063316	[1]Gross weight includes 375000 thousand tons oil shale and oil sand production wastes
Gasoline, natural	35568.00	0.180225	1	35568.00	0.061805	
Natural Gas	2633.00	0.013342	1	2633.00	0.004575	BGS World Mineral Statistics, conversion rate: 0.022m3 = 20 gr.
Iron ores-Fe content	603542.00	3.058187	5.2	3138418.40	5.453502	
Copper ores-Cu content	9311.00	0.047179	450	4189950.00	7.280706	
Nickel ores-Ni content	719.23	0.003644	560	402768.80	0.699875	
Bauxite, crude ore	100739.00	0.510451	3	302217.00	0.525150	
Lead ores-Pb content	2751.00	0.013939	32	88032.00	0.152970	
Zinc ores-Zn content	6953.00	0.035231	32	222496.00	0.386622	
Tin ores-Sn content	182.52	0.000925	100	18252.00	0.031716	
Manganese ores-Mn content	11097.00	0.056229	6	66582.00	0.115697	
Chromium ores-Cr content	3393.00	0.017193	2	6786.00	0.011792	
Tungsten ores-W content	24.81	0.000126	100	2481.00	0.004311	
Ilmenite-concentrates	3435.00	0.017405	25	85875.00	0.149221	
Tantalum & Niobium concentrates	45.66	0.000231	100	4566.00	0.007934	
Vanadium ores-V content	32.64	0.000165		0.00	0.000000	By-product
Zirconium concentrates	943.88	0.004783	100	0.00	0.000000	By-product
Antinomy ores-Sb content	147.13	0.000746	9	1324.17	0.002301	
Cobalt ores-Co content	15.20	0.000077	20	304.00	0.000528	
Silver ores-Ag content	13.26	0.000067		0.00	0.000000	By-product
Uranium ores-U content	32.97	0.000167	900	29673.00	0.051562	
Gold ores-Au content	2.25	0.000011	950000	2137500.00	3.714247	Net production figures: Nötstaller 1997.
Slate	5445.00	0.027590	1.5	8167.50	0.014192	
Building Stones: granite, porphyry, sandstone including marble and travertines. Aggregates: limestone flux and calcareous stone, gravel and crushed stone, sand, silica and quartz.	10430971.0 0	52.854408	1.36	14186120.56	24.650645	Net production figures: by correlation with energy consumption. (See Douglas & Lawson 1997b).
Clay	154205.00	0.781367	1.5	231307.50	0.401934	

Bentonite	7319.00	0.037086	4	29276.00	0.050872	
Kaolin	28475.00	0.144285	4	113900.00	0.197919	
Fullers Earth	7980.00	0.040435	4	31920.00	0.055466	
Andalusite	1239.00	0.006278	9	11151.00	0.019377	
Magnesite	9523.00	0.048254	1.2	11427.60	0.019857	
Chalk	22670.00	0.114870	1.2	27204.00	0.047271	
Phosphates, natural	119240.00	0.604197	4	476960.00	0.828794	
Potash Salts-K20 content	21803.00	0.110477	1	21803.00	0.037886	
Sulphur	18385.00	0.093158		0.00	0.000000	By-product
Iron pyrites, unroasted	7230.00	0.036635	5	36150.00	0.062816	
Fluorspar	3999.00	0.020263	2	7998.00	0.013898	
Barytes	4245.00	0.021510	2	8490.00	0.014753	
Borate minerals	3417.00	0.017314	1	3417.00	0.005938	
Arsenic trioxide	45.46	0.000230	20	909.20	0.001580	
Salt	165793.00	0.840084	1	165793.00	0.288092	
Diamonds, Industrial and gem (221738 thousand carats)	0.05	0.000000	2380000	109004.00	0.189412	
Gypsum, crude	99304.00	0.503180	1.2	119164.80	0.207068	
Abrasives, natural	8732.00	0.044246	1.2	10478.40	0.018208	
Graphite, natural	651.48	0.003301	2	1302.96	0.002264	
Asbestos	2507.00	0.012703	1.5	3760.50	0.006534	
Talc	6460.00	0.032733	1.2	7752.00	0.013470	
Peat, for agriculture and fuel	41799.00	0.211798	1.25	52248.75	0.090791	
Total	**19735290.54**	100.000000		**57548677.87**	100.000000	

Source of production figures, net weight (unless otherwise stated): Department of Economic and Social Affairs, Statistical Division of the United Nations.

[1]Oil won from oil bearing shales and sands is included in the net figure for production of Petroleum, crude. However, oil from these sands and shale deposits requires additional materials movement of 22 times the net quantity of oil produced. Oil products produced from oil-bearing shales and sands by the major producing countries amounted to 17,857 thousand tons in 1994 (United States Bureau of Mines, 1994).

Every tonne of mineral matter entering trade thus requires an average of some two tonnes of waste or overburden whose extraction consumes energy and adds to landscape change by human action. This "ecological rucksack" of mining, even if put back in the hole from which it is taken, alters the sustainability of the area affected, affecting the future erosion and slope stability of the site involved. Inevitably, the multipliers will vary from mine to mine and according to means of extraction. Nevertheless, they provide reliable estimates of the total earth moved during mining activities which enhance earlier estimates (Table 3). This multiplier methodology can be used with national and local data to estimate quantities of materials shifted through the mining of individual mineral products.

Table 3 Comparisons with other compilations of total earth materials moved during mining and quarrying

Study	Objectives	Methodology	Comparison of results with this study	Notes and principal sources
Sherlock, R.L. 1922 *Man as a geological agent.* Witherby, London, 21-86.	Assessment of the total quantities of materials moved by man over time in Great Britain between 1895 and 1913.	Rucksack:- Empirical evidence of coal mine and quarry wastes. Volumes of material excavated in Cornwall and Devon (copper and tin) used as a guide for other minerals.	Estimates of overburden and waste. Building stones and aggregates: about 50% less. Coal: 50% waste agrees with our estimate of 35% waste for deep mining of hard coal. Copper 1,000% and Lead: 2,600% considerably less Slate: x 10 x more waste .	Difficulty in estimating quantities (net) caused by changes in the compilation of published statistics. Output from quarries below 20 ft. (6 m) in depth were still being ignored in the annual reports on Mines and Quarries issued by the Home Office. Collins, J.H. 1895 and 1912
Hooke, R. Le B. 1994 On the efficacy of humans as geomorphic agents. *GSA Today 4* (9), 224-226.	Comparison, on a global scale, of the efficacy of various geomorphic agents, including humans. Quantification of total earth moved by human activity.	1988 USA production extrapolated to world-wide activity against GNP and energy consumption. Rucksack:- Aggregates: nil; Coal: one third production; Metals: concentrations for mine economic viability	GNP scaling : 30 Gt./yr. Energy use scaling: 35 Gt./yr.	US Bureau of Census Statistical Abstracts 1991; Dennen, W.H. 1989.
Warhurst, A. 1994 *Environmental degradation from mining and mineral processing in developing countries: corporate responses and national policies.* OECD, Paris, 20.	Environmental impacts of mining. Estimated ore production, average grade and waste generation of major minerals in 1991.	Application of average grade of ore of 12 minerals to calculate waste.	No meaningful comparison	Figures do not include overburden. US Bureau of Mines 1992.
United Nations Economic Commission for Europe 1992 *The environment in Europe and North America: annotated statistics.* United Nations, New York, 81.	Statistics covering generation of waste during all phases of the material cycle, from extraction of raw materials to consumption. Mining and quarrying wastes for selected countries.		UK an annual average of 230 Mt. mining and quarrying waste c 1988 is under half of an estimate for the UK based on our multipliers and 1989 mineral production.	Ad hoc data. United Kingdom: Estimated annual averages in the late 1980's. Limited surveys. Figures for 11 countries.
Von Weizächer, E., Lovins, A. B. and Lovins, L.H. 1997 *Factor four. Doubling wealth-halving resources.* Earthscan, London, 242-244.	Global assessment of ecological rucksacks carried by different metals and minerals.	Multipliers	18 multipliers shown are of the same order of magnitude, but generally 20-50% below our estimates	Modified after Schmidt-Bleek, 1994. Notes "valuable to have some-thing simple for the 'quick and dirty' assess-ment of ecological impacts".
Adriaanse , A., Bringezu, S., Hammond, A., Moriguchi, Y., Rodenburg, E., and Schütz, H. (1997) *Resource flows: the material basis of industrial economies.* World Resources Institute, Washington, D.C., pp 66.	Parallel materials flow analysis for the Federal Republic of Germany, Japan, the Netherlands and the United States.	National data from the four countries. Estimates of overburden and average grade of ore to establish the 'hidden' flows for major commodities, both domestic and imported.	Multipliers, where stated, are of the same order of magnitude but generally below our estimates.	Extensive use of data base of the Wuppertal Institute for Germany, the Netherlands and Japan. USBM/ USGS commodity specialists for the US.
Nötstaller, Richard. Mining advisor to United Nations Industrial Development Organization and The World Bank. Personal communication, 25/7/1998.	Estimate in 1997 of the materials flows of the 10 mineral commodities with the highest annual global production.	Calculation of percentage production open pit/underground; average stripping ratio; grade of ore.	48 Gt./year for 90% by volume of global mine production. Total material flow in world mining of 50 - 55 Gt./year.	

Informal mining

Official published statistics probably underestimate the total amount of mining and quarrying in many countries as most informal and, particularly, illegal, mining is not recorded The dominant informal activities are small-scale gold and gemstone mining and local brick clay and aggregate extraction in the developing world. Actual gold production in Sub-Saharan Africa is considerably higher than reported figures since an unknown quantity of artisanal production is not documented in official records (Nötstaller, 1997), but no reliable statistical data are available on the contribution of informal artisanal mining to the total mine production. Gold Fields Mineral Services of London's estimate of 175 tonnes of gold being produced in 1975 by informal miners world-wide may be an underestimate (Veiga 1998). Three million carats of diamonds may be mined annually in Africa (Holloway, 1997).

In many parts of the developing world, building materials are worked as small enterprises. People seek the clay, sand, gravel and stone that they need in the nearest most convenient place and it is inconceivable that these activities are accurately recorded. In Vietnam, for example, granite is quarried by individual entrepreneurs at headlands along the coast, while around towns and cities, small brick clay pits leave a series of derelict hollows and degraded soils. In inland China, villagers operate small crushers making aggregates from rock quarried from tiny rock outcrops near their fields. Many hundreds of thousands of tonnes of material are worked in this way and in clay pits (Edmonds, 1994) and inefficient unauthorised mines (Qu and Li, 1994) which degrade potential agricultural land. Road construction in remote areas, such as logging roads in Borneo, uses up to 370 t of gravel per km, and may involve the unrecorded quarrying of over 4000 t of rock per year in each major Borneo logging concession (assuming some 10 km of road construction or repair each year). Thus, the global amount of material moved by these informal, and largely unrecorded, mining activities is difficult to assess. Assuming that such mining involves 250 tons/man/year (Nötstaller, 1998) and noting that in India alone about 200,000 informal miners (Chakravorty, 1991) may be shifting about 50 million tons of material each year, about 2.5 percent of all mining related materials displacement in India (Lawson and Douglas, 1998). we find that whilst these activities result in substantial amounts of earth movement, they probably add no more than 1 - 5% to the global mass of materials moved during the extraction of minerals.

Conclusions

Estimation of aggregate production from energy consumption and the application of multipliers to mineral production statistics provides a reasonable guide to the "ecological rucksack" of mining. Informal small-scale mining for metals and other materials adds 1 to 5% to that recorded in statistics, but it has major local environmental significance. Such analyses contribute to the application of materials flow accounting approach to creating more sustainable cities. It is also a precursor to reducing the effects of mining and urbanisation on rivers and coasts and avoiding landslide disasters associated with mining spoil instability.

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A Dynamic Life Cycle Energy Model of the UK Paper and Pulp Sector 1987 - 2010

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Abstract
This paper discusses the methodological approach and results of a life-cycle materials flow and energy analysis of the UK pulp and paper sector. While a number of previous studies have addressed waste management options for the UK pulp and paper cycle, none have attempted to fully assess the whole life cycle impacts of this import dependant sector, or model the complex 'cascade' nature of the material system. This study accounts for all major industry processes and the significant imported energy "rucksack" associated with foreign forestry processes, particularly those prior to timber harvesting. Historical trend analysis and future trend forecasting have been carried out in order to investigate the energy implications of process technology improvements, waste paper utilisation rates, and pulp and paper consumption. The results indicate that policy options to increase recycling yield some energy benefits, but these are small by comparison with the benefits to be gained by reducing consumption of paper and improving process technology. The structure of the electricity supply industry in the UK means that global energy benefits could also be achieved by increasing the contribution from imported pulp.

Introduction
The environmental performance of the pulp and paper sector has attracted considerable interest for a number of reasons. In the first place, this sector has economic importance in both national and global terms. It also has a history of associated environmental problems. For example, the industry has traditionally been rather energy intensive. As a result, there have been a number of energy and environmental studies made of the sector (Leach *et al* 1997, Ruth and Harrington 1998, Jerkeman and Lagerstedt 1996 eg). Most of these studies have been carried out in countries which are net exporters of paper and the studies have tended to concentrate on the production cycle. By contrast, the scope of the study described in this paper is the lifecycle of paper products consumed within the UK – a country which relies heavily on imported paper to meet domestic demand. The central objective of this study was to develop a dynamic model of the material and energy flows associated with the consumption of paper in the UK between 1987 and 2010.

A "material cascade" system (Jackson 1996 eg) such as that associated with paper use and recycling is by nature both non-linear and dynamic, since it contains both feed-back loops and lag times (Parkinson *et al* 1998). These features, combined with the desire to include historical trends and make predictions about future trends, led to the choice of dynamic modelling software package called STELLA for the analysis undertaken in the study. Using this software, the authors constructed a model of the UK paper cycle which was used both to track historical changes in production, consumption and energy use in the sector, and also to investigate how future system energy consumption would change under different assumptions about critical parameters. These critical parameters included process technology efficiency, waste paper utilisation rates, the enduse demand for paper and the structure of the electricity supply industry. The study has also attempted to investigate whether the high import-dependence of paper consumption in the UK has significant implications for transport energy requirements.

The principal data source for mass flows and energy consumption in the study was the Paper Federation of Great Britain (RS 1996, Langdon 1998). Other data were gathered from a variety of sources (DETR 1997, FAO 1996 & 1998, Farla *et al* 1997, McKinney 1995, White *et al* 1995).

Methodology and model structure

The basic methodological approach followed by this study is a combination of materials flow analysis (MFA) and streamlined lifecycle assessment (LCA). The MFA was conducted in order to determine the mass flows through each stage of the pulp and paper cycle at a national level. But the study also adopted a cradle-to-grave perspective on paper as a product, and tracked the lifecycle energy requirements associated with the use of each tonne of paper consumed in the UK economy. Thus historical mass flows at each stage and primary energy use per unit of product were the principal model inputs. Using these inputs, the model computed a global system energy requirement for each year of the time series, under a variety of assumptions about critical parameters such as growth in demand, process efficiency improvement, and waste paper utilisation rate (WUR).

The global system energy requirement is taken to include both the domestic system energy requirement (i.e. for processes within the UK national boundary) and also the system energy requirements imposed by the need to import pulp and paper from overseas.

Paper is made of fibre in the form of either virgin pulp or recovered paper. But there is a multitude of different pulp, paper and wastepaper grades. Specific energy consumption varies widely across different grades, and between different pulping processes. In this model, virgin pulp processes were divided between three different categories: mechanical, chemical and semi-chemical pulping. The main parameters used for differentiating between the recovered waste paper grades are quality and purity. The recovered waste paper grades used in the model are high grade, old newspaper and bulk. Paper is, in its turn, divided into six grades depending on the enduse for which it is destined. Table 1 below shows the pulp and paper grades used in the model:

Table 1: Pulp and paper grades used in the model.

Papers – enduse category	**Virgin Pulp Process**	**Recovered paper grades**
Newsprint	Mechanical	High grade
Printing and Writing	Chemical	Old newsprint
Corrugating materials	Semi-chemical	Bulk
Packaging paper and board		
Sanitary and Household		
Other paper and board		

There are a number of feed back loops between the different pulp sources and paper productions, which yields some complexity in the model. For example, the paper grade “printing & writings” has five different material flow inputs. The factor which governs the wastepaper content in the various paper grades is called the Wastepaper Utilisation Rate (WUR). This critical parameter is defined by the following fraction:

$$WUR = \text{waste paper input/production output}$$

where the waste paper input is the amount of waste paper going to repulping before being used in paper production of each grade.

The scope of this study was defined by the demand for enduse paper products in the UK. Thus the system boundary was determined by the need to account for all processes relevant to the production, processing, transportation, collection and disposal of paper consumed in the UK. As we mentioned in the introduction, this sector is highly import-dependent. Thus, we have included within the system boundary those processes which are necessary to process the import requirement and to transport foreign pulp and paper into the UK. Since the focus is on consumption, papers and pulps manufactured in the UK purely for export purposes have been excluded from the system under consideration. Figure 1 shows the mass flows and total energy requirements associated with each stage in the pulp and paper lifecycle in the UK for the year 1998.

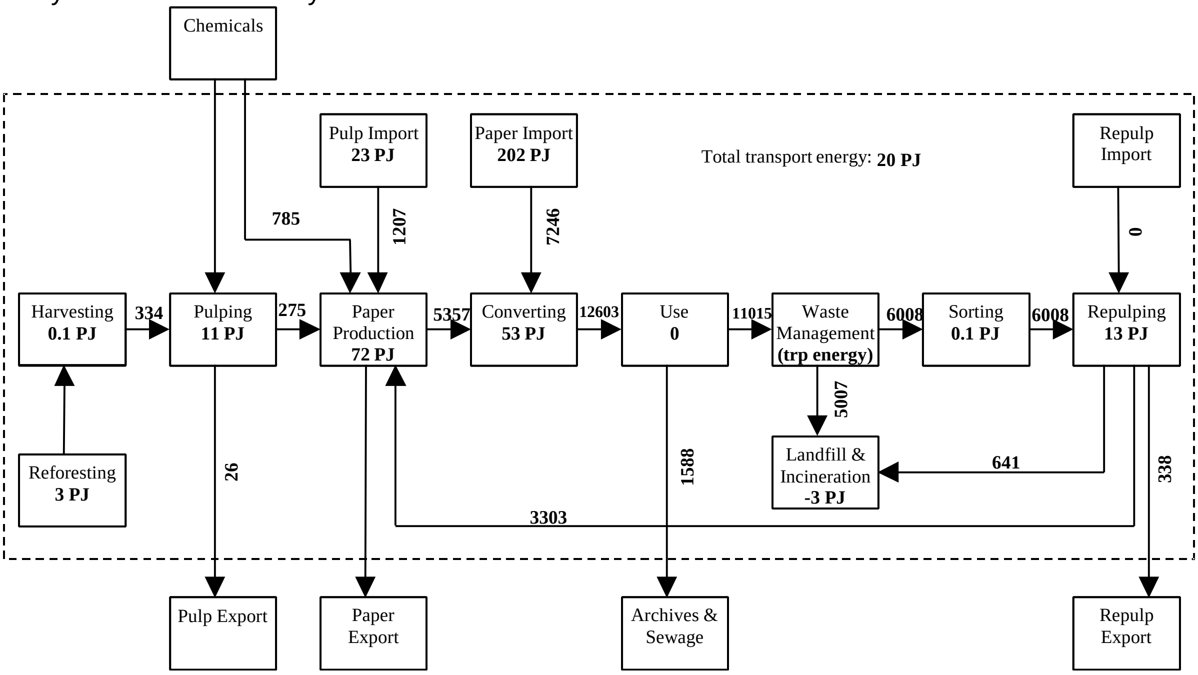

Figure 1: System boundary of the paper model showing mass flows (ktonnes) and energy consumption (PJ) for the year 1998.

