OECD Working Group on Environmental Information and Outlooks (WGEIO)

SPECIAL SESSION ON MATERIAL FLOW ACCOUNTING

Paris, 24 October 2000

PAPERS AND PRESENTATIONS

The Special Session on Material Flow Accounting was organised following a joint proposal by the United States and Japan at the 29th meeting of the Working Group on Environmental Information and Outlooks (former Working Group on the State of the Environment) (October 1999, Paris).

The purpose was to review national and international experiences in material flow accounting (MFA) as part of the WGEIO work programme, and as a contribution to the OECD work programme on resource efficiency and to the OECD initiative on sustainable development. The objectives were to:

- take stock of the development and use of MFA at national and international level;
- facilitate the exchange of experience on MFA, addressing in particular i) the policy-relevance of MFA, and ii) selected methodological issues (frameworks, definitions, classifications, system boundaries, etc.);
- identify areas for further progress at national and international level.

Questions addressed included the following:

- What are the most promising uses of MFA? Examples of the use of information derived from MFA in decision making.
- What are the main methodological and measurement issues?
- What indicators could be derived from MFA and how should they be interpreted?

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INTRODUCTION

Introductory speech by Ms. Joke Waller-Hunter
OECD Director, Environment Directorate

Mr. Chairman, Dear participants,

I am very pleased to introduce this Special session on Material Flows Accounting, organised by the Working Group on Environmental Information and Outlooks following a proposal of the United States and Japan last year.

It builds on earlier work carried out by the OECD and the WGEIO in particular on natural resource accounts and on the use of environmental accounting in decision making. The issues that you will address today also link closely to other areas of OECD work such as environmental indicators, resource use efficiency, sustainable development, and will provide useful input into the work we are doing on the environmental outlook and strategy.

LINK TO SUSTAINABLE DEVELOPMENT

Today, the goal of sustainable development has received wide international acceptance. For the OECD and its member countries it is a key priority. You probably know that the OECD is carrying out a three-year programme to help countries move towards sustainable development and to make the concept of sustainable development operational for practical policies. This project will stretch until early 2001, with the preparation of policy and analytical reports, including a chapter on measurement and indicators, and leading to a ministerial dialogue in May 2001 when environment and finance ministers meet together.

Progress towards a more sustainable development path requires that the objectives of increasing economic efficiency and material wealth be integrated with social and environmental objectives, and placed in an inter-generational framework. It also implies that the capital base of our economies and societies should be preserved for future generations.

OECD countries are collectively the biggest users of natural resources in the world and the environmental, economic and social consequences of the production and consumption patterns of their population and related economic activities extend far beyond their borders. From an environmental point of view, they exert three major types of influences within and outside the OECD area. Firstly, on the rate of extraction of non-renewable resources such as oil and minerals. Secondly, on the extent of harvest of renewable resources such as forests, agriculture, and wildlife, and of withdrawal of water resources. And thirdly, on the intensity of environmental stress associated with production, consumption and use of resources. Consequently, OECD countries have an important role to play in achieving more sustainable production and consumption patterns, and preserving the capital base of our economies.

The appropriate management of natural resources and their efficient use in our economies, is thus a key to sd and it is part of the many cross-sectoral issues with which we are increasingly confronted.

LINK TO INFORMATION AND DECISION MAKING

In this context, it is essential that effective policies are developed and implemented, and that environmental and resource aspects are taken into account at an early stage and throughout the decision making chain. It is further essential that these policies are based on appropriate factual information. Environmental accounting contributes to the provision of such information. It is at the basis of information supply and is a tool from which a number of useful indicators can be derived.

ENVIRONMENTAL ACCOUNTING

Over the past 10 to 20 years, general interest in environmental accounting, articulated by policy makers and NGOs, has been increasing. A considerable amount of work has been carried out in academia and by national administrations and international organisations to develop and refine methodologies for various environmental accounting tools, including environmental satellite accounts, environmental expenditure accounts, natural resource accounts, and material flows analysis. A lot of the work completed has shed light on the supply side of environmental accounting. Practical applications have also progressed, mainly in areas where the demand for accounting tools was clearly identified and linked to specific policy questions such as the management and planning of natural resource use (e.g. water, forests, energy) and associated indicator development.

USE OF ENVIRONMENTAL ACCOUNTING

Results from an OECD seminar held in 1994 to review the use of environmental accounting in decision making, showed indeed that there are three uses of environmental and material resource accounts that are relevant for decision-makers. They can be used as a tool for:

Resource management: To be suitable for this purpose, the accounts must provide extensive and detailed information; this tends to require well- developed and large statistical bases and a relatively sophisticated accounting system, often at the substance level.

Policy analysis: This use is less information-intensive than the use for resource management. Two types of uses are distinguished:

- Direct use of physical accounts: where NRA trace the flow of natural resources from the environment to the economy and within the economy, they provide information about the impacts of sectoral economic activities on the resource flows and stock and vice versa.
- Indirect use of physical accounting information through linking it to economic information in the context of integrated environmental and economic accounting or through introducing it into environment-economy models.

Indicator development: the construction of selected and/or aggregated indicators of resource use and pollution intensities is likely to be the least demanding application of resource accounts in terms of information requirements.

Last year, the OECD organised a Conference in Rome to take stock of national and international initiatives in the field of sustainable development indicators. The presentations made at this Conference showed that the wide variety of indicators of sustainable development already in use, generally include indicators drawn from accounting frameworks. Most countries that have developed a set of sustainable development indicators include in their set one or several indicators dealing with material use and related intensities.

The OECD itself uses a number of indicators derived form its work on natural resource accounting. These indicators are part of the OECD Core Set of environmental indicators and have proven to be useful tools in our policy analysis and evaluation work. They are also discussed as part of the OECD work on sd indicators.

OBJECTIVES OF THIS SPECIAL SESSION

In this Special session we wish to review progress made and progress to be made with material flow accounting at national and international level, and to provide a forum for a constructive exchange of experience on how to best use the information that can be derived from these accounts to support decision-making and policy development. As mentioned earlier, a lot of the accounting work that has been carried out to date, focuses on the supply side. We would like this session to establish a link with the demand side, and to help countries to make their MFA work operational for national policies.

One important question we have in mind is:

- What are the most promising policy uses of MFA? I.e. to what extent can MFA actually provide a basis for policy relevant, analytically sound and measurable indicators that i) monitor the use and management of resources in our economies, and the associated environmental stress; and ii) support related decision making and policies. In our opinion, such indicators should complement other indicators derived from natural resource accounting already in use such as the intensity of use of water resources, the intensity of use of forest resources, or energy indicators such as energy intensities and efficiencies.
- When answering this question, we need also to have a closer look at methodological and measurement issues, at system boundaries, at levels of aggregation, and how they affect the interpretation and policy relevance of derived indicators.

The roundtable at the end of the special session will give the opportunity to further broaden the debate. It will help to identify what role the different actors can or should play in turning MFA into a useful decision-making tool, and what role OECD countries as a group could play in refining the MF tool and fostering progress at international level.

Today’s discussions will also provide a basis for tomorrow’s seminar that will more specifically dwell on waste material flows. It will consider the potential role of MFA within waste policy generallly, and the use of MFA as an input to the design and evaluation of waste management and prevention efforts particularly.

Mister Chair, this gives this session a challenging task. Many of the participants have prepared documents for the meeting, for which we are extremely grateful. I am looking forward to a stimulating exchange of views and discussions.

OECD Working Group on Environmental Information and Outlooks - OECD Initiative on Sustainable Development

SPECIAL SESSION ON MATERIAL FLOW ACCOUNTING

CHAIR'S SUMMARY

Following a joint proposal by the United States and Japan at the latest meeting of the Working Group on Environmental Information and Outlooks (WGEIO), a special session on material flow accounting (MFA) was held on 24 October 2000, back to back with i) the formal meeting of the WGEIO and ii) a seminar on waste material flows and resource efficiency. The session was chaired by Mr. Yuichi Moriguchi (Japan) and was attended by more than 70 delegates and experts from OECD member countries and international organisations.

The aim of the special session was to take stock of the work carried out to date, to review progress made and progress to be made with material flow accounting at national and international level, and to explore how to best use the information that can be derived from these accounts to support decision-making and policy development.

PROGRESS TO DATE

Over the past 10 to 20 years, general interest in environmental accounting, articulated by policy makers and NGOs, has been increasing, stimulated by concern with the sustainable use of natural resources and the inappropriate treatment of the depletion of natural resources in economic accounts. A considerable amount of work has been carried out in academia and by national administrations and international organisations to develop and refine methodologies for various environmental accounting tools, including environmental satellite accounts, environmental expenditure accounts, and natural resource accounts. In recent years, material flow studies have gained renewed interest as a way of looking at the impacts of economic activity on the environment – the effects of mobilisation of materials from the environment and the flow of materials to the environment.

The presentations made showed that MFA includes a variety of approaches covering different flows at different levels of detail for different entities with different system boundaries. Reviewed experiences covered accounting of total material flows (collaborative effort carried out by Austria, Germany, Japan, the Netherlands, and the United States[1]), analysis of flows of specific substances (Netherlands) and accounting of natural resources (France). They were mainly at nation-wide scale, and examples of disaggregation by sectors and regions were presented. The linkages of MFA with economic accounting/modelling tools were also reviewed, in particular, applications of economic Input-Output models (Canada, Italy) for the analysis of indirect flows, and .the integration of MFA with Physical Input-Output Tables (Germany).

The discussion showed that there are several uses of MFA that are relevant for decision-makers. This includes indicator development, data provision to modelling, and direct use in waste and resource management. MFA may also contribute to improvements in environmental data quality (e.g. waste statistics, discharges to water) and vice-versa better environmental data are essential to improve the quality of basic data for MFA.

LINKS WITH ENVIRONMENTAL AND SUSTAINABILITY INDICATORS

The most promising use that was identified is the derivation of selected and/or aggregated environmental and sustainability indicators. This is also likely to be the least demanding application of MFA in terms of information requirements.

Indicators derived from MFA need to be policy relevant, analytically sound and measurable, i.e. feasible. They should i) monitor the use and management of resources in our economies, and the associated environmental stress; and ii) support related decision making and policies. MFA indicators can provide an overall metric to measure the material requirements of economies (resource use), or the absorptive capacity they demand of the environment (pollution). Material or resource

1. Joint research effort involving governmental and non-governmental institutions including the World Resource Institute; the Wuppertal Institute.

efficiency and pollution intensity, can be calculated on a per capita or per GDP basis to enable tracking of environmental progress and allow international comparisons. More detailed indicators might be used to track changes in material efficiency in particular industrial sectors, or the pollution intensity for particular media (air, land, water). Such indicators should be seen as a complement to other indicators derived from natural resource accounting already in use.

Most countries that have developed a set of sustainable development indicators include in their set one or several indicators dealing with material use and related intensities. Examples are indicators included in the set supporting the basic environmental plan of Japan, or indicators to monitor policy objectives in Sweden. The OECD itself uses a number of indicators derived from its work on natural resource accounting. These indicators are part of the OECD Core Set of environmental indicators and have proven to be useful tools in our policy analysis and evaluation work.

PROGRESS TO BE MADE

The discussions also showed that a lot of the work completed to date has been carried out by universities and research institutes, and has shed light on the supply side of environmental accounting. The actual use in policy making is still limited, and the potential of MFA as a policy making tool is often not sufficiently known.

This is also due to the fact that MFA covers many aspects within an integrated framework, and that the responsibilities for related policy use and data gathering are often scattered and handled by different administrations. Roles of national environmental and statistical institutions, research communities and international organisations should be further examined in order to strengthen the interface between policy-relevant uses and methodological developments, to improve data availability and quality, and to improve harmonisation of methodologies. Also, conceptual approaches still vary and merit further clarification and convergence.

If MFA has to be turned into a useful decision-making tool progress will need to be made to:

- Further explore and explain the links between MFA and other tools and indicators, and in particular the links and complementarities between indicators derived from MFA, other indicators describing natural resource use and other environmental indicators;
- Further explore how methodological issues, data quality and availability affect the interpretation and policy relevance of derived indicators;
- Further identify, within the broad scope of sustainable development, crucial issues to which MFA could contribute, in order to attract more focused attention of policy makers to the potential of MFA;
- Further harmonise methodologies for constructing simple MFA and provide guidance to countries on how best to use MF information to calculate indicators;
- Improve co-operation and communication between the various actors involved, including academia, national statistical offices, and environmental policy administrations.

NEXT STEPS

The discussion showed that MFA is a potentially powerful tool, especially for Member countries of the OECD, which still account for a major part of the world's resource consumption and waste generation. OECD countries as a group could thus play an important role in refining the MFA tool for use at national level and in fostering progress at international level. Possible first actions include:

- To invite Member country Delegates to express their interest in contributing to expand work to other countries
- To encourage voluntary contributions to construct simple MF indicators for member countries as an input to ongoing work on environmental and sustainable development indicators at national and international level;
- To set up opportunities for further exchanges of experiences and for tracking methodological progress, e.g. by meetings, documentation and electronic communications.

PART I. DEVELOPMENT AND MOST PROMISING USES

HISTORY AND OVERVIEW OF MATERIAL FLOW ANALYSIS[2,3]

1. Material flow analysis and accounting

Material flow analysis (MFA) refers to the analysis of the throughput of process chains comprising the extraction or harvest, chemical transformation, manufacturing, consumption, recycling, and disposal of materials. It is based on accounts in physical units (usually in terms of tons) quantifying the inputs and outputs of those processes. The subjects of the accounting are chemically defined substances (e.g. carbon or carbon dioxide) on the one hand and natural or technical compounds or ‘bulk’ materials (e.g. coal, wood) on the other hand.

MFA has become a fast growing field of research with increasing policy relevance. All studies are based on the common paradigm of industrial metabolism and use the methodological principle of mass balancing. However, there are various methodological approaches which are based on different goals, concepts and target questions, although each study may claim to contribute to sustaining the industrial metabolism. In 1996 the network ConAccount was established to provide a platform for information exchange on MFA (www.conaccount.net). A first inventory on MFA projects and activities was provided (Bringezu et al. 1998a). Several meetings took place (Bringezu et al. 1997a, 1998b, Kleijn et al. 1999) and a research and development agenda was defined through an interactive process (Bringezu et al. 1998c).

MFA has often been linked to the systems perspective of the metabolism of society ("industrial metabolism" coined by Ayres 1989). This paradigm perspective has been rooted in different scientific disciplines (Fischer-Kowalski 1997). MFA has been used for the analysis of biogeochemical cycles and the analysis of natural ecosystems. For the current debate on the necessities and possibilities to sustain the metabolism of industrial economies the analytical approaches to the interactions of man and nature deserve prior attention. To this respect historical traits relate to the report of the "President´s Materials Policy Commission" ("Paley report" 1952), the Princeton conference on "Man´s role in changing the environment" (Thomas 1956), and the Scientific American Issues of Sept. 1970 and Sept. 1971 on substance flows and energetic metabolism.

Pioneering work was performed by Wolman (1965) on the average metabolism of a city. Boulding (1996) stressed the necessary shift from an "cowboy economy" towards a "spaceman economy." The first analyses of material exchange between the US economy and environment had been performed by Ayres and Kneese (1969). Later in the 1980ies the analysis of various substance flows was performed to reduce the risk of exposure to hazardous chemicals such as heavy metals. In the 1990ies the analysis of the total material throughput of economies again attracted attention before the background of the sustainability debate and due to the rising demand for adequate indicators for policy support.

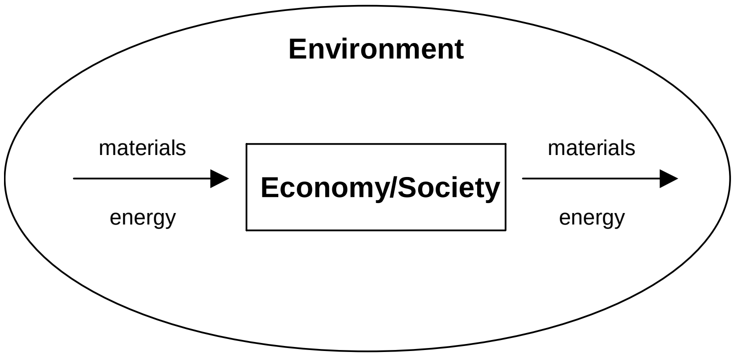
2 Paper prepared by Mr. Stefan Bringezu, Wuppertal Institute.

3. A more detailed description of the methodological issues of MFA together with extended review of the literature is presented in the contribution of S. Bringezu and Y. Moriguchi: Material Flow Analysis. In: R.U. Ayres and L. Ayres: Handbook of Industrial Ecology. Edwar Elgar, forthcoming.

2. Concepts for sustaining the metabolism of economies

The diversity of MFA approaches derives from different conceptual background. The basic concept common to many studies is that the industrial system together with its societal interactions is embedded into the biogeosphere system, thus being dependant upon factors critical for the coexistence of both systems (Ayres and Simonis 1994, Baccini and Brunner 1991) (Figure 1). The paradigm vision of a sustainable industrial system is characterised by minimised and consistent physical exchanges between human society and the environment with the internal material loops being driven by renewable energy flows (e.g. Richards et al. 1994). However, different strategies contribute to develop the industrial metabolism towards a sustainable fashion.

Figure 1. Figure 1. **Physical exchange between economy/society and environment**



One basic strategy may be described as *detoxification* of the industrial metabolism. This refers to the mitigation of the releases of critical substances to the environment by pollution reduction. In a wider sense, this relates to any specific environmental impact such as toxicity to human beings and other organisms, eutrophication, acidification, ozone depletion, global warming etc.. Regulatory governmental actions in terms of substance bans and restrictions of use represented the first measures of environmental policy in the 1970ies and 1980ies. The introduction of cleaner technology aimed primarily at the mitigation of critical releases to the environment. As a consequence of the effectiveness of such measures pollution problems in spatial-temporal short range could be solved. However, transregional and global problems and the problem shifting to future generations as well as the complexity of the industrial metabolism made it necessary to analyse the flows of hazardous substances, selected materials or products in a systems-wide approach, i.e. from cradle-to-grave, and with respect to the interlinkage of different flows.

Another complementary strategy may be regarded as *dematerialisation* of the industrial metabolism. Considering the current quantity of primary resource use by industrial economies an increase of resource efficiency by a factor of 4 to 10 had been proposed (Schmidt-Bleek 1994, Weizsäcker et al. 1995). Meanwhile this goal has been adopted by a variety of international organisations and national governments[4]. The factor concept aims at the provision of increased services and value added with reduced resource requirements[5]. The concept of eco-efficiency includes not only the major inputs (materials, energy, water, area) but also the major outputs to the environment (emissions to air, water, waste) and relates them to the products, services or benefits produced (EEA 1999a, OECD 1998, Verfaillie and

4 On the programme level the factor 4/10 concept was adopted by the special session of the United Nations (UNGASS 1997) and the World Business Council for Sustainable Development (WBCSD 1998). The environmental ministers of OECD (1996) expected progress towards this end. Several countries included the aim in political programmes (e.g. Austria, Netherlands, Finland, Sweden; see also Gardener and Sampat 1998). In scandinavian countries research was launched to test the broad scale feasibility of factor 4/10 (Nordic Council of Ministers 1999). In Germany the draft for an environmental policy programme (BMU 1998) refers to a factor of 2.5 increase in productivity of non-renewable raw materials (1993 to 2020). An increase in eco-efficiency is also being regarded as essential by the environmental ministers of the European Union (1999). The review of the Fifth (environmental) Action Programme (Decision No 2179/98(EC) emphasises resource use and efficiency.

5. Dematerialisation of the economy may imply a mitigation of all hardware products and thus the throughput of the economy as a whole, comprising the use of primary *and* secondary materials. However, dematerialisation may also be directed more specifically to the reduction of the primary inputs and/or final waste disposal.

Bidwell 2000). However, for the environment the reduction of the absolute impacts through material flows is essential. Thus, also the quantity of human induced material flows through the industrial system has to be adjusted to adequate levels of exchange between economy and environment.

3. Impacts of material flows and types of indicators

The impacts of human induced material flows on the environment can be short-term or long-term, direct or indirect, local to global, predictable or unknown. In general, the impacts are determined by the volume (weight flow per time period) and the specific impacts per unit of volume flow. Correspondingly, the impact potentials of material flows can be indicated by volume based and impact based indicators (Table 1).

Figure 2. Table 1. **Indicators for impact potentials of human induced material flows**

Volume based indicators	*Impact based indicators*
e.g.	e.g.
- Energy Requirements	- Global Warming Potential (GWP)
- Material Requirements	- Ozone Depletion Potential (ODP)
- Water Consumption	- Acidification Potential

Impact based indicators exist only for selected specific effects for which quantitative measures are available. Most of them relate to substance releases to the environment (output of the economy/society). Volume based indicators may not be used to indicate specific effects rather than a generic environmental pressure associated with resource consumption. Usually these indicators relate to resource extraction (input of the economy/society).

Both types of indicators are complementary in supporting policy for controlling specific hazards as well as generic impacts of human induced material flows.

4. Types of analysis

Before that background, two basic types of material flow related analyses may be distinguished according to the primary interest, although in practice a continuum of different approaches exists (Table 2). Both types I and II are not strictly coincident with the above mentioned two paradigmatic strategies. However, the importance of the detoxification concept seems highest in Ia and lowest in IIc. Vice versa, the intention to support dematerialisation seems highest in analyses of IIc and lowest in Ia. Nevertheless both complementary strategies are increasingly being combined, especially in Ic and IIa. Whereas type I analyses are often performed from a technical engineering perspective, type II analyses are more directed to the socio-economic relationship.

Type Ia

Substance flow analysis (SFA) has been used to determine the main entrance routes to the environment, the processes associated with these emissions, the stocks and flows within the industrial system as well as the trans-media flows, chemical, physical, biological transformations and resulting concentrations in the environment. Spacio-temporal distribution is of high concern in SFA. Results from these analyses are often used as inputs to further analyses for quantitatively assessing risks to substance-specific endpoints. A variety of studies has been conducted on heavy metals, nutrients, carbon, and halogenated compounds.

Type Ib

Selected bulk material flows have been studied for various reasons. The resource extraction by mining and quarrying was studied to assess the geomorphic and hydrological impacts. The flow of biomass from human production was analysed to evaluate the pressure to species diversity.

Table 1. Table 2. **Types of material flow related analysis (after Bringezu and Kleijn 1997)**

Type of analysis	I			II		
	a	b	c	a	b	c
Objects of primary interest	Specific environmental problems related to certain impacts per unit of flow of			Problems of environmental concern related to the throughput of		
	Substances	Materials	Products	Firms	Sectors	Regions
	e.g. Cd, Cl, Pb, Zn, Hg, N, P, C, CO2, CFC	e.g. wooden products, energy carriers, excavation, biomass, plastics	e.g diapers, batteries, cars	e.g. single plants, medium and big companies	e.g. production sectors, chemical industry, construction	e.g. total or main throughput, mass flow balance, total material requirement
	within certain firms, sectors, regions			associated with substances, materials, products		

On the one hand metals like aluminium, timber products like pulp and paper, construction aggregates represent important base materials for industrial purposes. On the other hand these flows – although per se rather harmless - may be *linked* with other flows significantly burdening the environment. For instance, the ‘red mud’ problem with alumina production and the energy intensive production of aluminium. Base materials such as plastics have been subject to various studies on the potentials and environmental consequences of recycling and cascading use.

Type Ic

When the environmental impacts of certain products and services is the primary interest in the approach is normally addressed as Life Cycle Assessment (LCA). In general, the system boundary of LCA (`cradle-to-grave´) corresponds with the systems perspective of the anthroposphere, technosphere or physical economy.

Type IIa

Following the sequence of Table 2 the primary interest may lie in the metabolic performance of a firm or household, a sector or a region. In this case, there may be no or insufficient information about specific environmental problems. Often the main task is to evaluate the throughput of those entities in order to find the major problems, support priority setting, check the possibilities for improvement measures and provide tools for monitoring their effectiveness.

Accounting for the physical throughput of a firm is becoming a more and more regular feature at least for bigger companies, as it is sometimes found in corporate environmental reporting. Materials accounts are used for environmental management. Attention is paid to indicate eco-efficiency on the firm level[6]. Flow analyses of materials have been applied for optimisation within companies. However, the limited scope of firm accounts calls for complementary analyses with a wider systems perspective, either through LCA type analyses for infrastructures and main products or by analyses of higher aggregates of production and consumption, i.e. analyses of total production sectors or whole economies.

Type IIb

When the primary interest is devoted to certain industrial sectors or fields of activity, MFA may be used to identify the most critical fluxes in terms of quality and/or quantity. For instance, different industrial sectors may be compared with regard to various inputs and outputs either from other sectors or the environment. Certain sectors or activities may be analysed in detail, e.g. the construction sector or activities such as nutrition, cleaning, dwelling and working, transport and communication.

Type IIc

A major field of MFA represents the analysis of the metabolism of cities, regions, and national or supranational economies. The accounting may be directed to selected substances and materials or to total material input, output and throughput. "Economy-wide MFA" on the national level has attracted special attention (see below). The main interest lies in the overall characterisation of the metabolic performance of the studied entities, in order to understand the volume, structure and quality of the throughput and to assess the status and trend with regard to sustainability.

The term *MFA* has usually been referred to analyses of type Ia, Ib, IIb, and IIc. Studies of type Ic are being dealt with under the heading of LCA. Accounting of type IIa is mainly related to environmental management. There are also combinations of regional and product oriented analyses. Nevertheless, all of those analyses use the accounting of material inputs and outputs of processes in a quantitative manner, and many of them apply a systems or chain perspective.

5. Use of material flow related analyses

In general MFA provides a system-analytical view of various interlinked processes and flows to support the strategic and priority oriented design of management measures. Following the history of environmental protection since the sixties, Type Ia analyses were applied to control the flow of hazardous substances. The results contributed to public policy in different ways (Bovenkerk 1998 and Hansen 1998):

- The analyses assisted in finding a consensus on the data which is an important pre-requisite for policy measures.
- MFA lead to new insights and to changes in environmental policy[7].
- The analyses discovered new problems (e.g. the mercury stocks in chlorine plants).
- They also contributed to find new solutions (e.g. source oriented input reduction in the case of non degradable substances).

The use and policy relevance of Type II analyses has been increased in recent years in the following aspects (Bringezu 2000):

- the support for policy debate on goals and targets, especially with regard to the resource and eco-efficiency debate and the integration of environmental and economic policies,
- the number of companies performing firm and product accounts,
- the provision of economy-wide material flow accounts for regular use by official statistics,

6. See WBCSD publications, for method overview and pilot study results Verfaillie and Bidwell (2000), for program activities Executive Brief Jan. 99'Measuring eco-efficiency with cross-comparable indicators', Geneva, www.wbcsd.ch.
7. e.g. abandoning the aim of closed chlorine cycling in favour of controlling the most hazardous emissions.

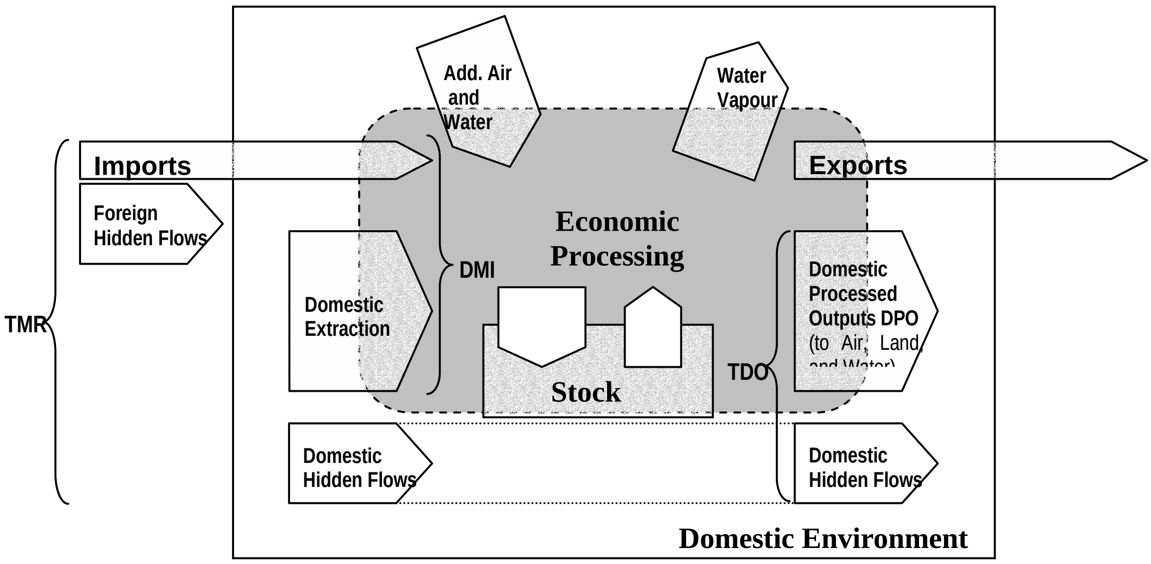
– the derivation of indicators for progress towards sustainability.