A number of other studies on the paper industry have left out critical elements in the lifecycle such as the replanting of trees or the conversion of paper into finished products. As Figure 1 shows, these aspects of the lifecycle are considerable in energy terms. Although quantitatively less significant in energy terms than some other stages, reforestation becomes particularly important when comparing recycling against virgin paper production. Along with other studies this model has excluded the energy requirements going to the manufacture of chemicals used in the pulping process. This is a limitation of the current model, but it is not believed significantly to affect the results.

Generally speaking, paper is regarded as being produced and consumed during each period of the study. Long-term paper use such as book sheets is modelled as enduse stocks. The use phase of the various papers is estimated to have a negligible contribution to system energy consumption and is therefore not included in the model.

Results

Figure 1 shows that production of paper is the most energy intensive process. The major contributor to this consumption is the energy allocated for drying paper. Figure 2 shows a snapshot of where the energy is consumed by industry sector in the UK paper cycle, for the year 1998. The largest sector, covering 51% of global system energy consumption, is foreign paper production. This is explained both by the large share of imported paper in UK consumption and by the fact that all energy consumption prior to foreign production has also been allocated to this sector. The second largest energy share is taken by domestic paper production (18%). More surprisingly, the domestic conversion of paper into paper products is a significant contributor to system energy consumption. (We have assumed that both imported and domestically produced paper is converted within the United Kingdom). This result illustrates the importance of including paper conversion in attempting to investigate the environmental burdens of the paper cycle. The pie-chart also indicates that transport generates relatively small energy requirements (around 3%) in an otherwise energy intensive industry.

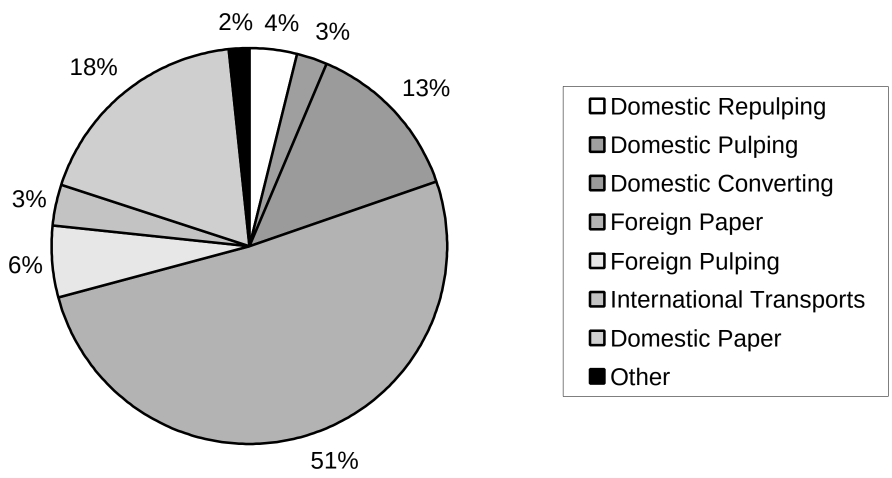

Figure 2: Distribution of the system energy consumption by sector 1998.

Having established the mass flows and system energy requirements of the historical UK paper cycle from 1987 to 1998, the study proceeded to simulate a number of possible future scenarios for the development of the industry. Figure 3 illustrates the global system energy for scenarios with alternative changes in the consumption of paper in the UK. Four scenarios were constructed with different assumptions about paper consumption and with the same process efficiency improvements. In the base case scenario, consumption was assumed to grow at a rate similar to the current growth in demand. The specific energy consumption in each process stage was assumed to continue falling at a rate equal to half the average rate of fall over the years 1987 to 1998. High and low variations in consumption growth provided two further scenarios. A fourth “stabilisation” scenario was constructed by assuming that the growth in consumption just fails to offset the improvement in process efficiency over the scenario period. This “stabilisation” growth rate was found to be approximately 25% of the current annual growth rate. Thus, under current trends, the global system energy requirement for the UK paper and pulp sector is projected to rise considerably. The “low” scenario is in fact a zero consumption growth scenario, and this is the only scenario under which the total system energy consumption falls significantly. Simulations with changes in process technology improvements shows differences in system energy consumption, which are similar in magnitude to the differences in figure 3.

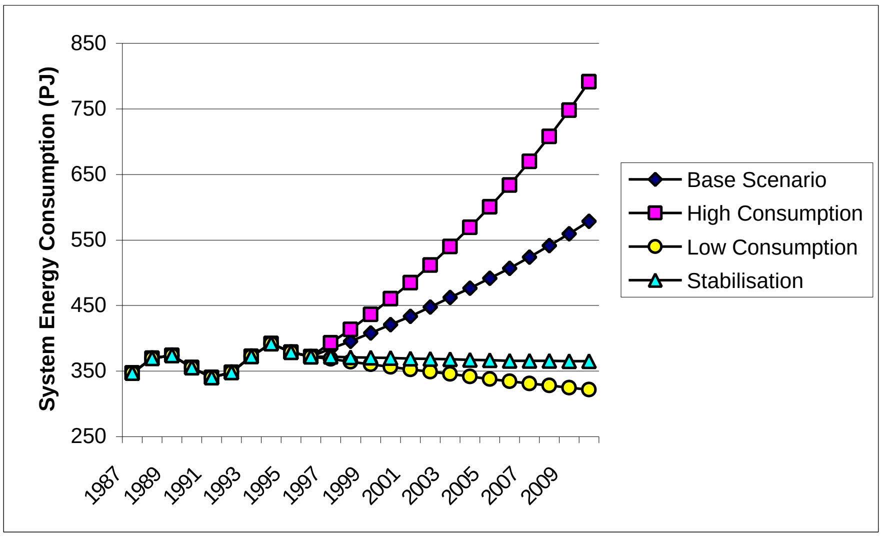

Figure 3: System energy consumption for different paper consumption scenarios.

An interesting and common question to ask is whether it is better to recycle paper than burn it for energy recovery. This study found that a high waste paper utilisation rate is marginally preferable from a global point of view. Global system energy consumption was 2 percent lower in 2010 by comparison with the base scenario (Figure 4). However, when looking at the same question from a UK perspective – i.e. taking only domestic system energy consumption into account – this result is reversed (Figure 5). In this latter case, the high-WUR scenario reduces foreign pulp production and increases domestic repulping of waste paper. This leads to higher energy consumption seen from a domestic point of view. Relative to the changes in energy consumption from reducing paper consumption or improving process technology, the benefits from changes in the waste paper utilisation rate are small.

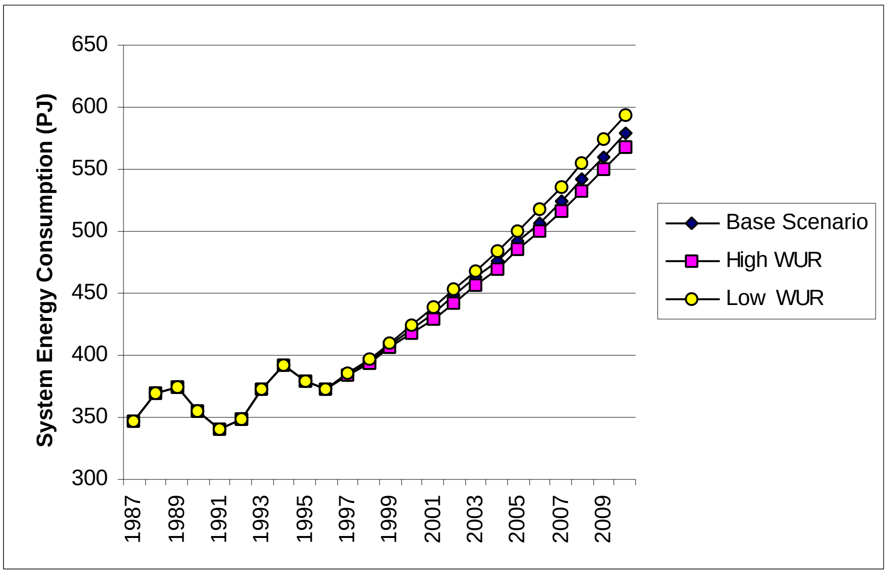

Figure 4: System energy consumption for alternative waste paper utilisation rates.

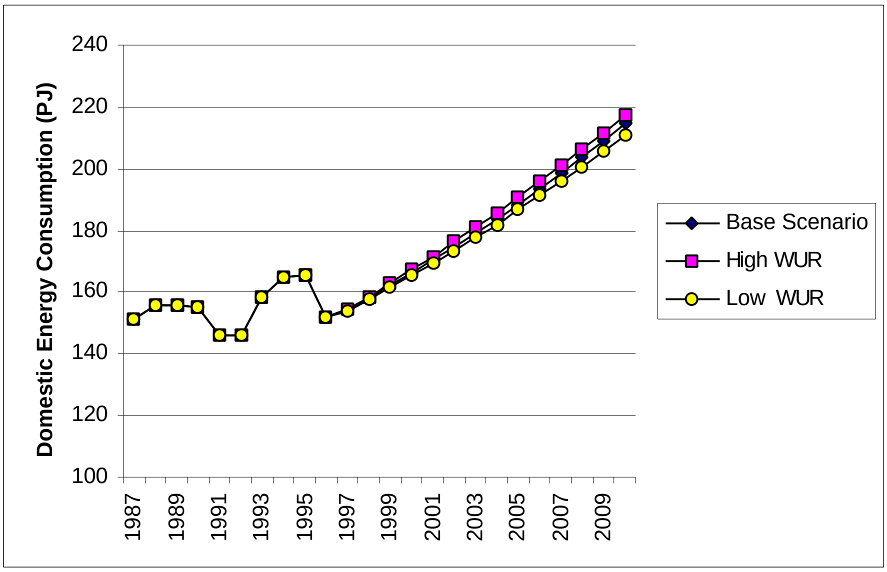

Figure 5: Domestic energy consumption for alternative waste paper utilisation rates

The study also simulated the impacts on domestic energy consumption of hypothetical changes in the Electricity Supply Industry (ESI). Figure 6 illustrates the difference between a system using the current UK ESI, and a system based on the Western European average ESI. This difference arises because of the high primary energy intensity of the UK ESI, and the result illustrates the importance of the ESI for an energy intensive sector such as paper. The energy benefit from improving the primary energy efficiency of the UK ESI could be as much as 20% of the domestic energy consumption for the paper cycle by the year 2010.

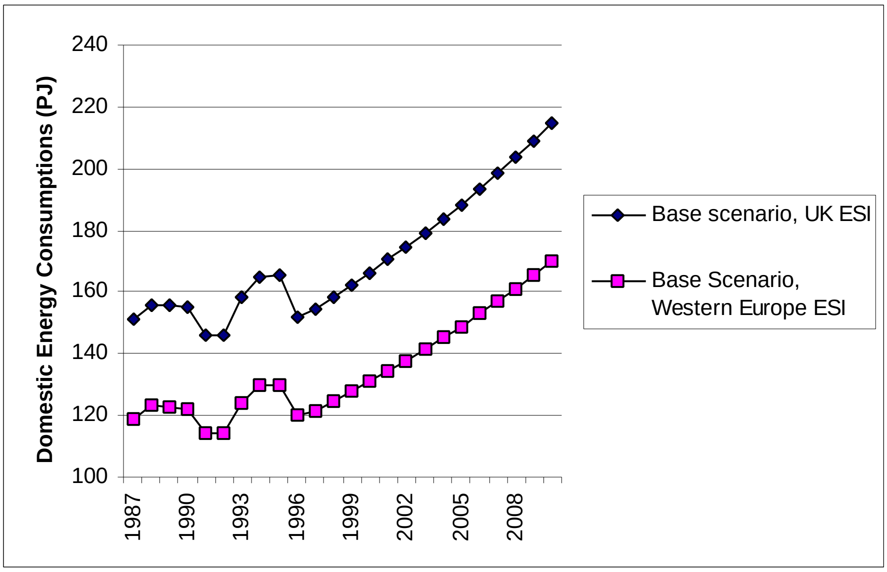

Figure 6: Domestic energy consumption for alternative ESI.

The importance of the manner in which electricity is produced is also evident from the global energy disadvantages attained by reducing the share of imported pulp and increasing domestic production. These disadvantages, illustrated in Figure 7, arise because of the current differential between the UK and the Western European average ESI. It is preferable (from a global energy perspective) to import pulp rather than produce it in the UK.

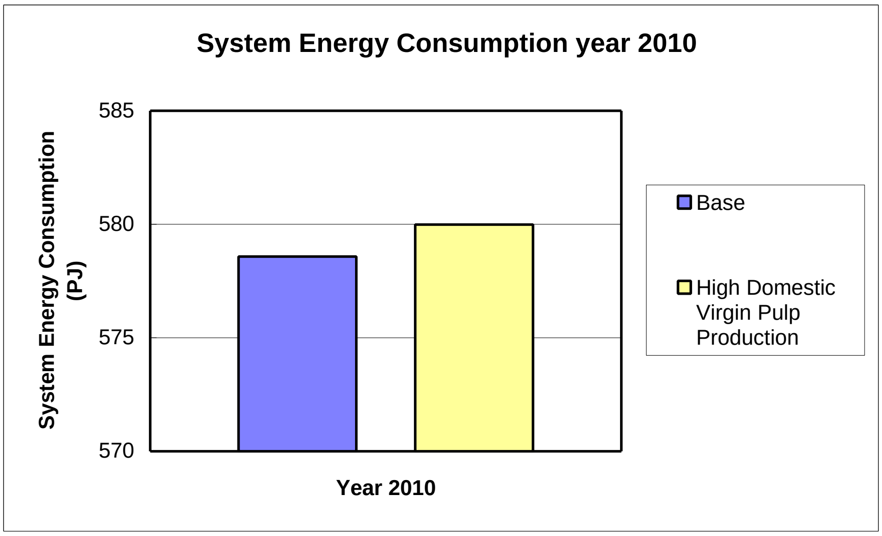

Figure 7: System energy consumption for changes in domestic pulp production

Conclusions

This study constructed a dynamic systems model of the UK paper cycle, and used the model to simulate various scenarios for the future development of the sector. Paper production was found to be the most energy consuming process step. This is also where the largest energy savings could be made in the future by reducing the demand for paper and stimulating improvements in process efficiency. The conversion of paper to paper products was seen to exert a considerable influence on total system energy requirements, and it is remarkable that this sector has been excluded in several earlier studies. Another exclusion from earlier studies – the energy associated with reforestation – was also shown to be significant, especially when comparing recycling with incineration as a waste management option. The present study found that a high waste paper utilisation is preferable from a system energy consumption view, but the benefits are small compared with changes in consumption and process technology.

It is also clear from this study that the choice of system boundary can have significant impacts on the results of the study. For example, the domestic system energy benefits of increased recycling were found to be negative even though the global system energy benefits were found to be positive. Finally, it is worth noting that the global energy requirement is being used in this study as a “proxy indicator” for both the resource and the environmental implications of the paper cycle. It would be relatively straightforward to extend this kind of analysis to include a number of further indicators of environmental impact.

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APPLICATION OF THE ECOLOGICAL FOOTPRINT TO BARCELONA: SUMMARY OF CALCULATIONS AND THOUGHTS ON THE RESULTS.

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Introduction
This article presents a summary of the results of the study conducted on the application of the indicator known as the Ecological Footprint to the city of Barcelona. It includes the final results of the calculation for the city (in spite of the current difficulties in quantifying certain parameters), an analysis of the variables acting therein, and an assessment of the usefulness of the Ecological Footprint as a tool for the environmental management of the city.

Antecedents
The Ecological Footprint has been applied to Barcelona in the frame of similar studies done by the experts who proposed the indicator, professors William Rees and Mathis Wackernagel (hereafter known as the Footprint authors), recently published in the books *Our Ecological Footprint* (1996), *Ecological Footprints of Nations* (1997) and *The Ecological Footprint of Santiago de Chile* (1998).

It should be noted that, in spite of an exhaustive search for municipal Footprints, no predecessors have been found in this field (with the exception of the city of Munich, for which the method of the Footprint authors was not been used in the calculations). Until now, the Footprint had been calculated only for countries or metropolitan regions. Therefore this study of Barcelona is innovative in so far as it is one of the first attempts to apply the indicator to a single city.

Concept: the Ecological Footprint Applied to Cities
Cities are characterised by being areas where a large part of the world's population is concentrated (according to the United Nations 45% of human beings live in cities). In Catalunya in 1996, 56% of the population lived in urban nuclei of over 50.000 inhabitants and 25% lived in Barcelona city (IEC, 1997). The fact that a large part of the world population is concentrated in urban areas with small extent does not signify that the rest of the territory is devoid of human activity; extensive areas of land are needed to support this activity in the cities. The Ecological Footprint indicator arose out of concern for measuring this impact on the environment by the urban nuclei.

The human activities carried out in a city depend on the supply of natural resources (water, materials and energy), on the absorption of waste and on other life-support functions which only nature can provide. People are part of nature and we depend inescapably upon it to meet our most basic needs: energy for movement, wood for furniture, trees to make paper, fibres for clothing, food, etc. Each of these services takes up a productive physical space, and the sum of these areas is called the city's Ecological Footprint.
The Footprint authors define this indicator more or less as "The ecologically productive territory (arable land, pasture, forest, aquatic ecosystems, etc.) required to produce the resources used and to assimilate the waste produced by a defined human population with a specific material standard of living indefinitely, wherever this area is located." (Rees & Wackernagel, 1996).

The Ecological Footprint is used at the level of nation, region or city, and it is expressed in hectares per capita. The Footprint is therefore a quotient which, if the population is known and the extent of the region under consideration is when making the calculation, may be translated into an area: that is, the number of times by which the extent of the region under consideration is exceeded. Thus, the calculation is used to ascertain whether the Ecological Footprint of Barcelona is 5, 50, 300 or 1000 times greater than the extent of its municipal territory, for example. Nevertheless, it is more helpful to use the Footprint in hectares per

capita when comparing local Footprints of different municipalities; therefore, hereafter, the Footprint shall be understood to mean the extent with reference to one inhabitant. [28]
The larger the Footprint of a city or country, the greater the environmental impact it will cause outside its administrative limits.

Method for Calculating the Ecological Footprint

Below is an explanation of the method established by the Footprint authors for calculating this indicator.

The calculations are based on finding the extents of Arable land, Pasture, Forest, CO_2 Absorption Area, Built-up Area and Sea necessary for the consumption of a limited number of products and in finding the surface area associated with the energy inputs of the country or region under consideration (Wackernagel, 1997). Therefore, the hectares per capita necessary are calculated for:

- The consumption of forest products (Forest).
- The consumption of agricultural or fish foodstuffs (Arable land, Pasture and Sea)
- Construction (Built-up Area)
- The direct energy consumption (or indirect through the consumption of imported good) translated into area of forests necessary to absorb associated CO_2 emissions (CO_2 Absorption Area).

Therefore, the calculations of the Ecological Footprint are based on two facts: I) the resources we consume can be accounted for physically (in tons) and II) these inputs may be translated into biologically productive surface area (hectares).
The calculations are made from data on annual consumption (annual consumption is understood to mean the consumption obtained by subtracting exports from and adding imports to annual production) and data on the productivity of land (hectares necessary for each ton consumed).

Due to considerations of data availability, to date the calculations made by the Footprint authors have been at the country level, with statistical data from the United Nations. Only estimates exist of Footprints for cities extrapolated from national calculations according to the number of inhabitants of the city and its extent. This is done on account of the impossibility of finding the necessary local data.

Furthermore, at the same time as they translate consumption (tons) into land extension (hectares), the Footprint authors opt for using data on average world productivity (tons per hectare) because in this way only a variation in the energy component of imported goods (not the land productivity component) can cause the Footprint of a region to decrease. If it were not done in this way, there could occur that the countries with more economic capacity in importing resources from the most productive places in the world in order to minimise their Footprint while the poorest would keep the least productive lands and thus have a larger Footprint.

With the data on consumption and land productivity, a matrix is drawn up which relates each consumption to the hectares per capita used of each type of land necessary (Arable land, Pasture, Forest, CO_2 Absorption Area, Built-up Area and Sea). The total Ecological Footprint per capita is the result of the sum of all the hectares per capita calculated.
Parallel to the calculation of the Footprint, the authors search for data on the real surface area of each type of land (Arable land, Pasture, Forest, CO_2 Absorption Area, Built-up Area and Sea) in the area for which the Footprint is calculated. The sum of these surface areas, referred to per inhabitant of the population considered, is the ***Local Carrying Capacity***, that is the hectares available for the consumption of the inhabitants. [29]

[28] See the section on final considerations.

[29] When comparing the Ecological Footprint with the Local Carrying Capacity (of the land considered), the Footprint authors introduce "Local Productivity Factors" which are applied to the Carrying Capacity values in order to translate the local values into world average values and thus be able to compare the Carrying Capacity with the Ecological Footprint of the region (previously calculated with the values of world and not local average productivity). This is one of the aspects that have varied when applying the method to Barcelona (see the section on application of the method to Barcelona).

The Carrying Capacity is defined as "the maximum population size (or maximum per capita consumption in the case of human beings) that an area can support without reducing its ability to support the same population in the future." (Catton, 1986). Therefore, in the case of the human species, the Carrying Capacity expressed in terms of per capita consumption may be translated into units of surface area and thus be compared with the Ecological Footprint.
In the calculations of Carrying Capacity the Footprint authors also include the space necessary to protect biodiversity. In this respect, 12% is subtracted from the Carrying Capacity calculated, which is the percentage of the world ecosystems that must be kept unexploited in order to conserve the rest of the species, according to the United Nations World Commission for the Environment and Development (*Brundtland Report*, World Commission for the Environment and Development, 1987).

Once the Footprint and the Carrying Capacity have been calculated, one can compare, for example, the hectares used by an inhabitant for annual food consumption (Ecological Footprint for food) and the hectares available in his/her region (Carrying Capacity for food expressed in units of surface area) and one can ascertain whether or not there is a deficit of surface area exists for the region's food production.

Application of the Method to Barcelona

For our application to Barcelona, for reasons of data availability, the methodology of the Footprint authors, William Rees and Mathis Wackernagel has been taken and the city's Footprint (Barcelona) has been estimated from the calculation of the Catalan Footprint (Barcelona is the capital of Catalunya, a region of Spain)

To calculate the hectares per Catalan inhabitant associated with their annual consumption of food, energy and other consumer goods (Catalan Footprint) we have used data from the Institut d'Estadística de Catalunya (IEC), the Department of Agriculture and Fishing, and the Catalan Energy Institute. The data on imports and exports published by the IEC are data on Catalunya's overseas trade (with the European Community and other countries) and do not include the trade with the rest of Spain.

The calculations are based on completing the matrix of consumption of productive surface areas that the authors give with Catalan data (given per inhabitant). The calculations have been divided into two major matrixes although finally the results are brought together in a single table.

In the **first matrix** the consumption of land is calculated (Arable land, Pasture, Forest and Sea) associated with the consumption of food, forestry products and other goods obtained from crops (tobacco, cotton, etc.). The rows in this matrix represent the types of resources consumed and the columns contain the consumption data in physical terms (consumption = production + imports - exports) and in terms of land productivity, to translate the physical units into surface area.

The result obtained for vegetables, for example, is as follows: in 1996 in Catalunya 676.120 tons of vegetables were produced and 64.224 tons were exported, so the local vegetable consumption was 100,47 kg/inhabitant. Knowing that the average productivity of vegetable growing in Catalunya is 24.648 kg/hectare, the hectares necessary for local vegetable consumption of an inhabitant of Catalunya are obtained. To these hectares should be added the appropriate hectares outside Catalunya with the import of vegetables, a not inconsiderable amount since in 1996 Catalunya imported 885.533 tons. The productivity used to transform these tons into hectares is that corresponding to a world average crop (18.000 kg/hectare instead of 24.648 kg/hectare), due to the difficulty that would be involved in obtaining data at origin for each type of vegetable and of each type of crop in each country of origin. [30]

[30] This distinction between local and world productivity is an alternative option which allows one not to have to use the "Local Productivity Factors" defined by the Footprint authors in their calculations; this distinction has been made because data for local productivity existed. This is the only difference

From the results of the first matrix, the Footprint associated with food consumption is worth highlighting. Catalans use a total of 2,1 hectares per capita and year for food alone. It is the consumption of fish that causes a greater individual food-related Footprint, due not so much to the amount consumed as the low productivity of the sea in comparison with farmland, for example. Lamb consumption is what most contributes to the meat Footprint that follows fish in ascending order of importance. The consumption of dairy products and grains is also important in the translation into hectares, while fruit and vegetables, despite high consumption, do not contribute a great deal to enlarging the Footprint for foodstuffs.
The productivity of the land we are considering is of great importance in estimating surface areas. Thus, meat consumption requires much more surface area than the same quantity of vegetables, since, first, pastureland has a much lower primary productivity, and second, it is lost in the transformation.

With the first matrix, the Footprint associated with the forestry sector is less than 0,1 hectares per capita, much smaller than the Footprint for food.

In the **second matrix**, the area is calculated that is required for absorbing the CO_2 emitted in the direct consumption of energy products (electricity, fossil fuels, and renewable energies) or used for manufacturing the goods consumed.

In order to calculate this matrix, the Footprint authors use productivity factors that directly convert the annual energy consumption (Gj/year) into hectares of surface area (ha). To elaborate the matrix for the Catalan area, the method has been adapted and these productivity factors have not been used. The calculation was different for each source of energy:
For the *fossil fuels*, emission factors were used directly in accordance with studies previously conducted in Catalunya and with the current trends in calculating emissions and areas of CO_2 absorption.[31] The factors used were as follows:

Table 1: CO_2 Emission Factors

Energy Source	Emission Factors (kg CO_2 /Gj)	CO_2 Absorption Area
Fossil fuels		
• Solid	141	1ha / 6,6 tons CO_2
• Liquid (PLG/Gas-oil, etc.)	63,5-73	
• Gases	65,8	
Electricity from thermal power (1)	141-65,8	
Electricity from nuclear power (2)	73	
Self-prod. electricity from thermal	83,5	
power	117	
Incineration of municipal waste	0	
Biomass (3)	0	*(Source: Terradas, 1998)*
Biofuels (Ethanol) (3)		

Source: Elaborated by the authors from data from Eurostat, DGE, Eurogas, Baldasano, 1998.
(1) Depends on the fuel used. It should be noted that if the electricity is generated from fossil fuels (efficiency 30%) the Footprint per final energy unit consumed is 3 times greater than if fossil fuels had been used directly.
(2) Emission factor assimilated to liquid fuels, (even though nuclear energy does not emit CO_2, this is at present the only way of converting it into units of surface area)
(3) CO_2 generated in combustion is reabsorbed by Biomass and Biofuels.

For *nuclear energy*, the Footprint authors combine the consumption of electricity produced in the nuclear power stations with the consumption of liquid fossil fuels, and apply to them the same emission factor. Even though this estimate reflects neither the real situation nor that of

incorporated into the first matrix in respect of the calculation method established by the Footprint authors.

31 In fact, the productivity factors used by the Footprint authors were calculated from emission factors, therefore this change in respect of the original methodology does not make the results vary but further details them and specifies them (since it differentiates between different consumptions of fossil fuels).

other effects of nuclear energy use, at present it is the only way of converting the energy consumption of nuclear-produced electricity into units of surface area, therefore the same emission factor is used for this consumption as that for liquid fossil fuels (just as the Footprint authors themselves chose to do.)

The Ecological Footprint of the *renewable energy* consumption (hydraulic, aeolic, photovoltaic electricity and solar heat energy) has been estimated from local data on solar panel surface area, aeolic parks and dams in Catalunya, instead of using factors from other countries or specific studies as the Footprint authors do.[32]

Part of the energy consumed is used in the export of goods, and with the import of goods energy from elsewhere is consumed. In order to bring in these two aspects, the second matrix includes an energy balance for the trade of goods. That is to say, the energy consumed in the import of goods (Gj/ton) is added to the energy expenditure of fossil fuels, electricity and renewable energies. All this energy is assumed to be of fossil origin, as established in the methodology of the Footprint authors. This calculation yields the Gj/per capita associated with the balance of import minus export of merchandise, which should be included in the matrix of energy consumptions added to the consumption of fossil fuel, electricity and renewable energies. It should be mentioned that the energy conversion factors associated with the life cycle of each item of merchandise (Gj/ton) used by the balance are given by the Footprint authors, and that these are the result of considering a complete standard process of the life cycle of each product.

What is worth stressing from the results of the second matrix is that the energy consumption that most contributes to the energy Footprint per capita is the consumption of liquid fuels (gasoil, gasoline and fuel oil), for this consumption alone more than 0,79 hectares are necessary to absorb the CO_2 associated with its consumption, more than 75% of the energy Footprint. Of the direct energy consumptions one should also highlight the electricity from nuclear power stations for its large contribution to the Footprint.

With the second matrix, one also observes, by type of commercialised products, the importance of the export of products from of the chemical sector, the construction sector and automotion in the balance of Catalan imports and exports overseas. This fact has a positive repercussion on the Footprint, since it is production not consumed here, which must therefore be subtracted from the initial energy consumption we had considered. This fact, which stems from the application of the method established by the Footprint authors, should be analysed in detail, because a case might arise where, in order to minimise the Footprint of a country, a decision were made not to import products with a low energy content but to produce products with high energy and then be a great exporter, so that the Footprint would be maintained without the process being within the limits of the global Carrying Capacity.

The final results of the combination of the two matrixes are expressed in hectares of productive land consumed per Catalan inhabitant, and through the number of inhabitants in the city of Barcelona, the Ecological Footprint of the city is approached.

Results: Estimating the Ecological Footprint of Barcelona

The calculation projection that is shown in this section, is the one normally carried out for calculating Ecological Footprints at city level. The fact that the Barcelona Footprint is estimated from the Catalan Footprint means that it is not specific for the city, a fact which we should bear in mind when reading the results that follow.

From calculations of the two matrixes (land consumption matrix: Arable land, Pasture, Forest and Sea; and energy consumption matrix: CO_2 Absorption Area) and addition of the fact that in Barcelona 75% of the land is built (*Anuari Estadístic de la Ciutat de Barcelona,* 1996) and a population of 1.508. 805 people (*Ajuntament de Barcelona,* 1996 census), the following results are obtained:

[32] The area currently required for the consumption of renewable energies is 0,002 hectares per capita, much lower than that needed for the consumption of non-renewable energies (CO_2 absorption area), which is in the order of 1 hectare per capita (See the Results section).

Table 2: Ecological Footprint of Barcelona estimated from Catalan data, 1996

	Ecological Footprint of Barcelona estimated from the Catalan Footprint	
	Hectares /capita	**Total hectares**
Arable Land	0,49	739.314
Forest	0,08	120.704
CO_2 absorption Area	1,02	1.538.981
Pasture	0,99	1.493.717
Sea	0,65	980.723
Built-up Area	0,005	7.544
TOTAL	**3,23**	**4.880.983**

Source: Elaborated by the authors, 1998.

According to the estimate based on the Catalan data and according to the number of inhabitants of the city, in 1996 each inhabitant of Barcelona used 3,2 hectares of land for the consumption of food, goods and energy products, for housing and the built infrastructures in the city.[33]

Mention should be made of several facts which mean that this estimate does not fully correspond to reality:

I) Consumption behaviour patterns do not correspond between cities; the consumer profile in Barcelona differs from that for other places in Catalunya. However, in these calculations, the Footprint of an inhabitant of Barcelona and that of an inhabitant of Vic, Tremp, Lleida or Sitges, for example, are distinguished only by the number of inhabitants and the extent of their municipality.

According to a comparative analysis (carried out in the study) of the differences in Catalunya and Barcelona consumption patterns, the following figure shows in what respects the Footprint calculated is believed to have been overestimated or underestimated.

Table 3: Under or overestimation of the Ecological Footprint for Barcelona, 1996.

	Barcelona Footprint estimated from Catalan Footprint
Arable Land	Underestimated
Forest	?
CO_2 absorption Area: -Consump. energy prod. -Consump. imported goods and assoc. energy	 Overestimated Underestimated
Pastures	Underestimated
Sea	Underestimated

Source: Elaborated by the authors, 1998.

II) The city of Barcelona has a real population larger than the census population. The fact that there are no data on the population which actually uses the city (non-resident students, non-resident workers, tourists, etc.) means that the individual Footprint for the city is overestimated.

The Ecological Footprint should be compared with the availability of land or Carrying Capacity. In calculations referring to cities it does not make too much sense to calculate the Local Carrying Capacity, so the Carrying Capacity of the Earth has been calculated so as to ascertain whether an inhabitant of Barcelona appropriates more or less productive space than would fall to him/her in a fair distribution at world level. In the following figure a number of simple calculations are summarised for obtaining the world productive surface area currently available.

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[33] If the Ecological Footprint of Barcelona is 3,23 hectares per capita, this means that it is 4.880.983 hectares, that is, 492 times bigger than the extension of the municipality which is 9.907 hectares.

Table 4: Productive surface area available in the world, 1996

World population: 5,5 thousand million people
Surface area of Earth: 51,5 thousand million hectares
Arable land:
1,35 thousand million hectares in world, 10 million of which are abandoned every year.
0,25 hectares / person
Pasture land:
3,35 thousand million hectares in world. Expanding to the detriment of forestland. **0,6 hectares/ person**
Forest land:
3,44 thousand million hectares in world. **0,6 hectares / person**
Built land:
0,16 thousand million hectares in world. **0,03 hectares / person**
Sea:
36,6 thousand million hectares. 71% of the earth's surface is sea. **6,6 hectares / person.**
Of this surface area, only 8,2% gives 96% of the world marine production. Total: 29-33 kg/ha, **0,5 hectares/ person.** This yields 16-18 kg/cap·year, of which only 12 reach the table.
TOTAL= approximately **2 hectares/person**. *Subtracting 12% of the surface area for preserving the rest of the animal species, this means* **1,75 hectares / person** *available at world level.*

Source: Elaborated by the authors from Wackernagel, 1996.

It should be pointed out that the data in the preceding table is constantly variable, since, for example, every year forests burn or 10 million hectares of arable land are abandoned, according to the United Nations.

Comparing these data with those of the Ecological Footprint of Barcelona, we observe that each inhabitant of the city takes up more than his/her share as citizen of the world, in a hypothetical fair distribution of resources.[34]

Table 5: Barcelona Ecological Footprint and World Available World Land, 1996

	World available land (hectares / capita)	Est. Barcelona Footprint (hectares /capita)	Difference (hectares /capita)
Arable land	0,25	0,5	- 0,25
Pasture	0,6	0,9	- 0,3
Forest and CO_2 absorption area	0,6	1,0	- 0,4
Sea	0,5	0,6	- 0,1

Source: elaborated by the authors from Figure 6 and Wackernagel, 1997.

Introduction of New Local Aspects

In line with the tendency of other European level studies found the application of the preceding calculation to Barcelona was completed with the introduction of some new aspects of a more local nature not considered in the conventional studies. It was deemed opportune to add to the traditional calculations of the Footprint (consumption of pasture, crops, sea, forest, built land and area necessary for the absorption of CO_2) the areas necessary to:

- *Absorb the municipal solid wastes produced by the city:* an estimate has been made of the surface area necessary for absorbing the equivalent CO_2 emitted by the Garraf landfill and by the incineration plant at Sant Adrià del Besós, the main destination points for the waste generated in Barcelona. According to the studies recently published by Helena Barracó, to absorb the emissions from the waste of Barcelona dumped at the Garraf landfill, 0,09 hectares of forestland per Barcelona inhabitant are required, a relatively low figure when compared with the other areas of CO_2 absorption calculated. Also according to Barracó, to be absorbed, the emissions from the incineration of waste

34 In the calculations of world land available, the 12% necessary for preserving the rest of animal species with which we share the planet have not been subtracted, because of the difficulty of distributing this percentage among the different types of land considered. If this percentage were included in the calculations, the difference between available land and the estimated Footprint would increase. In the calculations, neither has the CO_2 absorption capacity of the sea been considered.

at the plant require 0,03 hectares of forestland per Barcelona inhabitant. A change in waste management would also bring a change in the Ecological Footprint for these. Thus, for example, according to Ferran Relea, use of the biogas produced at Garraf would decrease the city's CO_2 emissions by 44% and, consequently, their Footprint calculated from the emissions associated with the city's waste production.

- *Supply the city with drinking water:* the consumption of drinking water requires a surface area which in many cases is compatible with other uses (for example a basin which at the same time absorbs CO_2 also serves to collect the water consumed in Barcelona); this, in order to preclude double accounting, is not included in the calculations. However, what is sometimes included in the analysis of the Footprint is the cost of opportunity of not having this water in rivers, or the energy consumption associated with transport to the place of consumption. For example, in the cities of Australia, the provision of water supply requires 0,27 to 0,37 hectares of surface area associated with these costs (Wackernagel, 1997). In Barcelona, an approximation has now been made of the order of magnitude of the area needed to supply the city with water (Prat, 1998). If we fix with the extents of basin area needed to supply the city, we obtain the following: that the equivalent to the Ecological Footprint of Barcelona's water supply, namely "the appropriation of the drainage area for supplying Barcelona with water", is between 0,02 hectares/inhabitant in a normal year and 0,05 hectares/inhabitant in a dry year.

Conclusions: Pros and Cons of the Calculations

The Barcelona Footprint is *estimated* at between 3 and 3,5 hectares/person; it is not possible to give the exact figure due to the lack of existing data.

The aspect that most contributes to this footprint is the city's consumption of energy, especially of fossil energy, calculated as the area of forestland necessary to absorb the CO_2 emissions associated with this energy consumption, as opposed to other consumptions and their associated areas (crops, pasture, etc.)

In the light of these results, along the lines of the discussion already generated throughout this article, we would underline the following points:

- The Barcelona Footprint was obtained by estimating the Catalan Footprint according to the number of inhabitants on the city's census, and completed with some local aspects. This estimate has the disadvantage of being based on the "administrative" city and of not considering the real functional area of Barcelona which at present spills beyond the administrative limits of the city.
- The Catalan Footprint was calculated with the available data, not with all the necessary data, since the data on the trade inside Spain is missing.
- The method for the calculation has weak and strong points. The following table sums up these gaps in the method of calculating the Footprint indicator in order to provide a framework for the final result obtained:

Table 6: Strong and weak points in the calculation method used to estimate the Ecological Footprint of Barcelona.