6. Economy-wide MFA

Material flow accounts may quantify the physical exchange of national economies with the environment[8]. Aggregated material flow balances comprise domestic resource extraction and imports (inputs) and domestic releases to the environment and exports (outputs) (FIGURE 2). Upstream or downstream flows associated with imports and exports (resource requirements or emissions) may also be accounted. A sectoral disaggregation can be provided by physical input-output tables.

MFA was applied by official statistics within the framework of integrated environmental and economic accounting (SEEA) and a methodological guide has been prepared by EUROSTAT (2000). National material accounts exist for Austria, Denmark, Germany, Finland, Italy, Japan, the Netherlands, Sweden, United Kingdom and USA. Work is ongoing for China, Egypt, and Amazonia.

Figure 3. Figure 1. **Economy-wide material flows (prepared by IFF for Matthews et al. 2000)**



7. MFA based indicators

Material flow accounts provide an important basis for the derivation of environmental indicators and indicators for sustainability (Berkhout 1999, Jimenez-Beltran 1998, Ministry of the Environment 1999). In order to monitor and assess the environmental performance of national and regional economies a variety of indicator systems has been proposed (Moldan et al. 1997). As a framework the Driving Force-Pressure-State-Impact-Response[9] (DPSIR) scheme has been established (EEA 1999, 1999a, OECD 1998a). The extraction of resources on the input side and the release of emissions and waste on the output side relate to environmental pressures, (sectoral) activities represent driving forces, the flows may change the state of environment which give rise to various impacts and the societal or political response may influence the metabolic situation towards sustainability.

8. After the first comprehensive approaches of Ayres and Kneese (1969), domestic MFA had been established independently for Austria (Steurer 1992), Japan (Japanese Environmental Agency 1992) and Germany (Schuetz and Bringezu 1993).

9. Since the early nineties as PSR used especially by OECD.

MFA based indicators have been introduced to official reports to provide an overview on the headline issues of resource use, waste disposal and emissions to air and water as well as eco-efficiency (EEA 2000, DETR 1999, Hoffren 1999).

On the one hand, economy-wide material flow accounts provide a more comprehensive picture of the industrial metabolism than single indicators. On the other hand, they can be used to derive several parameters which - when taken in time series and for international comparison - provide certain aggregated information on the metabolic performance of national or regional economies (Figure 2). First international comparisons have been provided on input and resource efficiency indicators by Adriaanse et al. (1997), on output and balance indicators by Matthews et al. (2000).

Input indicators

Direct Material Input (DMI) measures the input of used materials into the economy, i.e. all materials which are of economic value and are used in production and consumption activities; DMI equals domestic (used) extraction plus imports. Materials which are extracted by economic activities but that do not normally serve as input for production or consumption activities (mining overburden, etc.) have been termed ‘hidden flows’ or ‘ecological rucksacks’[10]. They are not used for further processing and are usually without economic value. DMI plus unused domestic extraction comprises Total (domestic) Material Input.

Total Material Requirement (TMR)[11] includes, in addition to TMI, the upstream hidden material flows which are associated with imports and predominantly burden the environment in other countries. It measures the total ‘material base’ of an economy, i.e. the total primary resource requirements of the production activities. Adding these upstream flows converts imports into their ‘primary resource extraction equivalent’.

Data for TMR and DMI (incl. composition, i.e. input structure of the industrial metabolism) have been provided for China, Germany, Netherlands, Japan, USA, Poland, Finland and the European Union. DMI is available for Sweden. Work is ongoing for Italy and Amazonia. TMI was accounted for Australia.

Output indicators

*Domestic Processed Output (DPO***)** represents the total mass of materials which have been *used in the domestic economy*, before flowing into the environment. These flows occur at the processing, manufacturing, use, and final disposal stages of the economic production-consumption chain. Exported materials are excluded because their wastes occur in other countries. Included in DPO are emissions to air from commercial energy combustion and other industrial processes, industrial and household wastes deposited in landfills, material loads in wastewater, materials dispersed into the environment as a result of product use (dissipative flows), and emissions from incineration plants. Material flows recycled in industry are not included in DPO.

*Total Domestic Output (TDO)***:** The sum of DPO and disposal of unused domestic extraction. This indicator represents the total quantity of material outputs to the environment released on the domestic territory by economic activity. *Direct Material Output (DMO):* The sum of DPO and exports. This parameter represents the total quantity of direct material outputs leaving the economy after use either towards the environment or towards the rest of the world. *Total Material Output (TMO)* includes also exports and therefore measures the total of material that leaves the economy; TMO equals TDO plus exports.

10. Hidden flows (Adriaanse et al. 1997) or rucksack flows (Schmidt-Bleek et al. 1998, Bringezu et al. 1996) comprise the primary resource requirement not entering the product itself; hidden flows of primary production = unused domestic extraction; hidden flows of imports = unused and used predominantly foreign extraction associated with the production and delivery of the imports.

11. In studies before Adriaanse et al. (1997), TMR had been defined as TMI (Total Material Input) (Bringezu 1997).

Consumption indicators

Domestic material consumption (DMC) measures the total amount of material directly used in an economy, excluding hidden flows. DMC equals DMI minus exports.

Total material consumption (TMC) measures the total primary material requirement associated with domestic consumption activities. TMC equals TMR minus exports and their hidden flows.

Balance indicators

Net Additions to Stock (NAS) measures the physical growth rate of an economy. New materials are added to the economy's stock each year (gross additions) in buildings and other infrastructure, and materials incorporated into new durable goods such as cars, industrial machinery, and household appliances, while old materials are removed from stock as buildings are demolished, and durable goods disposed of.

Physical Trade Balance (PTB) – measures the physical trade surplus or deficit of an economy. PTB equals imports minus exports. Physical trade balances may also be defined including hidden flows associated with imports and exports (e.g. on the basis of TMC accounts).

Efficiency indicators

Services provided or economic performance (in terms of value added or GDP) may be related to either input or output indicators to provide efficiency measures. For instance, GDP per DMI indicates the Direct Materials Productivitiy. GDP per TDO measures the economic performance in relation to material losses to the environment. Setting the value added in relation to the most important inputs and outputs provides information on the eco-efficiency of an economy. The interpretation of those relative measures should always consider the trends of the absolute parameters. The latter are usually also provided on a per capita basis to support international comparison.

MFA and its indicators are going to provide the basis for political measures and the evaluation of their effectiveness. For that purpose bulk material flow analyses and substance flow analyses can be combined, and the monitoring of progress towards sustainability could be gradually improved in a stepwise approach.

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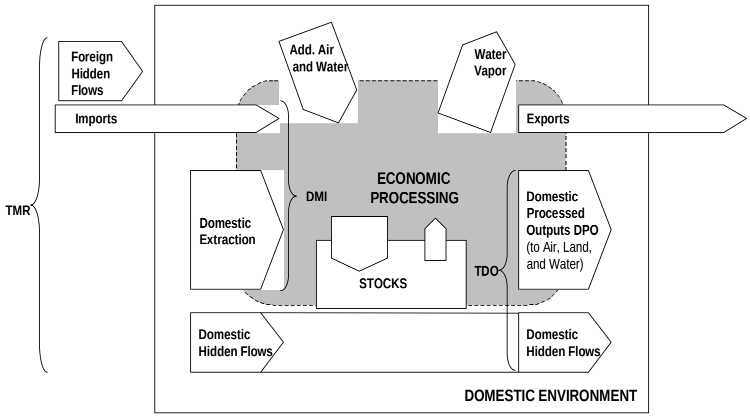
INTERNATIONAL COMPARISON OF INFLOWS AND OUTFLOWS[12]

The examples below are based on the report "The Weight of Nations: Material Outflows from Industrial Economies" published in September 20, 2000. They present the results of an international research project whose goal is to establish a complete set of physical accounts for each participating country, documenting resource inputs and waste outputs in tonnes and paralleling monetary accounts. "The Weight of Nations" documents waste flows and hidden flows and is a follow up to the report "Resource Flows: The Material Basis of Industrial Economies", published in 1997 and focusing on inputs. It builds on an international collaboration between the WRI and other research institutes in Europe and Japan including: the Wuppertal Institute, Germany; the University of Vienna, Department of Social Ecology, Austria; the University of Leiden, Centre of Environmental Science, the Netherlands; the National Institute for Environmental Studies, Japan.

THE MATERIAL FLOWS CYCLE



DMI (Direct Material Input)
= Domestic Extraction -+ Imports
TMR (Total Material Requirement)
= DMI + Domestic Hidden Flows + Foreign Hidden Flows
DPO (Domestic Processed Output)
= DMI – Net Additions to Stock - Exports
TDO (Total Domestic Output)
= DPO + Domestic Hidden Flows
NAS (Net Additions to Stock)
= DMI – DPO - Exports

- Absolute size of flows (conventional and hidden)
- Use vs. waste
- Composition of flows (dominance of energy system, hazardous materials)
- Links to economy and population (concept of decoupling)

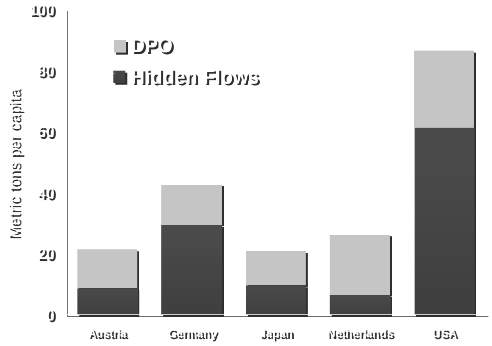
MATERIAL FLOWS TRACKED FOR THE STUDY

Non-Renewable Material Flows	**Industrial Minerals**	**Metals**	**Fossil Fuels**
	Asbestos	Aluminum	Liquid
	Bromine	Arsenic	Natural gas
	Clay	Cadmium	Solid
	Fluorspar (fluorine)	Chromium	Coal combustion products
	Gypsum	Copper	
	Nitrogen (ammonia)	Gold	
	Phosphate	Iron metal (steel)	
	Potqash	Iron and steel slag	
	Salt	Lead	
	Chlorine	Manganese	
	Caustic soda	Mercury	
	Sand and Gravel, Industrial	Molybdenum	
	Soda ash	Nickel	
	Sulfur	Tin	
		Zinc	
	Construction Materials	**Movements of Earth**	**Nonrenewable Organic Material**
	Crushed stone	From soil erosion	Petroleum
	Cement	For highway construction	Asphalt
	Lime	For general construction	Petrochemicals
	Sand and gravel	From dredging operations	Plastics and resins
			Medical chemicals
			Synthetic rubber
			Petroleum coke
Renewable Material Flows	**Agriculture**	**Forestry**	
	Animal biomass and manures	Natural rubber	
	Crops biomass	Wood products	
	Human wastes and manures	Paper and pulp products	

12 Presentation prepared by Ms. Emily Matthews, World Resources Institute (WRI). See also: http://wri.igc.org/materials/ and Matthews, Emily, C. Amann, S. Bringezu, M. Fischer-Kowalski, W. Hüttler, R. Kleijn, Y. Moriguchi, C. Ottke, E. Rodenburg, D. Rogich, H. Schandl, H. Schütz, E. van der Voet, H. Weisz (2000), The weight of nations: Material outflows from industrial economies, WRI, Washington D.C.

International Comparison of Material Flows

Total Domestic Output, 1996

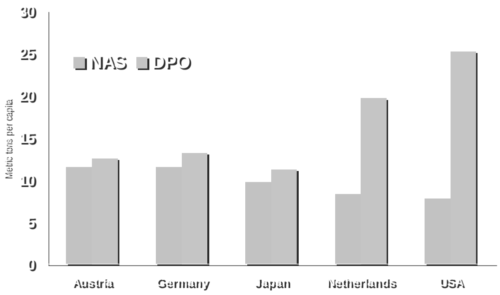


Comparing countries by using per capita data shows the following:

- The U.S., the biggest economy, generates the biggest flows with the mining, construction and agriculture sectors generating large hidden flows.
- Conventional wastes (emissions, discharges, solid wastes, system losses). i.e. Domestic Processed Output (DPO) are more directly comparable across countries.

N.B. The size of flows is not a measure of environmental impact. Macro-indicators of flows are physical descriptors of an economy, just as GDP and other economic indicators are monetary descriptors of the economy. The size of flows, however, and in particular changes over time (growing or shrinking) are a good proxy indicator of an economy's demands on the resource and assimilative capacity of the environment.

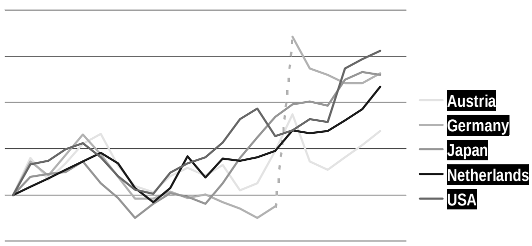
Net Additions to Stock, and Domestic Processed Output, 1996



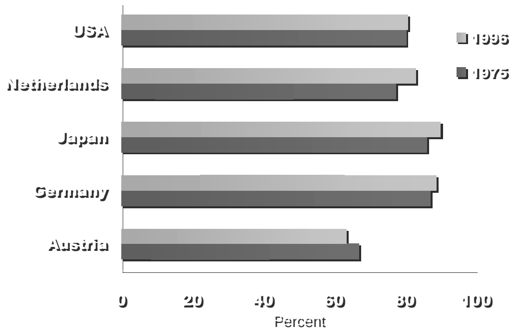
The second chart shows the following.

- The proportion of material that is retained in the economy vs. material that is lost as waste outputs: the ratio of net additions to stock to outflows. In the U.S. the ratio is about 1:4 reflecting a high throughput rate, and a relatively low recycling rate
- The actual quantities of material going to stock appear to be higher in Europe on a per capita basis. Interpretation of these figures is however not easy; they may reflect differences in building practices (bricks and stone in Europe, versus wood frame construction favoured in much of US).

CO2 Output from Fossil Fuel Combustion and Industrial Processes, Index, 1975-96



CO2 Output as a Percentage of DPO, 1996

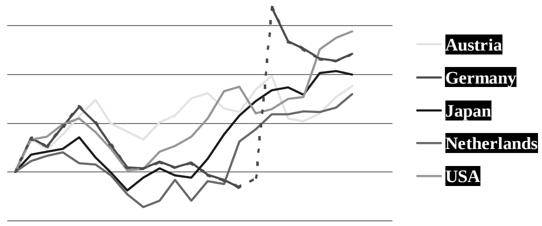


Carbon dioxide from fossil fuel combustion and other industrial processes accounts for over 80% by weight of material outflows from industrial economies (excluding hidden flows). This proportion has not changed much since 1975. Austria is a partial exception, because the country has implemented policies to encourage the use of biomass and energy efficiency. Carbon emissions resulting from biomass combustion are not included in the accounting of outflows in our project, because they are assumed to be carbon neutral (compensated by planting biomass crops).

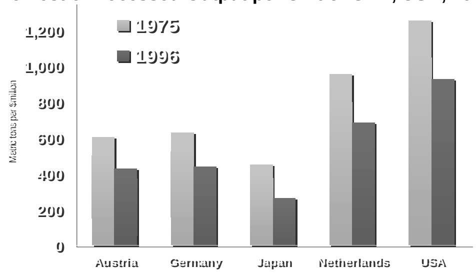
MATERIAL FLOWS AND DECOUPLING

A big issue in documenting resource throughput is that of decoupling. Are industrial economies becoming more efficient; do they use fewer resources and generate less waste to produce the same amount of wealth?

Domestic Processed Output, Index, 1975-96

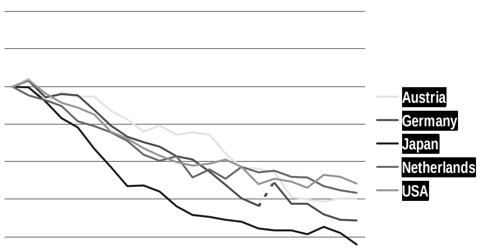


Domestic Processed Output per Unit of GDP, USD, 1975, 1996



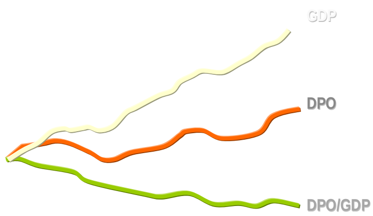
The data reflect an important decline in tonnes of wastes generated per unit of GDP (million constant USD) between 1975 and 1996, though DPO in absolute terms has increased over the same period.

Decoupling between Material Outputs and GDP, 1975-96

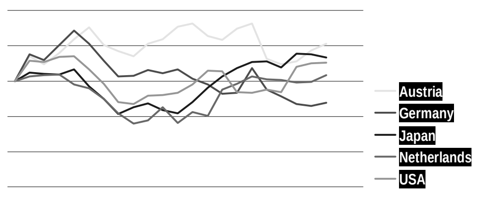


Decoupling between Material Outputs and GDP in the U.S., 1975-96

GDP has risen 74%; outflows by about 30% reflecting some decoupling between outputs and economic growth (DPO/GDP).

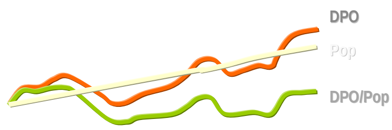


Decoupling between Material Outputs and Population, 1975-96



Decoupling between Material Outputs and Population in the U.S., 1975-96

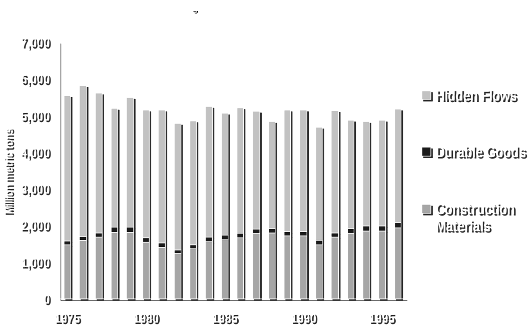
Population grew by about 25%; waste outputs by about 30%. No decoupling from population growth; waste generation per capita today is slightly higher than in 1975.



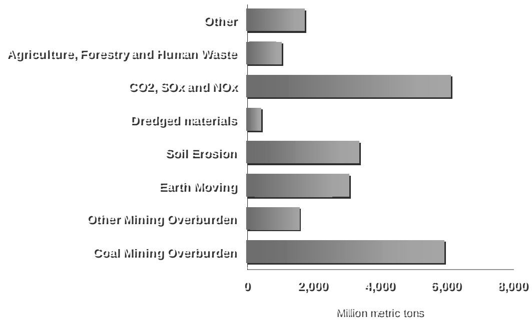
Detailed Composition of Flows: the U.S. example

Material flow data can be disaggregated in a number of ways as shown in the examples below based on data for the U.S. .

A. Stock Materials and Associated Hidden Flows, 1975-96



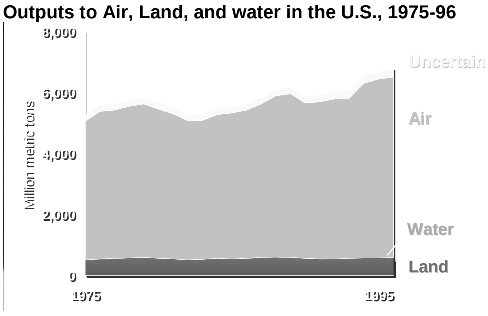
B. Composition of Total Domestic Output, 1996



The more detailed composition of U.S. flows shows the importance of hidden flows, and the dominance of energy related flows, coal mining wastes and CO2 emissions, that together account for about half of the total material outflows in U.S.

A disaggregation of outputs by environmental media (air, land, water) shows that.

Outputs to Air, Land, and water in the U.S., 1975-96

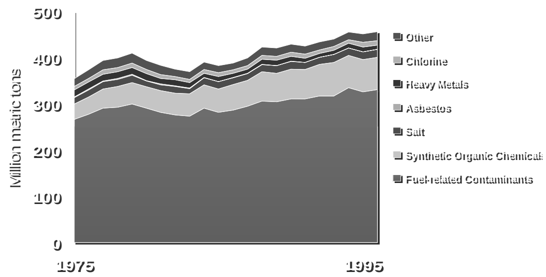


- Outputs to air are dominated by fossil fuel combustion and rise with increased consumption.
- Outputs to land are relatively stable.
- Outputs to water are poorly documented.

N.B.: "Uncertain" refers to materials for which fate in environment cannot be determined.

Selected individual flows in the U.S.

Potentially Hazardous Outflows to the U.S. Environment, 1975-96

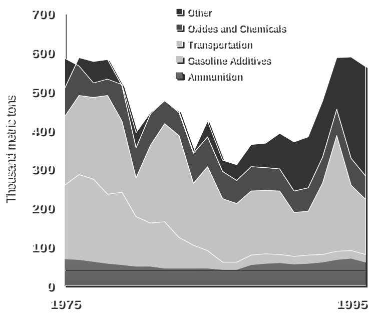


This chart shows not just substances officially listed as hazardous - regulated or listed under the Toxic Release Inventory (TRI) - but all materials that are potentially harmful in the environment.

Many of these substances occur not at the processing or manufacturing stage, but further up or downstream. Many of them are embodied in products.

NB: the category of fuel-related contaminants contains over 200 flows, but is dominated by coal fly ash, methane leaks, and oil spills.

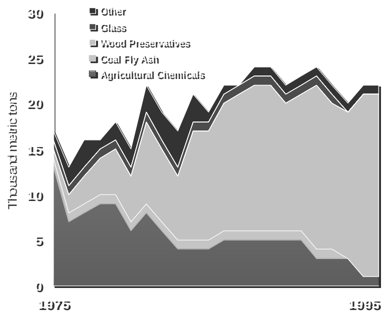
Lead Outputs to the U.S. Environment, 1975-96



This chart shows the influence of regulation on airborne lead emissions from gasoline use that were largely eliminated. Overall outflows have not declined. A major new application in the "other" category is electrical and electronic goods, notably computer monitors.

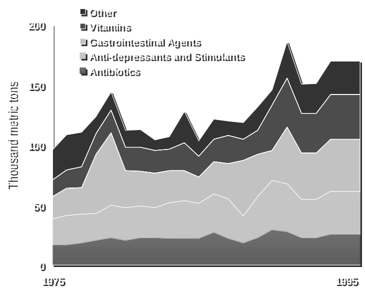
N.B.: The 1994 spike in transportation use (lead acid batteries) is a data anomaly.

Arsenic Use in the U.S., 1975-96



Arsenic use in US: largely regulated out of agricultural pesticides but increasingly used in pressure treated wood products. Currently this material held in stock but at end of useful life (15-30 years) wood is chipped, or burned, or landfilled. Arsenic will be going up in the air, or leaching out into soil and groundwater.

Medical Chemical Outputs to the U.S. Environment, 1975-96



Medical chemicals are a "watch this space" set of flows. US consumption is increasing. Many medical chemicals that are highly biologically active end up in the soil and in water.

MATERIAL FLOW ACCOUNTING:
The experience of Canada[13]

1. Introduction

The Canadian initiative to develop environmental and resource accounts had its origins with exploratory work carried out during the late 1970s and early 1980s (Friend and Rapport, 1979; Friend, 1981). At that time, data representing the interactions between human activity and the environment were recorded using the Stress-Response Environmental Statistical System. This framework had as its focus the physical measurement of the environment's response to various human stresses. Although useful as a means of organising physical data, the framework did not attempt to incorporate monetary data or to provide links to the economic variables most often employed in policy development; namely, the variables of the Canadian System of National Accounts (CSNA).[14]

Building on this early work, the Canadian System of Environmental and Resource Accounts (CSERA) has been developed with the specific objective of organising physical and monetary statistics related to natural resources and the environment using classifications, concepts and methods that are compatible with those of the CSNA. Thus, the statistics of the CERA can in large part be directly integrated with those of the CSNA. The integration of these two data sets—one environmental, the other economic—represents a significant milestone in assessing economic activity and its dependence upon the natural environment. This capacity is particularly relevant today, given the increasing focus of governments, businesses and individual Canadians on the objectives of sustainable development.

The main objective of this paper is to present one component of the CSERA: the Material and Energy Flow Accounts. These accounts record the flows of materials and energy—in the form of natural resources and wastes—between the economy and the environment. The two other components of the System, the Natural Resource Stock Accounts and the Environmental Protection Expenditure Accounts, are described in detail in Statistics Canada (1997).

2. Material and Energy Flow Accounts in Canada

The Material and Energy Flow Accounts (MEFA) record in substantial detail the annual flows of materials and energy—in the form of resources and wastes—between the Canadian economy and the environment. The accounts record the quantities of natural resources produced (that is, harvested or extracted) by industries, households and governments, and show how these resources are consumed by these same agents. Likewise for wastes, the accounts show the quantities produced by each agent and how these wastes are "consumed," either as recycled materials or as flows into waste disposal sites or to the environment. The MEFA share their classifications of industries, households and governments with Statistics Canada's Input-Output Accounts (Statistics Canada, 1999). This allows the environmental data in the MEFA to be linked directly and easily with the economic data found in the Input-Output Accounts, adding value to both data sets.

The true strength of the MEFA is that detailed data on resource and waste flows are directly linked with the rich body of economic statistics available. The analytical power that this linkage offers,

13. Paper prepared by Mr. Martin Lemire, Statistics Canada, and based on previous work done by Statistics Canada (1997). Consequently, opinions expressed here reflect those of Statistics Canada.

14. The CSNA, which has a history of more than 40 years, is the source of a number of Statistics Canada's most important indicators of economic activity, including Gross Domestic Product.

within the well-established and widely-used framework of the CSNA, contributes substantially to our ability to study the Canadian economy and the demands it places on the environment. Such understanding has an important role to play in the informed management of the economy toward the simultaneous realisation of our economic and environmental goals. This linkage allows the calculation of important indicators of the resource and waste intensiveness of economic activity.

The MEFA are compiled using the sectoral classifications of the Input-Output Accounts. Likewise, the geographical scope of the MEFA is national and the frequency with which they are compiled is annual, matching the scope and frequency of Input-Output Accounts.

2.1 Why account for materials and energy?

The rationale for developing the MEFA rests on arguments that economic use of the environment has exceeded (or is approaching) critical thresholds. Although human degradation of the environment is not new, there are both qualitative and quantitative differences between the environmental impacts of economic activity in the past and those of today. A major difference is that of scale. While the environmental degradation that occurred in ancient times was mainly localised and attributable to a few activities, today it is wide spread and associated with myriad activities. Another important distinction is the fact that the environment has essentially no assimilative capacity for many of the waste materials released from modern economic activities. For example, the family of chemicals known as the halocarbons best known for their role in depletion of the ozone layer have atmospheric lifetimes that range from a few thousand to tens of thousands of years.

Consequently, it is clear that economic activity has long since passed the point where the environment can be taken for granted as a source of resources and a dump for wastes. Both local and global environmental capacities to absorb wastes are being pressed upon today in unprecedented ways. Likewise, the environment’s capacity to supply the resources needed to meet the economy’s growing material demands is increasingly being exceeded. The measurement of the quantity of material and energy flows in the Canadian economy and the “intensity” with which we use the environment has thus become essential.[15]

It is perhaps easier to make a case for the importance of the MEFA in terms of what they reveal about our waste flows than what they reveal about the production and consumption of resources. Most people are familiar with the impacts of waste from first hand experience of air, water and land pollution; fewer directly feel the environmental impacts of excessive resource use. A reasonable person might therefore ask, “Is there as compelling a reason to account for resources as there is for wastes?” Two arguments suggest there is.