Calculations	Strong points of method	Weak points of method
Matrix for consumption of arable land, pasture, forest and sea (calculated at the Catalan level given the availability of data)	Direct translation of food consumption into hectares of arable land or pasture required according to their local or world productivity. Thus estimating directly the surface area necessary for the food consumption of a region.	Do not penalise highly productive crops for environmentally incorrect use of fertilisers, pesticides, etc. These are favoured over the use of other crops or pastures by the simple fact that the same consumption requires fewer hectares than the former, and therefore a smaller Ecological Footprint.
Matrix for consumption of energy and associated CO_2 absorption area (calculated at the Catalan level)	Considers that the consumption of energy products encompasses both energy consumption associated with goods production processes, and direct energy consumption made in housing or transport.	Does not differentiate between energy consumption associated with each sector: transport, industrial production and housing.
	Translates fossil energy consumption into hectares necessary for absorbing the CO_2 associated with its combustion, according to different emission factors.	Translates imports and exports of goods into energy consumption without differentiating between the different production processes used and the different energy sources used in the production of each good, and using factors of typical processes of production.
	Includes consumption of nuclear produced electrical energy even though emissions of CO_2 associated with its production are few.	Combines nuclear energy with fossil energy without considering other impacts translatable into units of surface area.
	Excludes non internal consumption of energy (associated with the export of goods which are consumed in other regions).	Subtraction of exports paradoxically mean that one region may have a small Footprint producing with low-efficiency energy processes and exporting these products, while importing products manufactured with lower energy content.
Estimation of city Footprint according to number of inhabitants	With the two preceding matrixes calculated for Catalunya, one obtains the hectares of arable land, pasture, forest, sea and CO_2 absorption area necessary per inhabitant of Catalunya.	The Barcelona Footprint is estimated from the number of inhabitants of the city. The two main disadvantages are 1. No differentiation between an inhabitant of Barcelona and one of the rest of Catalunya. 2. The city has more inhabitants than those strictly on the census.
Hectares of built land	To obtain the final result the built hectares (per inhabitant) of the region are added to the hectares of arable land, pasture, forest, sea and CO_2 absorption area needed per inhabitant of Catalunya	In general has little importance in the context of the rest of areas forming the Footprint. Does not differentiate between a scattered or concentrated urbanisation.
Inclusion of other aspects of the Footprint: 1. Hectares necessary for absorption of waste. 2. Hectares associated with water consumption.	1. Includes CO_2 as only output of the region considered. 2. Not included in the calculations so as not to cause double accounting. At the same time the drainage basins perform other ecological functions (forest, pastures, etc.)	1. Does not include the hectares necessary for treating the waste generated by the region under consideration. In city-level calculations this is an important gap. 2. Should include whether the region uses large reservoirs or imports water from other regions with high-energy costs.

Individual results	The Footprint expressed as hectares necessary per person and year is the most appropriate when comparing with the Footprints of other regions.	
Final results as number of times the extension of the region.	This is the most widely used way of expressing the Footprint of a region. Has the advantage of being easy to understand and sums up all the preceding calculations in one piece of data	With this way of expressing the Footprint, the regions with higher population densities are penalised. Concentrated cities appear to have a much larger Footprint than more scattered ones with the same individual Footprint.

Source: Elaborated by authors, 1998

Final thoughts

Global Footprint and Local Action
The local authorities, in this case Barcelona City Council, have an extremely important role to play in the implementation of environmental policies in their territories. The extent of the territory, its spatial location (coastal, good communications...) and the manner in which the population is settled (concentrated, scattered) condition policy and local management. Barcelona's population density rules out possibilities for surface expansion, a fact which conditions the options for future development.
This fact is particularly important in the analysis of the city's Ecological Footprint, but by contrast, we are confronted with an indicator of still too global nature. In spite of attempts to apply it at the local level, the method used thus far is for larger areas.
The Ecological Footprint poses many problems for obtaining the data required to carry out the full calculation, and even at the Catalan level there are major gaps in information which prevent the results from fully reflecting the real situation. This means that the Footprint has to be calculated at a level which later makes it difficult to use as a tool for local action to reduce the city's impact on the environment.

Therefore, the Footprint is a good indicator of the city's global impact, but for the moment has not reached the point of being usable as a tool for local environmental action, since it has not yet been calculated with specific data for the city.

Individual Footprint and Municipal Extent
In the Ecological Footprint Indicator two factors basically have an influence:
- The consumption of the inhabitants in the area under consideration.
- The extent of the area.

The examination of predecessors in the calculation of regional Ecological Footprints, despite problems of comparability between the different calculations, shows the following:

I. There are small differences between the individual Footprints for different cities or regions. For example, the following Footprints are obtained: Santiago de Chile (2,6 hectares/inhabitant), Vancouver (4,3 hectares/inhabitant), London (2,8 hectares/inhabitant), Munich (3,5 hectares/inhabitant), Helsinki (2,6-3,5 hectares/inhabitant).

II. There are great differences between the Footprints for different regions in terms of comparison of the extent of the city. The above studies give Santiago de Chile (16 times the extent of the region), Vancouver (19 times the extent of the region), London (125 times the extent of the region), Munich (145 times the extent of the region).

It follows therefore that if the city or region is scattered, its Footprint (which is understood to mean a number of times the extent of the region) is smaller than if the city is compact, taking the same individual Footprint, that is to say, the same consumption and associated impact. Discussion of whether the compact city has a larger or smaller impact than the city spread out over its territory is beyond the scope of this article, but what should be mentioned here is that as calculated, the Footprint increases the more compact a region is in density of inhabitants.

Therefore, when comparing the Footprints for different cities of the world, the indicator per capita should be considered, that is, the Ecological Footprint expressed in hectares per person. Otherwise, it is impossible to distinguish which part of the Footprint is due to higher or lower consumption and which part is associated with the extent of the region.

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Combined economic and environmental accounting

Optimal policy for materials flows: an integrated modelling approach

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Abstract
We use Koopmans' Activity Analysis approach to specify seven production activities in terms of materials flows. The production relations satisfy mass balance and are unidirectional, in accordance with the Entropy Law. The production relations are expressed in input-output form, with one production sector (Construction) duplicated, so that we can model the use of both virgin and recycled raw materials. We consider four types of environmental damage, resulting from CO_2 emissions, spoil deposition, slag deposition, and aggregate extraction. We use a linear programming model to minimise an environmental damage function, subject to minimum required final outputs and the production technology. Results are presented for four illustrative scenarios.

Introduction
There are two thermodynamically-based aspects of material transformation that any policy-relevant model must take into account: materials balance (at the elemental level) and the irreversibility of transformations. In this paper we show that both of these necessary aspects can be embodied in an extended linear (input-output) modelling framework, drawing on Koopmans' Activity Analysis approach. This framework also allows policy-relevant scenario analysis, using linear programming.

We follow the usual input-output approach, by representing a hypothetical model economy as consisting of a number of sectors, interlinked by economic intersectoral trading, with corresponding material flows. We then represent the production processes as a set of linear material transformations, such that the entire history of each material, from extraction to final disposal to the environment, can be followed in detail. In particular, we wish to examine the economy-wide consequences of substituting virgin extracted material with recycled material.
The model we present is structured as follows. We specify a number of quasi-realistic production processes, with their corresponding input-output coefficients. These include alternative technologies for using virgin or recycled materials. This then enables us to construct a corresponding physical input-output table, the accounting identities of which are used, in conjunction with the thermodynamic principles, as the constraints for a linear programming model. The objective for the LP policy analysis is the minimisation of total weighted environmental emissions, for which some simple illustrative results are presented.
The model described in this paper is so far for illustrative purposes only. We intend to apply this model to real-world materials processing for the case of the UK, using empirical data.

The Model
We construct an input-output table, representing materials flows, using Koopmans' Activity Analysis approach (Koopmans 1951). Our model uses seven activities, all with multiple inputs and multiple outputs.

In our model, we distinguish between two categories of inputs and two categories of outputs. These are:

Natural Inputs:	Coal Bearing Material (consisting of Coal and Spoil)
	Iron Bearing Material (consisting of Iron Ore and Spoil)
	Aggregate Bearing Material (consisting of Aggregate and Spoil)
	Oxygen
Social Inputs:	Labour, Capital
Principal products:	Coal, Iron Ore, Iron, Aggregate, Construction
Secondary products:	Spoil, Slag, CO_2

All quantities are measured in physical units (e.g. tonnes), except for labour and capital use, which are in their own units. The symbol '⊕' represents 'combination with', and the symbol '→' represents 'transformed into'.

In our model we use the following seven activities:

1. Coal Extraction; 2. Iron Ore Extraction; 3. Iron Making; 4. Aggregate Extraction; 5. Aggregate from Slag; 6. Construction 1; 7. Construction 2.

We note that there are two possible ways of producing aggregate material, for use in construction. Either it can be extracted as virgin raw material (Activity 4) or we can manufacture it (Activity 5), using the by-product slag from Iron Making (Activity 3).

The two types of aggregate are used respectively by Construction 1 (Activity 6) and Construction 2 (Activity 7), which are otherwise identical in their inputs and outputs. This differentiation for the construction sector enables us to model the choice between the use of virgin or recycled materials. This choice has consequences not only for the amount of net slag produced, but for other environmental variables also, as we shall indicate below.

In detail, the seven production activities are as follows:

1. Coal Extraction
2 Coal Bearing Material ⊕ 0.05 Coal ⊕ 0.13 Oxygen ⊕ 0.4 Labour ⊕ 25 Capital Use
→1 Coal ⊕ 0.18 CO_2 ⊕ 1 Spoil

2. Iron Ore Extraction
4 Iron Bearing Material ⊕ 0.1 Coal ⊕ 0.26 Oxygen ⊕ 0.8 Labour ⊕ 50 Capital Use
→1 Iron Ore ⊕ 0.36 CO_2 ⊕ 3 Spoil

3. Iron Making
4.43 Iron Ore ⊕ 5.0 Coal ⊕ 12.91 Oxygen ⊕ 0.2 Labour ⊕ 70 Capital Use
→1 Iron ⊕ 18.34 CO_2 ⊕ 3 Slag

4. Aggregate Extraction
Aggregate Bearing Material ⊕ 0.025 Coal ⊕ 0.07 Oxygen ⊕ 0.22 Labour ⊕ 15 Capital Use
→1 Aggregate 1 ⊕ 0.095 CO_2 ⊕ 0.1 Spoil

5.Aggregate from Slag
1 Slag ⊕ 0.05 Coal ⊕ 0.13 Oxygen ⊕ 0.8 Labour ⊕ 18 Capital Use →1 Aggregate 2 ⊕ 0.18 CO_2

6. Construction 1
0.05 Iron ⊕ 0.95 Aggregate 1 ⊕ 0.05 Coal ⊕ 0.13 Oxygen ⊕ 0.5 Labour ⊕ 16 Capital Use
→1 Construction ⊕ 0.18 CO_2

7. Construction 2
0.05 Iron ⊕ 0.95 Aggregate 2 ⊕ 0.05 Coal ⊕ 0.13 Oxygen ⊕ 0.5 Labour ⊕ 16 Capital Use
→1 Construction ⊕ 0.18 CO_2

Representation in Input-Output Form

We can represent the activities in input-output form, treating each activity as corresponding to a productive sector, with its corresponding column of input coefficients, relating inputs to one unit of output for the corresponding sector. Clearly, the coefficients on the left-hand side for each activity described above are these input coefficients. (For an extensive discussion of environmental input-output models, see Proops et al. (1993)).

Conventional input-output analysis identifies only one product for each sector. However, an essential feature of the activities identified above is that they all produce more than one output. This feature is handled by identifying as primary inputs the requirements for disposal facilities for outputs which have no commercial value. Thus the 'secondary' outputs from the sectors appear not as 'output' columns, but rather as 'input' rows. Using this approach, we construct the input-output coefficients matrix in Table 1.

The final three rows in the input-output table enable us to calculate the environmental impact, in terms of CO_2, Spoil and Slag, of the production of any output mix from the seven sectors. Before moving on to the scenario analysis, we need first to introduce a little input-output theory.

In input-output analysis we distinguish between three types of output. First, there is output to Final Demand. This is the part of production which leaves the economic system, to meet the demands of consumers and investors. Also produced is output which goes immediately to other productive sectors, to act as their inputs (e.g. in the above table, iron ore is an input to iron making). These constitute Intermediate Demand. Finally, the sum of Final Demand and Intermediate Demand is known as Total Output.

Table 1: Input-Output Coefficients Matrix

		1	**2**	**3**	**4**	**5**	**6**	**7**
	Sectors	Coal	Iron Extraction	Iron Making	Aggregate 1	Aggregate 2	Construction 1	Construction 2
1	Coal	0.05	0.1	5	0.025	0.05	0.05	0.05
2	Iron extraction	0	0	4.43	0	0	0	0
3	Iron	0	0	0	0	0	0.05	0.05
4	Aggregate 1	0	0	0	0	0	0.95	0
5	Aggregate 2	0	0	0	0	0	0	0.95
6	Construction 1	0	0	0	0	0	0	0
7	Construction 2	0	0	0	0	0	0	0
Value Added	Coal Bearing	2	0	0	0	0	0	0
	Iron Bearing	0	4	0	0	0	0	0
	Agg. Bearing	0	0	0	1.1	0	0	0
	Oxygen	0.13	0.27	13.33	0.07	0.13	0.13	0.13
	Labour	0.4	0.8	0.2	0.22	0.8	0.5	0.5
	Capital	25	50	70	15	18	16	16
Other Outputs	CO_2 Disposal	0.18	0.37	18.33	0.09	0.18	0.18	0.18
	Spoil Disposal	1	3	0	0.1	0	0	0
	Slag Disposal	0	0	3	0	0	0	0

If we assume that the inputs to each sector (or activity) are proportional to the outputs from it (as assumed in Activity Analysis), then we can represent the input-output model in matrix form. If we represent the matrix of coefficients as **A**, the vector of final demands as **y**, and the vector of total outputs as x, then we can write:

$$\mathbf{Ax + y = x}. \quad (1)$$

Here Ax is the vector of intermediate demand, so the above equation is simply stating:

Intermediate Demand + Final Demand = Total Output.

Reorganising equation (1), using the unit matrix **I**, we obtain:

$$(\mathbf{I-A})\mathbf{x = y} \quad (2)$$

If we can find the inverse of (**I-A**), writing this as $(\mathbf{I-A})^{-1}$, we can represent total output in terms of final demand, as:

$$\mathbf{x} = (\mathbf{I-A})^{-1}\mathbf{y} \qquad (3)$$

In the scenario analysis below, our strategy will be to specify a required vector of final demand. This in turn, through equation (3), leads to the identification of the required total outputs, and the corresponding environmental emissions of the three sorts mentioned above.

Scenario Analysis with Optimisation

We now use our materials input-output model as the basis for an optimisation exercise. We define a linear objective function, in terms of environmental impacts. We include four environmental damage variables;

- CO_2 emissions
- Total Spoil generated
- Net Slag generated
- Total Aggregate extraction

The constraints on the model are:

- Specified outputs of final products (i.e. coal, iron and (total) construction)
- A maximum labour availability (capital is unconstrained)
- The input-output coefficients are used to construct linear inequality production constraints

Four hypothetical scenarios are modelled, in each of which the objective is to minimise the impact of one of the four forms of environmental damage. The main scope for variation in the pattern of productive activity lies in the possibility of substituting recycled for virgin aggregate in the Construction sectors. While the total requirement for final output of the Construction sectors is specified, the mix between the two types can vary (subject to non-negativity of output). Although the direct environmental impacts of the two Construction sectors are the same, the indirect effects are different, because of the different technologies for aggregate production upon which they draw.

In Table 2 we show the results with respect to CO_2. We see that all of the construction is from the first sector, using aggregate as material input. This is intuitively reasonable, as Construction 1 has a much lower indirect level of CO_2 emissions per unit of output than Construction 2, because aggregate extraction is less coal intensive that slag recycling. As a consequence, there is no slag recycling, and all of the slag produced by Iron Smelting remains as Net Slag.

Table 2: Scenario 1 - Minimise CO_2

Sector	y min	y actual	x	Environmental Damage	Quantity
Coal	20	20.0	57.0	CO_2	135.6
Iron Ore Extraction	-	0.0	26.6	Spoil	138.6
Iron Smelting	5	5.0	6.0	Net Slag	18.0
Aggregate Extraction	-	0.0	19.0	Aggregate Extraction	19.0
Slag Recycling	-	0.0	0.0		
Construction 1 (Agg.)	-	20.0	20.0		
Construction 2 (Slag)	-	0.0	0.0		
Construction (Total)	20	20	20.0		

In Table 3 we show the result of minimising spoil. In this case, most construction is by sector 2, which uses recycled slag. This is because the generation of slag is already required to meet the (direct and indirect) demand for iron. Extracting aggregate would generate extra (avoidable) spoil. As a consequence, only a small amount of construction is carried out by Construction 1, because even when all slag is recycled, the target for Total Construction is not met by Construction 2 alone.

Table 3: Scenario 2 - Minimise Total Spoil

Sector	y min	y actual	X	Environmental Damage	Quantity
Coal	20	20.0	57.5	CO_2	137.3
Iron Ore Extraction	-	0.0	26.6	Spoil	137.3
Iron Smelting	5	5.0	6.0	Net Slag	0.0
Aggregate Extraction	-	0.0	1.0	Aggregate Extraction	1.0
Slag Recycling	-	0.0	18.0		
Construction 1 (Agg.)	-	1.1	1.1		
Construction 2 (Slag)	-	18.9	18.9		
Construction (Total)	20	20.0	20.0		

Table 4 shows the results from minimising Net Slag. These are identical to the results for Scenario 2, as in that scenario Net Slag was already zero. The intuition for this scenario is that Construction 2 will operate until the slag from Iron Smelting is all used, and only then will Construction 1 be used.

Table 4: Scenario 3 - Minimise Net Slag

Sector	y min	y actual	x	Environmental Damage	Quantity
Coal	20	20.0	57.5	CO_2	137.3
Iron Ore Extraction	-	0.0	26.6	Spoil	137.3
Iron Smelting	5	5.0	6.0	Net Slag	0.0
Aggregate Extraction	-	0.0	1.0	Aggregate Extraction	1.0
Slag Recycling	-	0.0	18.0		
Construction 1 (Agg.)	-	1.1	1.1		
Construction 2 (Slag)	-	18.9	18.9		
Construction (Total)	20	20.0	20.0		

In Table 5 we show the outcome from minimising Aggregate Extraction. In this case only Construction 2 operates, allowing total aggregate extraction to be zero. This is achieved by actually requiring the production of iron for final demand to he higher than the minimum required. This produces sufficient extra slag to ensure that all 20 units of construction can be produced by Construction 2. This rather unrealistic result derives from our ignoring all other costs than that reflected in the objective function.

Table 5: Scenario 4 - Minimise Aggregate Extraction

Sector	y min	y actual	x	Environmental Damage	Quantity
Coal	20	20.0	59.4	CO_2	144.4
Iron Ore Extraction	-	0.0	28.1	Spoil	143.6
Iron Smelting	5	5.3	6.3	Net Slag	0.0
Aggregate Extraction	-	0.0	0.0	Aggregate Extraction	0.0
Slag Recycling	-	0.0	19.0		
Construction 1 (Agg.)	-	0.0	0.0		
Construction 2 (Slag)	-	20.0	20.0		
Construction (Total)	20	20.0	20.0		

Further Research

As mentioned above, the current version of the model is for illustrative purposes only. We intend to extend the model in the following ways:
We shall increase the numbers of sectors and materials in line with current UK input-output practice.

We intend to use materials coefficients derived from actual industry processes.
Prices will be introduced, so that the optimisation can be in term of cost minimisation. This will permit the exploration of the use of financial incentives to encourage recycling, under a range of fiscal regimes (Symons et al. 1994)

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OMEN - An Operating Matrix for material interrelations between the Economy and Nature. How to make material balances consistent.

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Introduction

One of the major methodological challenges in material flow accounting is the complete balancing of a system. How can one get comprehensive and comparable material input/output balances from incomplete, insufficient and diverse statistical data? With the OMEN table we present a method of material balancing that aims at an integration on various levels. One is the integration of input accounting and output accounting, which can connect strategies of resource efficiency to emission and waste management. Another is the connection between economic and physical accounting, leading to strategies of delinking. Finally this approach aims at flexible sectoral disaggregation, leading to different benchmark indicators. The OMEN matrix substantially supports these aims.