First, although Canada is not in immediate danger of running out of most of its natural resources, there are certain instances where our resource stocks have been depleted almost, or completely, to extinction. The disappearance of commercially viable stocks of northern cod off the East Coast is perhaps the best recent example of this. One could cite as well the near disappearance of old-growth forests across the country and the slow, but continual loss of prime agricultural land to urban development. In such cases, it is important to measure both how much of the remaining resources we are consuming and how they are being consumed. Even for resources that are abundant in supply, it is sensible to monitor use, particularly for non-renewable resources that will, by definition, run out one day. The MEFA are designed to provide measures of resource use that can facilitate monitoring of this sort.

The second argument in favour of measuring resource flows is related to the concerns already raised with respect to waste production. This is quite simply that the quantity of waste produced by economic activity is directly related to the quantity of raw materials and energy consumed in the first place. The basic law of conservation of mass and energy demands that all material and energy entering the econ-

15. In this context, intensity is taken to be the degree to which the environment is used as a source of raw materials or a sink for wastes per unit of economic output.

omy must leave it again at some point (or be permanently stored within it). Thus, any problem of excessive waste *output* is in the first place one of excessive material and energy *input*.

3. The MEFA accounting framework

Flows of produced goods and services are well articulated in monetary terms in the existing national accounts. The Input-Output Accounts provide annual estimates of the production and consumption of 476 commodities by 167 industries and 122 categories of final demand (Statistics Canada, 1999). The Material and Energy Flow Accounts build on this substantial detail by incorporating physical estimates of natural resource and waste flows into the accounting framework of Statistics Canada's Input-Output Accounts. In modifying the framework to make it suitable for the MEFA,[16] several objectives were sought.

- The framework should be structured in such a way that it is suitable for recording *all* material and energy flows related to economic activity, regardless of the nature of this relationship.[17]
- The framework should represent both the production *and* consumption of materials and energy. In doing so, the traditional accounting identity between production and consumption should be respected.
- All sectors of the economy should be covered in the framework. The definitions of these sectors should conform with those of the CSNA.
- The framework should facilitate the integration of material and energy flow data with the economic statistics in the Input-Output Accounts.

3.1 Benefits of the input-output framework

The benefits of using input-output accounting frameworks to analyse material and energy flows have long been recognised. Corresponding with the environmental movement of the late 1960s, several economists suggested the use of input-output techniques for environment-economy analysis (Cumberland, 1966; Daly, 1968; Isard, 1969; Ayres and Kneese, 1969; Leontief, 1970; and Victor, 1972). The work of Victor in particular has influenced the approach to material and energy flow accounting taken in the MEFA. His work represents the most comprehensive of the original frameworks and, importantly, he employed Statistics Canada's input-output accounting framework in his study.

Despite the relatively long-standing interest in the use of input-output techniques for environment-economy analysis, there was not a great deal of empirical development in the field during the 1970s and 1980s. Indeed, one of the authors cited above noted for his contributions to the field of material and energy analysis over the last three decades found cause to note that the "approach deserves much greater attention that it has received to date" (Ayres, 1996). There are several reasons why the approach is worthy of attention.

To begin with, the Input-Output Accounts are very detailed. At their most elaborate, they present production and consumption statistics for 243 industry groups, 679 commodity groups and 162 categories of final demand, in both current and constant dollar measures.[18] This detail is of great benefit when analysing material and energy flows. It allows one to move beyond highly aggregated measures, such as total energy use per unit of GDP, that are sometimes proposed as environmental indicators. Changes from year to year in such "economy-wide" indicators can be difficult to interpret because so many factors are at play. For example, a decrease in energy use per unit of GDP might result from a real increase in the energy efficiency of production processes, or it might result from a reduction in the contribution of energy

16. Full details of the modify framework are available in Chapter 4 of Statistics Canada, 1997, Concepts, Sources and Methods of the Canadian System of Environmental and Resource Accounts, Catalogue No. 16-505-GPE, Ottawa.

17. Economic activity in this context includes all human activities associated directly or indirectly with the production or consumption of commodities.

18. The accounts are actually produced at three different levels of aggregation. Many data at the most detailed level are not publicly available, as the legal requirement to protect respondents' confidentiality prevents their release. Thus, the accounts are released to the public at the so-called "medium" level of aggregation.

intensive industries to the total output of the economy. Determining which factor is the actual cause is difficult. In contrast, when energy use is measured for individual industries, the effect of the changing structure of the economy is largely eliminated. A decrease in energy use per unit of GDP for the electric power industry, for example, can be interpreted unambiguously as an increase in the energy efficiency of electric power production processes.

Another reason for choosing the Input-Output Accounts as the basis for the MEFA is that they are flow accounts. This means that many of the concepts already well defined in the Input-Output Accounts are easily transferred to the MEFA (which, as their name implies, are also flow accounts). Production in the Input-Output Accounts, for example, is defined as the fabrication of goods and services for sale in the open market. It is not a significant leap to adapt this concept for use in the MEFA; three extensions suffice:

- the measurement of production must be allowed in physical units as well as monetary units;
- non-traded resource flows for self-consumption purposes must be treated as production; and
- the production of unwanted "bads" (wastes) along with the production of "goods" must be recognised.

The fact that many of the concepts of the Input-Output Accounts can be transferred to the MEFA enhances the degree to which the data from the two sets of accounts can be integrated. This, in turn, enhances the analytical power of the MEFA.

Another important benefit of linking to the Input-Output Accounts is the fact that these accounts have been produced annually by Statistics Canada for over 30 years. Moreover, since they form a cornerstone of the CSNA, a great deal of effort is put into ensuring that they are as reliable, consistent and comparable as possible. Thus, the Input-Output Accounts represent a rich data set to draw on for the development of historical material and energy flow accounts. Equally importantly, Statistics Canada is committed to continued production of the Input-Output Accounts for the foreseeable future. Indeed, current plans call for the expansion of their scope to include annual provincial input-output accounts in addition to the current national versions.

Despite these strengths, one limitation of the Input-Output Accounts should be mentioned. This is the fact that the accounts are only released four years after the reference year. This delay is explained by two factors. One is simply their complexity—the enormous detail they present demands a long time to amass. The other is the aforementioned fact that the Input-Output Accounts are used as Statistics Canada's benchmark estimate of GDP. Because they represent the "final word" on GDP, the Input-Output Accounts cannot be completed until the most detailed source data are available in final form. In the case of some sources (income tax files for example), this can take several years. The delay in releasing the Input-Output Accounts means that the MEFA cannot be used for analysis of material and energy flows within the last four years. Of course, it is possible to compile material and energy flow data for more recent years, just not to combine these data with input-output data.

4. Uses of the Material and Energy Flow Accounts

Considerable use has already been made of MEFA data in university research projects. Other researchers accustomed to using Statistics Canada's economic data and concepts also find the MEFA useful, as their classifications allow easy incorporation of material and energy flow data into existing models built around these concepts.

Journalists as well may find the MEFA of interest, particularly for the new context that they provide for reporting on the economy. In addition to the economic indicators that journalists are accustomed to using from Statistics Canada (GDP, unemployment rates, inflation rates and so on), the MEFA provide important environment-economy indicators that shed additional light on the nature of economic development in Canada. These are quantitative measures that define the extent to which the economy places demands on the environment as a source of raw materials and as a sink for waste materials.

As for policy use of material and energy flow indicators, it is still not clear how these indicators are used in Canada for setting national policy. At the micro-level, the work has focused on eco-efficiency and material intensities in enterprises.

5. Material and Energy Flow Indicators

The indicators that could be developed from the MEFA include:

- resource intensity of industrial output
- resource intensity of household consumption
- resource intensity of net exports
- waste intensity of industrial output
- waste intensity of household consumption
- waste intensity of net exports
- renewable energy as a proportion of total energy production
- recycled proportion of total resource use (in progress)

The rationale underlying all of these indicators is, as argued above, that current material and energy flows approach or exceed those that are environmentally sustainable in the long-term. The indicators have been selected as key variables to monitor in this regard as the economy develops over time. Each one considers an important aspect of the economy's use of the environment as a source of material or as a sink for wastes. By uniting the environmental data in the MEFA with the economic data in the Input-Output Accounts, these indicators tell us how our economy is developing with respect to its demands on the environment. While they cannot themselves answer the question "What is a sustainable level of material and energy flows?", they can demonstrate broadly whether the economy is heading toward or away from environmental sustainability. Other things equal, if fewer demands are placed on the environment (in terms of resource and waste flows) per unit of economic output over time, the development path is leading toward sustainability. As more scientific information regarding the environment's capacities to provide resources and absorb wastes becomes available, these indicators will allow more concrete statements about the absolute environmental sustainability of the economic activity to be made.

A core set of material and energy flow indicators based on the MEFA is published annually along with other economy-environment indicators developed by Statistics Canada. These environment-economy indicators provide important counterparts to the long-standing economic indicators published by Statistics Canada. Their creation makes it possible now to consider the development of the economy *vis à vis* our economic goals while at the same time considering the accompanying growth (or decline) in resource consumption and waste production. The environment-economy indicators allow this by answering questions of the following sort:

- what raw materials and energy are consumed by the economy, in what quantities and by whom;
- what is the "intensity" of our resource use; that is, how much raw material and energy is required to produce one unit of economic output;
- what waste products are emitted from the economy, in what quantities and by whom;
- what is the "intensity" of our use of the environment for waste absorption; that is, how much waste is released per unit of economic output;

- is resource use/waste output increasing or decreasing over time, both in absolute terms and per unit of output;
- what wastes are recycled, in what quantities and by whom; how much raw material and energy input is avoided by the use of recycled wastes?

6. Data gaps

Despite the substantial progress made in compiling material and energy flow data for the MEFA, significant gaps remain in the coverage of the accounts, particularly for waste flows. The following areas in which existing data are weak or there is a complete lack of data can be noted.

- Reliable, detailed data on the quantities of non-toxic solid waste (e.g. household solid waste) generated and recycled in Canada do not exist. Those data that do exist are not highly detailed with respect to material composition. More detrimental from the perspective of the MEFA, the data do not classify solid waste flows according to producer. Instead, they generally report just a single measure dubbed “municipal solid waste”, which includes all solid waste collected by, or on behalf of, local municipalities and disposed of in local landfill sites. This aggregate comprises part or all of the solid waste generated from households, light industrial and commercial establishments, office buildings, public institutions and government operations. In the absence of information with which to disaggregate these flows according to producer, aggregate solid waste data are not suitable for use in the MEFA.
- Waterborne waste data are weak for all sectors of the economy, particularly for sewage flows. Although some data exist on the quantities and composition of sewage treated in municipal sewage treatment plants, these data suffer from the same problem as the solid waste data described above. That is, the data do not detail the composition of the sewage, and they do not distinguish sewage flows according to producer.
- Data on the production of durable-good wastes are almost entirely lacking. Although the possibility exists to model these waste flows using historical data on purchases of durable goods, this approach is currently unproven.
- Data on leakages from waste inventories are inadequate. Only some rather crude estimates have been made for methane emissions from landfill sites. Estimates of other gaseous emissions and liquid leachates from landfill sites are unavailable.
- Data on public sector waste production are almost entirely lacking. This includes data describing the wastes generated in government office buildings, those associated with the operation of public institutions (hospitals, prisons, military bases, schools) and with the provision of government services (road building and maintenance, for example).
- A general shortcoming in the waste data that are available, even those that are detailed and reliable, is that they do not exist as long time-series. It is rare to find waste data that extend further back in time than the mid 1980s; most begin in the 1990s.
- With respect to resource flows, the major shortcoming is the lack of data representing the flows of recycled materials. Although some data are available on the quantities of municipal solid wastes collected for recycling, again these data do not classify the wastes by producer. Data representing the quantities of waste materials collected for recycling outside of municipal recycling programs are not readily available at all.

7. Future directions for Material and Energy Flow Accounts

Although the conceptual framework of the MEFA is well-established, their current state of empirical development represents only a small fraction of the material and energy flows that would be ideally covered. With respect to waste flows, estimates of greenhouse gas emissions are the sole statistics to have been compiled to date (see section 6). With respect to natural resource flows, current plans call for the development of estimates for timber, metallic and non- metallic minerals and possibly land. Statistics Canada collects many of the raw data required to incorporate these flows into the MEFA framework. Integrating these data is a high priority for the future development of the MEFA. Estimating the quantities of recycled wastes that are used in place of virgin resources is also a high priority.

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ANALYSIS OF MATERIAL FLOWS FOR SUSTAINABILITY POLICY:
The experience of Italy[19]

1. Introduction

In the course of time, and especially in the last years, the scientific debate concerning the environmental effects of material flows has been more and more influenced by authors who shifted attention from direct and well-known effects to systemic interaction and uncertainty and from environmental emergencies to precaution and long-term sustainability. This has brought about a shift in emphasis from the emissions of specific substances to the whole of material flows induced by human activities. While in the traditional approach an *ex-post* aggregation of a myriad of indicators of environmental pressures is needed in order to come to a "policy-friendly" synthetic index of total pressure, the "modern" material flows approach tries to tackle the problem directly at the aggregate level. The claim at its basis is that it is not possible, both for practical and for theoretical reasons, to measure and put under control the overall environmental disruption potential of human activities by using hundreds of indicators, each of which is very precise in its meaning, but also very limited in scope. Moreover, *ex-post* aggregation does not grant unambiguous results as far as the meaning of the index is concerned (weights have to be chosen for the different pressures). In order to overcome the impasse, paradoxically given by "too much detailed information", a more synthetic catch-all – though necessarily fuzzy in its meaning – accounting, in terms of tons, of all the material flows induced by man has been proposed, from which indicators suited to monitor systemic progress towards ecological sustainability can be derived.

This enlargement of the perspective to the overall dimension of human activities with respect to nature, has been accompanied by the growth of the activities of production and elaboration of data referred to the whole of the material flows caused by human activities, and especially to the inputs to the economy ("what comes in will eventually come out": therefore, a reduction of inputs is needed in the first place). The patterns of materials' use through economic growth revealed by the evidence collected so far show no strong tendency to "dematerialisation" of the economies, even the most advanced ones, or show such a tendency only in relative terms (i.e. in terms of intensity of use of materials per GDP unit)[20].

We will not discuss here the issue of the significance of these aggregate measures of material flows, which will be assumed as indeed very meaningful when long-term ecological sustainability is concerned, but try to make a step forward from sheer accounting into analysis, showing how the determinants of material flows in terms of prevailing technology and structure of the economy can be identified and measured, and highlighting the way they interact in determining the observed material flow aggregates. These determinants can be seen as the intermediate objectives of an ecological-economic policy. The trends recalled above, indeed, highlight the inadequacy of the "efficiency" strategies followed so far, based mainly on technology improvements, and the necessity of a "sufficiency" policy, based on improvements of societal organisation and profound structural change of the economies and lifestyles.

A policy that does not want to be confined to the ecological dimension but aims at taking into consideration several aspects of sustainability at once, needs to be based not just on environmental indicators but also on indicators which are specific of the other dimensions considered, and on an equivalent analysis of their determinants. The main problem, in this analytical setting, is then how to link

19 Paper prepared by Mr. Aldo Femia, ISTAT, Italy.

20. See Femia-Hinteberger-Renn, "Economic Growth with less Material Input? De-Composing the Empirical Trend of De-Linking", paper presented at the World Congress of Environmental and Resource Economists, Venice, June 25-27, 1998.

indicators concerning the social, economic and ecological dimensions, in a way that the trade-offs between the respective objectives are correctly highlighted. In this paper we attempt to show how this can be done, drawing from an application to the Italian case of Leontievian input-output analysis of material inputs and of value added. The application is limited in many respects, but its main aim is to show how material flow accounting, fed into a research program based on the application of input-output logic, can contribute to the formulation of a sustainability policy attentive to the (socio-)economic dimension of development as well as to the ecological one.

2. Data and method of analysis

The data used in this application are referred to the material content of the direct current material inputs to the Italian productive activities carried out in 1988. Due to the limitations of the data, which do not allow very meaningful further aggregations, we could not derive the "total material requirement" indicator, the one that mostly characterises the approach, but had to keep 8 different categories of materials, to be separately analysed[21].

In order to perform the analysis described below, the data have been organised in a very simple NAMEA-type environmental accounting scheme[22]. In particular the matrix of *direct material inputs* reported in Table 1 has been linked to the monetary input-output table of the Italian economy of 1988. The material input matrix collects the data on the direct intake of the 8 types of materials by the 44 NACE branches and the 5 final demand categories of the input-output table. From this scheme, direct input coefficients are derived, expressing – branch by branch – intermediate and primary inputs per unit of total product.

The application of the input-output technique is based on recursive use of these unitary coefficients in order to reconstruct (backwards) the whole production chain that "stays behind" the final production of any given branch. This "disentangling" of the intermediate exchanges among industries, can be seen as a virtual separation of the production chains; the activities are collected in fictitious branches, which we will call "vertically integrated" after Pasinetti, according to the final purpose for which production is carried out. These fictitious branches, therefore, produce only for final demand directly from primary inputs. The application of this technique thus allows to calculate, for any given branch of the economy the total (i.e. direct plus indirect) inputs needed to satisfy the final demand for the products of the branch, or – in other words – the total inputs "activated" by this final demand. This applies to material inputs as well as to any other input of the economy (employment, services of capital…) and also to the generation of value added, which is what we consider in this application in order to represent the economic dimension of sustainability. For any given primary resource, the sum of its total input in all the vertically integrated branches gives the quantity of that input used in the whole economy.

The absolute dimension of the use of inputs by vertically integrated branch is by itself not sufficient to design a policy framework, because it is heavily dependent on the sheer dimension of the branch itself, i.e. on statistical aggregation. It is therefore necessary to adopt some standardisation method, as for instance the division of the quantities of the inputs of the vertically integrated branches by the values of the respective deliveries to final demand. The measures derived this way express the *intensities of use* of the inputs, which can be considered inverse indicators of the *efficiency* with which material resources are transformed into products suited to satisfy final demand. Summarising, the total quantity of a given input

21. No attempt has been made to reconstruct the flows of non-used materials accompanying those of used inputs, nor to assess the indirect material inputs of imported goods and services. As a consequence, domestic and imported direct material inputs cannot be summed together due to the different nature of the materials to which the data refer: imported products are not a direct intake from nature, and represent much bigger flows of materials than the quantities they actually embody. The materials contained in some of the imported goods, moreover, could not be identified, and have therefore been collected in the residual category of "undetermined" materials.

22. The NAMEA (National Accounting Matrix with Environmental Accounts) is an extension of the matrix presentation of national accounts (NAM), in which indicators of environmental pressures are reported in additional modules using the same aggregation keys and classifications as those used in the national accounts.

used in the economy will be expressed as the scalar product of two vectors, one expressing the intensities of use of that input in the vertically integrated branches, the other one the level and composition of final demand[23].

The first vector is actually a vector of "vertically integrated input coefficients", and can therefore be seen as the one describing the role of technology in the determination of the use of inputs and put in relation to the "efficiency" side of the problem of reducing material inputs to the economy. The latter vector can be put in relation to the issue of "sufficiency" mentioned in the introduction, and is important for its level (*ceteris paribus*, less consumption leads to less material inputs) as well as for its composition. Concerning composition, it can be observed that in many cases a given need can be satisfied with different mixes of products (think for instance of different transportation means, or also of communication as a substitute of mobility), which have greatly different implications in terms of activated material flows, due to the different efficiency in the use of resources of the different branches[24].

Moreover, for any given vertically integrated branch, it is possible to compare the results on the use of different inputs (in our case, materials and value added). In this way we can obtain measures such as, for instance, the "use of biotic inputs per unit of value added" by vertically integrated branch, which expresses the trade-off between the environmental and the economic objectives, useful to answer questions such as for instance: "how much value added must be given up in order to reduce biotic inputs of the given vertically integrated branch of a predetermined quantity, assuming that technology in that vertically integrated branch will become more efficient in the use of biotic resources by x% and all other things being equal?". Since this indicator is available for all branches, it can help identifying the mix of incentives and disincentives that achieves the desired reduction of use of biotic input with the minimum possible loss of income generated.

This kind of analysis can be extended – if data are available for a period of time – in order to identify the causes of the past observed changes in the total intake of an input, to assess to which extent has technology progressed and/or structural change influenced materials' use, and to project in the future the effects of past trends of technology improvement and structural change; moreover, simulation exercises can be performed, hypothesising evolution patterns for intensities of use and final demand, helping to figure the effects of alternative sustainability policy.

3. Main results

3.1 Absolute material use by vertically integrated branch

The figures in the annex report the total quantities of materials used by the vertically integrated branches.

Due to the high aggregation of the 44-branches input-output table and to the kind of materials available in the Italian territory, which is poor of metals and energy carriers, an important share of the use of materials of domestic origin is concentrated in the same branches in which their removal from nature occurs. As a matter of fact, often the activities that further transform th e materials belong to the same

23. In the presence of economies of scale, the intensities of use cannot be considered fully independent from the absolute dimension of demand for the products of the branch. This is relevant when simulations are performed, but does not subtract anything from the descriptive power of the model. The intensities of use, moreover, can be split into an "extraction technology" component and another one referring to interindustry exchanges (the former is the vector of direct input coefficients, the latter the Leontiev inverse).

24. The way in which this vector depends (in turn) from income generation, the constraints in its composition given by complementarity and substitutability and therefore the room for policy to change it in order to influence the use of primary inputs are all parts of the research program mentioned above which we cannot discuss here, but should be kept in mind for their crucial importance in the derivation of policy prescriptions.

Table 1. **Direct material inputs of productive branches and final demand categories**
Italy, 1988 (tons)

	Materials of domestic origin				Imported materials			
I/O (NACE) branches	Biomass (excl. fodder)	Non-energy minerals	Energy minerals	Endogenous steam	Biomass	Non-energy minerals	Energy minerals	Undetermined
01	77.462.041	0	0	0	2.249.039	94.758	104.299	386.484
03	0	0	1.648.771	0	0	683	67	0
05	0	0	0	0	0	5.628	960.319	0
07	0	56.907	17.716.085	0	24.456	18.692	24.147.766	60.781
09	0	0	0	31.458.439	4.011	42.269	3.534.071	10.443
11	0	0	0	0	0	0	27	0
13	0	172.652	0	0	611.698	13.521.619	464.310	63.401
15	0	343.928.030	45.638	0	102.523	10.339.253	711.748	118.732
17	0	0	0	0	1.524.356	3.238.120	2.271.418	3.093.391
19	0	0	0	0	38.836	5.299.193	238.489	89.291
21	0	0	0	0	6.081	3.530.436	243.398	17.578
23	0	0	0	0	1.371	713.244	13.265	21.629
25	0	0	0	0	54.661	2.605.536	77.165	77.244
27	0	0	0	0	27.094	1.984.938	536.930	108.323
29	0	0	0	0	5.031	758.564	67.675	5.721
31	0	0	0	0	3.179.016	15.107	19.803	1.792
33	0	0	0	0	168.758	5.518	21.679	434
35	0	0	0	0	6.819.675	1.018.944	303.589	41.539
37	0	0	0	0	243.555	606.729	29.851	13.824
39	0	0	0	0	349.684	1.778	1.229	44
41	0	0	0	0	2.965.712	127.072	163.112	675.471
43	0	0	0	0	1.228.649	79.029	34.419	74.390
45	0	0	0	0	4.394.972	273.519	157.797	39.550
47	0	0	0	0	3.326.607	86.153	126.241	121.483
49	0	0	0	0	811.438	64.393	1.155.186	1.193.433
51	0	0	0	0	59.633	2.831.253	44.778	39.024
53	0	0	0	0	412.934	11.719.725	272.101	160.326
55	0	0	0	0	14.080	696.867	32.981	32.173
57	0	0	0	0	107.103	55.809	577.368	3.702
59	0	0	0	0	1.259.633	345.062	351.588	301
61	0	0	0	0	14.040	75.405	394.311	4.257
63	0	0	0	0	132.142	284.583	1.132.691	11.814
65	0	0	0	0	3.922	20.094	39.080	58
67	0	0	0	0	546	11.057	14.535	313
69	0	0	0	0	0	13.153	15.790	178
71	0	0	0	0	40.082	33.045	86.466	16.296
73	0	0	0	0	0	20	0	27
75	0	0	0	0	2.552	1.667	25.082	1.653
77	0	0	0	0	7.253	7.142	48.029	9.241
79	0	0	0	0	45.026	108.614	57.882	75.592
81	0	0	0	0	225.964	229.686	309.435	22.426
85	0	0	0	0	2.123	65.996	53.416	2.116
89	0	0	0	0	29.882	155.039	143.468	37.271
93	0	0	0	0	4.172	0	10.392	12
Households	0	0	0	0	9.212.574	7.108.788	8.110.710	824.662
P.A. Cons.	0	0	0	0	0	0	0	0
Investments	0	0	0	0	621.709	2.348.713	5.646	19.806
Inventories	0	0	0	0	12.663	-10.043	-287.826	22.930
Export.	0	0	0	0	669	0	136.288	0
Total	77.462.041	344.157.589	19.410.494	31.458.439	40.345.922	70.532.851	46.958.063	7.499.156

Source: Author's processing of ISTAT and Foreign Trade Statistics data.

branches to which the activities that take them from nature agriculture belong: and forestry for biomass (branch 01); oil, refineries and gas for energy carriers (branch 07, which comprises both the extraction of these materials and their refinement); electricity generation for endogenous steam (branch 09 – in this case the activities of extraction and transformation coincide); and cement, glass, ceramics for non-energy minerals (branch 15, which also comprises their extraction). Exceptions to this rule are the activation of extraction of non-energy minerals by the final demand of the products of the construction branch (53), which is the and the use of biomass in the vertically integrated branches of food industries (31-35) and catering (59).

The materials embodied in imported goods show a more complex pattern:

- undetermined materials are mainly demanded for the production of final chemical products (17), textiles (41), rubber (49) and for the construction and maintenance of buildings (53);
- energy materials are imported for the delivery to final users of refined petroleum products (07), of chemical products (17), buildings (53), and of some services like commerce (57), hotels, restaurants and bars (59), transport (61 and 63) and Public Administration (81);
- non-energy minerals from abroad are demanded for the purpose of construction (53) as well as for the final sales of the industries of metal and non-metal minerals (13 and 15), of all kinds of metal products, machinery and vehicles (19-29), and of chemicals (17); among services, those provided by the P.A. (81) require substantial inputs of these materials;
- imports of biomass are activated by the final demand of agricultural products (01), of some products of food industries (meat and cereals mainly, branches 31 and 35), of chemicals and of some typical “made in Italy” products such as textiles, clothes, furniture… branches 41-47) and also by services of hotels, restaurants and bars (59).

3.2 Intensity of use of materials by vertically integrated branch

As observed before, the absolute quantities of materials used by the vertically integrated branches are *per se* not very significant: to a certain extent they simply reflect the importance of the branches in final demand. Therefore it is useful to consider coefficients expressing the ratios between the quantities of materials used and value of the products delivered to final demand by branch (intensities of use). Figure 1 gives the “vertically integrated material input coefficients”, i.e. the average “intensities of use”, of the eight types of materials, in a highly aggregated form (each of the sectors reported in the figure groups together several NACE branches). It is important to bear in mind that the ij-th bar represents the quantity of material i *directly and indirectly* (i.e. through other sectors) used (*activated)* by sector j in order to deliver one unit of its product to final demand (expressed in the figure in tonnes per LIT million of product).