Methodologically this approach takes up a discussion about economic input/output analyses adopted for environmental purposes (see Daly 1968, Ayres and Knees 1969, 1970). More recent attempts focus on introducing physical Input/Output analyses to the MFA community (Katterl and Kratena 1990, Fleissner 1993, Schandl and Zangerl-Weisz 1997, Stahmer, Kuhn and Braun 1997, WI).

OMEN is a modification of standard economic input/output analysis, working solely with physical data and considering the law of conservation of mass. OMEN is a highly aggregated input/output matrix which should provide a helpful tool to researchers, who are on the way to establishing a national MFA and who have an interest in connecting the input side to the output side. It takes into consideration that data for the output side are less available than for the input side. Using OMEN calculation means making use of the available data, carrying out consistency checks and estimating any remaining data gaps.

Conventions for physical accounting

Material balances estimate the sum total of all materials that cross the border of a given system per time period (usually per annum). Material balances have to fulfil the law of conservation of mass.

National material balances have two boundaries. One is the boundary between the national economy and the domestic natural environment. A clear definition of this boundary is crucial for a consistent estimation, but difficult to argue. Our definition follows the concept of „Society's Metabolism" which regards artefacts, the human population and bred animals as material parts of society (for a more detailed discussion see Fischer-Kowalski 1998). The second is the boundary to other national economies. Here we can build on the definition of standard economic statistics.

According to the above definition bred plants, which are cultivated for society's purposes, are not considered as a material component of the economy. The main argument for these definitions of accounting is that physical and monetary economic accounts have to be communicable. That means the boundaries should not be overextended. The definition of the border also depends on data availability and the extent of plausible estimations available. Of course these two arguments are strongly interrelated. The closer a material flow is to the border, the further away it is from socio-economical thinking, and as a result the data available will be less reliable (e.g. overburden, erosion and translocation).

General structure of the OMEN - matrix

An OMEN table as well as any OMEN subtable consists of three quadrants, the input quadrant (left below), the processing quadrant (left above) and the output quadrant (right above).[35] All input flows within the table are shown vertically along the columns from the bottom up whereas all output flows are shown horizontally along the rows from left to right.

Table 1: The general structure of an OMEN table

	Primary production	Industry	Services, households	stock changes		Export	Emissions	Deliberate disposals	
Primary production	x_{11}	x_{12}	x_{13}	x_{14}	domestic goods (Σ $x_{12}+x_{13}+x_{14}$)	o_{11}	o_{12}	o_{13}	output (Σ o_{11} to o_{13})
Industry	x_{21}	x_{22}	x_{23}	x_{24}	domestic goods (Σ $x_{21}+x_{23}+x_{24}$)	o_{21}	o_{22}	o_{23}	output (Σ o_{21} to o_{23})
Services, households	x_{31}	x_{32}	x_{33}	x_{34}	domestic goods (Σ $x_{31}+x_{32}+x_{34}$)	o_{31}	o_{32}	o_{33}	output (Σ o_{31} to o_{33})
stock changes	x_{41}	x_{42}	x_{43}	x_{44}	**stock outputs** (Σ $x_{11}+x_{42}+x_{43}$)	o_{41}	o_{42}	o_{43}	output (Σ o_{41} to o_{43})
	secondary input (Σ $x_{21}+x_{31}+x_{41}$)	secondary input (Σ $x_{12}+x_{32}+x_{42}$)	secondary input (Σ $x_{13}+x_{23}+x_{43}$)	**stock inputs** (Σ $x_{14}+x_{24}+x_{34}$)	total Σ processing matrix (Σ $x_{11}+x_{12}+ ... +x_{44}$)	exports (Σ o_{11} to o_{41})	emissions (Σ o_{12} to o_{42})	deliberate dis-posals (Σ o_{13} to o_{43})	**direct output**
Domestic Extraction	i_{11}	i_{12}	i_{13}	i_{14}	domestic extraction (Σ i_{11} to i_{14})				
Water	i_{21}	i_{22}	i_{23}	i_{24}	water (Σ i_{21} to i_{24})				
Air	i_{31}	i_{32}	i_{33}	i_{34}	air (Σ $i_{31}$to i_{34})				
Imports	i_{41}	i_{42}	i_{43}	i_{44}	imports (Σ $i_{41}$to i_{44})				
	primary input (Σ i_{11} to i_{41})	primary input (Σ i_{12} to i_{42})	primary input (Σ i_{13} to i_{43})	primary input (Σ i_{14} to i_{44})	**direct input**				

Source: iff-Social Ecology

The input quadrant contains all inputs into the system. We call these inputs primary inputs because they cross the border of the system to be balanced. For an OMEN calculation on the national level we differentiate between four input categories. Domestic extraction of resources (raw materials, water and air) and imports (inputs from other economies). The sum total of the primary inputs is the direct input.

The processing quadrant contains all material flows within the system. Rows and columns are equally differentiated into three highly aggregated economic sectors, the primary production sector (agriculture and mining), the industry sector (including construction) and the service sector (including public and private households). These are the sectors where the sectoral input has to equal the sectoral output. In addition stock changes are treated as a separate sector. Here stock inputs do not have to equal stock outputs.

The crossline in the processing quadrant contains intrasectoral flows, that means flows that are transferred between actors within the same sector. Sectoral inputs which are transferred within the economic system by other sectors of the same economy are defined as secondary inputs. These secondary inputs make up the total secondary input of a sector (intrasectoral flows are not included). Primary inputs and secondary inputs make up the total input of a sector.

Analogous, output flows that go from one sector within the economy to other sectors of the same economy can be aggregated to domestic goods produced in one sector.
The output quadrant contains all flows that go out of the system to be balanced. We distinguish between exports, emissions (gaseous, liquid or solid) and deliberate disposals

35 Additional quadrants which allow to estimate e.g. flows within nature, flows between other economies, ecological rucksacks, labour, etc. are possible.

(i.e. fertilisers, seeds, pesticides). All flows of the output quadrant can be summed up to make the direct output.

For the total consistency check the calculation of the OMEN table has to fulfil the equation:

direct input = direct output + stock inputs – stock outputs

For a sectoral consistency check, total sectoral input (i.e. primary input plus secondary input) has to equal total sectoral output (i.e. domestic goods plus output into nature and into other economies). This sectoral equation rule is true for the economic sectors within the OMEN table but is not be valid for stock changes.

SubOMENS and aggregation to a national balance

A highly aggregated material balance of a national economy is still too complex to be calculated in one step. For this reason we divided the material flows, into five groups and calculated the balances separately for each group, using subOMENs. SubOMENs have to be structured in a way that allows for aggregation to a national balance by summing up. The difficulty with this approach is, that both double countings must be avoided and completeness must be given[36].

We defined subOMENs according to five major groups of input materials, namely water , air, biomass, fossils and minerals. A consequence of this definition is that a substance logic is introduced into the structure of OMEN, which generates some consistency problems. We want to illustrate this by using the subOMEN for fossils as an example (see figure 2).
The input quadrant contains the gateways from which fossil materials enter the economy. These gateways are domestic extraction and imports. Difficulties emerge if the materials are not raw materials but half finished or finished products. The later contain usually a mix of different raw materials and cannot easily be related to either fossils, minerals or biomass. On the input side this is the case for imports. We finally decided to integrate imported products according to their main components into the different subOMENs.

Within the economy substances get more and more mixed up as they advance along the production chain. This results in overlaps between the different subOMENs, which have to be considered when summing up.

Most important in any production chain are incorporations or losses of water and air. For that reason water and air are part of the input quadrant of all subOMENs[37].The processing quadrant of the fossil subOMEN is structured differently to the general structure presented in figure 1. We first structured the processing quadrant according to the substance logic, that is along the production chain. That means the sectors primary production, industry and final demand are not defined as economic sectors, but as actors along the production chain of fossils. Primary production is therefore the economic actor, who extracts fossils from the natural environment, industry is the actor, who processes fossils and transform them into other goods and final demand refers to all actors, which transform fossils into wastes and emissions, mostly by burning them. That means for example the energetic use of fossils by the industry is in our example counted in final demand. This explains also why there are no processing flows from or into primary production.

This way of structuring produces serious problems when subOMENs are summed up, because the definition of the three sectors of the processing quadrant are not consistent to each other. We consider to change the structure of the processing quadrant according to the scheme presented in figure 1.

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36 Of course double counting is a general problem of any MFA. The decision for subOMENs adds another double counting problem.

37 Thus they represent water and air, that are part of products or processes within the economy, e.g. oxygen used for burning fossils, or water content of harvested biomass.

Table 2: SubOMEN Fossils, Austria 1992 [in Mio tons]

	Primary Production	Industry	Final demand	Stock changes	**domestic goods**	Exports	Emissions	Deliberate Disposals	primary output	**sectoral Output**
Primary Production		3,1	0,1		**3,2**	0,01			**0,01**	**3,2**
Industry		7,3	9,0	0,6	**9,5**	2,4	12,2		**14,7**	**24,2**
Final demand				1,3	**1,3**	1,0	16,7		**17,8**	**19,1**
Stock changes		0,7	0,2		**1,0**				**0,0**	**1,0**
Secondary Input	0,0	3,8	9,3	1,9	**22,3**	**3,5**	**29,0**	**0,0**	**32,4**	
Domestic Extraction	3,2				**3,2**					**33,4**
water and air		6,2			**6,2**					
Imports		14,1	9,8		**23,9**					
Primary input	**3,2**	**20,4**	**9,8**	**0,0**	**33,3**					
Sectoral Input	**3,2**	**24,2**	**19,1**	**1,9**						

Source: own calculation based on data from the Austrian Federal Statistical Office, foreign trade, energy, operational and waste statistics

However, the problems associated with the consistent distinction between the five subtables would not be solved totally. At the moment we are also considering an alternative mode of disaggregation into subOMENs, which is more compatible to standard economic input/output tables. The basic idea is to distinguish not according to groups of raw materials but rather groups of materials, that represent different stages of the production chain. This could lead to subOMENs for raw materials, half finished goods, products and wastes. A similar structure was realised in the German physical input-output model PIOT (Kuhn et al. 1997).

Indicators obtainable from OMEN calculation

One result from OMEN calculation is that various indicators, that describe the scale of the economy, can be estimated. They therefore represent a material reflection of the GDP. These national material flow indicators are commonly seen as a main part of the construction of an environmental satellite system to the SNA (Uno and Bartelmus 1998). From the OMEN calculation we can obtain standard material flow indicators such as the Direct Material Input. Present material flow studies describe efficiency by calculating the ratio between material input and GDP (see Adriaanse et al. 1997). OMEN allows for the calculation of a material to material efficiency indicator.

According to this we have the standard indicators like direct material input (DMI)[38] and domestic material consumption (DMC)[39]. Whereas DMI can be seen as the material basis of the production system, the DMC represents the characteristic material requirement of a society. This gives a general impression of a specific way of life. Both indicators can directly be obtained from the OMEN-table.

The ratio of these input indicators to GDP makes it possible to characterise the relationship between resource use and economic activity, thus providing a first measure of eco-efficiency.

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38 The direct material input consists of the sum of the primary inputs to all sectors of the matrix. It is therefore the cross-sum of the input quadrant.

39 The domestic material consumption is calculated as direct material input minus exports (Fischer-Kowalski et al 1997).

This DMI/GDP ratio can be expressed mathematically as an environmental kuznets curve that provides information of delinking processes within a national economy. Such delinking could in the long run, lead to a dematerialization of the industrial mode of production and consumption (De Bruyn and Opschoor 1997). For a more detailed discussion about delinking effects within industrial economies see Hüttler et al. in this volume.

Using the OMEN matrix we can calculate different kinds of efficiency indicators, both on the national and the sectoral level, using the information gathered from the processing matrix. Efficiency on the national level can be interpreted as (1) ratio of direct material input to the total amount of economically processed material (2) as the proportion of recycled flows of the total sum of secondary inputs or (3) as the proportion of recycled flows of direct material input.

On the sectoral level efficiency is described as (1) the proportion of products of sectoral inputs and (2) as the ratio products to emissions. These indicators focus on the capacity of a sector to use his material inputs in an efficient way.

Conclusions

The OMEN calculation provides a method for material balancing on a highly aggregated level. It incorporates a procedure for input/output consistency checks. The already known examples of national MFA generally concentrate on the input side (Fischer-Kowalski and Hüttler 1998). OMEN helps to calculate the outputs and considers processing within the economy, which normally remains a black box. This enables us to focus on sectoral information which is indispensable for policy relevant sustainability indicators. Furthermore the information within the OMEN table can be easily transferred into Material Flow Diagrams, that improve the public communication of sustainability issues. Finally, the OMEN table eventually allows for a quick estimation of various MFA based indicators.

However there are still open questions. First, regarding the definition of the sectors within the processing quadrant we have to decide, whether to aggregate data along economic criteria (primary production, industry, services) or along material criteria (primary production, processing, final demand). Secondly, for the definition of subOMENs it is not clear whether to use material categories (like water, air, biomass) or process categories (like raw materials, semi finished products, goods). These questions are interrelated and have to be solved together. Its near at hand to use the categorisation suggested in the PIOT for Germany (Kuhn et al. 1997) or within a methodological case study for the chemical industry (Schandl and Zangerl Weisz 1997).

At the moment the OMEN project is work in progress. The next step will be to calculate the output side of the Austrian economy within a research project co-ordinated by the World Resources Institute (WRI 1998) using the OMEN calculation for input output balancing. Furthermore we will try to apply OMEN for sectoral disaggregation, or for other input factors like labour and energy.

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Flux: a tool for substance flow analysis

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Introduction

This paper presents a concise description of a software tool (**FLUX**) that has been developed for the analysis of patterns of materials use (physical flows & physical stocks) in an economy and of associated patterns of environmental pollution. The research builds on a twenty year history of SFA - also known as mass balance studies and materials Flow analysis (MFA) - in the Netherlands, starting with studies of flows of phosphor, mercury and sulphur in the end of the seventies. Feenstra (1982) gives an overview of these early studies. Since then a series of researches have been made by various institutes (e.g., Anzion et al., 1980; Olsthoorn et al., 1986; Fong, 1994; Voet, 1996). Schmidt et al., (1995) and Vellinga et al., (1998) present recent reviews and contexts to SFA.

A software tool for performing SFA is useful for various reasons. Firstly, such tool can facilitate the groundwork for SFA, that is creating its empirical basis. Experience (e.g., Annema et al., 1995; Olsthoorn et al., 1986; Wernick and Ausubel, 1995; Van der Voet, 1996) shows that finding and processing of suitable statistical information for establishing values for flows and stocks is a tedious job, since sources of appropriate information vary widely in nature, and data is often not compatible and mutually consistent. A properly designed database can be helpful in managing this task. In conjunction with the database function, dedicated software can facilitate analysis of the data and modelling. A third reason is that software can facilitate the linking of SFA information to other types of models, e.g., economic models.

FLUX was developed in the context of a five year research programme - Flows and accumulation of heavy metals in the Netherlands (Guinee et al., 1999) - that was carried out by five university institutes. The programme was funded by the Dutch Science Foundation.
This paper is structured as follows. First we briefly discuss the goal and the concept, then we describe the various task that FLUX supports and, finally, we conclude.

Concept and objectives

The concept of a substance flow account

The chemical cross-section of the physical economy-environment system in some geographical area - the actual unit of analysis - is viewed as a network that comprises (*i*) nodes, (*ii*) flows of a selected chemical substance between nodes and (*iii*) stocks of that substance which are hold by the nodes. The law of mass conservation must hold over each node. This concept distinguishes nodes in two domains, the economic system and the ecological system. An economic node refers to an economic entity as they are distinguished in economics (e.g., a firm, an economic sector). Ecological nodes (or environmental nodes) refer to parts of the ecological system (e.g., atmosphere, a soil, water). The substances that 'flow' into a node are subjected to a **material transformation** in that node. In economic nodes transformation refers to chemical or physical processes that are managed by humans, in ecological nodes transformation refers to dispersion of substances, which process is governed by natural laws. This difference in the nature of the transformation constitutes the main distinction between nodes of both domains

Objectives of FLUX.

Against the background of this construction of the physical economy and its adjacent environment, FLUX addresses - within the context of the research supported by the Dutch Science Foundation (Guinee et al., 1999) supports the following tasks:

- the compiling of statistical data on the uses of materials and their chemical composition, and keeping a database for retrieval of this information;
- the description networks of nodes and flows of different substances in a consistent way and to characterise them with indicators;
- performing database functions that support analysis;
- the construction of solvable and meaningful models that represent substance flows and stocks and their development over time;
- simulation of the behaviour of the substance flow network over time for performing policy scenario analysis.

An important FLUX characteristic is that the system allows dynamic modelling, that is it can calculate future substance flow accounts. Input data for such calculations are: scenarios for the development of flows that are assumed to be drivers of the system (e.g., 'final demand' flows), and also scenarios for change in technology (technological coefficients) and the time horizon.

Performing SFA with FLUX

This section explains the workings of FLUX as it is experienced by its users. This explanation uses two figures for structuring and illustrations. Figure 1 shows the steps that are typical for an analysis of flows and stocks of a substance and that are supported by FLUX. Figure 2 shows a typical computer screen that is used by FLUX.

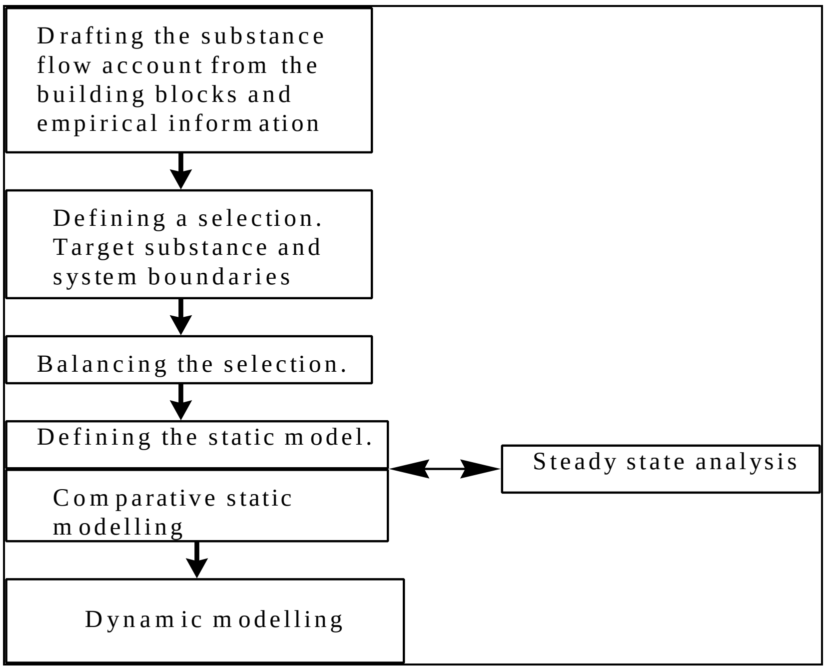

Figure 1: Steps in performing SFA that are supported by FLUX.

Creating building blocks and drafting the substance flow account

The very first step in performing an SFA with FLUX is creating the building blocks, that is the listings of (economic) sectors, (technological - environmental) processes, materials (nature and chemical composition) and substances (chemical elements) that initially is thought to be relevant to the analysis to be made. These listings can be organised according to a taxonomy. For instance - in the case of the location attribute - one can define that a city is a located in a province, which is in turn located in a region and again in some country. This structure is useful for searching the database (but searching is also possible using key words) and also for defining the boundaries of the systems to be modelled, in a next step.

Once entered these building blocks can be used for analysis of other substances or materials. At any time building blocks can be edited (deleting, rephrasing, adding and commenting on items). They constitute a separate database.

Given the building blocks a substance flow account can be constructed from whatever information that is relevant to estimating flows and stocks. Thus drafting a substance flow account is actually three step procedure: (*i*) define the nodes, (*ii)* define the materials that flow and their chemical composition and (*iii*) enter the data on flows (and stocks) into FLUX. The nodes are defined using the building blocks mentioned above. Figure 2 shows two nodes (N19 - a source node - and N38 a destination node).

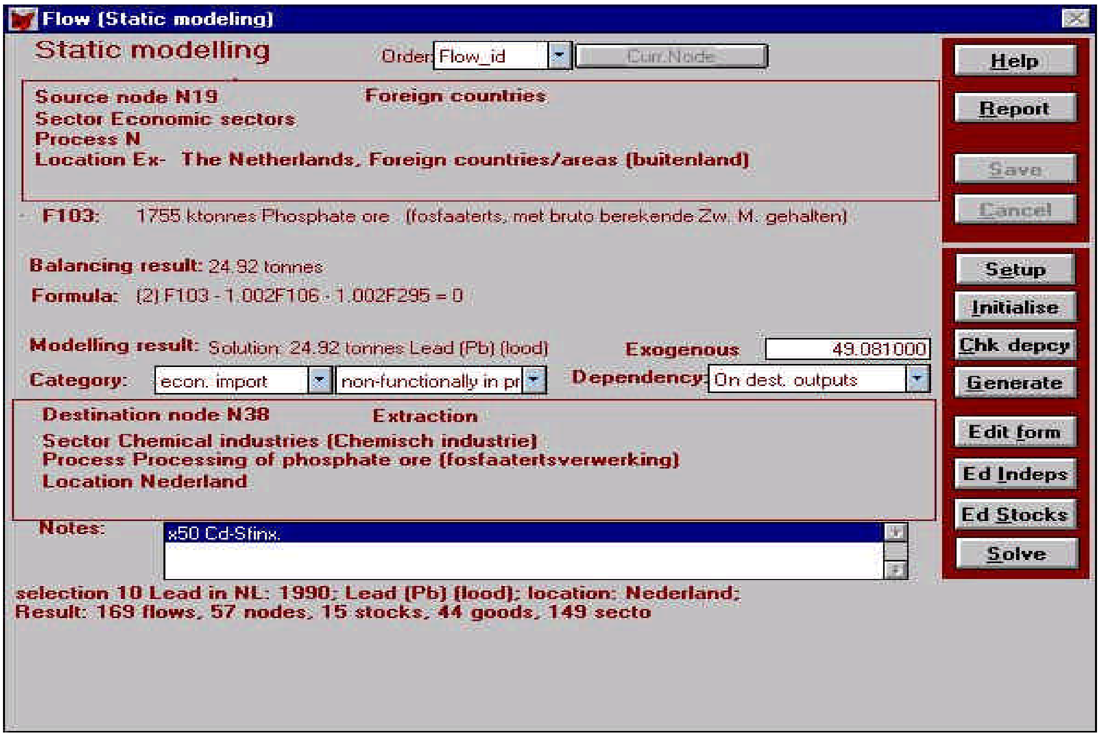

Figure 3: The FLUX interface for comparative static modelling.

The attributes of node N38 are the chemical industry (economic attribute), Processing of phosphate ore (technological attribute, fairly general) and the Netherlands, indicating that this node refers to Dutch industries. The building blocks of N19 - the node that represents all economies beyond the Dutch borders - are self explaining. In the Netherlands there are a number of different industries that process phosphate using different technologies. The description of the process of Node N38 is rather obvious. This is due to lack of data on the amounts of ore processed in these different plants - different processes -. Therefore we were forced to identify and define only a single node. When more data would be available, N38 could be split up and more detailed information on type of processes and firm names and location could be added.

Defining a selection

The second step is to select a target substance and cut the corresponding chemical cross-section of the data and to define the boundaries (which nodes to include or exclude). This is called the selection step. Its result is an account of the flows and stocks for the selected target substance (lead in figure 2). Actually, it is in this step that FLUX creates a flow account at the substance level, by recalculating flows while taking account of the chemical composition of the materials. For instance, the flow of iron ore into the node “Primary metals industry” is recalculated into a flow of zinc to this node, using the data on the zinc content of iron ore. In other words, FLUX selects a substance flow account from the materials flow account. The lines in the bottom of the screen (figure 2) shows the properties (e.g., numbers of flows, stocks and nodes) of the lead flow account that results from making the lead selection.

Balancing the selection

It is unlikely that a SFA statistician will succeed in finding data that allows to draw up an account that fully complies with the law of mass conservation. Therefore, we developed procedure for balancing the entire network. This procedure reduces mass unbalances simultaneously over all nodes, using the classes of uncertainties in flows that have been attributed to the flow data (each class of uncertainty represents values for uncertainties). The balancing problem is identified as a so-called discrete optimisation problem. FLUX solves this problem by iteratively minimising:

$$P_f = f\sum_p \left(I_p - O_p\right)^2 + \sum_i g_i \left(w_{in} - w_{io}\right)^2$$

Where

P_f = overall measure for the 'balance of the network'

f = an adjustable factor that controls the balancing procedure

p = index for nodes

I = Input

O = output

g_i = a weighting factor that is derived from the uncertainty in flow i. Under large uncertainty g_i (adjustable) will relatively small.

$\left(w_{in} - w_{io}\right)$ = the adaptation of flow i. w_{io} is the old value, w_{in} is the new value

Static modelling

The fourth step is the specification of the relations between the flow and stocks of the substances. The resulting model is a mathematical representation of the structure of substance 'stocks and flow' account for the reference year, taking account of the mutual dependencies of the flows. The principal assumption of the model is that flows depend linearly on other flows or on stocks. Flows may be proportional to:

- the total output of its destination node (by definition a flow has a source node (origin) and a destination node);
- the total input of its source node;
- the stock that constitutes its source;
- to a balance item in a mass balance over a node (e.g., the use of a virgin feedstock depends on the total use of feedstock minus the available amount of secondary feedstock).

Under the entry Formula, Figure 2 shows how F103 depends on two other flows (F106 - sales of (lead in) fertiliser; F295 discharge of lead into surface water). The formula is actually the mass balance for lead over the node (N38), and derived from the flows that result after the balancing procedure and the assumption - see window "Dependency" in Figure 2 - that F103 (linearly) depends on the total output of node N38. In matrix notation these equations can be written as:

$$\mathbf{Ax=y}$$

where:

- **y** is the vector which contains the selected independent variables (F3, F11 and N4 of Figure 3);
- **x** is de vector of dependent variables (flows and stocks), and;
- **A** the square matrix of coefficients.

Entering the correct dependencies (see figure 2) is crucial, since one may easily specify a model which is not solvable. Using the button "Chk depcy" (see column of buttons on the right side of figure 2) results in an evaluation of the solvability of the specified model.

FLUX asks the user to indicate dependencies of the various flows, and to indicate those flows that are considered to be the independent variables. FLUX then creates - button "generate" the model (**A** and $\mathbf{A^{-1}}$) after checking the consistencies of the indicated dependencies in order have the basis for a solvable model. Next, given a vector **y** (the independent variables), the flows and stocks (**x)** are calculated according to $\mathbf{A^{-1}.y} = \mathbf{x}$. FLUX allows to change **A** before carrying out calculations (under the button "Ed form", figure 2). In such way it is possible to examine the effects of technological change as represented by changed coefficients.

Figure 3 shows an example. In this example F3 and N4 are the independent variables (vector **y**). Pane A gives the intitial "empirical" flows, while pane B shows what happens *ceteris* *paribus* to the flows when F3 increases from 17 to 20. Pane C shows the results when the assumption is that the stock of N4 increase from 21 to 30, other independent variables not changing. Finally, Pane D shows that it is possible to model the technological change: the model as it is used in the two other examples assumes that the F5/F4 ratio (to interpret as a recycling rate) is 70%. By changing the coefficients (matrix **A**) of the model (under the Ed form button of figure 2) we can change this ratio to 90%. The result is shown in Pane D.

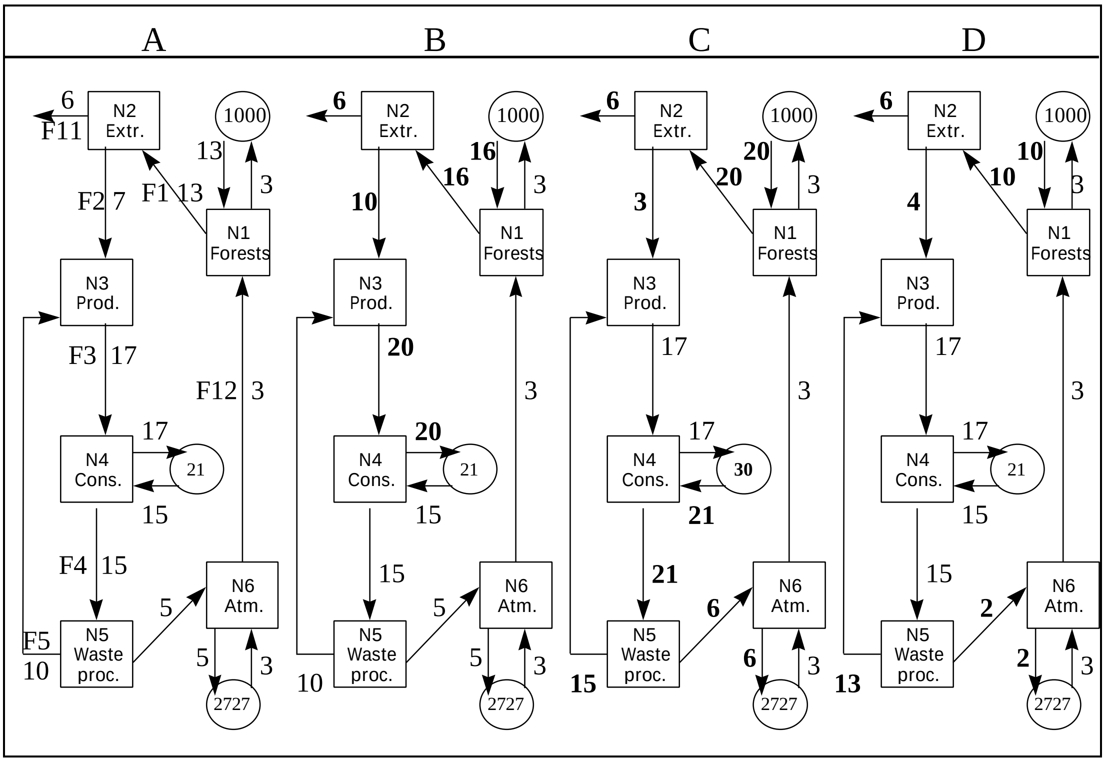

Figure 3. Examples of comparative static modelling. See text.

Dynamic modelling

FLUX allows also dynamic modelling, that is explicitly taking account of time and calculating in developments of flows and stocks over time paths. Inputs to the model are (*i*) scenarios (time paths) for the development of selected independent variables (**y(t)** comprising for instance a time path for the final demand for phosphate fertilisers in agriculture) and (*ii*) scenarios for the development of matrix **A**, the coefficients. The calculations are technically straightforward: for every year of the chosen scenario period FLUX calculates

$$\{A(t)\}^{-1}.y(t)=x(t+1).$$

y(t) includes all stocks. Next the stocks of **y(t+1)** are calculated from the stocks in t and the deficit/surplus of mass balance of the node at **t**. Then, the calculation is repeated until the final year of the scenario period.

Steady state modelling

Van der Voet et al. (Voet, 1996) propose a particular way of dynamic modelling: steady state modelling. Assuming no change in independent variables or parameters over time, after an infinite time a system of stocks and flows will reach a steady state when flows and stocks will not change. This situation can be calculated by reformulating the model (Guinee et al, 1999) into a single set of linear equations. A steady state gives a picture of the direction in which a stocks and flows system eventually evolves under a given 'flow regime'.

Conclusions

There is a need for software that is suited for information management, analysis and modelling. FLUX has been developed to perform these tasks in a single system. FLUX supports modelling of substance flow systems, both comparative static and dynamic. The specification of the models is supported by a network balancing procedure that facilitates the construction of substance flow accounts that better meet the condition of mass balance.
The development of FLUX is not finished, in particular with respect to the user-friendliness of FLUX, and there is room for improvement (Boelens et al., 1998). However, SFA will continue to be a complicated work, since its intention to be chemically comprehensive in its description of flows in an economy and the adjacent environment. The amount and the variety in the nature of empirical data that have to taken account of and interpreted will continue to require expertise that cannot be easily incorporated into software tools.

A model that is built with FLUX intends to comprehensively describe the flows and stocks of some substance in an area, covering both intentional and unintentional flows and stocks of that substance. Ultimately, these models should inform about future environmental risks and about approaches to address these risks. FLUX was linked to models that do such (Guinee et al., 1999, Voet et al., 1997), still future efforts to develop FLUX will be guided by this wish.

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Mixed session

CO_2 emission reduction by improved use of packaging materials

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Abstract
A large part of the global energy use and emission of CO_2 is related to the production and use of materials. More efficient use of materials is therefore likely to lead to substantial reductions in CO_2 emissions. The objective of this study is to calculate the potential and cost-efficiency of CO_2 emission reduction by means of improved management of material use of packaging in Western Europe. Many measures for improved use of packaging material are evaluated. We show that it is technically possible to reduce the CO_2 emissions related to the production and use of primary and transport packaging by about 40% and that the majority of the measures are cost effective when taking life cycle costs into account.

Introduction
Modern economies require massive amounts of fossil fuel. The combustion of fossil fuels leads to the production of carbon dioxide. The emission of carbon dioxide changes the earth energy balance, which is likely to influence the global climate. In 1997 targets and timetables were set at the third Conference-of-the-Parties in Kyoto to reduce the emission of greenhouse gases[40]. The member states of the European Union have jointly committed themselves to a reduction of 8% of the emission of the 6 most important greenhouse gases in the period 2008 - 2012 compared to the 1990-emissions [UNFCCC, 1997]. Reduction of energy consumption is considered to be one of the main opportunities to attain this objective.
A large part of the global energy consumption is related to the production and use of materials. The industrial sector, that produces materials and products, consumed 41% of total world primary energy use in 1995[41] [Price et al., 1999]. Reduction in the energy consumption associated with the production and use of materials can be achieved by energy efficiency improvement in the production route of materials and by improved management of material use.

Improving the energy efficiency of production processes has been the subject of many studies for a long time. Management of material use has had hardly any attention in the light of energy and carbon dioxide reduction. Studies on material management generally have a waste reduction perspective. The few studies that have been done on management of material flows for carbon dioxide reduction show that an integrated approach to the improvement of energy efficiency and material use can lead to more cost-effective reduction options and a larger CO_2 emission reduction potential [Worrell et al., 1995, Gielen et al., 1998].

All the materials that are used in the economy are at some point in the life-cycle discarded as waste. A large part of the municipal solid waste in Western Europe (about 40%) is related to the use of packaging [APME, 1996, OECD, 1997]. Therefore, it is useful to focus on packaging materials when studying improved material management. The production and consumption of packaging materials is good for about 4% of Western Europe's CO_2 emissions [Hekkert et al., 1998]. This share is significant enough for a focus on CO_2 emission reductions.

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[40] The greenhouse gases considered in the third Conference of the Parties are CO_2, CH_4, N_2O, HFC, PFC and SF_6
[41] Excluding refineries

The objective of our study is to calculate the potential and cost-efficiency of CO_2 emission reduction by means of improved management of material use of packaging in Western Europe[42].

Method

In Worrell et al. (1995) an approach for analysing material efficiency improvement is presented. The approach consists of four steps. First, the current consumption of material is analysed. Second, the material life cycle is broken down in individual life-cycle stages (see Figure 1). To calculate the total energy requirement of the life cycle, the energy requirements and costs of the individual life cycle stages are summed. Third, material efficiency measures as depicted in Figure 1 are defined that reduce the CO_2 emission over the packaging life cycle. Implementation of these measures leads to new life cycles. Fourth, the effect of these measures is calculated by subtracting the energy requirement of the reference life cycle by the new life cycle. We used this method to calculate the potential of CO_2 emission reduction by improved management of packaging materials[43]. To evaluate the cost-effectiveness of the investigated measures a supply curve is constructed. In For construction of supply curves, choices about the order of implementation are important because measures can influence the potential savings of each other, or even prevent the each other's application. The order of implementation is not shown in the supply curve as it shows the measures in order of cost-effectiveness; this shortcoming of the supply curve is often criticised. We will present a supply curve where the order of implementation is visible.

We have chosen to implement the individual measures in order of implementation difficulty. The reason for this choice is that the potential of 'easy to implement' options becomes visible in respect to options that are more difficult to implement. This is important knowledge because to actually reach CO_2 emission reduction, the measures leading to the technical potential as calculated in this study need to be implemented.

To determine the implementation difficulties associated with the individual options is hard because many factors influence the difficulty of implementation. These factors may be technical, social or economical. For a good insight in all these factors additional research is necessary that is beyond the scope of this study. However, we can make a first assessment of the difficulty of implementation by assuming that the most critical factor that determines the difficulty of implementation is the necessary change in the entire packaging system. This means that measures that change only a small part of the packaging system are relatively easy to implement and factors that result in changes in the whole system are more difficult to implement.

Based on the assumption stated above we cluster the improvement measures in terms of implementation difficulty. The measures with low implementation difficulty are implemented first and measures with high implementation difficulty are implemented later.

Material use for packaging in Europe

To estimate the potential of improved management of packaging material, information is needed about the current material input for packaging. In Figure 2 the material input per packaging category is stated for primary packaging and in Figure 3 the material input for transport packaging is depicted. Because many different packaging products exist with a large variety in packaging characteristics we have clustered them in several categories. To create a breakdown of the total material input for packaging in Western Europe as stated in PPI (1997), APME (1996) and dePijpere (1996) over the packaging categories we used consumption data of the packed products and made the following assumptions [EC, 1997]: We assume that all steel and aluminium cans are used to pack carbonated drinks. All non-

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[42] Western Europe is defined as the European Union (15) which includes Austria, Belgium, Denmark, France, Finland, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom plus Norway and Switzerland.

[43] To calculate the CO_2 emissions of the packaging life cycle and the life cycle costs, energy and cost data are needed for all life cycle stages. For an extensive description of the used data and a more detailed description of the methodological choices we refer to Hekkert et al., (1998a) and Hekkert et al. (1998b).

carbonated water is packed in PVC bottles. All wine is packed in glass bottles and the remainder of the glass bottles used in Europe is used to pack carbonated beverages. All dairy products, except milk are packed in either PS or PP packaging. 75% of the cardboard boxes are used in the food sector and 25% are used in the non-food sector. For plastic blister packing we assume that 20% is used in the food sector and 80% in the non-food sector. For the division of films over susceptible and non-susceptible food products and non-food products we used the 1990 data of APME (1992). This shows that 65% is used for non-susceptible food packaging, 23% for susceptible food packaging and 12% for non-food packaging.