For what concerns materials of domestic origin, it is also interesting to consider more specifically the *indirect* activation of materials (indirect intensity of use):

- in general, this is relatively high in the same branches that directly take the materials from the environment: endogenous steam in the production of electricity (branch 09), energy minerals in that of carbon (03) and oil (07), non-energy minerals in the processing of metals (13) and in production of cement, glass and ceramics (15), biomass in agricultural production (01); this shows that a significant part of the use of these materials is activated by the final demand for products of the same branch that removes them from the national environment, rather than by the intermediate demand of the other branches; again, this can be partly attributed to the high aggregation of the input-output table, partly to the type of materials available in Italy;
- since endogenous steam is immediately used in electricity production, its indirect activation by the vertically integrated branches mostly reflects the energy intensity of their deliveries to final demand; this activation is substantially higher than average in minerals’ extraction and

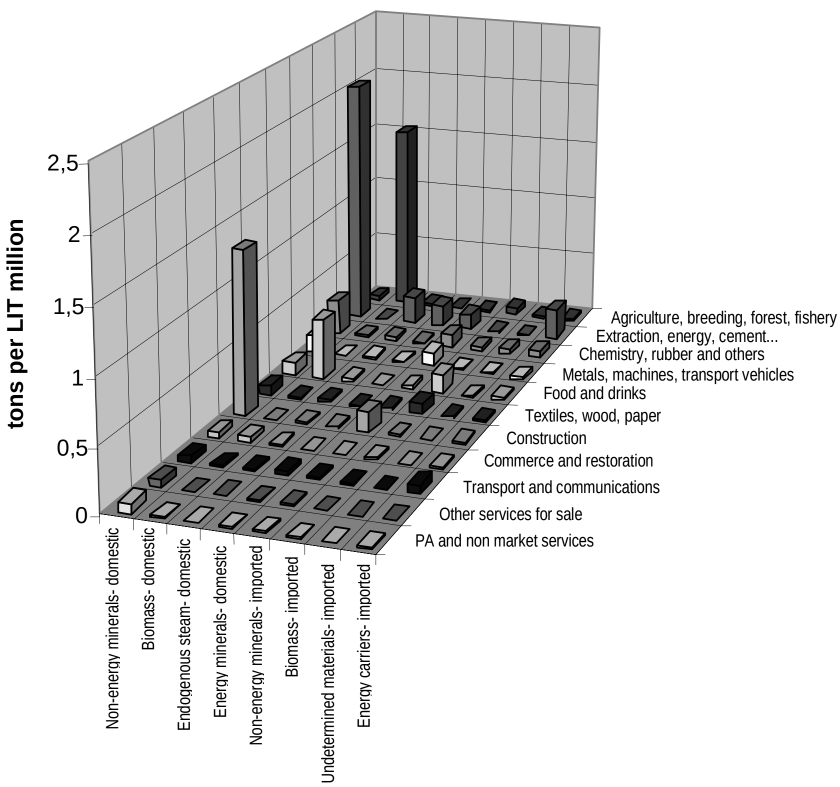
first processing (03, 13 and 15) and in coke production (05), while all other branches (except tobacco products) are not far from the average of 25 kg. per LIT million of final products;

– similarly to the previous case, the presence of energy generation in the productive chains of all vertically integrated branches implies that all branches indirectly activate the extraction of energy minerals from the Italian territory; the only branches that show particularly high values of indirect activation are the production of manufactured gas and electricity itself (09) and transport activities (61 and 63), which are the main users of refined petroleum products;

– not surprisingly, indirect activation of non-energy minerals is very high in the construction branch; it is also high in the beverages branch, probably due to the use of glass. Most of the other industrial sectors are not far from the average of about 280 kg. per LIT million of final product;

– biomass shows a very clear pattern of indirect activation, with all food industries (31-37) and services of hotels, restaurants and bars (59) far above the average (which is 6.3 kg. per LIT million), and all other branches far below it.

Figure 1. **Average Intensity of use by vertically integrated sector**



As shown above, the branches through which imported materials enter the economy are much more numerous than those extracting materials from the domestic territory. This is reflected in the much smoother profiles of the total (direct and indirect) intensities of use of imported materials with respect to those of the materials of domestic origin. As a matter of fact, imported intermediate inputs are demanded by almost all vertically integrated branches. The main feature of the resulting picture is a strong differentiation between service activities on the one hand and all other activities on the other hand, with the only noticeable exception of the textiles-wood-paper compound, which shows unitary activation coefficients that are almost always the lowest among industrial activities.

3.3 Intensities of use of materials by type of final demand

Intensities of use can be calculated not just by vertically integrated branches, but also, using a different aggregation of the data, by category of final demand, basically corresponding to the different institutional sectors to which final goods and services are delivered. In Table 2 we show an example of this type of analysis, that allows to identify the most material-intensive final users (the numbers in brackets give the share of total final demand going to the respective uses). Attention can be drawn, for instance, on the particularly high values of some material intensities of households' consumption. To show this in a different way, also the ratio between the share of final demand and that of material input can be considered: if this higher than unity, the corresponding intensity of use will be higher than average. Thus, households consumption accounts for "only" 52% of final aggregate demand, it activates 68% of endogenous steam and of energy minerals of domestic origin, 86% of domestic biomass, 67% of imported energy minerals and 73% of imported biomass. Since expenses for buildings are investments (inventories if not finished), the values present in the row of domestic non-energy minerals are not surprising.

Table 2. Table 2. **Materials' intensities of use of final demand by institutional sector**
Italy 1988 (kilograms per LIT million of final demand)

	Households (52%)	P.A. (15%)	Investments (16%)	Inventories (1%)	Export (16%)	Overall average
Endogenous steam	34	12	17	28	22	26
Domestic energy minerals	21	7	9	6	16	16
Domestic non-energy minerals	92	75	831	1.590	436	281
Domestic biomass	104	11	3	78	51	63
Undetermined imported materials	6	2	4	17	10	6
Imported energy minerals	50	15	23	12	42	38
Imported non energy minerals	34	16	142	138	84	58
Imported biomass	47	7	16	31	30	33

3.4 An indicator of the trade-off between ecological and economic objectives

As explained above, the same operation of "vertical integration" can be (and traditionally is) performed on variables other than material inputs (or outputs), such as value added, profits, employment, taxation revenue and so on. Comparing the results for material flows with the results for these other variables gives interesting measures of the sector-specific trade-offs faced by an economic policy for dematerialisation. Table 3 summarises the results of this comparison.

The results are quite similar to those concerning the intensities of use shown in Figure 1. The gap between service activities and the rest of the economy is confirmed: one unit of value added is generated with the need of much less materials in services than elsewhere. This is not as obvious as it may seem: it must be kept in mind that we are considering all the upstream material flows, and not just direct inputs, to the final production of services. Only in the textiles-wood-paper vertically integrated sector the shares between material inputs and value added are not much different from those of service activities, while all other vertically integrated sectors display a strong specialisation in the use of some specific materials, clearly of great importance for their production activity, like for instance in the case of non-energy minerals for constructions, and of biomass for food industries.

Table 3. Table 3. **Ratio between activated material input and value added by groups of NACE branches**
Italy 1988 (Kilograms per LIT million of domestic product)

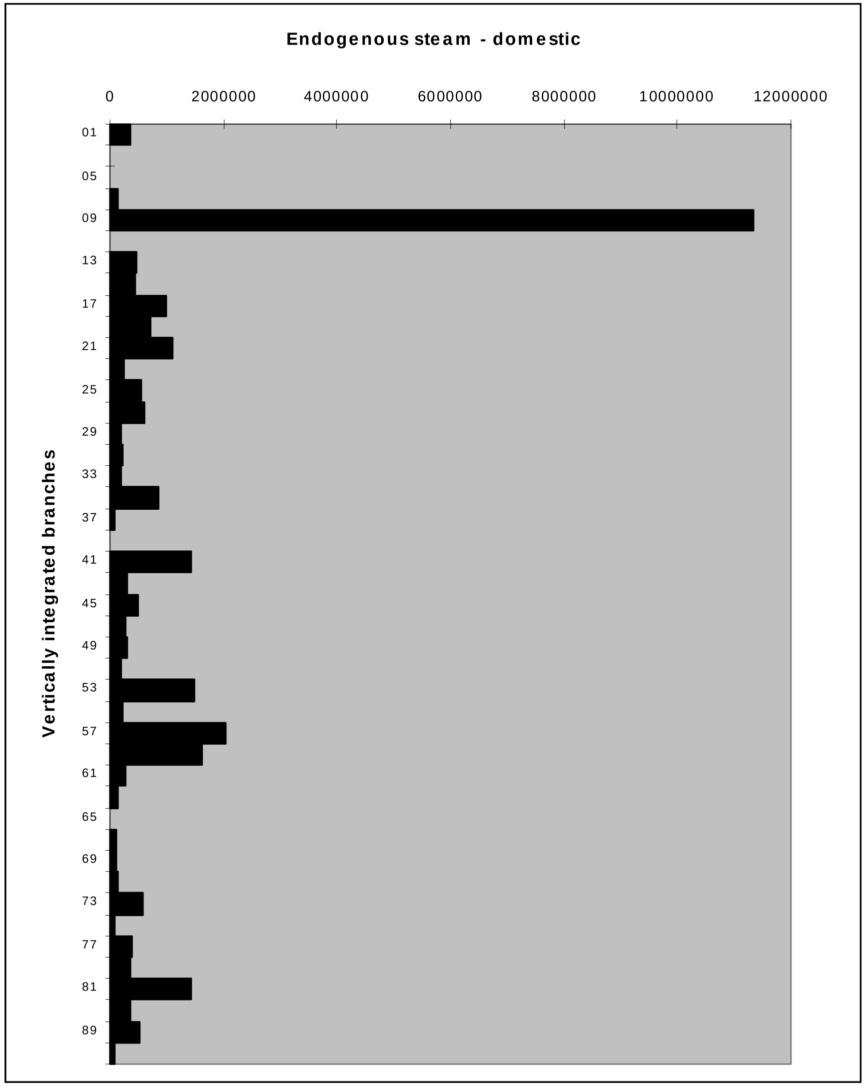
	Intra-regional Inputs				Imported Materials			
	Non-energy minerals	Biomass	Endogenous Steam	Energy minerals	Non-energy minerals	Biomass	Undeter-mined	Energy minerals
Agriculture, breeding, forests, hunting and fishing	34	1721	19	10	10	66	11	20
Extraction, energy, cement...	2541	3	283	217	156	8	4	323
Chemistry, rubber and others	397	21	37	17	153	43	59	76
Metals, machines, vehicles	185	4	26	9	149	10	6	31
Food and drinks	127	613	29	12	35	186	6	28
Textiles, wood, paper	92	20	28	9	19	103	14	22
Construction	1478	3	16	9	179	13	5	24
Commerce and catering	54	47	17	10	9	19	1	19
Transport and communications	56	7	13	35	20	8	2	78
Other services for sale	62	3	11	4	10	3	2	8
PA and non-market services	76	11	13	7	16	8	2	15

4. Conclusions

Accounting of the material inputs of an economy is not of much use if we are not able to *analyse* these flows, i.e. to say something about their socio-economic determinants, on which policies have to act in order to cause our way of life to evolve in overall terms towards a less material well-being (“dematerialisation”). One of the most important instruments for the analysis of determinants is input-output analysis, via which technological (interlinkages between economic activities) and structural (relative shares of the branches of the economy in final demand) components of the overall demand for materials from nature can to some extent be disentangled.

With this kind of analysis it is possible, as we have shown, to identify the kinds of final demand (according to the products demanded and to the subjects from which it originates) which are “responsible” for the removal of materials from nature at the start of the production chains, as well as for the creation of value in the economy. In turn this allows to quantify the reductions of economic activity and/or gains in efficiency needed to achieve environmental goals expressed in terms of material inputs, and to simulate the repercussions on economic and social variables of the different changes of demand or technology that can lead to the achievement of those goals. This is crucial for the purpose of identifying sustainability policies that are at the same time effective on the environmental side an not unbearable on the economic side.

Figure 4. Annex 1. **Material inputs by vertically integrated branch,** Italy 1988 (tons)



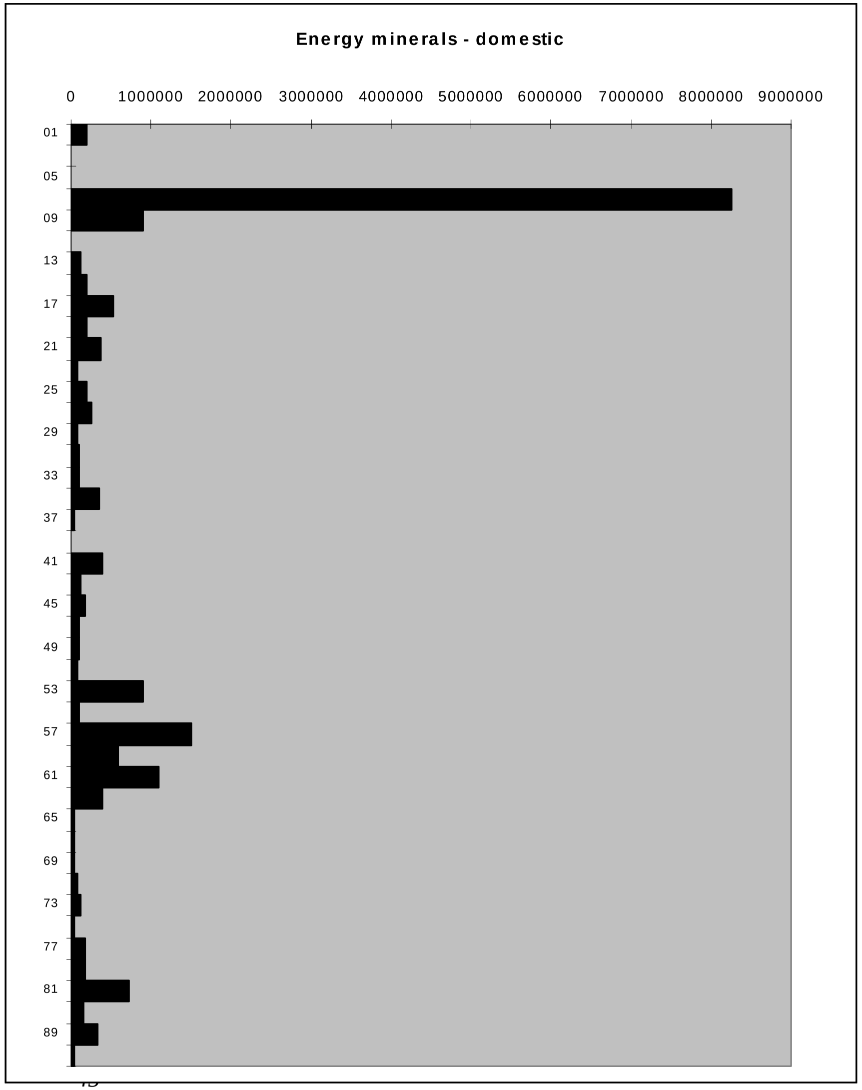
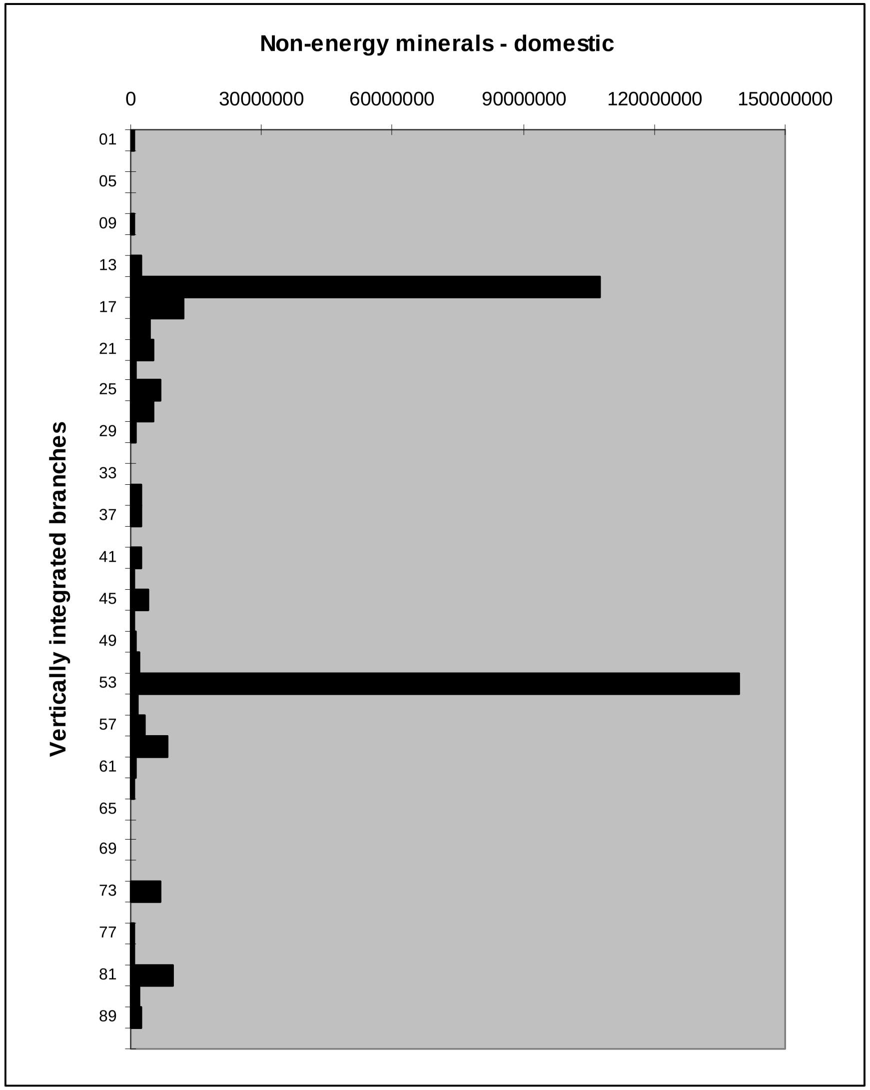


Figure 5. Annex 1 (continued). **Material inputs by vertically integrated branch,** Italy 1988 (tons)



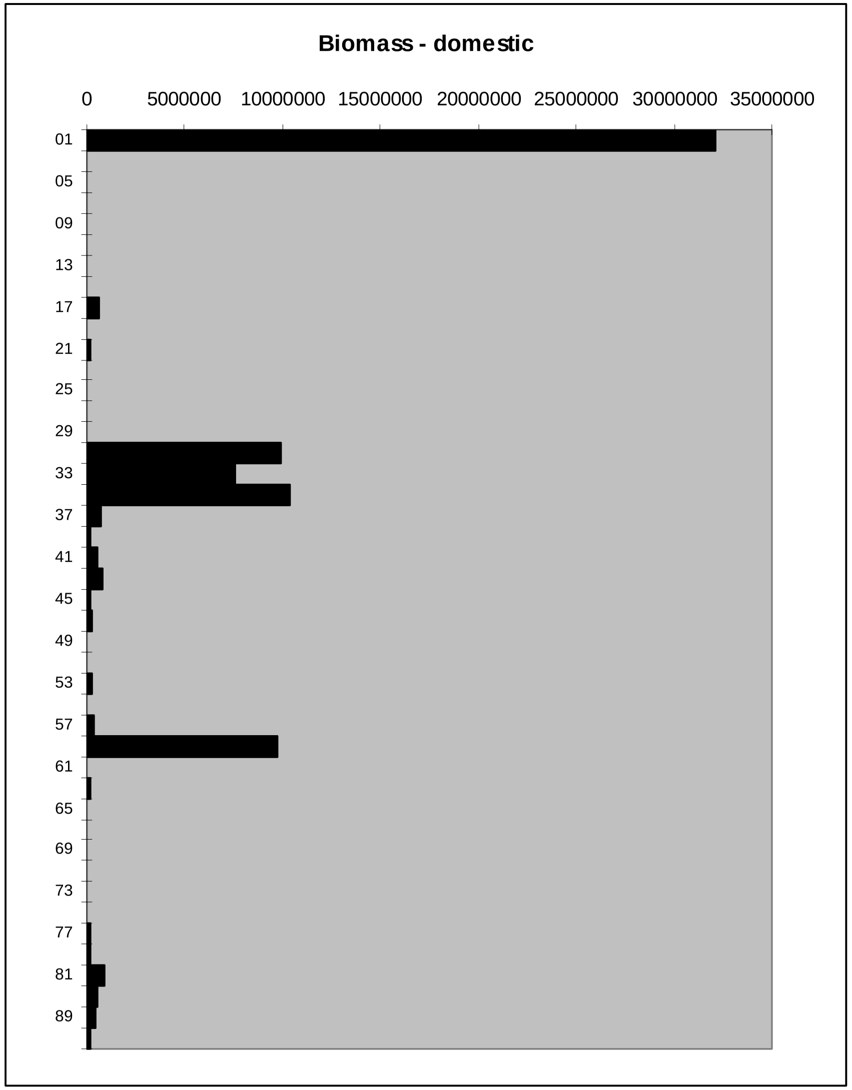
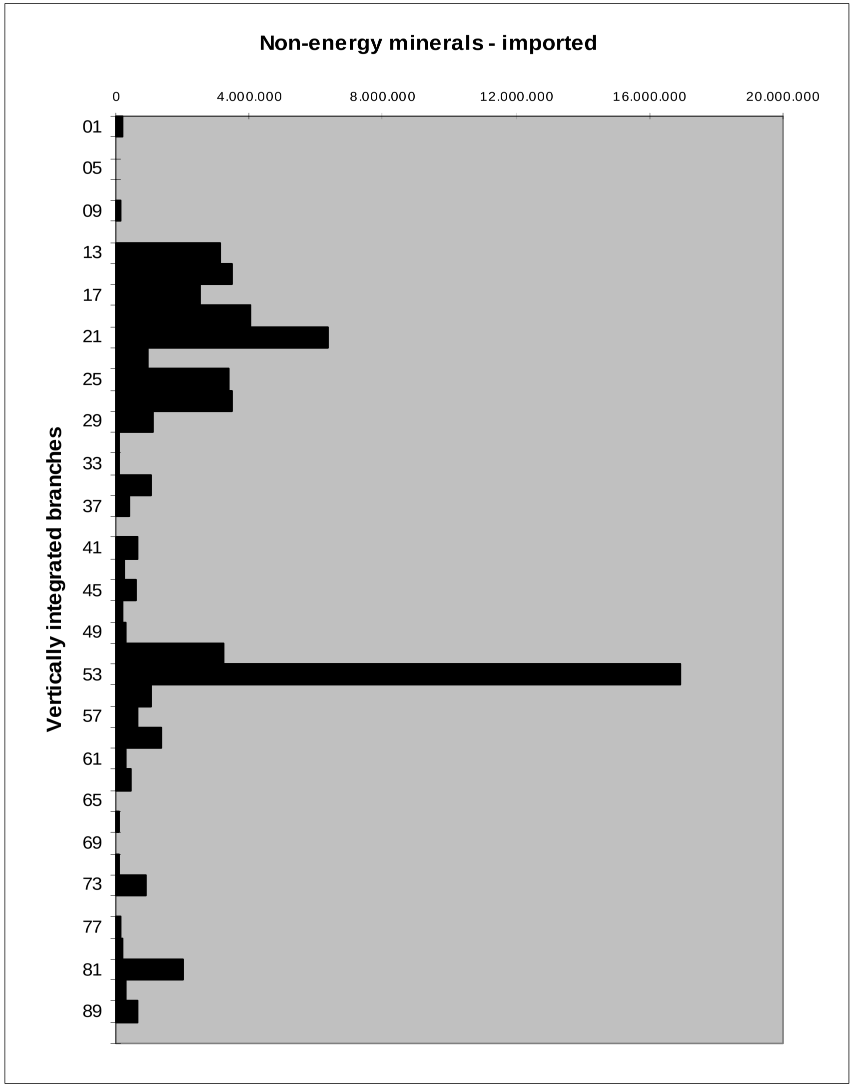


Figure 6. Annex 1 (continued). **Material inputs by vertically integrated branch**, Italy 1988 (tons)