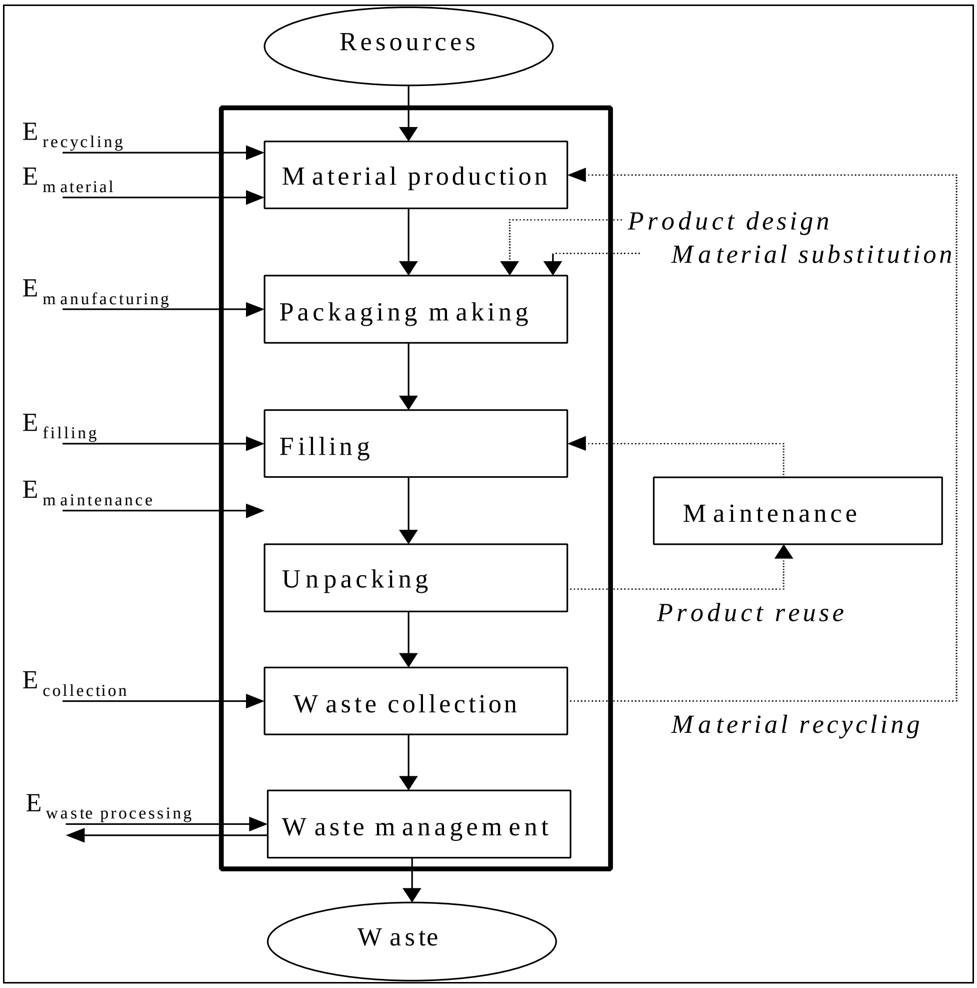

Figure 1: life cycle of packaging, including improvement measures

For transport packaging we discerned fewer categories. We used the following assumptions to determine the material use per category. The plastic demand for production of carrier bags is estimated at 430 ktonnes [APME, 1992, 1996]. Carrier bags are most often made out of PE. The amount of plastic (PE) industrial bags is estimated at 460 ktonne [APME, 1992]. Industrial bags can also be made out of paper. The amount is estimated based on the cement production in Europe because these bags are used mainly for cement packaging. The amount of paper is estimated at 85 ktonnes and due to the PE layer the PE demand is estimated at 15 ktonnes [Ayoup, 1997]. Transport boxes can either be made out of corrugated board (11700 ktonnes) or PE (884 ktonnes) [PPI, 1997, APME, 1996]. The amount of grouping films amounts to 290 ktonnes in 1990 [APME, 1992]. We estimate the 1995 demand at 310 ktonnes based on the average growth of PE consumption in Europe [APME, 1992, 1996]. The demand for pallets in Europe is 280 million per year [Belkom, 1994]. The majority of these pallets are made from wood (96%). Taking into account that a single use pallet weighs 17 kg and a multiple use 25 kg and that 66% of the pallets are single use results in a total wood use of 5000 ktonnes [Renia and Sikkema, 1991, Belkom, 1994].

The remainder of the pallets is assumed to be made from PE which adds 336 ktonnes to the material use when an average weight of 30 kg is assumed [TNO, 1994]. Transport films can be subdivided in shrink covers (380 ktonnes of PE) and stretch film (320 ktonnes of PE) [APME, 1992][44]

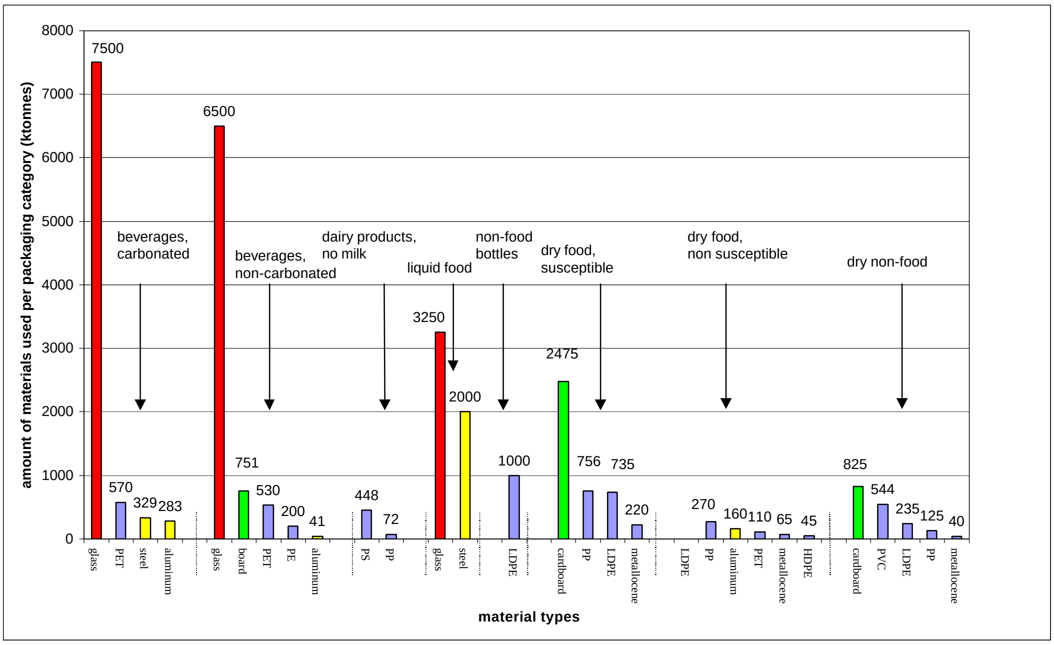

Figure 2: Material input for primary packaging per packaging category

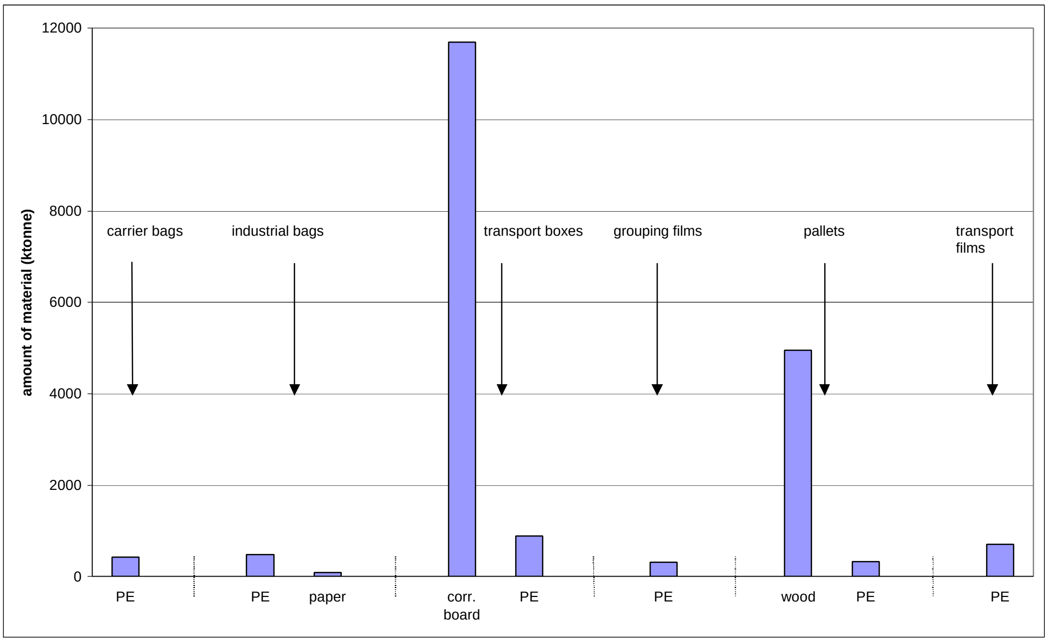

Figure 3: Material input for transport packaging per packaging category

Potential for CO_2 emission reduction

As stated in section 2 we defined reference packages in order to model the current packaging practices. The characteristics of the reference packages are based on literature review, expert opinions and own observations. Information on the improvement options is gathered based on recent developments in the packaging and material producing industries[45]. By

[44] 1990 data from APME (1992) extrapolated to 1994 with growth rate of PE consumption

[45] All reference and improved packages are described in detail in Hekkert et al. (1999a) and Hekkert et al. (1999b).

implementing improved packages for reference packages savings in CO_2 emission can be achieved. Tables 2 and 3 show the CO_2 emission reduction potential of the individual improvement measures (replacing reference packages by improved packages) and the cost efficiency of these options measured in ECU per tonne CO_2 saved. The CO_2 emission reduction figures in Table 2 and Table 3 are relative savings in 2010 compared to 1995 *assuming fixed packaging consumption*.

Table 2: Potential savings and costs of improved material management for primary packaging in 2010 compared to 1995 for Western Europe assuming fixed packaging consumption

No.	**new packaging concept**	**Old packaging Concept**	**degree of substitution (%)**	**CO_2 emission Reduction (%)**	**Costs ECU/tonne CO_2 saved**
s1	PP film thin	PP film	100	1.1	-1200
s2	cardboard box light	Cardboard box	100	0.5	-1200
s3	LDPE film thin	LDPE film	100	1.1	-1100
s4	honeycomb food can	Steel food can	50	1.0	-360
s5	light glass bottle large	Glass bottle large	100	2.4	-280
s6	glass jar light	Glass jar	100	0.2	-280
s7	Steel bev can light	Steel bev can	100	0.2	-230
s8	Aluminium bev can light	Aluminium bev can	100	0.2	-190
s9	light HDPE bottle	HDPE bottle	100	1.8	-130
m1	PET bottle one way	Glass bottle large	100	2.8	-470
m2	Steel bev can light	Aluminium can	100	1.0	-150
m3	PP cup	PS cup	100	1.4	-120
M4	PET bottle to be recycl.	PET bottle one way	100	1.0	0
M5	recycled HDPE bottle	Light HDPE bottle	100	1.2	0
m6	cardboard blister	PVC blister	100	2.2	0
l1	Pouch	Liquid board	25	3.5	-390
l2	glass bottle small refill.	Glass bottle small	100	5.6	-230
l3	pouch	HDPE bottle	100	3.5	-160
l4	PET bottle reuse recycl.	PET bottle one way	100	8.9	-40
l5	PC bottle	Liquid board	25	1.5	1100

The potential reduction of CO_2 emissions for each improvement measure is corrected for inter-measure influences, by assuming that measures are implemented in order of implementation difficulty where the least complex measures are implemented first. In section three we described that in this paper we link the difficulty of implementation to the necessary change in the entire packaging system. Table 2 states the improvements for primary packaging and Table 3 for transport packaging. In Table 2 and Table 3 the change in the packaging chain is indicated by a division of the possible measures in three categories. The tables discern measures with small complexity of implementation (s), measures with medium complexity of implementation (m) and measures with large complexity of implementation (l). The measures with small complexity of implementation correspond to the use of less, lighter and thinner materials. Only changes at the level of the packaging manufacturer are necessary. Measures with medium implementation difficulty involve measures where material substitution takes place. Material substitution leads to changes in the material production sector and the packaging-manufacturing sector.

When the characteristics of the materials differ strongly, also changes in the filling stage might be necessary. Measures with a large complexity of implementation involve returnable packages where changes in all stages of the packaging life cycle are necessary. Also measures that rely on a change in consumer behaviour are part of this category.
The results as presented in the Tables 2 and 3 are also depicted by means of supply curves (Figures 4 and 5). Contrary to normal supply curves, in this figure the order of implementation is visible. Within the categories 'low', 'medium' and 'large implementation difficulty' the

measures are ordered by cost-effectiveness. Figure 4 shows that the total cumulative CO_2 emission reduction that can be achieved for primary packaging amounts to **41%**.

Table 3: Potential savings and costs of packaging efficiency improvement measures in Europe for the reference year 1994.

no.	new packaging concept	old packaging concept	degree of substitution (%)	CO_2 emission reduction (%)	costs (ECU /tonne CO2)
s1	light corrugated box	corrugated box	100	-6.9	-400
s2	light LDPE grouping film	LDPE grouping film	100	-1.2	-288
s3	light shrink cover	shrink cover	100	-1.3	-238
s4	light stretch film	stretch film	100	-1.1	-238
s5	light HDPE carrier bag	LDPE carrier bag	100	-1.5	-238
m1	stretch film	corrugated box	20	-4.0	-179
m2	glue	stretch film	100	-2.3	-37
m3	recycl. PE carrier bag	light carrier bag	50	-3.3	0
m4	corrugated one way pallet	wood one way pallet	100	-1.3	2
m5	recycl. PE return. pallet	return. wooden pallet	100	-0.8	20
m6	paper carrier bag	light carrier bag	50	-1.7	125
l1	reusable carrier bag	light carrier bag	100	-0.9	-685
l2	plastic crate	light corrugated box	50	-5.3	-142
l3	wooden crate	corrugated crate	100	-0.9	-126
l4	FIBC	industrial bag	25	-1.3	-74
l5	Recycled PE return pallet	wood. one way pallet	100	-4.2	-73
l6	FIBC returnable	industrial bag	25	-1.8	-73

The vast majority of this potential is calculated to be cost-effective, namely a reduction of CO_2 emissions of 40%. The potential cost-effective savings on CO_2 emissions of measures that are easy to implement (low complexity) is 8% savings and measures that are more difficult to implement can add another 10%.

The potential for emission reduction is increased by another 22% by implementing measures with a large complexity of implementation due to many actors involved in the implementation process. Figure 5 shows that the total cumulative CO_2 emission reduction that can be achieved for transport packaging amounts to **38%**. Also for transport packaging most measures are cost-effective due to large savings on material costs.

It is not necessary to follow the same order of implementation as we have chosen to calculate the potentials of the measures. Changes in implementation order will influence the reduction potential of the specific measures but the cumulative reduction in CO_2 emissions will not change since we have corrected for inter-measure influences. We have done this by calculating the potential of measures relative to measures that are implemented earlier.
The total CO_2 emission related to primary packaging is calculated at **107 Mtonne per year**. A reduction of 40% corresponds to a reduction of **43 Mtonne per year.** This is 1.5% of Western Europe's anthropogenic CO_2 emissions in 1990 due to fossil fuel combustion; calculated from emission data by UN-FCCC (1996).

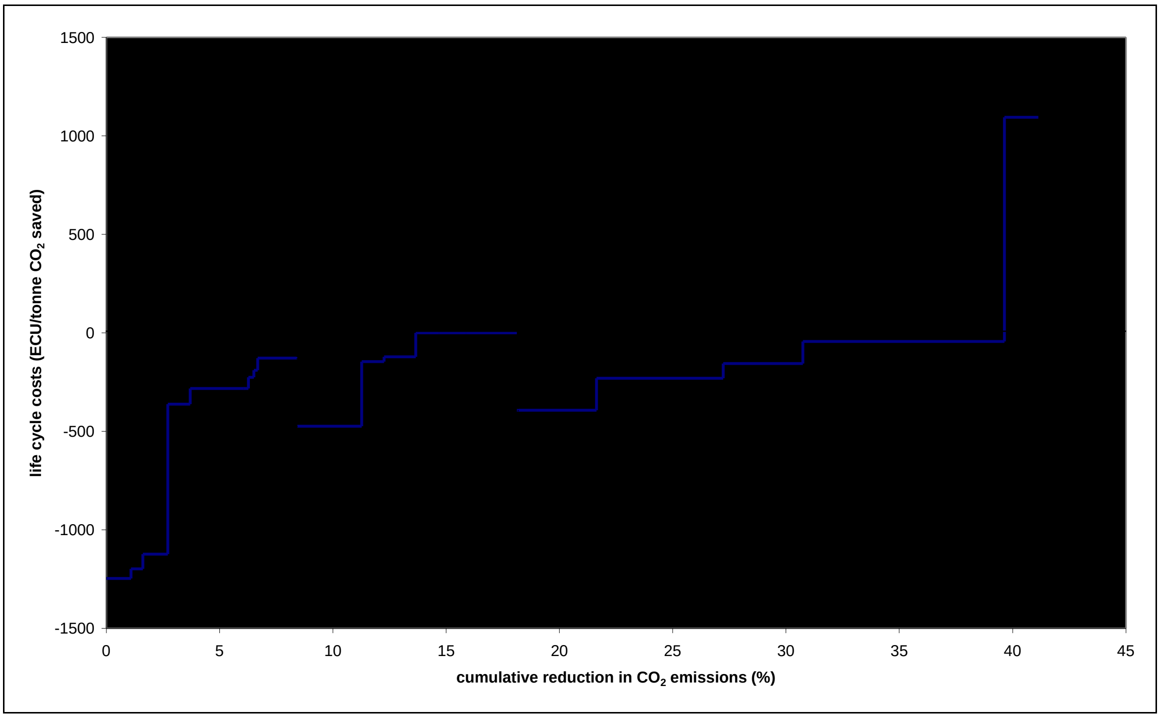

Figure 4: a supply curve for the reduction of CO_2 emissions by improvement of the material efficiency of primary packaging in Europe

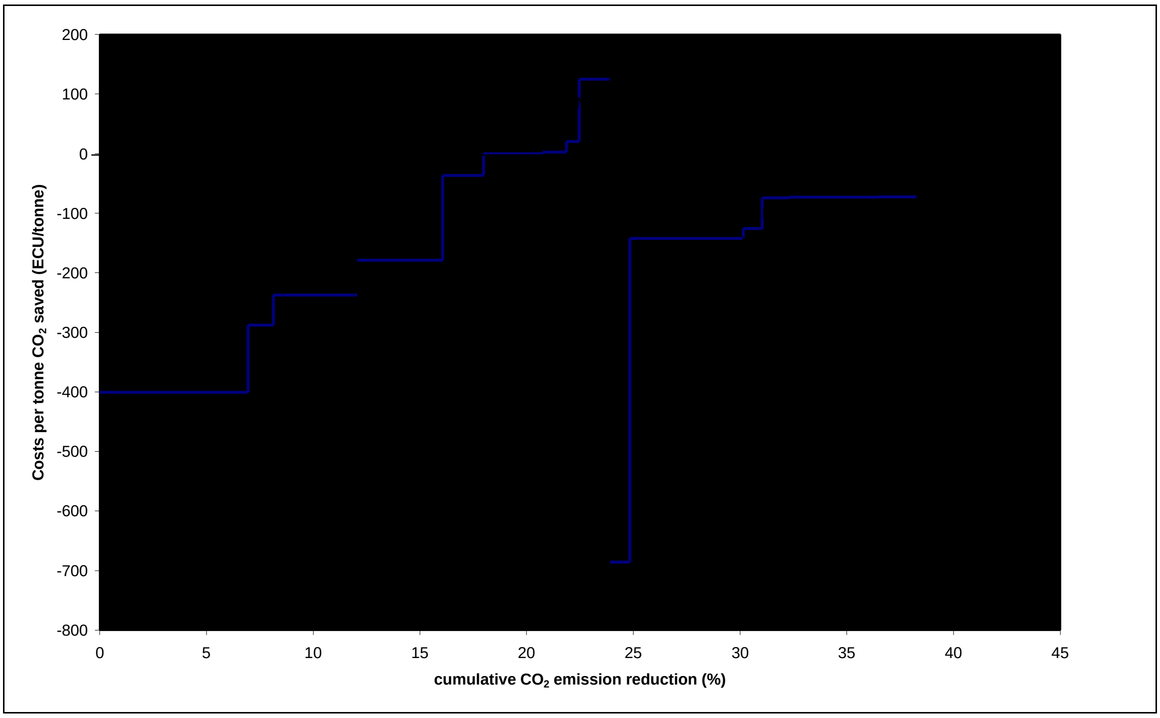

Figure 5: a supply curve for the reduction of CO_2 emissions by improvement of the material efficiency of transport packaging in Europe

Conclusions

Many measures can be taken to reduce the CO_2 emission related to production and consumption of packaging in Western Europe. The total savings on CO_2 emissions that are possible for 2010 are calculated at 40% when assuming fixed packaging consumption. Most measures are cost-effective when taking life-cycle costs into account.