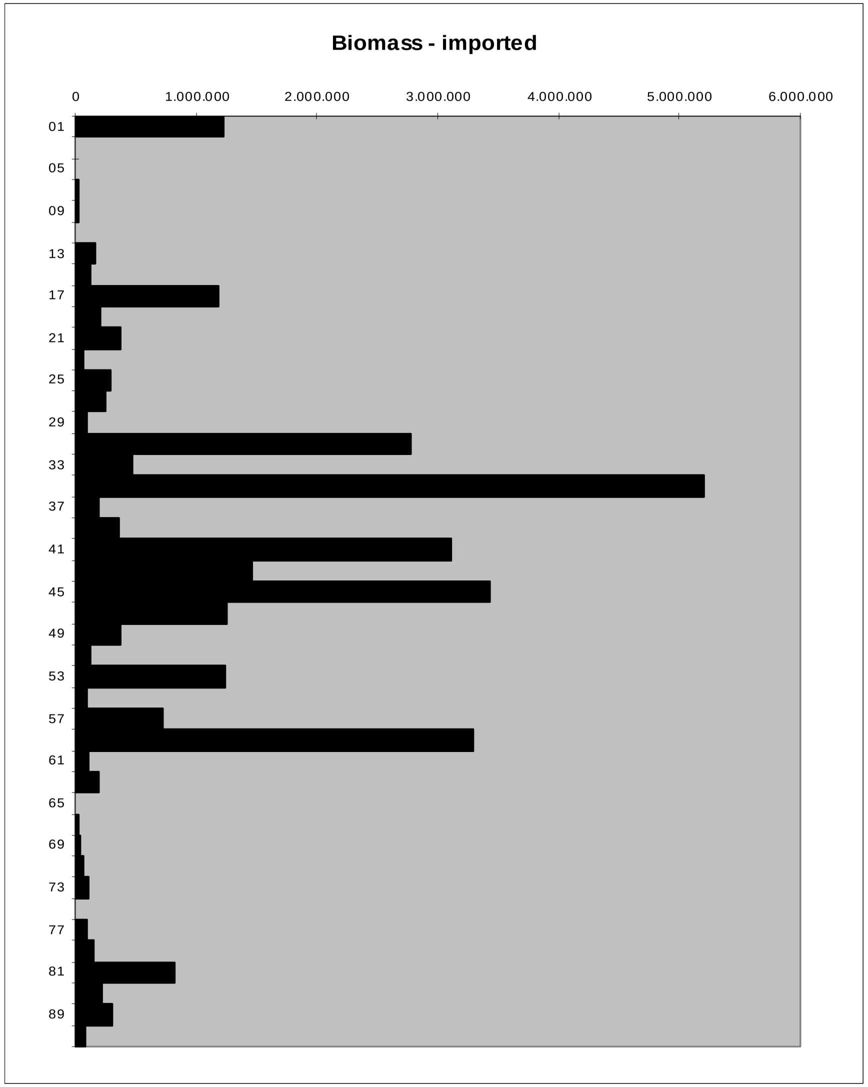
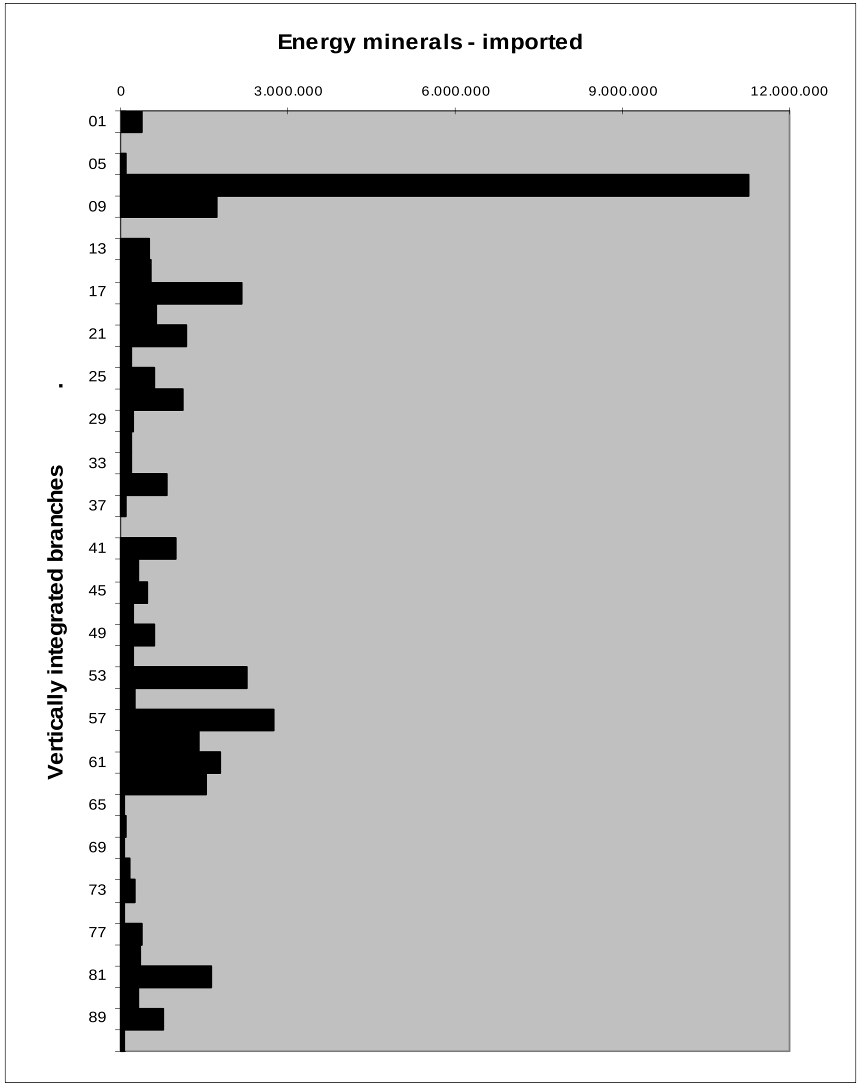
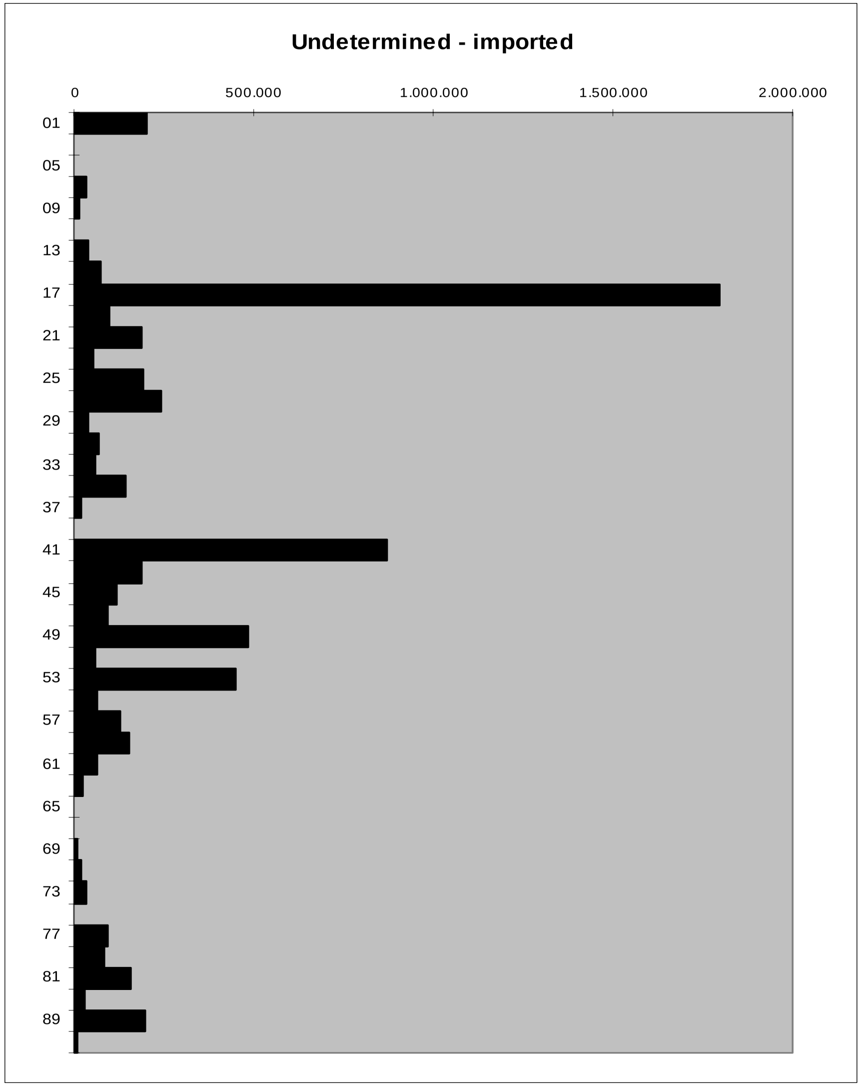


Figure 7. Annex 1 (continued). **Material inputs by vertically integrated branch**, Italy 1988 (tons)





**MATERIAL FLOW ACCOUNTING AND ITS APPLICATION:
The experience of Japan**[25]

1. Background

Japan experienced severe environmental pollution involving serious health damages in 1960s to early 1970s, the era of rapid industrialization. End-of-pipe technologies for large point sources, such as desulfurization and denitrofication have successfully contributed to improve such traditional environmental pollution problems. Can we continue to rely on such end-of-pipe approach to solve all of emerging environmental problems at the end of huge energy and material flows of the industrialized economy?

The answer seems to be rather negative. Many of present environmental issues have their roots in the basic structure of our society, characterized by ‘mass-production, mass-consumption and mass-disposal’, and we need to transform our production and consumption patterns to more sustainable manner. Such recognition is clearly stated in recent Japanese national environmental policy documents such as the Basic Environment Plan. Based on this standpoint, a basic law for promoting recycle-based society is enacted in 2000 towards more sustainable material management. It seems that ‘looking upstream’ is being built in environmental policies.

Such paradigm shift in Japanese environmental policy may be interpreted differently in global and domestic contexts. Increasing attention is being paid to global environmental problems, and the concept of sustainable development is being spread. Recognition that the environment is finite as a source of resources supply and as a recipient of residuals is the most essential standpoint to discuss the sustainable development. At local level, on the other hand, limitation of the end-of-pipe approach becomes evident (Moriguchi, 1999). It has to be kept in mind that such recognition in Japan can not be prevailed without urgent visible problems on municipal solid wastes and industrial wastes. We are suffering from the shortage of final disposal site capacity, but the development of new dumping site faces to difficulty because of potential negative impacts on the environment. Cost for dumping industrial solid wastes is expensive enough to call industries’ attention for waste minimization. Incineration of solid waste has been effective in reducing the size of final disposal, but recently revealed problem of dioxins from waste incineration works as another driving force to recall people’s attention to negative aspects of mass-disposal-society.

2. Overview of studies on MFA and inter-related tools

2. MFA and similar physical accounting

As will be later described more in detail, Japan highly depends on imported natural resources, which often have environmental relevance. Harvest of timbers from tropical rainforest is a typical issue. Japan’s participation to the OECD’s pilot study on natural resource accounting (NRA) in the beginning of 1990s (OECD 1994) was driven by such situation. This experience of the forest resource account was later applied to Asian countries (Koike 1999).

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On the other hand, material flow accounting (MFA) was studied mainly to respond to the domestic issues of increasing solid wastes. A flow chart describing Japan's macroscopic material flow balance has been published on the annual 'Quality of the Environment' report, what we call 'White Paper' since its 1992 edition. Dissemination of an English edition of the report created the opportunities for European experts on MFA to involve Japan to international collaborative efforts in this field. In 1995, the SCOPE (Scientific Committee for Problems on Environment) organized a scientific workshop for indicators of sustainable development at the Wuppertal Institute in Germany. Participants to this workshop from four industrialized nations, Germany, the United States, the Netherlands and Japan agreed to launch an international collaborative study to compare their overall material flows at national level. The results will be shown later in this paper.

Inter-industrial flows of some individual materials such as non-ferrous metals have been studied mainly from the viewpoint of material recycling (Clean Japan Center 1997). Substance flow analysis (SFA), which captures the flow of specific elements of environmental concern, was applied to some case studies such as an analysis of nitrogen flow and its impacts on eutrophication. The SFA framework for toxic substances has yet been explicitly adopted until recently.

Inventories of pollutants' emissions, what we call 'emission inventories' may be categorized as one specific form of MFA in broader sense. Official inventories are compiled for Greenhouse gases (GHGs) along with an international convention, whereas those for others, even for traditional air pollutants, have not been made available until recently. This is mainly because institutional basis for environmental statistics is rather weak compared to other countries. PRTR (Pollutant Release and Transfer Register) system has been tested by pilot studies in late 1990s, and a nationwide system by the newly enacted law will start in the fiscal year 2001.

2.2 Input-output analysis with environmental extension

Application of economic input-output analysis (IOA) including case studies for Japan was undertaken by Leontief himself, the pioneer of IOA, in early 1970s. This might be one reason why environmental application of IOA has been and is being active in Japan. Another reason is that the Japanese IO table consists of some 400 sectors, and is thought to be one of the most detailed and qualified ones in the world.

IOA was already applied for what we call 'energy analysis', in late 1970s. Energy consumption by sectors is indicated in physical unit tables, which is officially accompanied with national IO tables. Other official statistics on energy consumption are often used in order to supplement the data in physical unit tables, of which data coverage and accuracy are not complete. Once sectoral direct energy consumption per unit output is quantified, one can easily calculate overall sectoral energy intensity, which includes indirect energy consumption in upstream industries by applying Leontief's inverse matrix. This calculation process has been applied to energy consumption, CO_2 emission (Kondo et al. 1996), traditional air pollutants (SOx, NOx) (Hondo et al. 1997), water pollutants (BOD, N, P), solid wastes, and so on. They have been often used for life cycle inventory analysis, and other examples of application include an analysis of structural changes of CO_2 emissions from the viewpoint of final demand of the economy and an analysis of influences by international trade (Kondo et al. 1998).

More recently, application of IOA to the issues of waste management and recycling is getting active. A Waste Input Output (WIO) model was proposed (Nakamura 2000) to describe an interdependence of goods producing sectors and waste management sectors, in which both monetary and physical flows were dealt with. Description of whole material flows within the economy and their interaction with the environment is also attempted, to link sectoral IO studies and macroscopic MFA studies. Learning from the German pioneering experiences (Stahmer et al. 1998) in PIOT (Physical Input-Output Tables), a framework of 3DPIOT (3 dimensional PIOT) is being proposed, and case studies are being undertaken. These environmentally extended IO studies have many common features with MFA studies.

2.3 Monetary environmental accounting

Monetary environmental accounting in micro economic level, i.e., corporate environmental accounting is being widely spread, since the Environment Agency of Japan published a guideline in 2000. Many leading companies disclosed their trial of environmental accounts around this period. In many cases, physical accounts are not accompanied, but some companies published overview of physical material flows around their activities as a part of environmental reporting.

Environmental accounting for macro-economy has been studied along with international discussion on Integrated System of Environmental and Economic Accounting (SEEA). Worldwide experts in this field gathered at Tokyo in 1996 (Uno and Bartelmus 1999), which stimulated the international exchange of experiences. Economic Planning Agency of Japan published its trial calculation of environmentally adjusted net domestic product (EDP). Though this monetary accounting study and the physical material flow accounting study led by the author have been undertaken within the same research project, they have not been fully integrated.

3. Characterization of Japanese Material Flows

3.1 Geographical and historical background

About 125 million people densely inhabit in Japan, whereas domestic stock of natural resources is not sufficient and its exploitation is costly for sustaining these populations. Therefore, Japanese material flows should not be discussed without international trade flows. The history of international trades of Japan has an interesting profile. The Edo era when Japan closed the country is often referred to as a model of environmentally sustainable society because of its self-sufficiency of resources. On the contrary, present Japanese economy heavily depends on international trade, both imports and exports. Without tremendous amount of imported natural resources, such as fossil fuels and metal ores, Japanese economy can not be sustained. Growing export of products by raw material industries and assembly industries have been a major driving force of rapid economic growth.

In the following sections, Japanese material flows will be characterized, based on a database recently compiled through participation to the international joint project on MFA (Adriaanse et al., 1997, Matthews et al. 2000). By the joint study, in addition to direct material inflows and outflows, hidden flows (originally named ecological rucksacks in Germany) were quantified. They refer to ancillary material and excavated and/or disturbed material flow along with the desired material.

3.2 Material inflows

An overview of Japanese material flows is shown in Fig. 1. Material input flows that support the Japanese economy are characterized by high dependency on the import of natural resources. Imported commodities account for about one-third of the mass of direct inputs (DMI) to the economy, and account for one-half of the total material requirement (TMR), which is the a sum of the DMI and hidden flows.

Imports provide the Japanese economy with essential materials, including fossil fuels, metal ores, agricultural and forestry products. Import dependency is particularly high for metal ores and fossil fuels, as we have only poor stocks of these resource categories in domestic territory. Dependency is also high for timbers, in spite of the fact that the two third of our land is covered by forest. Timber imports to Japan contribute significant portion to whole international trade in the world. Recent trends revealed that commodities increasingly tend to be imported in more manufactured form, for example, refined metals rather than metal ores, or plywood rather than round wood. Imports of semi-manufactures and final products have also been increasing. Large hidden flows are associated with metals (particularly with copper and iron), coal, as well as agricultural and forestry products.

Domestic material flows, both commodity mass and rucksacks, are dominated by construction activities, nearly 90 percent in early 1990s. Domestic construction minerals including limestone, crushed stone and sand and gravel are used to create and improve buildings, roadways, water reservoirs, and other infrastructure.

3.3 Material outflows

The largest output flow from the economy to the nature is emission of carbon dioxide. Apart from the fact that CO_2 is famous as a greenhouse gas, which is also of our important concern, we have to recognize another fact that CO_2 is the heaviest waste from industrialized economies.

After CO_2, waste disposal to controlled landfill sites is the next major component of Direct Processed Output (DPO). This is of greater environmental significance than the nominal weight implies. Japan has a shortage of landfill sites for waste disposal. Reclaiming coastal areas for this purpose has sometimes caused the decrease of habitats for wildlife. The weight of waste disposal to landfill is much smaller than that of waste generated. The difference between the amount generated and the amount sent to landfill is the amount recycled or reduced by incineration and drying. Three quarters of MSW is incinerated to reduce waste volumes. The amount of landfill wastes was almost constant until 1990, but is now decreasing trend, thanks to waste minimization and recycling efforts.

Input of food and feed are balanced by return flows of CO_2 and water after digestion. Dissipative use is another important category of output flows. Dissipative flows are dominated by applications of animal manure to fields. Fertilizers and pesticides are intensively used in Japanese agriculture to enhance productivity and compensate for the limited area of available farmland.

However, total of these output flows is still much less than input flows. This is because more than half of direct material inputs is added to the stock, including consumer durables, capitals of industries and public infrastructures. They can be deemed as potential sources of wastes in the future.

3.4 Domestic Hidden Flows

Excavated soil during construction activities dominates domestic hidden flows. Only surplus soil, which means the soil excavated then moved out of the construction site to landfill or other sites for application, is quantified by official surveys. The total quantity of soil excavation by construction activities is much greater, because excavation work is usually designed to balance 'cut and fill', to use excavated soil on site, and minimize the generation of surplus soil.

Hidden flows associated with mining activities are trivial in quantity, because of the limited resources of fossil fuels and metal ores in Japan. Consequently, the contribution of domestic hidden flows to Total Domestic Output (TDO) is relatively small, compared with more resource-rich countries. It should be borne in mind that the small size of domestic hidden flows is counterbalanced by imported hidden flows associated with imported metals and energy carriers; this represents the transfer of Japan's environmental burden to its trade partners, which the first joint report emphasized.

3.5 International comparison of MFA-based indicators

Japanese TMR is about 45 tons per capita, which is much lower than other three countries (around 85 tons per capita). This is mainly because smaller energy consumption per capita and lower dependency on coal. In terms of DMI per capita, Japanese figure is only slightly smaller than Germany and the United States. DMI per capita for the Netherlands is also in the similar level, if huge transit import flows to other European countries are excluded

Dependency on imported material flows varies largely among countries, from less than 10 % for the United States to 70 % for the Netherlands. Ecological rucksacks accompanied by imports imply various environmental impacts in trade partners. More specific analysis will be necessary to identify individual problems behind ecological rucksacks.

The absolute level of DPO per capita in Japan is about 4 metric tons without oxygen and 11 metric tons with oxygen. These values are relatively small among the countries studied.

3.6 Recent trends

According to the analysis of historical trends of indicators, Japanese TMR per capita has shown upward trends. This coincides with the increase of waste flows. DPO and TDO in Japan grew 20 percent during the period 1975-1996. These growths occurred mainly after the late 1980s. Before then, DPO was almost constant and TDO decreased slightly.

On per capita basis, there was a downward trend in TDO from the late 1970s to the mid 1980s. DPO per capita also decreased slightly in this period. Growth in DPO per capita and TDO per capita were particularly evident in the late 1980s, when the country experienced the so-called ‘bubble-economy’.

Material output intensity, that is, DPO or TDO per constant unit of GDP declined until 1990 because of larger growth in the monetary economy than in physical throughput (the physical economy). However, since 1990, de-coupling between economic growth and material throughput has not been improved, because DPO and TDO have continued to increase, while economic growth has slowed down. This recent trend can be explained by structural changes in energy consumption, i.e., thanks to relatively cheap oil prices. Household energy consumption including gasoline consumption by private cars has increased and contributed to larger CO_2 missions, but this trend has contributed little to GDP growth.

Net additions of materials to the stock (NAS) in the Japanese technosphere have fluctuated in accordance with patterns of governmental and private investment. NAS increased significantly in the late 1980s, then stabilized at a lower level in 1990. Because Japan has a shorter history of industrialization than other Western countries, construction work is still active and significantly contributes to the country's overall picture of material flows. As much as 60 percent of direct material input (DMI) is added to the stock. This figure also has a close relation with inputs of construction materials as well as with soil excavation. Increasing quantities of stock imply that demolition wastes will also increase in the future. Currently, the government is attempting to encourage recycling of demolition wastes.

4. Use of MFA for the development of environmental indicators

4.1 Japanese Basic Environmental Plan and indicators development

In 1993, the law named "Basic Environment Law" was enacted as a new basic law for environmental policy in Japan. In 1994, the first "Basic Environmental Plan" was established by cabinet decision based on the Law. The plan mandated the government to develop comprehensive indicators for implementing the Plan and for reviewing policy performance towards four long-term policy goals set by the Plan, namely ‘sound material cycle’, ‘harmonious co-existence’ with nature, ‘participation’, and ‘international activities’. These indicators are also expected to be utilized for revising the Basic Environment Plan. An expert advisory committee was established in the Environment Agency to elaborate the concept and show options of indicators, drawing upon related activities in international organizations such as OECD and UNCSD, as well as those in other countries. The author has been involved in this process as an expert to support the secretariat of the committee. After seven times of plenary meetings of the committee since November 1995 as well as many meetings of subsidiary working groups, the committee published "A draft set of comprehensive environmental indicators" in July 1997. The draft set was disseminated to the related Ministries within the national government, local governments, academic societies, industries, as well as NGOs to invite their comments on the draft set and to improve it to establish final set of indicators. In November 1999, the committee submitted a revised report to the Central Environmental Council, to be used for the planning process of new Basic Environment Plan that is scheduled to be decided by the Cabinet in FY2000.

4.2 Outline of indicators set and relevance to the MFA

Summary of the set of indicators for four policy goals is tabulated in Table 1 and Table 2. The set is not based on a single framework, but incorporate multiple different frameworks. Out of the four policy goals of the Plan, the first one, "sound material cycle" has direct relevance to the MFA. Up-to-date information about international research activities for the MFA was introduced in the early stage of discussions at the advisory committee. The set of indicators for sound material cycle is subdivided into three subsets. The first is a subset of indicators for material and energy flows, which directly deals with material flows. The second is a subset for sound water cycle, which is also relevant to the MFA in broader sense. The third is a subset of indicators using D-S-R framework for environmental issues associated with material and energy flows.

The first subset indicators for material and energy flows stands for the recognition that the prevailing socioeconomic activities and lifestyles marked by mass-production, mass-consumption, and mass-disposal are essential sources of the burdens on the environment. This subset is further subdivided into indicators for material flows and those for energy flows. Indicators for material flows include those for inputs of resources, outputs of wastes as well as recycling of materials. Needless to say, indicators in this field are strongly influenced by recent progress in international research activities for the MFA. For example, not only direct material input (DMI) but also the concept of hidden flows (ecological rucksacks) is included in indicators.

4.3 Pending issues of the MFA for indicators development

The concept and practical application of the MFA contributed much to the process of preparation of the draft set of indicators. Data compilation through international joint study with Austria, Germany, the Netherlands and the United States was timely, which enabled us to present actual figures of historical trends of some indicators. However, there still remain many issues to be solved.

The first essential problem is data availability, in particular, poor data availability for estimating imported hidden flows. Japanese part of the international joint study mostly relied on the data provided by the Wuppertal Institute, but we may have to collect our own country-specific data reflecting origin of natural resources imported to Japan.

Many other detailed technical questions arise from indicators of recycling. For example, definition of "recycle ratio of specific materials" is not simple. Denominator could be domestic production, supply including import, consumption, or consumption plus abandoned stocks. Numerator could be recovered, input of secondary material to production, production of refined material from secondary input, including/excluding imported secondary materials and/or materials refined from recycled materials.

Disaggregation of the MFA by industrial sectors and by type of materials is another important subject, in order to link indicators and policy measures to improve environmental efficiency of industrial activities. If this disaggregation of MFA is made consistent with the Input-Output table, it will provide us with further opportunity of integrated analysis of the environment and the economy.

5. Conclusion and future perspective

Recently, studies on Material Flow Accounting in Japan have been activated through international collaborations in this field, and MFA has already been used as a part of the state of the environment reporting. The use of MFA in the development of environmental indicators for the Basic Environmental Plan is just a first step of potential policy applications of MFA. Planning and target setting processes based on the new basic law for promoting recycle-based society may give another great opportunity for policy-relevant use of MFA.

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Table 1 Summary of "Set of comprehensive environmental indicators" for the Basic Environment Plan of Japan (tentative translation)

*:core indicators
+:supplementary indicators

A. Sound Material Cycle

(1) Indicators set for material and energy flows

Indicators for "Material" Flows	Indicators for "Energy" Flows
*Direct Material Input (total)	*Total Primary Energy Requirement
+DMI disaggregated by sector	*Total Final Energy Consumption
+DMI per capita	+TFEC disaggregated by sector
+DMI per GDP in constant price	*TPER per GDP
+Domestic Hidden Flows(Ecological Rucksacks)	*TFEC per GDP
+Imported Hidden Flows(Ecological Rucksacks)	*Ratio of renewable energy to TPER
*Total waste generation	+Energy efficiency by sector
+Waste generation disaggregated by sector	
+Waste generation per capita	
+Waste generation per GDP in constant price	
*Recycle ratio of waste generated	
*Recycle ratio of specific materials (steel, aluminum, paper, glass, plastics)	
+ Nitrogen and phosphorus cycle	

(2) Indicators set for sound water cycle

*Natural water cycle indicator
=function (runoff ratio by type of ground surface, measures to enhance infiltration)
*Man-made water cycle indicator
=function (reuse of industrial water, public water and rainfall)

(3) DSR Indicators for environmental issues associated with material and energy flows

DSR indicators by 15 environmental themes	(See separate table 2)

B. Harmonious Co-existence with nature

(1) State of the nature

Driving force indicators	State indicators	Response Indicators
*Land use conversion	*Spatial continuity of forest	*Protected areas
	*Degree of human disturbance to vegetation	
	*Indicative animal species	
	*Total number of spieces - endangered spieces	
	+Function for land conservation	

(2) Access to the nature

Actual	Potential
*Indicators for recreational use of the nature	* Indicators of space for recreational use
	* Indicators of demand for recreational use
	* Indicators of support for access to the nature

C. Participation

Indicators for actions by national government
Indicators for actions by local government
Indicators for actions by industry
* Indicators for actions by citizens

D. International activities

(1) Indicators for international partnership for global environmental policy
(2) Indicators for support to developing countries (fund & personnel)

Remark:This table is a tentative, not-authorized translation of Japanese original one.

Table 2. **List of D-S-R indicators by 15 environmental themes**

+:supplementary indicators

Environmental Theme	Driving Force Indicators	State Indicators
Global warming	GHG emissions aggregated by GWP Emissions of each GHG (CO_2,CH_4, N_2O,HFCs,PFCs,SF_6,CFCs,HCFCs) CO2 emission per capita	+ Atmospheric Concentration of GHGs
Ozone layer depletion	ODS emissions aggregated by ODP	+ Total ozone amount above Japan
Acid Deposition	SOx emissions NOx emissions	Total deposition of $SO4^{(2-)}$ and $NO3^{(-)}$ Deposition of $NH4^{(+)}$ + Deposition of $H^{(+)}$ or pH of precipitation
Photochemical oxidant	NOx emissions NMHC emissions	Achievement rate of EQS for Ox Percentage of stations above alarm level of Ox
Urban air pollution	NOx emissions in specific polluted areas	Achievement rate of EQS for NO2 Achievement rate of EQS for SPM
Hazardous air pollution	T.B.D	Achievement rate of EQS for hazardous air pollutants
Nuisance (Noise, Vibration and Odors)	Traffic volume of trunk roads Total number of the Shinkansen Railway trains Areas exposed to aircraft noise	Population exposed to noise above specified levels or Achievement rate of EQS for Noise + Grievances about vibration + Grievances about odors
Organic pollution of water	(Rivers) Organic pollutants emissions (Coastal areas & Lakes) COD emissions Nitrogen emissions Phosphorous emissions	(Rivers) Achievement rate of EQS for BOD (Coastal areas & Lakes) Achievement rate of EQS for COD,N,P
Safety of water	T.B.D	Achievement rate of EQS for toxic substances
Marine environment	T.B.D	T.B.D
Soil pollution	T.B.D	Agricultural areas requiring measures Urbanized areas requiring measures
Ground subsidence	Drawn groundwater	Areas where subsidence is recognized
Solid waste	Amount of municipal wastes Amount of industrial wastes	+ Cumulative total of areas reclaimed by disposal of wastes
Toxic waste	T.B.D	T.B.D
Environmental risk of chemicals	T.B.D	T.B.D

Remarks:
Response indicators for all themes will be selected later.
This table is a tentative, not-authorized translation of Japanese original one.

GHG:Green House Gas
GWP:Global Warming Potential
ODS:Ozone Depleting Substances
ODP:Ozone Depleting Potential
NMHC:Non-Methane Hydro Carbons
EQS:Environmental Quality Standard
T.B.D:To be determined

MATERIAL FLOW ACCOUNTING: MATERIAL USE FOR NATIONAL CONSUMPTION AND FOR EXPORT: The experience of Sweden[26]

This report was prepared for the Third International Conference of the European Society for Ecological Economics Theme 9. Ecological Economics Modelling and Material & Energy Flows that was held in the spring 2000 in Vienna, Austria.

Abstract

Statistics Sweden has developed economy-wide material flow accounts for Sweden, as a part of an assignment for the government. The main purpose with the analysis is to be able to link the flows of materials in the society to the existing data on economic activity and environmental impacts. The approach aims to improve our knowledge of how materials are used in society and to enhance the efficient use of resources. The study shows possibilities of enhancing international comparability of aggregated data on material use, by making a division between consumption and export purposes. Direct Material Input (DMI), including production and imports, per capita amounts to 24-27 tonnes per capita for the period 1987-1998, with highest values 1989 and 1995. The fossil fuel input varies only slightly over the period, from 3,2 tonnes/capita in 1991 to 3,6 in 1996, a level which is unsustainable according to the Swedish EPA. Renewable raw materials vary between 8 and 9 tonnes per capita. The non-renewable categories ores and minerals vary between 11 and 15 tonnes/capita. Around 5 tonnes per capita are exported, while the rest, around 20 tonnes per capita, is national consumption. This calculation puts Sweden above the estimates made for Germany, USA and Japan, and in the same size as the Netherlands. There are several explanations for the differences, mainly the relative size of exports and the data sources. Total Material Requirements (TMR) mounts to at least 45 tonnes per capita. Comparisons of the input with waste statistics indicate that waste (excluding mining waste) amounts to about 10 % of the input. The recycled materials are about 5% of the amount of virgin resources brought into society each year. The materials that can be classified as hazardous for health (metals and imported goods excluded) amounts to around 20% of the direct flows.

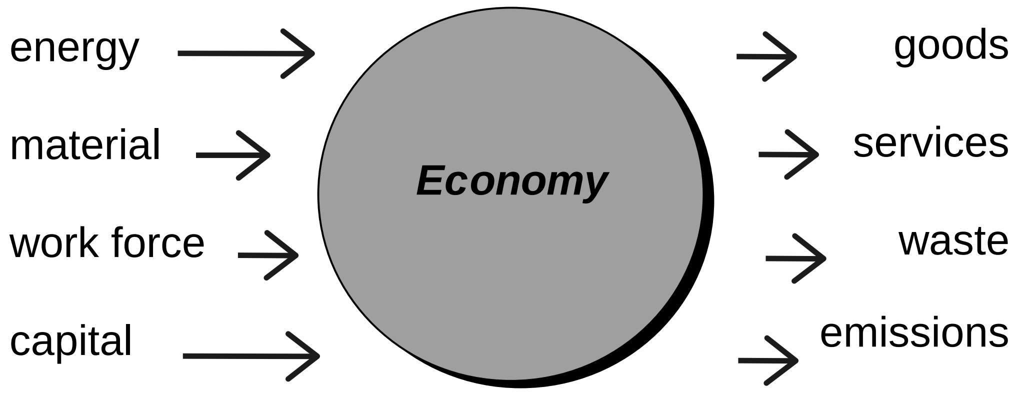
1. Introduction

Many environmental problems are connected to production and use of materials and energy. It would therefore be desirable to have an information system that gives consistent and complete information on material and energy flows. Such a system would even be more useful if it could be connected to economic data. The environmental accounts provides such a framework, but comprehensive statistics on material flows have not been available until now. Statistics Sweden is now in the process of developing material flow statistics for Sweden. One part of this work focuses on an aggregate description of the total material throughput for the society, with a methodology similar to what has been suggested internationally (WRI, 1997). This knowledge can be used to work towards eco-efficiency by improving the resource productivity. The results contribute to the work with environmental accounts and provide a link between society's use of materials and natural resource accounting.

We are interested in describing the environmental pressures from a nations economic activities through its producers and consumers. The producers purchase energy, materials, labour and capital to produce goods and services. This production process also produces waste, air emissions and water emissions (Figure 1).

26 Paper prepared by Ms. Viveka Palm and Ms. Kristina Jonsson, Statistics Sweden (SCB).

Figure 8. Figure 1. **Input to and output from the economy**



The environmental accounts aim at quantifying these resource flows and the relationships between them. From a sustainable development point of view, the economic system should produce the desired goods and services with a minimum of environmental impacts. This can only partly be achieved by reducing emissions from specific processes by end-of-pipe solutions, and reducing waste by recycling.

The size and composition of the inputs in the production process is of great importance for the resulting environmental pressure. This is particularly clear for carbon dioxide emissions from fossil fuel input, as well as for the use and spreading of chemicals. As the economy grows, so do the inputs of materials into the system. However, a counter-balancing factor is the energy and material efficiency gains that occur in the development of new products and new equipment.

If, for example, these effects balance out each other, we are facing a development with constant environmental pressures. This is not a satisfactory situation, as the recently defined Swedish environmental quality objectives will only be met if the environmental pressures are reduced.

Until now, there has been no coherent statistics on material flows to follow the development of material inputs. By establishing material flow statistics, policies on materials and eco-efficiency will have a firmer point of reference.

The forming of material flow statistics has been guided by two principles: to start with existing statistics, and to start with a wide range of materials. These principles lead to a suggestion to divide the materials description into three different areas. Natural resources, Chemical indicators and Substance flows for a limited number of chosen substances. The results couple to the newly suggested environmental quality objectives of primarily ‘a non-toxic environment’, ‘a good urban environment’, and ‘limited influence on climate change’. Here we will present some results from the natural resource area, expressed as an aggregate description of the total material throughput for the society.

The model used is organised similarly as the System of National Accounts. Main primary categories of direct material inputs (DMI) in the society are included (total inputs from foreign trade, agriculture, forestry, mining and fuels). Time series from 1987-1997 are presented. The time series have its main focus on the input side. Attempts are made to link the input data on natural resource use to emissions and waste by means of input/output analysis. However, the results point to that a further disaggregation of the monetay input/output tables are needed in future studies.

In the future, results from similar studies may show the increase of stocks in society. However, due to incomplete solid waste data, no such estimates are included now. The time series have their main focus on the input side, as the output statistics have not been produced with the same frequency. To make it possible to compare the use of material between different sectors of society, the input and output is divided into aggregated industries (by NACE).

2. Method

This study is an attempt to calculate the total national yearly input of raw materials with an economic value. In order to avoid double counting, those materials *that are taken from biosphere to technosphere during the year* are singled out. The method concentrates on the primary input, and avoids calculating the materials, substances and products that have already been accounted for as primary input.

This means, for example, that figures from plastic industry are not of primary interest in this work, since their raw material is already counted for as crude oil, industrial minerals or other primary goods. It also means that meat from the food industry is mainly recorded as the feed to produce poultry, etc. However, as the nation's material use is also covered by imports of raw materials as well as products, this method has its limitations. In accordance with similar studies, the import of goods is therefore recorded separately. Ideally, these goods should of course have been recalculated to their primary input. Since methods and data are lacking for that kind of recalculation, they are merely presented by their weight.

The method gives an aggregated figure of yearly raw material input. It shows the total and the share of renewable and non-renewable materials. In this form, it can be compared with figures from similar studies, and possibilities for resource efficiency can be highlighted.

As a further development, the figures have also been complemented with export figures. This is made in order to single out the input for national consumption from the input used in production for export purposes. Sweden is dependent on its export of raw materials such as ores and pulp. If consumers in Sweden would become more resource efficient, while the exports of raw materials to other countries increased, it is important that our measures on resource use can distinguish between these phenomena. Final demand is presented as national consumption and exports. National consumption is defined as domestic production plus imports minus exports.

The food referred to in the report consists of beef, pork, lamb, reindeer meat, game, poultry, fish, milk and eggs. Also cereals, fruit and vegetables. With regard to beef cattle, pigs and poultry, we have chosen to show the passage from nature to society by means of the feed they consume. Where sheep are concerned, we have assumed that the bulk of their fodder comes directly from nature, even if some auxiliary feeding generally occurs.

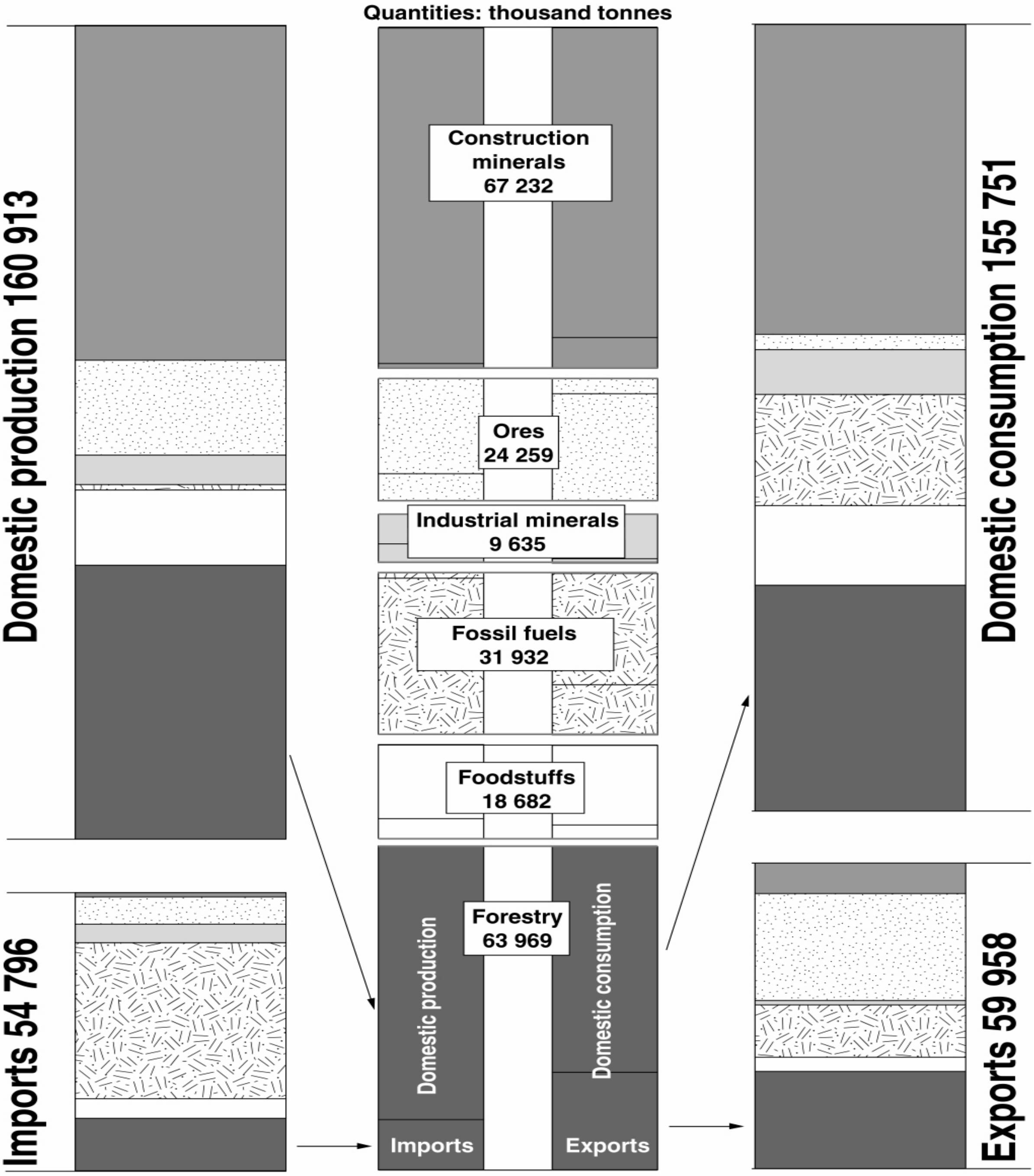
3. Results

The total material flows consist of one third renewable materials and two third non- renewable materials. Note that 20% of the non- renewable materials are fossil fuels. Construction minerals cause the largest material flow, followed by forestry and ores. Domestic production in Sweden consists mainly of construction minerals, ores and forestry. Construction minerals are consumed in Sweden, while ores and forest products are exported to a large extent. Seventy per cent of the Swedish exports consist of ores and forestry.

The Swedish imports consist mainly of fossil fuels. The greater part of raw material for food production come from domestic production, only a small amount is imported. The use of raw material for food production is mainly domestic material consumption, only a small part is exported.

One third of the domestic material consumption is renewable materials, mostly forestry. Construction minerals also stand for one third of the domestic material consumption. Twenty percent of the non- renewable materials consumed in Sweden are fossil fuels not stored in society, but consumed and dispersed as carbon dioxide.

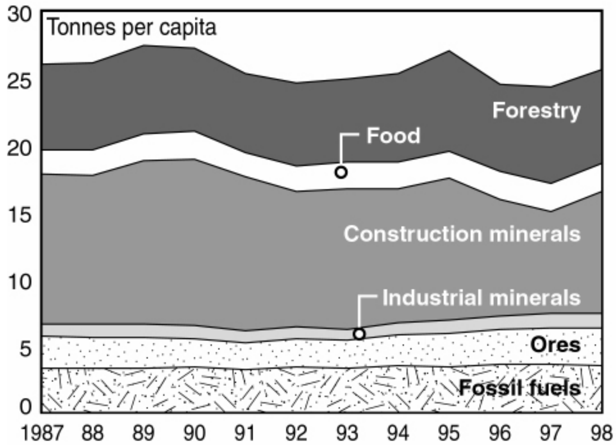
Figure 9. Figure 2. **Material flows in the Swedish economy,** 1997



DMI per capita

DMI per capita amounts to 24-27 tonnes per capita for the period 1987-1998, with highest values 1989 and 1995. The fossil fuel input varies only slightly over the period, from 3,2 tonnes/capita in 1991 to 3,6 in 1996. Renewable raw materials vary between 89 and 9 tonnes per capita. The non-renewable categories ores and minerals vary between 11 and 15 tonnes/capita. Around 5 tonnes per capita are exported, while the rest is national consumption (Figure 3).

Figure 10. Figure 3. **DMI per capita in Sweden,** 1987- 1997



International comparisons

This calculation puts Sweden above the estimates made for Germany, USA and Japan, and in the same size as the Netherlands. There are several explanations for the differences. Differences can be explained by system boundaries, by data sources and by how the exports are treated. In the table (Table 1) below the comparisons are shown. (WRI, 1997 and own calculations). For the Netherlands, we have chosen not to compare the disaggregated figures, as they were partly erroneous. For the total DMI, Sweden and the Netherlands appear to be of the same size however.

For the fossil fuels, Sweden and Japan have similar per capita figures of about 3 tonnes/capita. The industrial minerals are also on the same level as the other countries.

For the construction minerals, Sweden has a high figure. This can be explained by what statistics have been available, as the economic statistics may have different system boundaries than what is wished for. In this study, raw material statistics was often taken from other sources than the industrial statistics. Earlier studies (Bergstedt et al, 1999) have shown that construction materials are underestimated in the Swedish industrial statistics, as the cut-off on numbers of employees have excluded many small companies.

For the renewable materials, Sweden’s per capita input appears to be about 5 tonnes higher than the other countries, which is probably explained by the dominating forest industry.

The system boundary chosen for the ores has a major impact on the results. The international comparison made it clear that earlier studies have had a boundary different to the one chosen in the English study (Eurostat, 2000). In the international study from the World Resource Institute *the concentrates* of metals have been considered direct flows, while in the Eurostat report we considered *the ores* (but excluded the rock) as direct flows. In our Swedish study (SCB, 2000) the ores are recalculated as concentrates, and those figures are presented here. The calculation based on ores rather than concentrates gave much higher figures, between 2,0 to 2,8 tonnes/capita over the time period (not shown). A preliminary calculation of the total material requirement (TMR), where so-called hidden flows such as mining waste are included, shows figures of about 45 tonnes per capita.

Table 4. Table1. **DMI in tonnes per capita for USA, Japan, Germany and Sweden in 1991**

	DMI/ capita				DMC/ capita
	USA	**Japan**	**Germany**	**Sweden**	**Sweden**
Non- renewables					
Fossil fuels	8	3	6	3	2
Ores	1	1	1	2	0
Industrial minerals	0	2	1	1	1
Construction minerals	7	9	10	11	11
Total non- renewables	**16**	**15**	**18**	**17**	**14**
Renewables					
Raw material for food production				2	2
Forestry				6	4
Total renewables	**4**	**2**	**3**	**8**	**6**
Total non- renewables and renewables	**20**	**17**	**21**	**25**	**20**

Domestic material consumption

The DMI can be divided into domestic consumption and exports (see for example Hüttler et al, 1998). In order to distinguish the Swedish domestic material consumption, DMC, DMI have also been complemented with export figures. This is made in order to single out the input for national consumption, from the input used in production for export purposes. Sweden is dependent on its export of raw materials such as ores and pulp. If consumers in Sweden would become more resource efficient, while the exports of raw materials to other countries increased, it is important that our measures on resource use can distinguish between these phenomena.

Final demand is presented as national consumption and exports. National consumption is defined as domestic production plus imports minus exports. This estimate has its limitations and ought to be refined in future work.

Especially for small countries such as Sweden or the Netherlands the effect of export goods may dominate international comparisons between countries. To be able to assess the resource input for consumption, export will have to be subtracted from the DMI.

Apart from construction minerals, the time series of material use are fairly constant during the twelve year period. What natural resource use could then be regarded as sustainable? By comparing with scenarios that have been produced by the Swedish EPA in a project on sustainable Sweden, the current use of fossil fuels is clearly unsustainable, as a reduction of carbon dioxide emissions with more than 80% is needed to reach the environmental goal on climate gases by 2050. A phase out of the fossil fuels put greater stress on the use of forest resources both for transportation and heating purposes. A sustainable level of wood use was also established, with criteria for meeting the environmental goals on biodiversity, which is higher than today’s use. Also for the food sector some changes were recommended, in order to reach the environmental goals on eutrophication. To compare these scenarios with the consumption of material resources in tonnes is a future task. In future studies, we also intend to account for the energy consumption needed to handle these materials today, in order to estimate the options for energy efficiency measures such as recycling and substitution of materials.

4. Conclusions

DMI per capita amounts to 24-27 tonnes per capita for the period 1987-1998, with highest values 1989 and 1995. The fossil fuel input varies only slightly over the period, from 3,2 tonnes/capita in 1991 to 3,6 in 1996. Renewable raw materials vary between 8 and 9 tonnes per capita. The non-renewable categories ores and minerals vary between 11 and 15 tonnes/capita. Around 5 tonnes per capita are exported, while the rest is national consumption.

This calculation puts Sweden above the estimates made for Germany, USA and Japan, and in the same size as the Netherlands. There are several explanations for the differences, such as the relative size of exports and the data sources. For the fossil fuels, Sweden and Japan have similar per capita figures of about 3 tonnes/capita.

For the construction minerals Sweden has a high figure. This may be explained by what statistics have been available for the different studies. The so-called industrial statistics, which are primarily used for economic assessments, have system boundaries that cover most of the economic flows, but not necessarily the physical flows. In this study, raw material statistics was often taken from other sources than the industrial statistics.

For the renewable materials, Sweden's per capita input appears to be 5 tonnes higher than the other countries, which may be explained by the dominating forest industry. Also for food production the figures are higher than the USA, Germany and Japan. This may be due to the choice of statistic sources.

The fact that Sweden is a small country with a relatively large export of raw materials such as forestry and ores is evident in the results. If we separate the export from the domestic material consumption the per capita figures decrease with about 5 tonnes per capita. This difference is important to be able to distinguish, in order to separate life style changes from exports of raw materials.

Acknowledgements

The results are based on two reports. A Swedish report, financed by the ministry of environment, and an English report prepared on commission from EUROSTAT, who supports and co-ordinates development of environmental accounts in the EU member states. The European commission (DG XI) has contributed financially to the latter project. Several people have been engaged in different areas and in preparing these reports. Thanks to Annica Isacsson (emissions and waste), Irene Linder (renewable materials), and Anders Wadeskog (input-output analysis).

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PART II. METHODOLOGICAL ISSUES

MATERIAL FLOW ACCOUNTING – FRAMEWORKS AND METHODS:
Presentation by Eurostat[27]

Material flow accounts (MFA) have a role to play in informing policy formation. For example, resource use and resource efficiency is listed among the future key policy issues in the Review of the EU's Fifth Environmental Action Programme (Decision N° 2179/98/EC) and the Presidency conclusions of the informal meeting of the EU Environment Ministers in Helsinki, 23-25 July 1999. Key long-term themes of the new (6th) EU Environmental Action Programme 2000-2010 will be related to material flows (incl. climate change and use of resources). The UNSD Sustainable Development Indicator set and the EU Environmental Headline Indicator set include Resource Use indicators.

This paper looks at the various kinds of MFA approaches (with a focus on economy-wide MFA), their uses in policy, the frameworks and methods adopted for compiling MFA, the derivation of indicators from the accounts and the interpretation of these indicators. Finally, the paper identifies key issues for future advancement in MFA. As the basic framework for MFA is fairly simple, key issues in practice relate to availability of the primary data needed for the accounts, their comparability across countries and over time and the interpretation and uses of MFA results. As MFA will rarely be the only information source for policy formation, links to, and complementarily with, other data sets and information systems need to be fully understood.

1. Introduction

MFA are accounts in tonnes describing the extraction, transformation, consumption and final disposal of chemical elements, raw materials or products. Many applications focus on the flows of materials through the economy but some also include flows of natural origin and within nature. The first law of thermodynamics (conservation of matter) provides the conceptual basis for MFAs and ensures that inputs and outputs balance. The technique has been widely applied to materials and substances of specific environmental importance including fuels, strategic metals, timber, pesticides, solvents, zinc, cadmium, etc. The principles of statistical approaches towards material flow accounts and material balances have been formulated in the 1970s.[28] In Europe, MFAs are part of official statistics in several EU Member States and EFTA countries.[29]

With environmental policy focus shifting towards waste, health/chemicals, climate change and sustainable development, interest in materials management policies and accounts increased and recent years saw a strong increase in MFA applications and research. The European Commission funded ConAccount concerted action (1996-1998) was instrumental in advancing research and establishing networks.

A key development in the 90's was the wide application of economy-wide MFA and material balances starting from early beginnings in Austria,[30] Germany,[31] Japan[32] and the USA.[33] Unlike single-material or substance accounts, economy-wide MFA and the indicators derived from these accounts provide an aggregate picture of the entire material and energy throughput of a society/economy. Terms such as 'industrial metabolism'[34] or 'societal metabolism'[35] metaphorically suggest to consider modern

27 Papers prepared by Mr. Anton Steurer, European Commission - Eurostat.

28 United Nations (1976): Draft guidelines for statistics on materials/energy balances - UN document E/CN.3/493.

29 Eurostat (1997), Materials Flow Accounting: Experience of Statistical Offices in Europe. Luxembourg.

30 Steurer, A. (1992), Stoffstrombilanz Österreich 1988. Schriftenreihe Soziale Ökologie, Band 26. Wien.

31 Schütz, H. and S. Bringezu (1993), Major Material Flows in Germany. Fresenius Env. Bull. 2: 443-448.

32 Japanese Environmental Agency (1992), Quality of the Environment in Japan 1992. Tokyo.

33 Rogich, D.G., et al (1992), Trends in Material Use: Implications for Sustainable Development.

34 Ayres, R.U. (1989): Industrial Metabolism. In: Ausubel, J.H. and H. Sladovich (eds.): Environment and technical change, Washington DC

economies as living organisms whose dominance in, and impact on, a given eco-system can be indicated by the size and structure of its 'metabolic profile'.[36] The material throughput of mature economies is a central sustainability issues not just because of using up natural resources but also and foremost from the point of view of reducing and managing the output of residuals and other environmental impacts associated with the extraction, production or use of materials, including that socio-economic systems accrue more and more of total biomass production and of land.

2. Mapping MFA activities with policy issues

MFA activities in research and statistics cover a wide field along several dimensions and do not easily lend themselves to a simple categorisation. The materials covered range from bulk materials such as water, wood or total material throughput to selected priority substances such as heavy metals or chlorinated chemicals. MFA are made for a diverse range of economic, administrative or natural entities including whole economies, industries or establishments; nations, regions, cities; and catchment areas or eco-zones. The SEEA[37] offers the following categories: flow accounts of non-produced raw materials, product flow accounts, residual flow accounts and asset (stock) accounts. A distinction often found in research is between material and substance flows, where substances tend to mean 'pure' chemical elements or compounds and materials the actually observed flows of raw materials, products and residuals which are often (but not always) a mixture of various substances.

In view of the many dimensions it may be unnecessary to develop a rigorous classification of types of MFA. There are strong links, overlaps and synergies among different types and in practice various aspects are treated simultaneously. For example, accounts for substances are often derived - by application of technical coefficients - from the flows of observed 'carrier' materials (e.g. carbon content of biomass or fuels, zinc or cadmium content of steel or fertiliser, etc.). The issue is rather to develop a set of tables tailored towards the specific uses the accounts are made for.

Figure 1 below gives a very stylised presentation of the main area of interest for MFA accounts in relation to categories of policy use. The materials in the ellipse are assumed to have environmental impacts (specific impact per tonne multiplied by the volume of the flow) of broadly the same order of magnitude. Flows outside this range are of lesser interest from an environmental point of view or simply do not exist.

Three overlapping clusters or groups of materials may be identified:

- Low volume flows with a high specific toxicity (hazardous substances). The key issue is the characteristics of the substances (eco-toxicity, etc.). Policy focuses on control of the uses or releases.
- Basic industrial materials ranging from packaging materials to cement, steel and timber. Here the policy focus is on materials and resource management, resource efficiency, waste minimisation, etc. These materials are of interest for various reasons including life-cycle considerations (e.g. highly polluting or energy intensive production processes, transport, etc.) and economic importance.
- High volume flows ranging from e.g. timber or sand and gravel to the total material throughput of an economy. In this area often more general sustainability considerations apply, related to efficiency of use, long-term sustainability of supply, economic restructuring, etc.

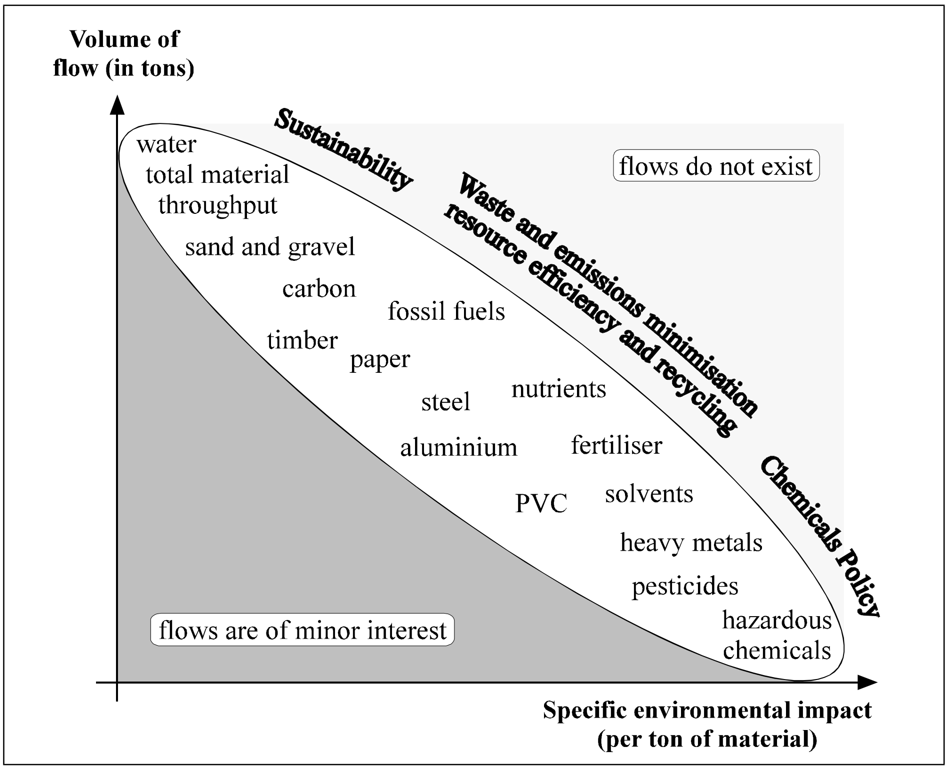
35 Fischer-Kowalski, M, and H. Haberl (1993), Metabolism and Colonisation. Modes of Production and the Physical Exchange Between Societies and Nature. Wien.

36 Schandl, H. and Schulz, N. (2000): Using Material Flow Accounting to operationalise the concept of Society's Metabolism. A preliminary MFA for the UK 1937-1997. ISER Working Papers, Paper 2000-3, University of Essex.

37 United Nations (1993): System of Integrated Environmental and Economic Accounting, New York. The SEEA is currently under revision by the London Group on Environmental Accounting. Draft chapters of the new SEEA are posted for public review at http://ww2.statcan.ca/citygrp/london/publicrev/pubrev.htm.

The three clusters may also be related to types of policy instruments with 'hard' policies (bans and phase-out protocols) dominating the policy mix for hazardous substances and 'soft' instruments for the high-volume end (e.g. taxes, voluntary agreements or information). This in turn may be related to the policy planning horizon which tends to be longer-term at the sustainability end (this does not exclude the need for regular monitoring of e.g. hazardous substances).

Figure 11. Figure 1. **A stylised map of the materials of particular interest for accounting**



Source: Steurer (1996),[38] as developed with W. Radermacher (StBA) in 1995

For some groups of MFAs there is an immediate policy and management use (e.g. linked to chemicals policy or recycling). Others are intended to serve longer-term environmental policy objectives and sustainability considerations (e.g. economy-wide MFA describing the material metabolism of a nation). For the latter, the policy uses (and instruments) are only just developing. Future applications and analyses have to prove that MFAs are a useful and efficient tool.