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Substance Flow Analysis of Cadmium in Society's Waste

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Abstract
Use of cadmium has been restricted in Sweden since the early 1980´s. However, this has not included the import of cadmium-containing products. In this article we study the occurrence of cadmium in solid waste and sewage in a Swedish region, fifteen years after these restrictions. Local governments have the unrewarding role of being responsible for these vital parts of the material flows without the ability of influencing their composition very much. Systems for waste and sewage management are centralised to a large extent, leading to a concentration of elements in sinks like sewage sludge and land-fill for bottom and fly ashes. The continuos occurrence of cadmium in waste and sewage can partly be explained by the natural occurrence of cadmium as a pollutant of many media and products, but possibly also through the increased use of Ni-Cd batteries and the delay of outflow from older products.

Cadmium in a Swedish region
The use of cadmium as pigment, stabiliser and for plating has since the beginning of the 1980's been almost totally restricted in Sweden by legislation. However, simultaneously the use of cadmium-containing products, mainly Ni-Cd batteries has rapidly increased. Thus, you could say that the decreased use in industrial applications was compensated for by increased use in products.

Today, about fifteen years after the ban of cadmium in many applications it is well known that cadmium still occurs in solid waste and sludge generated in Sweden. This article describes an attempt to study the flows of cadmium related to municipal solid waste(MSW) and sewage to see what effect the restrictions of the use of cadmium may have caused. It is interesting to focus on the flows of cadmium in MSW and sewage partly because they are managed by local governments. The role of local governments in managing material flows is somewhat unrewarding. They are responsible for the treatment of both MSW and sewage, but still they have very small opportunities to influence the composition of the waste and the sewage. Still, it is most important for them to identify and quantify stocks and flows of cadmium since they manage the incineration plants, the sewage treatment plants and the land-fills, and thereby have to cope with the environmental impact generated by cadmium in society's waste.

The spatial dimension of this study is restricted to the region of Östergötland (Figure 1), a county in south-eastern Sweden. The region covers an area of about 10 000 km^2 and has a total population of about 415 000 people which corresponds to about 5 % of Sweden's total population. In this study the time dimension dealt with is the last 50 years, since cadmium in Sweden did not become a common used metal before World War II (Bergbäck et al, 1994).

Substance flow analysis (SFA) was used to identify and quantify the regional stocks and flows of cadmium. The main data sources have been national, regional and local statistics. Data related immediately to the waste and sewage are specific to this region and is generated by local and regional authorities. Other important data sources used in the SFA are Flyhammar (1995) and Lohm et al. (1997) whose data have contributed in the areas of product stocks and land-fills. The result from the SFA are then presented in an empirically based and non-technical flow-chart model. In this paper, only the flows and stocks immediately relevant for solid waste and sewage are presented.

About 70% of all MSW generated in the region becomes concentrated to one incineration plant centrally located in the region (Tekniska Verken, 1998). The remaining part of the MSW is composted, digested or land-filled without treatment. In this article we concentrate on the

MSW that reaches the incineration plant since it dominates the waste handling of the region. There is also an import of waste to the incineration plant from neighbouring municipalities outside the region and a small amount from other countries in northern Europe (Figure 2). In all, the plant receive waste from about half a million people, corresponding to about 200 000 tonnes annually.

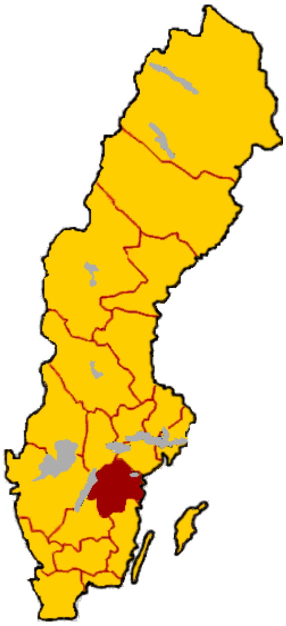

Figure 1: Sweden and the region of Östergötland, marked with dark grey.

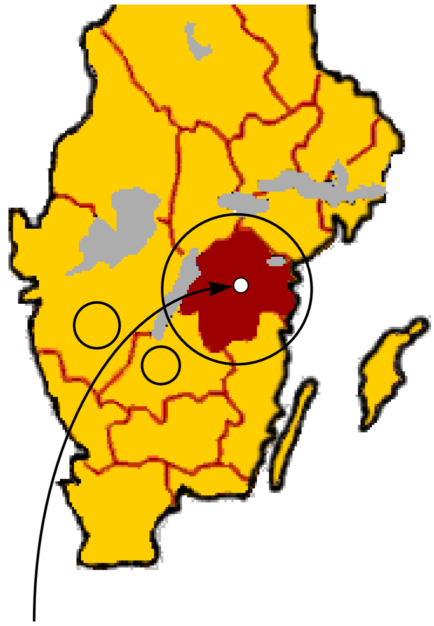

Figure 2: The location of the incineration plant and it´s collection zone for MSW indicated as circles (imports from other countries indicated with an arrow)

As well as the treatment of MSW the sewage treatment is organised in large scale systems managed by the local governments. About 350 000 people or 80% of the regions inhabitants are connected to a sewage system and by this to one of the regions 18 main municipal wastewater treatment plants. These plants also handle wastewater from some smaller industries but surface water and wastewater from larger industries are treated separately.

Substance flow analysis of cadmium in waste and sewage

The flow chart in Figure 3, is an illustration of those parts of the regional cadmium metabolism that is connected to the treatment of MSW and sewage sludge. The ”technosphere” in the flow-chart represents the non-living material created by humans and the ”environment” includes the atmosphere, biosphere, geosphere and hydrosphere. There is a large stock of cadmium accumulated in products in the technosphere, for example products in private households. Import of new products gives a significant inflow of cadmium to the region. From the stock of cadmium in products there are two main outflows of waste, MSW and sewage. These waste categories are both effected by the total stock and the annual flows. Treatment of MSW, is as previously described, concentrated to one incineration plant. Due to several pollution prevention measures there occur almost no emissions of cadmium to air or water from the plant. Instead, all the cadmium remains in the residues. The residues from the incineration is divided into two categories, fly ash and bottom slag, and most of the cadmium is to be found in the fly ash (Tekniska Verken,1998 and Uppsala Energi, 1998). Both the fly ash and the bottom slag is then deposit at the incineration plants landfill. The leakage of cadmium from the landfill is today almost insignificant (Tekniska Verken, 1998), and the generated leakage water is distributed to one of the region's municipal waste water treatment plants. After sewage treatment about two-thirds of the cadmium stays in the sewage sludge and the rest remain in the water transported to the recipient. Most of the produced sewage sludge is then deposit on landfills and just a small part is used in agriculture as fertiliser.

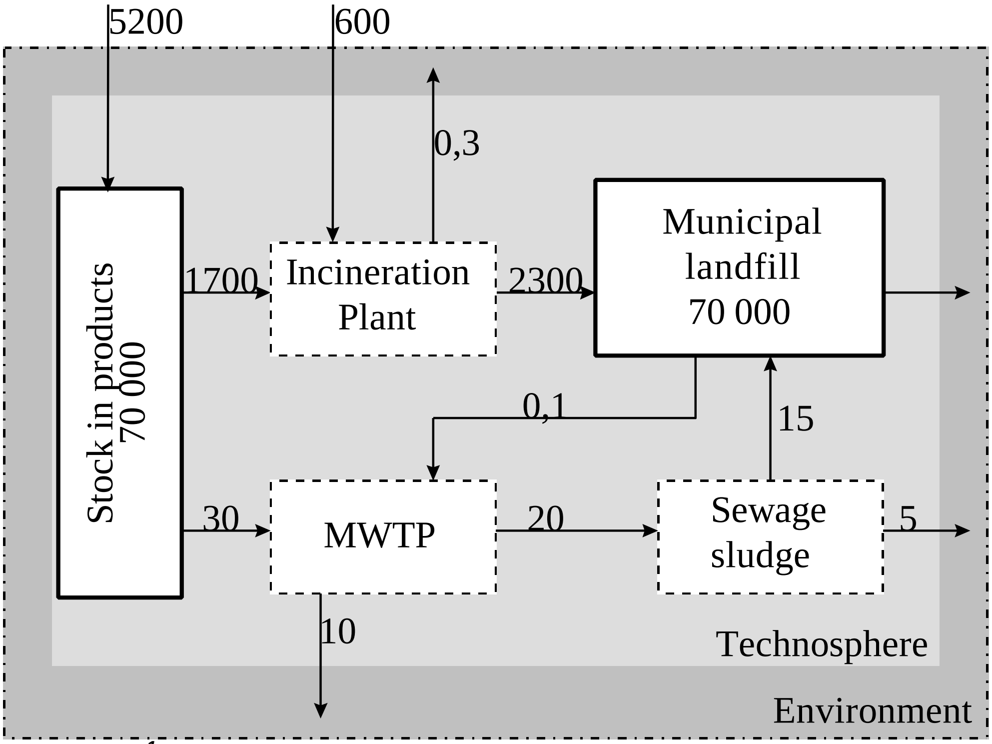

Figure 3: (Kg yr^{-1}), Flow chart illustrating the stocks and flows of cadmium connected to the treatment of MSW and sewage sludge in the Östergötland region, Sweden. Waste flows of cadmium connected to the use of Ni-Cd batteries are not included in the flow chart. Approximately 2000 kg of cadmium in Ni-Cd batteries is annually exported out of the region for recycling, calculated from SOU 1996:8.
MWTP (Municipal waste water treatment plant)

illustrates the system boundary, represents stocks and the represents processes.

MSW generated in the region and distributed to the incineration plant contains annually about 1700 kg of cadmium. An additional inflow of 600 kg reaches the incineration plant through import of waste from other regions (figure 2). The incineration plant has been in operation since the middle of the 1980’s, and with an annual flow of about 2000 kg of cadmium within the incinerated waste, this implies that there is an accumulated amount of cadmium on the incineration plant’s landfill of between 20 000 - 30 000 kg. The stock of 70 000 kg in figure 3 represents the total amount of cadmium on municipal landfills in the region and includes the amount accumulated on the incineration plant’s landfill. Consequently, this large-scale treatment of MSW has resulted in a considerable concentration of cadmium to one location in the region during the last decades.

In order to investigate if the restricted use of cadmium in Sweden during the last two decades has caused any effects of the amount of cadmium in the MSW, we searched for data describing the trend over the last ten years (figure 4). The diagram is based on data from a Swedish incineration plant with the same technical properties as the plant in the region studied (Uppsala Energy, 1998), and illustrates the ratio between the amount of cadmium in the incineration residues (fly ash + bottom slag) and the amount of incinerated waste. It is not possible to identify either a positive or a negative trend of the cadmium concentration in the MSW over the last ten years. One reason for this could be that cadmium generally has been used in long-lived products. These products, which constitute the stock, continue to cause a flow to the waste-management even long after they are no longer sold (Baccini and Brunner, 1991). Furthermore, the restricted use of cadmium in pigments, stabilisers and for plating was in the end of the 1980’s counterbalanced in the increased use of Ni-Cd batteries. Thus, the total amount of cadmium being used remains in the same magnitude as in the early 1980's (Lohm et al. 1997). Cadmium is also a natural pollutant in zinc, which implies that there is flow of cadmium to MSW from zinc products. Taken together, these factors will, in large-scale treatment of MSW, result in a continuous accumulation of cadmium on municipal landfills.

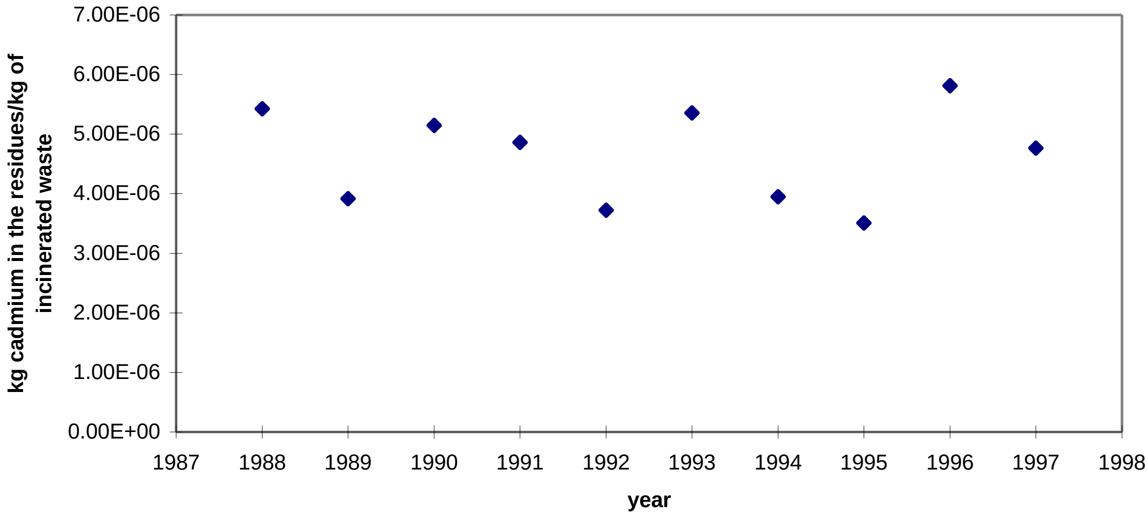

Figure 4: Ratio between the amount of cadmium in the residues and the amount of incinerated waste, based on data from Uppsala Energi, Sweden 1998.

There is a slightly decreasing trend of cadmium in sewage sludge per capita and year (figure 5). This is mainly an outcome of the last decade's efforts to reduce the point sources of the sewage system, for example plating industries and car-washers. The 20 kg of cadmium that today remains in sewage sludge (figure 3), is still enough to prevent the utilisation of sewage sludge as fertiliser. These 20 kg
are most likely explained by diffuse emissions from consumer products.

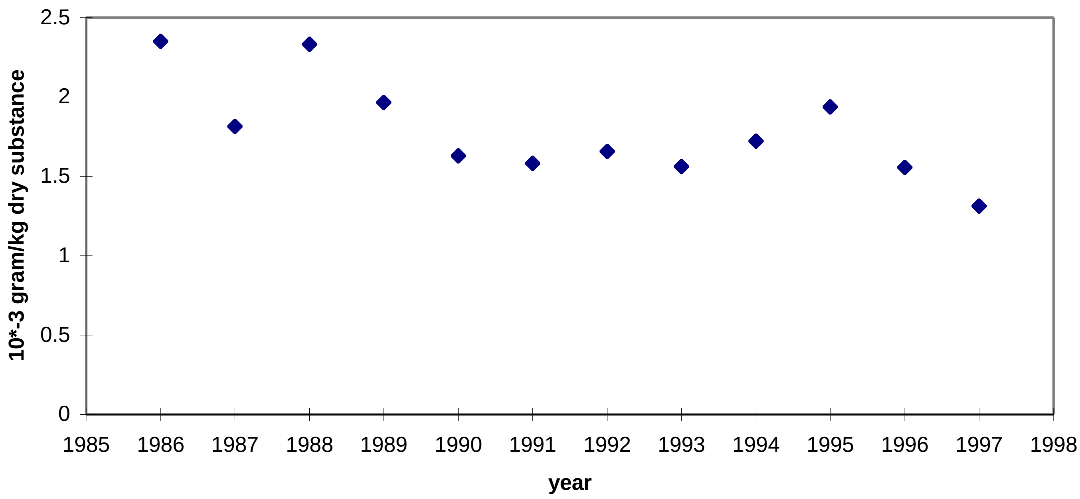

Figure 5: Concentration of cadmium in sewage sludge (10^{-3} gram/kg dry substance per capita). Based on data from Östergötland County Administrative Board,1998.

When comparing the management of MSW and sewage, there seems to be no connection between the efforts to reduce the amount of cadmium and the actual amount in these categories. MSW treated at the incineration plant studied contains annually about 2000 kg of cadmium. Nevertheless, this is not a debated issue. Instead the 20 kg in the sewage sludge from the regions municipal waste water treatment plant's is much more discussed. Above all, the desired reduction of cadmium in the sewage sludge is based on the risk of exposure and the decrease in technical flexibility. In the case of high concentrations of cadmium in the sewage sludge there is a risk of contaminating crops, resulting in increased exposure for humans. Hence, most of the sewage sludge today is deposit on landfills. Since land filling of sewage sludge will be an expensive alternative from 2005, local governments intend to distribute the produced sewage sludge to regional farmers. High concentrations of cadmium in sewage sludge reduce the possibility of it´s utilisation. This is an example of decrease in technical flexibility.

The residues from incineration of MSW are not at present used in any application, with the exception of experimental uses of bottom slag in road construction. Hence, cadmium in MSW is not an element which limits the use of any product. As mention above, the incineration residues are deposit on landfills. Today, there is almost no emissions of cadmium from these landfills (Flyhammar, 1995). Consequently, the risk of exposure to humans is not so obvious as in the case of high concentrations of cadmium in sewage sludge.

Conclusions

The occurrence of cadmium in waste and sewage cannot easily be controlled by restrictive legislation aiming at reducing the use of cadmium in industrial production, excluding the restriction of cadmium in products. Even if the use of cadmium in products would be restricted there will be a long delay before this effects the composition of waste and sewage, since many products are long-lived. Furthermore, there is a natural occurrence of cadmium in the environment implicating the presence of a base-line level which is an interesting challenge to try to assess.

Cadmium in sewage sludge is frequently debated in Sweden while cadmium in solid waste is not. However, in this regional study the solid waste flow contains roughly two magnitudes higher of cadmium. This can be explained by that cadmium related to the solid waste does not restrict the technical flexibility of any product, since all slag and fly-ashes are deposited in a land-fill. Neither it is likely to effect human health since humans are not exposed for the cadmium. However, with increased tax on deposition of waste, market solutions will be sought for this waste fraction as well. Hence, from the perspective of the manager, it is most important to identify and quantify the flows of cadmium in society's waste.

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Dematerialization and the environment: theoretical concepts and practical implications

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Abstract

In the 1980s the dematerialization hypothesis was proposed and investigated by Williams, Larson and Ross. This hypothesis states that the material intensity of modern industrial society is declining and that this decline offers substantial advantages for the environment. The mechanism of dematerialization is comparable to the mechanisms controlling the environmental Kuznet curve. Since the 1980s the supposed implications of the dematerialization hypothesis have been frequently used in the definition and evaluation of scenarios aiming at sustainable development.

The 'factor four' goal is largely based on the assumption that far reaching dematerialization is at reach. The indicator "Intensity of Material Use" defined to be the amount used in production of a given (bulk) material divided by the amount of Gross Domestic Product [kg/$] is used regularly to investigate dematerialization.

However, this indicator is related poorly to the environmental impacts of (total) material use in the society because it does not cover the whole cycle of materials in the society. This indicator does not account for dynamical processes, such as build up of infrastructure, material substitution and shifts in the demand of goods and services.

In this paper some alternative indicators for (de)materialisation in the society are developed from a theoretical (lifecycle) perspective and discussed, which may be more relevant for environmental purposes than the "Intensity of Material Use" indicator. These indicators are applied on two cases: passenger cars and household durable consumption goods.

A full paper was not available.