3. Frameworks for MFA

At a conceptual level MFA can be considered as the grand parallel to monetary economic accounting and the importance of MFA (and physical accounting more generally) is widely accepted in the context of environmental accounting.[39] At a practical level the parallel does not hold as easily. While money is a common numeraire, the goods consist of a vast range of materials with greatly varying economic and environmental importance and impact. Moreover, money circulates and serves a variety of transactions, whereas materials in circulation change their form and composition and losses (waste and emissions) occur at each stage in the production and consumption chain.

38 Steurer A. (1996): Material Flow Accounting and Analysis: Where to go at a European Level. In: Statistics Sweden (ed.): Third meeting of the London Group on Natural Resource and Environmental Accounting – Proceedings Volume, Stockholm, pp. 217-221.

39 Chapter 3 of SEEA 2000, draft for public review of 1 May 2000, available at: http://ww2.statcan.ca/citygrp/london/publicrev/pubrev.htm.

The basic principle used for MFA is the first law of thermodynamics which states that matter (mass/energy) is neither created nor destroyed by any process but only converted from one form into another so that for any transformation the total inputs and outputs are identical (taking account of residuals and of changes in stocks). This allows to apply accounting techniques when making MFA, to interpret discrepancies in a meaningful way and to fill gaps in basic data with informed estimates.

The basic framework for MFA is very similar to the national accounts framework. In its most comprehensive form, the framework used is directly based on the input-output tables or supply and use tables.[40] The input-output framework provides for two basic equations:

1. along the rows of an input-output table (commodity flow) the basic equation for a given commodity is: domestic production plus imports equals domestic use plus exports (plus/minus changes in stocks). Domestic use can be intermediate consumption or final consumption or fixed capital formation (i.e. investment goods).
2. down the columns of an input-output table (production function) the basic equation for a given production process is: total input of materials equals total output of goods (including by-products) and residuals (waste and emissions to air and water).

In both cases, the equations can be calculated in terms of a (composite) material or a particular substance or element carried; or both, since often the accounting for substances is based on information on the use of materials. For the whole economy the total amount of materials taken from nature (and imported) equals the total amount of residuals generated plus the goods exported plus the net accumulation of material in the economy.

MFAs often provide detail adapted to the characteristics of the material studied with separate tables for:

- extraction/harvesting (e.g. agriculture, forestry, mining and quarrying)
- transformation/conversion (e.g. refineries, basic metal industries)
- intermediate uses (e.g. in manufacturing)
- final uses (e.g. households)
- accumulation (capital formation, durable consumer goods)
- imports/exports
- waste management and recycling
- residuals (waste and emissions)
- Flows and accumulation in nature

This general framework is in practice very much adapted to the characteristics of the materials analysed and to their profile of use. For example, if uses are direct or dissipative (e.g. fuels, nutrients or solvents) so that the materials enter the environment quickly, stocks do not play a major role. In other cases the accumulation in the economy (e.g. for construction materials, metals or PVC) or in the environment (e.g. heavy metals, persistent chemicals) is important. For some materials recycling is important (e.g. for paper, glass, metals or CFC) but not for others, etc.

Actual applications can range from very elaborated and detailed accounts to very simple indicators of apparent consumption only derived from production and foreign trade statistics. An example for the first approach is the 'Zinc Balance for the Netherlands, 1990' by Statistics Netherlands, an example

40 See for example the Eurostat Working paper Nr. 2/1998/B/1: 'Physical Input-Output Tables for Germany, 1990', by C. Stahmer/M. Kuhn/N. Braun of the German Federal Statistical Office, or 'Material Flows and Input-Output Analysis' by P. Konijn/S. de Boer/J. van Dalen (1995), Statistics Netherlands.

for the latter approach is ‘Hazardous Chemicals’ by the Swedish Chemical Inspectorate and Statistics Sweden[41].

The level of detail chosen (and hence the resources needed) for an MFA will depend on the purpose of the account and on the characteristics of the material. For the analysis of policy options and for policy formulation more detailed accounts with links to economic information will be needed whereas monitoring of the broad trends in material use will require less detail. Dangerous materials which are used for a variety of purposes and for which substitutes are not readily available (such as zinc) will require more effort. Data availability is of course important. For example the good representation of a material or substance in the standard product classifications or the existence of a chemicals register can be very helpful.

4. A framework for economy-wide MFA

Eurostat is developing a framework and recommendations for economy-wide MFA with the aim of harmonising terminology, coverage, categories of materials to be distinguished and practical compilation and estimation procedures. A project is ongoing to establish economy-wide MFA EU-wide following this methodology. The basic outline of the framework is summarised in a composite material balance (Fig. 2).

Figure 12. Figure 2. **Economy-wide material balance with derived resource use indicators**

INPUTS (origin)	**OUTPUTS (destination)**
Domestic extraction	**Emissions and wastes**
Fossil fuels (coal, oil…)	Emissions to air
Minerals (ores, sand…)	Waste landfilled
Biomass (timber, cereals…)	Emissions to water
	Dissipative use of products and losses
Imports	(Fertiliser, manure, seeds, corrosion...)
DMI - direct material inputs	***DPO - domestic processed output to nature***
Unused domestic extraction	**Disposal of unused domestic extraction**
From mining/quarrying	From mining/quarrying
From biomass harvest	From biomass harvest
Soil excavation	Soil excavation
TMI – total material input	***TDO - total domestic output to nature***
	Exports
	TMO – total material output
Indirect flows associated to imports	
TMR - total material requirements	***Net Additions to Stock (NAS)***
	Infrastructures and buildings
	Other (machinery, durable goods, etc.)
	Indirect flows associated to exports

Note: excludes water and air flows (unless contained in other materials).
Source: Eurostat (2000): Economy-wide Material Flow Accounts and Balances with derived Resource Use Indicators. Draft for Public Review 10 October 2000.

41 See Eurostat (1997): Material Flow Accounting - Experience of Statistical Institutes in Europe, Luxembourg.

5. Indicators derivable from a material balance

A set of indicators can be derived from the composite balance including:

Input indicators

- Direct Material Input (DMI)
- Total Material Input (TMI)
- Total Material Requirement (TMR)
- Domestic Total Material Requirement (domestic TMR)

Output indicators

- Domestic Processed Output (DPO)
- Total Domestic Output (TDO)
- Direct Material Output (DMO)
- Total material output (TMO)

Consumption indicators

- Domestic material consumption (DMC)
- Total material consumption (TMC)
- Net Additions to Stock (NAS)
- Physical Trade Balance (PTB)

These indicators are linked by accounting identities. For example, DMI = DPO + NAS + Exports = DMO + Exports, TMI = TMO + NAS, NAS = DMC – DPO, etc. DMC and TMC are calculated as follows:

- DMC (domestic material consumption) = Domestic extraction (used) + Imports - Exports
- TMC (total material consumption) = Domestic extraction (used and unused) + Imports + indirect (‘hidden’) flows associated to Imports - exports - indirect flows associated to Exports

More indicators could be derived from the accounts, e.g. by setting the boundaries of the accounts differently or by compiling indicators per broad material category (biomass, fossil fuels, construction minerals, etc.). Most of the indicators listed above, taken individually, can be derived from individual accounts (see the sequence of accounts below) without the need to compile a complete material balance. For presentational purposes it is useful to relate these indicators to socio-economic indicators such as GDP or population.

Which resource use indicator will be considered the most relevant and useful in the longer term is difficult to predict at this stage - only future use in analysis can provide a sound basis for such recommendations. The choice of the most relevant indicators will depend on the policy focus and on proven usefulness and applicability of indicators in policy analysis. At this stage, only a set of criteria for the selection of indicators can be offered:

- Ease of understanding the meaning of an indicator
- Ease of compilation
- Compatibility with the national accounts
- Potential for policy use
- Data availability
- Completeness of the indicator

At present it appears that good candidates for core indicators would be the input indicators DMI and TMR as well as the consumption indicators DMC and, maybe, TMC (the latter being difficult to estimate because of the need to estimate also indirect flows associated to exports). NAS and PTB may be interesting supplementary indicators.

'The Weight of Nations'[42] documents the feasibility and usefulness of output indicators. However, the availability of primary data for regularly compiling output indicators is currently more limited than for input indicators (e.g., data on waste disposal and emissions to water are often incomplete).

Compilation of fully-fledged economy-wide material balances (or aggregated input-output tables) describing both inputs and outputs of materials by broad material groups is instrumental for ensuring that the accounts balance but is also resource-intensive. A (sub)set of economy-wide material flow accounts should be compiled annually, starting with accounts for direct material flows. Full-fledged economy-wide material balances should be compiled at regular intervals, for example linked to availability of e.g. waste and waste water statistics.

6. A sequence of accounts

For practical compilation work a system of accounts has been set up. The sequence of these accounts is such that the material flows for which data are more likely to be available are presented first. Progressing through the sequence of accounts, more primary data and compilation work will be required. The individual accounts are:

1. Direct Material Input Account,
2. Domestic Material Consumption Account,
3. Physical Trade Balance Account,
4. Net Additions to Stock Account,
5. Physical Stock Account,
6. Direct Material Flows Balance,
7. Unused Domestic Extraction Account,
8. Indirect Flows Account,
9. TMR account,
10. TMC account.

It is important to have the indicators in a long time series in order to identify longer-term trends and isolate changes that are due to economic cycles.

7. Basic data

Data sources include the following:

- Industry or production statistics: extraction of non-agricultural raw materials, recycling (partly),
- Agricultural and forestry statistics: extraction/harvest of renewable resources,
- Trade statistics: imports and exports,
- Energy statistics, i.e. energy balances: extraction of energy carriers,
- Environmental statistics: several output flows (air emissions, solid waste, waste water) and recycling,

These data sources will be complemented by estimates as needed. Information from other institutions (trade associations, government agencies) and especially direct contacts with the producers of the materials under consideration are also often used.

42 Matthews, E. et al (2000): The Weight of Nations: Material outflows from industrial economies, World Resources Institute, Washington D. C.

8. Selection and interpretation of indicators

Resource use and resource efficiency has emerged as a major issue for long-term sustainability and environmental policy at EU and Member States level. Objectives include to substantially increase the resource efficiency of the economic system, thereby reducing the use of natural resources and the related negative impacts on the environment. Two main themes have been identified as policy relevant: the 'total quantity used' and the 'efficiency in use'. This implies that the resource issue should be analysed in terms of 'resource efficiency or productivity' - a main current policy focus - and in terms of absolute use levels and the 'scarcity' of resources.

Resource use indicators must be seen in context with other indicators. For example, in the EU set of Headline Indicators the resource use indicator is complemented by other resource-related indicators, such as 'water quantity' (water use), 'waste', 'climate change' or 'land use'. Thus, a resource use indicator should focus on the total resource use by the economic system, thereby complementing other indicators which focus on specific environmental themes. For the first publication of EU Headline Indicators, Resource Use will be described by Gross Inland Energy Consumption, in addition to a material use indicator.

As resource indicators are typically related to GDP at constant prices to show trends in resource productivity (efficiency), it is useful to compare the way resource use indicators are constructed with the way GDP is defined. GDP can be defined in several ways. The closest parallel to material flow accounting can be established for the calculation of GDP as the sum of final uses. The textbook formula for this is GDP = C+I+X-M, with C for final consumption of households and government, I for investment (gross capital formation), X for exports and M for imports. Exports are added and Imports are deducted whereas for material input indicators Imports are added, and for DMC and TMC Exports are deducted. This is because physical and money flows have opposite directions.

Consumption indicators are the closest equivalents to national accounts aggregates (GDP, NDP or gross capital formation, as the case may be). DMC or TMC are thus best integrated with macroeconomic performance indicators such as GDP and better suited for calculating overall efficiency or productivity measures in which the numerator and denominator are consistent. Note also that key energy indicators such as Gross Inland Energy Consumption are consumption indicators.

9. The trade bias in material input indicators

The difference between input and consumption indicators can be of practical importance, especially for small economies. Recent results for Austria and Finland[43] illustrate that efficiency increases are higher when measured as GDP (at constant prices) per tonne of material consumption (TMC and DMC) and compared with GDP per tonne of material input (TMR and DMI). and that this gap widens over time. One reason for this is that both imports and exports of materials have grown fast over the past decades, due to trade liberalisation and EU accession (internal market). Special factors may magnify trade-induced biases, e.g., the 'Rotterdam' or 'Antwerp' effect.[44] Table 1 shows preliminary results of ongoing analysis related to differences between DMI and DMC. As could be expected, for the EU as a whole the difference is small and does not change much over time, whereas for small economies the differences tend to be more important (and increasing).

43 Muukonnen (2000): Material flows accounts - TMR, DMI and material balances, Finland 1980-1997, Eurostat Working Paper 2/2000/B/1, Luxembourg. Mäenpää, I. (1999): Towards a sustainable Finnish economy, Helsinki. Gerhold, S. and B. Petrovic (2000): Material flow accounts - material balance and indicators, Austria 1960-1997, Eurostat Working Paper 2/2000/B/6, Luxembourg.

44 Rotterdam (NL) and Antwerp (B) are important EU entry points for materials. For an analysis of the Dutch case see Adriaanse, A., S. Bringezu, A. Hammond, Y. Moriguchi, E. Rodenburg, D. Rogich, H. Schütz (1997): Resource Flows - The Material Basis of Industrial Economies. Washington: World Resources Institute.

Table 5. Table 1. **Comparing resource use indicators – DMI and DMC**

DMI in % of DMC, 1997	
EU-15	105.5
IRL	107.7
E	109.7
EL	112.0
P	112.0
I	113.8
D	114.1
F	116.9
FIN	119.2
A	120.1
UK	120.1
DK	123.9
S	129.3
B/L	**180.2**
NL	**187.8**

Increase in distance DMI – DMC between 1980 and 1997, in %	
EU-15	1.3
EL	3.1
F	3.1
E	3.2
IRL	3.5
D	4.5
I	5.9
P	6.3
UK	7.2
A	8.7
DK	10.4
FIN	11.9
NL	15.3
S	16.6
B/L	22.6

Source: Eurostat and Wuppertal Institute (2000), preliminary results

There may also be other reasons for possible biases in input indicators: For example, the quickly increasing domestic extraction of North Sea oil in the 70s/ 80s and the subsequent increase in physical exports (partly compensated by a decrease in imports) in the UK or Norway could affect time series of input indicators. However, comparable data and analyses are still limited. More data, research and analyses are needed before firm conclusions on indicator selection and interpretation and on the practical importance of country-specific factors can be drawn.

Apart from ensuring comparability of data sets across countries, more research will be essential to guide interpretation of indicators in future. This includes research into the precise meaning of the various indicators and their relation to key socio-economic indicators, more experience with analytical applications and analysis and improved understanding of the reasons for changes in the indicators. Analysis of the correlation between different indicators is highly relevant in this context.

10. Conclusions and outlook

The basic framework of MFA is simple and universally applicable. The main data sources are often standard statistics of output, inputs and trade. The details of the accounting procedures are adapted to the characteristics of the materials chosen. For accounts of e.g. hazardous materials technical expertise as well as direct information from individual firms is often as important as the standard statistical sources.

Approaches vary from simple indicators of apparent consumption derived from standard statistics to detailed analyses of all aspects of the materials under consideration, even including flows of natural origin or within environmental media.

Material flow accounts are often made at non-regular intervals, or as an ad hoc reaction to specific user demands or policy debates.

The resource requirements for MFA vary but are often considerable. Regular accounts can only be made for a limited number of materials/indicators.

For economy-wide MFA, data availability is a crucial factor for defining the scope (and level of detail) of the accounts and the derived indicators. As a first heuristic, data on the input side are often available in long time series, whereas data on the output side (e.g. waste) still need some development. Data on indirect (‘hidden’) flows are generally not directly available and must be estimated.

A material balance approach (or even fully-fledged physical Input-Output tables) will facilitate derivation of indicators tailored to satisfy future policy needs. The underlying data-structure will support more detailed analyses. However, primary data needed for full material balances are not always readily available. Simple input or consumption indicators should thus be produced annually, whereas full material balances and physical input-output tables could be compiled at intervals.

MFAs are rarely the sole tool for decision support. Rather, they complement other sets of information. The links to other information systems need to be taken into account to optimise the MFA work and to ensure compatibility with other approaches (e.g., the NAMEA system[45]).

The role of imports and exports is worth considering to assess a nation's contribution to world-wide trends on resource exploitation (including e.g. land use or emissions abroad due to imports). Therefore, indirect or 'hidden' flows should be included in the framework and development of data on indirect flows advanced.

Economy-wide MFA have seen enormous progress in recent years. It is essential now to:

- ensure comparability of the accounts across countries so as to support policy use and analysis,
- advance the understanding of the meaning of the various indicators that can be derived from the accounts,
- advance the analysis of results, including by analysing the correlation among indicators and by identifying the impact of country-specific factors on the indicators,
- identify ways to reduce the costs of compilation.

45 For an overview see e.g. European Commission (1999): Pilot Studies on NAMEAs for air emissions with a comparison at European level, Office for Official Publications, Luxembourg.

MATERIAL FLOW ACCOUNTING – METHODOLOGY AND FRAMEWORKS:
Presentation by the United States[46]

1. Introduction

All accounting for material flows (MFA) has, at its basis, a mass balance approach to understanding economic activity. Whether at the macro-level of a national economy, or on the scale of a region, economic sector, firm, substance, or even product life cycle, MFA, in principle, attempts to account for all material inputs to that scale, the transformations, if any, of those inputs, and all the final outputs from that scale – products, emissions, leakages, and wastes – by balancing the materials that go into the economy with those that leave the economy (less materials added to stocks-in-use). The purpose of understanding an economy in material terms is to identify inefficiencies, understand the environment/economic nexus, and provide policy makers with the information necessary to set priorities, identify points of policy leverage, and gain insight into the potential unforeseen consequences of material, technological, and policy intervention.

2. The national economy

The goal of MFA at the national level is to provide an overall picture of material flows and so identify broad trends, the magnitude of various flows, and the interaction of those flows with the monetary economy. MFA at this scale allows the creation and tracking of indicators of the whole economy – a necessary overview of how the economy works and where important flows exist. Because of its broad nature, MFA at the national scale cannot be a materials management tool, but it can highlight areas where such tools are needed.

The data required for painting a material picture of the national economy is much less detailed than that required to understand smaller economic scales. While detailed inventories of materials at the smaller levels would be valuable in constructing the national picture, in practice investigators are forced to deal with only partial inventories, information on gross flows, a generalized understanding of processes (extraction, transformations, emissions, leakages), and limited information on final use and the ultimate fate of materials.

3. Frameworks

There are two frameworks that are used to construct and understand material flows at the national level. One is the national mass balance approach that looks at the physical inputs to the economy and the physical outputs from the economy (e.g., Figure 2). This is the approach used in the recent publication of *The Weight of Nations: Material Outflows from Industrial Economies*. (Matthews, et al., 2000) The second is the creation of physical input-output tables that, in their final form, parallel the monetary input-output tables of the system of national accounts. These track materials from industrial sector to industrial sector with the additional dimension of flows to the environment. This is the approach used in the recent publication *Physical Input-Output Tables for Denmark* (Pedersen, 1999). This approach also requires the creation of mass-balances, but at a more detailed level than does the first. The choice of frameworks depends on the purpose of the MFA activity. In the first framework the purpose was international comparison and a comparison of trends in material use efficiency. In the second, the purpose was to create

46 . Paper prepared by Mr. Eric Rodenburg, Minerals and Materials Analysis Section, U.S. Geological Survey, U.S. Department of the Interior.

a component of a system of "green" national accounts that does not assign monetary value to resource depletion, and pollution.

Figure 13. Figure 1. **A materials flow view of an industrial economy** (Matthews, et al., 2000, p.7)

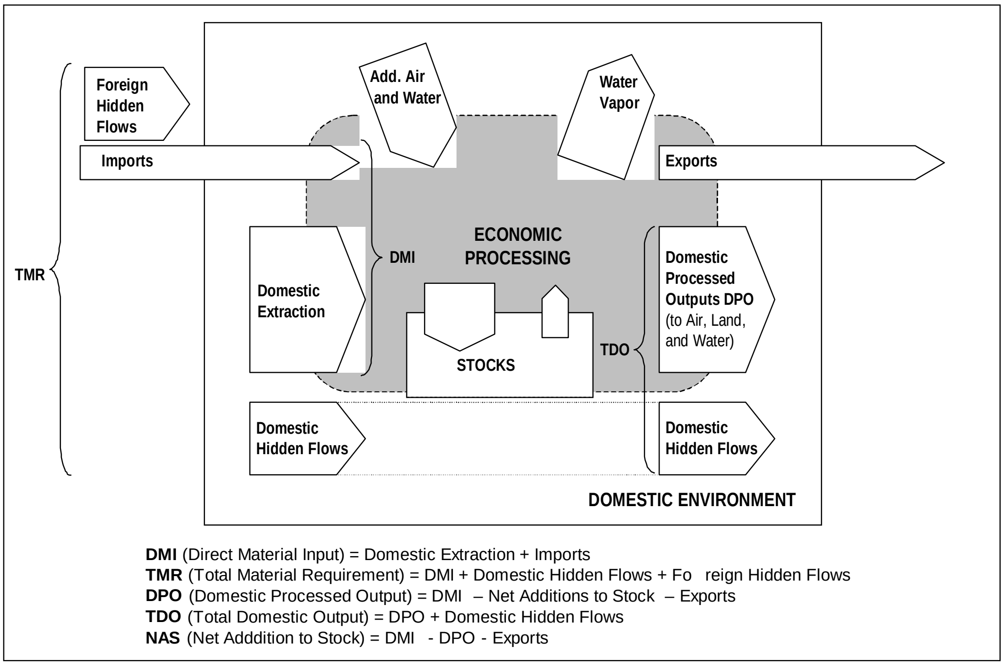
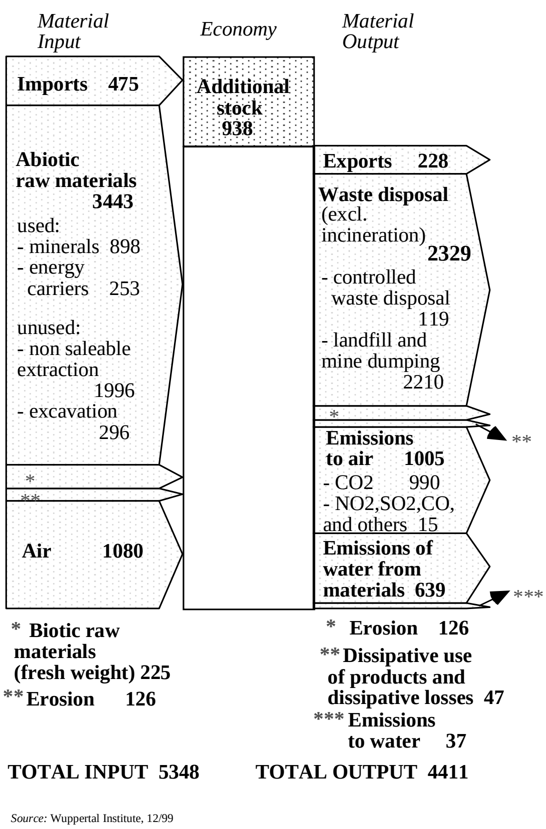


Figure 14. Figure 2. **The material flow balance of Germany** (Matthews, et al., 2000, p.37)

1996 - Million tons



4. Boundary Conditions

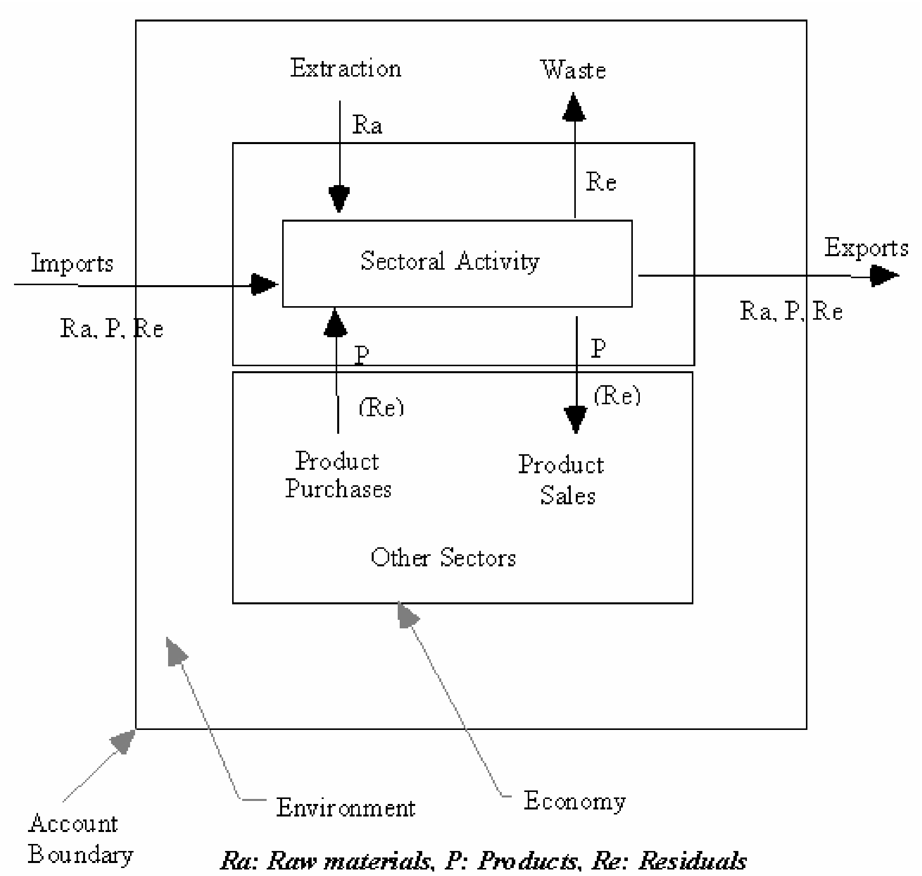
MFA requires an explicit definition of the conceptual boundaries of the system under study. National borders make up one such arbitrary, yet sensible set of boundaries. But this is equally necessary when developing MFA at the level of the firm, or a region, or a household.

Figure 15. Table 1. **Categories of boundary decisions**

Economic– national, firm, household
Geographic – national, region, international
Temporal – instantaneous, time series
Material – exclusions

In national MFA using input-output tables, the boundary is set narrowly to within the monetary economy and within national borders. In Pedersen (2000), only materials that are priced are included. In order to maintain parallelism with the monetary input-output tables, physical input-output tables represent the transactions in materials that are priced that occur between industrial sectors.

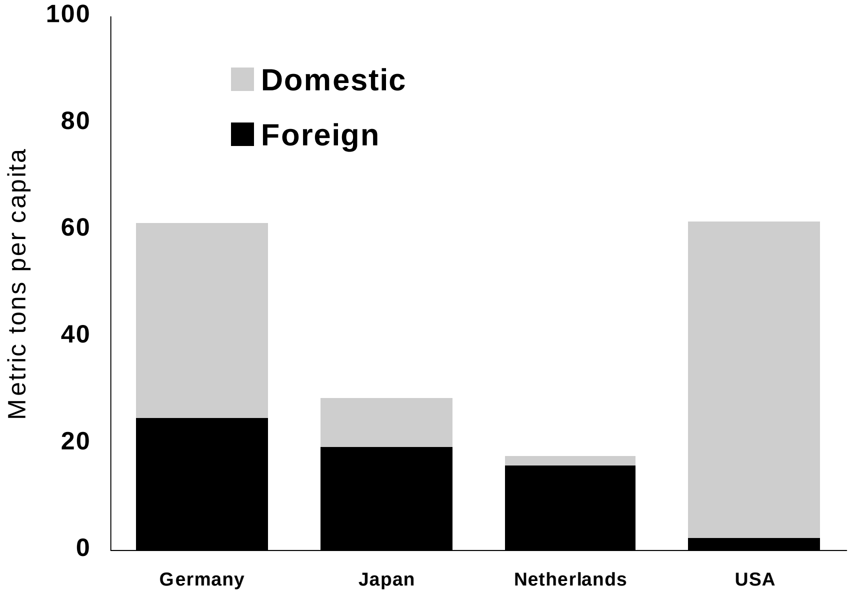
Figure 16. Figure 3: **Conceptual model of physical input-output tables with boundaries** (Wuppertal Institute for Climate, Environment, Energy, 1998)



In the national level material balance MFA (Matthews, 2000), the boundary is also set at the national border, but includes flows that are created ancillary to the production of commodities or the creation of infrastructure (hidden flows or environmental rucksacks) and sets as its economic boundary those materials that are priced and enter the economy and those that exit the economy. The distinction between hidden flows and commodity flows is crucial. Hidden flows are not priced, but are large in magnitude. They include such materials as overburden, eroded soil, and tailings. Commodities are counted as materials at their first monetary transaction. This definition means some overlap occurs. Tailing piles at copper mines are derived from a non-priced ore and so are defined as hidden flows. The functional equivalent of tailings (red mud) from the production of alumina from bauxite ore can occur either before or after the sale of bauxite and so could be considered a hidden flow or a process waste.

Industrial economies are characterized by international trade and so raw materials, semi-manufactures, and finished products are imported. Hidden flows associated with these imports, while occurring in other countries, can also be included in a material balance MFA if the total burden – foreign and domestic – of material use on the planet is an important purpose of the study. *Resource Flows: The Material Basis of Industrial Economies* (Adriaanse, et al., 1997) explicitly includes these foreign hidden flows to allocate responsibility for offshore environmental effects of material use.

Figure 17. Figure 4: **Foreign and domestic hidden flows in four industrialized countries**, 1994. (Adriaanse, et al., 1997)



Not all material flows need be included in MFA. Water is often excluded or is counted only as water embodied in another material flow. The flow and use of water, for cooling, power generation, and waste disposal is often well documented, but is so large, that it would overwhelm the flows of other materials. Air moved for ventilation, is similarly large in quantity and relatively benign and is usually excluded from MFA. The products of combustion (carbon dioxide, water vapor, carbon monoxide, sulfur dioxide, and nitrogen oxides), on the other hand, include oxygen and sometimes nitrogen derived from the air. These oxides are sometimes counted with the embodied oxygen (Matthews, et al., 2000) and sometimes without (Adriaanse, et al., 1997). The choice depends on the purpose of the MFA and is somewhat arbitrary.

MFA accounting can focus on a single year or be given a time dimension. A set of input-output tables, by definition, looks only to a single base year. In contrast, material flows are shown in a twenty-two year time series in the five countries in Matthews, et al. (2000). In the U.S. data in that study, outflows to the environment are instantaneous, that is, the outflows are reported in the year of production. The other four countries report actual outflows.

5. Approaches

There are several basic approaches to constructing national MFA systems. The Physical Input-Output Tables for Denmark (Pedersen, 1999) is based upon the construction of material balances for 2940 different commodities associated with the goods and services found within the Danish economy. These were distributed across industries according to the relative share of transactions found in the monetary input-output tables and aggregated to a 27 X 27 industry input-output matrix. Residuals, that is, flows to the environment, are characterized by mass only and not by material.

With the exception of the data for the United States, the data shown in *Weight of Nations: Material Outflows from Industrial Economies* (Matthews, et al., 2000) was based, in general, on estimates of inputs and separate estimates of output (emissions, wastes, and other flows to the environment) using relatively good governmental statistics and extrapolations from special studies. Of special importance were studies that defined emission factors associated with the processing of materials.

The United States data shown in *Weight of Nations: Material Outflows from Industrial Economies* (Matthews, et al., 2000) were based on calculations of 460 individual material flows – in part due to limited data on waste flows compared to the European countries in the same report. Production, imports, and exports combined to give inputs to the economy. Estimates of extraction and process losses, emissions, and ancillary flows were calculated. Information on the final use of products from these flows was used to allocated them to the environment. Each flow to the environment of any kind was characterized by one of seven modes of first release, (e.g., M1. Flows contained or controlled on land as solids), five quality categories (e.g., Q3. Flows that have not been chemically processed but are chemically active [salt], or biologically hazardous [asbestos]), and three categories of velocity through the economy (e.g., V3. Flows that stay in the economy for more than 30 years). This allows a first order characterization of potential effects of these flows on the environment.

6. Estimation

In the best of all worlds, governments would collect all the data required to characterize the physical economy. But, this is Earth and here investigators must deal with data gaps, including inappropriately aggregated data, missing data, aged data, and time series data that abruptly end. Investigators must use a variety of means to estimate flows where such constraints exist. Good work on MFA requires that such means be explicitly documented for analysts and policy makers.

Where available, existing governmental datasets provide the starting point for MFA. In general, good data are available for commodities entering the economy through production or importation. But, this is not always the case. Especially for imports, data are usually available for the value of products entering a country in aggregated categories, but disaggregation of those flows and conversion of value to mass are sometimes problematical.

Special studies can be used to supplement production data. For example, studies of coal chemistry can be used to characterize emissions to bottom ash, fly ash, and the atmosphere from coal combustion. In *The Weight of Nations: Material Outflows from Industrial Economies* (Matthews, et al., 2000) participating institutions sometimes used emissions coefficients developed by the others to estimate flows by analogy. Not all imports are consumed in country, some are transshipped (especially in smaller trading countries, e.g. the Netherlands) some are used as materials that are then exported. These special cases require special handling. Academic research such as *Accounting for Resources, 1: Economy-wide Applications of Mass-Balance Principles to Materials and Waste* (Ayers and Ayers, 1998) provide essential information on process losses and the universe of materials that flow through processes. Expert opinion is another source of information on otherwise intractable information problems, especially related to the efficiency of processes, the life of materials, and the ultimate fate of products. The filling of gaps through extrapolation is a universal strategy and one that should be documented.

Detailed review of the data, assumptions, and sources is required to ensure that MFA provides the best data possible. At the national level, MFA statistics should provide a view of the economy that is correct in the magnitude and nature of flows.

7. Indicators

The purpose of material flow accounting is to inform, not simply to amass statistics. Data are not information. The statistics generated by MFA must be aggregated in a way that tells the story of the material economy while maintaining accuracy and transparency. The monetary accounts of a nation use indicators in this way. Gross domestic product (GDP) is a measure of the monetary economy and how it changes over time that has meaning to the public. Analogous indicators must be constructed for the environment. Both *The Weight of Nations: Material Outflows from Industrial Economies* (Matthews, et al., 2000) and *Resource Flows: The Material Basis of Industrial Economies* (Adriaanse, et al., 1997) provide such indicators – Total Material Requirement (TMO) and Total Domestic Output (TDO) – that measure, respectively, the dependence of economies on material flows and the burden on the environment from those flows.

But, just as GDP is made up of an underlying database that is also used to construct a host of economic indicators, the database created under MFA can be used to generate a number of other relevant indicators that describe the economy/environment interaction. Material that flows out to the environment can, for example, be aggregated by material specific carcinogenicity factors to suggest the potential cancer burden. Greenhouse gas emissions, ozone depletion, GDP, aquatic toxicity, are other characterizations can be applied to the data to create policy relevant indicators.

8. Conclusion

MFA provides a tool to understand the economy in a new and policy-relevant manner. It is applicable at a variety of scales, but at the national level it provides measures of the burden of national economic activity on the planet. Based on the mass-balance approach, MFA accounts for everything that is mobilized from or delivered to the environment. Until now, governments have not tended to collect comprehensive data that would allow investigators to compile MFA in detail and analyze the data to manage the impact of material use on the environment. But, MFA has been developed to where countries can look at the changes in their physical economies over time and compare their experience with those of other countries. Indicators of these changes and comparisons provide previously unavailable information to the public and policy makers. MFA provides a powerful and necessary complement to the monetary system of national accounts.

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PART III. LINKS WITH INDICATORS AND OTHER ACCOUNTING TOOLS

LINKS BETWEEN THE MICRO AND THE MACRO FLOWS: SUBSTANCE FLOW ANALYSIS: Presentation by the Netherlands, Leiden University[47]

1. Introduction

Many of the environmental problems we are facing today are a result of society's processing of materials. One of the challenges of economics is to relate the generation of waste and emissions to societal developments. This can be approached from many sides. One possibility is to look at the societal system in environmental terms. This approach is taken by Ayres (e.g. Ayres 1989; Ayres et al.1989; Ayres and Simonis 1994) in his introduction of the concept of industrial metabolism. This concept argues the analogy between the economy and environment on a material level: the economy's "metabolism" in terms of materials mobilisation, use and excretion to create "technomass" is compared to the use of materials in the biosphere to create biomass. Whereas the biosphere has had billions of years to evolve and attune its processes to such a state that waste generated in one process is converted into a resource for another, the economy is still in its early stages of wastefulness. In order to speed up 'economic evolution', society must look to the biosphere for guiding principles. The description of the economy thus is limited to a description of the physical economy. The research area of industrial ecology (e.g. Jelinski et al., 1992; Socolow et al., 1994; Graedel and Allenby, 1995; Ayres and Ayres, 1996; Allenby, 1999) occupies itself among others with elaborating and operationalizing this concept, and takes the physical economy as its primary subject.

An important research principle in this field is the materials balance, (e.g. Kneese et al., 1970; Ayres and Ayres, 1996) a tool for describing the materials regime of the economy based on the Law of Mass Preservation, analogous to the long-standing practice of investigating ecological materials cycles. Analytical tools based on the materials balance are Materials Flow Analysis (MFA) and Substance Flow Analysis (SFA). These tools are useful for supporting environmental policy (Bringezu et al., 1997): they enable policy makers to trace the origins of resource depletion and pollution problems and to evaluate the appropriateness of the societal management of materials and substances.

2. Material Flow Accounting (MFA)

MFA is a widely used technique within environmental science. Studying the material basis of the world's economies can generate valuable insights in the process of formation of environmental hazardous emissions and waste flows and of depletion of natural resources. MFA studies vary in complexity, ranging from a "simple" materials bookkeeping for a certain year to complex dynamic analyses calculating future flows and stocks. Next to that, the aim of the MFA can be very diverse: studies focussing on the metabolism of industrial systems like the metals industry the chlorine industry, pioneered by Robert Ayres, studies focussing on the total or bulk material flows within modern economies (brought into the political arena mainly by the Wuppertal Institute), and studies focussing on the flows of one specific (group of) substance(s) within economy and environment (mainly in Scandinavia, Austria, Switzerland and the Netherlands). However diverse these studies and their aims may be, the techniques which are used within the analyses are similar. The fact that, in the end, inflow equals outflow is the simple central argument in all studies.

47 . Paper prepared by Mr. Rene Klein and Ms. Ester van der Voet, Centre of Environmental Science (CML), Leiden University, Netherlands.

3. Bulk-MFA

The type of MFA which is also called *bulk-MFA* ,is characterised by the fact that all material flows are accounted for on a mass basis regardless of their nature. The result of such studies normally consists of a list of inflows and outflows for the studied country, region or city. The material flows are then aggregated on a mass basis into single indicators like DMI and DPO (excluding hidden flows) and TMR and TDO (including hidden flows). These indicators are often used as general indicators for societal metabolism and compared with economic and social indicators like GDP and population.

Material flows generated by human societies are at the heart of many of the most important environmental problems. The material metabolism of societies should thus be an important object of study. In order to get insight in the functioning of the metabolism of societies a complete quantitative overview of flows of materials entering, leaving and accumulating within the system is needed. A bulk-MFA provides such information on the metabolism of societies. The accounts are set up in a systematic manner which make the results comparable between different countries and different moments in time.

The desegregated information which is being collected in bulk-MFA studies provide useful insights in the material basis of human societies. In industrial societies the dominance of water and fossil fuels is vividly illustrated for example. Flows of drinking water dwarf all other material flows which emphasises the excessive need for clean fresh water in those societies. The next largest type of flow are those connected to the use of fossil fuels which indicates our dependence on unsustainable sources of energy.

An important strength of bulk-MFA is the fact that the results can be presented in the form of one aggregated indicator. Because of this the methodology provides a macro-indicator which can be compared with the main macro economic indicator: GDP. Decoupling of economic growth and material flows can thus easily be analysed. However, like GDP, completely aggregated indicators like DMI and DPO clearly have their limitations. A substitution of material intensive processes by processes with emissions of small quantities of toxic compounds for example will result in a decrease in bulk-MFA indicators while actual environmental impacts will most likely increase. Thus bulk-MFA indicators are not always good indicators for environmental pressure since the differences in environmental impacts of the materials are not taken into account. If the focus is on specific environmental problems linked to specific (groups of) substances another type of MFA is needed: Substance Flow Analysis (SFA).

4. Substance Flow Analysis (SFA)

SFA aims to provide relevant information for an overall management strategy with regard to one specific substance or a limited group of substances (van der Voet, 1996). In order to do this, a quantified relationship between the economy and the environment of a geographically demarcated system is established by quantifying the pathways of a substance or group of substances in, out and through that system. In SFA the economy thus is viewed only in terms of flows of a specific (group of) substance(s). The methodology is similar to bulk-MFA but the applications may be different. Mass and bulk flow studies provide macro economic indicators (von Weizsäcker et al. 1997; Adriaanse et al. 1997), while studies on flows of substances can be related to specific environmental problems and thus provide input for a pollutants policy. An example of the aggregated results of an SFA is given in Figure 1.

In general terms, substance flow studies comprise the following three step procedure (van der Voet et al. 1995b): (1) definition of the system, (2) quantification of the overview of stocks and flows, and (3) interpretation of the results. All three steps involve a variety of choices and specifications, each of which depends on the specific goal of the study to be conducted, as will be argued below. The first step in any materials flow study is to define the system. The system must be determined with regard to space, function, time and materials. If necessary, the system can be divided into subsystems. The various categories of processes, stocks and flows belonging to the system must be specified. Finally, this results in a flow chart: the specification of the network of nodes. To define the SFA system, a number of choices must be made with regard to the following aspects: (1) spatial demarcation, (2) functional demarcation, (3) time horizon, and (4) materials to be studied.

4.1 SFA modelling

The quantification of the network is the next step. This involves identifying and collecting the relevant data on the one hand, and modelling on the other. Three possible ways of modelling the system are briefly discussed here, all three types having their own data requirements, as well as their own potential for policy support: (1) accounting or bookkeeping, (2) static modelling, (3) dynamic modelling

Accounting

The first way to 'model' the system is to treat it as an accounting system. The input for such a system consists of data regarding the size of the system's flows and stocks of goods and materials, that can be obtained from trade and production statistics, and if necessary also data regarding the content of specific substances in those goods and materials. Emissions and environmental flux or concentration monitoring can be used for the environmental flows. A combination of those data together with application of the mass balancing principle then must lead to the desired overview of flows and stocks.

The accounting overview may also serve as an identification system for missing or inaccurate data. Missing amounts can be estimated by applying the mass balance principle. In this way, inflows and outflows are balanced for every node as well as for the system as a whole, unless accumulation within the system can be proven. This technique is most commonly used in materials flow studies, and can be viewed as a form of descriptive statistics (e.g. Ayres et al. 1988; Olsthoorn 1993; Fleckseder 1992; Palm and Östlund 1996; Tukker et al. 1996, 1997; Kleijn et al. 1997; Hansen and Lassen 2000). There are, however, some examples of case studies that specifically address societal stocks (Bergbäck and Lohm 1997; Bergbäck, Johansson and Molander 2000) and use these as an indicator for possible environmental problems in the future.

Static modelling

In the case of static modelling, the process network is translated into a set of linear equations describing the flows and accumulations as dependent on one another. Emission factors and distribution factors over the various outputs for the economic processes and partition coefficients for the environmental compartments can be used as such variables. A limited amount of accounting data is required as well for a solution of the set of equations, but the modelling outcome is determined largely by the distribution pattern. The description of the system as such a matrix equation opens possibilities for various types of analysis: the existence of solutions, the solution space, and the robustness of the solution can be studied by means of standard algebraic techniques, as is shown by Bauer et al. (1997) and by Heijungs (1994, 1997) for the related product Life Cycle Assessment.

Static modelling can be extended by including a so-called origin-analysis in which the origins of one specific problematical flow can be traced at several levels (van der Voet et al. 1995c; Gleiss et al. 1998). Three levels may be distinguished:

- direct causes, derived directly from the nodes balance (for example, one of the direct causes of the cadmium soil load is atmospheric deposition);
- the economic sectors, or environmental policy target groups, directly responsible for the problem, identified by following the path back from node to node to the point of emission (for example, waste incineration is one of the economic sectors responsible for the cadmium soil load);
- ultimate origins, found by following the path back to the system boundaries (for example, the import of zinc ore is one of the ultimate origins of the cadmium soil load).

Furthermore the effectiveness of abatement measures can be assessed with static modelling.

The result of steady state modelling may be regarded as a caricature of the present management regime. It is therefore most suitable for comparisons between management regimes. Static and steady state models have been proposed by Anderberg et al. (1993) and applied for example by Schrøder (1994), Baccini and Bader (1996), Boelens and Olsthoorn (1998), van der Voet et al. (2000) and also, for purely environmental flows, by Jager and Visser (1994).

Dynamic modelling:

The main difference between static and dynamic SFA models lies in the inclusion of stocks in society (Ford 1999): substances accumulated in stocks of materials and products in households or in the built environment. Until recently, MFA has concentrated mostly on flows. During the past few years, MFA researchers have realised that stocks may be equally or sometimes even more important. One of the environmental issues where stocks play an important role in SFA is in the prediction of future emissions and waste flows of products with a long life span. In some way or another information on the societal stocks of PVC is needed to supply policy makers with information about future outflows: today’s stocks are tomorrow’s emissions and waste flows. In some studies the magnitude of the anthropospheric stocks has even been the primary focus of the study (e.g. Bergbäck & Lohm 1997 and Patel, 1997). These exercises have established the importance of considering stocks. Large stocks have accumulated in the societal system which must be dealt with in some way or other (Brunner & Baccini, 1992; Obernosterer et al., 1998). Future CFC emissions from present (1998) stocks for example are estimated, even assuming a world-wide successful implementation of the Montreal protocol, to roughly equal 75% the total added past emissions (Kleijn & Van der Voet, 1998). Other studies that are dedicated to the analysis of accumulated stocks of metals and other persistent toxics in the societal system are: Gilbert and Feenstra 1992; Bergbäck and Lohm 1997; Baccini and Bader 1996; Fraanje and Verkuijlen 1996; also Lohm et al. 1997; Kleijn, Huele and van der Voet 2000. Such build-ups can serve as an ‘early warning’ signal for future emissions: one day, the stocks may become obsolete or recognisably dangerous (as has happened with asbestos, CFCs, PCBs and mercury in chlor-alkali cells). Then the stocks may be discarded and end up as waste and emissions. In some cases, this delay between inflow and outflow can be very long indeed. Bergbäck and Lohm (1998) also draw attention to stocks of products no longer in use, but not discarded yet: old radios or computers in basements or attics, out-of-use pipes still in the soils, old stocks of chemicals no longer produced such as lead paint or pesticides. They conclude that such “hibernating stocks” could be very large. In order to estimate future emissions, which is a crucial issue if environmental policy makers are to anticipate problems and take timely action, it appears that such stocks cannot be ignored.

When using MFA or SFA models for forecasting, stocks therefore should be a vital part. Flows and stocks interact with each other: stocks grow when the inflows exceed the outflows of a (sub)system and certain outflows of a (sub)system are proportional to the stocks.

For this dynamic model, additional information is needed with regard to the time dimension of the variables: the life span of applications in the economy, the half life of compounds, the retention time in environmental compartments and so forth.

Calculations can be made not only on the ‘intrinsic’ effectiveness of packages of measures, but also on their anticipated effects in a specific year in the future, and on the time it takes for such measures to become effective. A dynamic model is therefore most suitable for scenario analysis, provided that the required data are available or can be estimated with adequate accuracy

4.2 SFA Indicators

The use of indicators can be great help in the interpretation of the results. SFA indicators can be selected from the overview of flows and stocks, by singling out a specific flow or stock as the relevant one to follow, or they can be calculated directly from the overview. Indicators may be defined for environmental flows and/or stocks, as an addition to the numerous environmental quality indicators already existing. Other possibilities are indicators for economic substance flows, or indicators for integrated chain management, which bear on (possible, future) losses from the economy to the environment; i.e. 'leaks' out of the economic cycle. Examples include materials intensity, economic throughput, the technical or energy efficiency of groups of processes, secondary vs. primary materials use and so on (Ayres 1997a). Another possibility is to compare economic mobilisation of a certain substance with natural mobilisation; as a measure of potential risk (Huele, Kleijn and van der Voet 1993). This goes in the direction of the study of biogeochemical cycles and their transformation by man's activity into anthropo-biogeochemical cycles.

Indicators should be designed to provide information of relevance for an integrated substance chain management policy, for example regarding: (1) the existence and causes of environmental problems related to the substance; (2) the management of the substance chain or cycle in society; (3) early recognition of future problems and (4) the influence of policy measures, including both their effectiveness and various types of problem shifting. In addition, requirements can be defined for the indicators as a group, which must be suitable for evaluating an SFA overview for a specific year but also for evaluating changes in flows and stocks over time as well as alterations thereof, as induced by environmental policy. Therefore, a comparison between different regimes must also be possible. See also Guinée et al.(1999) and Moolenaar et al. (1997) for agricultural soils and systems.

4.3 Studying substance flows in relation to each other

One of the most important aspects of SFA is that the flows of substances are studied in relation with each other. An example of this comes from the study of the flows of chlorine and its compounds through society. Chlorine flows within industrial systems are very much interlinked. A large number of processes within the chlorine industry, including the incineration of chlorinated waste flows, produce hydrochloric acid as a by-product. This hydrochloric acid is often used within the production of PVC, which by some will be regarded as a great example of industrial ecology while others will think of it as just another argument to ban PVC. Because of this link between the production of PVC and the rest of the chlorine chain a ban on PVC will have an enormous impact on the whole chlorine industry: one of it’s most important by-products will run into a ”dead-end” and become a major waste flow which would have to lead to a major restructuring of the chlorine industry.

Another example can be found within the realm of metal flows. The use of cadmium in diffuse applications can lead to critical levels in the environment. Emission prevention, and maybe even a ban on certain cadmium containing products therefore seem rational actions for policy makers. However, MFAs have led to the insight that emission prevention and even product bans will not solve the problem. Since inflow always equals outflow the only way to reduce the outflow to the environment is to reduce the inflow to society. Cadmium however, is produced not on demand but as a by-product of the zinc industry. Like when one tries to close the exit of a colony of ants, immediately after closing one exit, another one will be created. The only real solution to this problem is thus to either reduce the amount of zinc being produced or to immobilise the cadmium directly after production. Some have already argued that the production of statues would be a good option.

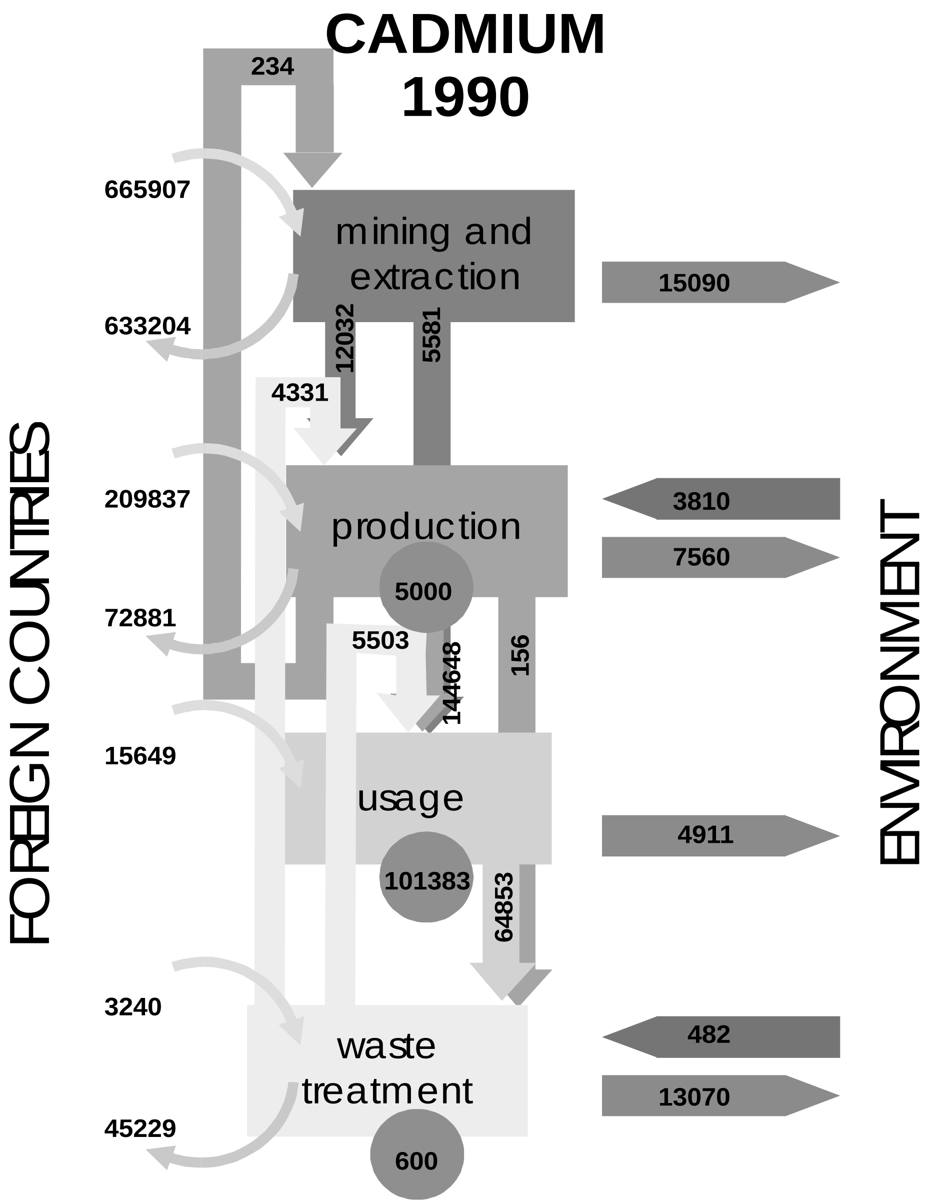
5. Links between bulk-MFA en SFA

As discussed above there are important similarities between bulk-MFA and SFA. The type of accounting and the mathematical techniques which are used are almost identical. The object of study however is different and therefor the applications are different. Where the outcomes of bulk-MFA can be used single indicators of the material basis of societies, SFA can be used to trace back and analyse the substance flows which are related to specific environmental problems. In our view however bulk-MFA and SFA strengthen each other when the are used in combination. The following Links between the two can be thought of:

- with the aid of e.g. mass fractions of substances in products or materials the data generated by the one can be used as an input for the other;
- bulk-MFA is usually focussed on the inflows and outflows of the system while in SFA the focus is on the internal flows in society and the relations between those flows. Physical Input/Output tables may function here as a *traité d'union*;
- one of the most common criticisms on bulk-MFA is that the link between the on mass base aggregated flows of materials and environmental problems is very indirect. This problem is at least partly solved when bulk-MFA is combined with a number of SFAs quantified in kg relevant substance or in environmentally weighted kg;
- in SFA different types of modelling are used to evaluate policy measures and to predict future flows and stocks. The modelling that is used in SFA could be introduced in bulk-MFA;
- SFA and bulk-MFA get very close when flows of bulk materials are studied such as water, steel or paper;

Since a number of important links exist between bulk-MFA and SFA, both tools can benefit from the combining the two. Also in a policy context the use of both tools together will broaden the scope of their possible applications.

Figure 18. Figure 19. **Example of an overview of the results of an SFA-study for cadmium**



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LINKS BETWEEN MACRO AND MICRO FLOWS: THE SECTORAL APPROACH: Presentation by Austria, IFF[48]

1. Introduction

Looking at developments regarding the theoretical and methodological approach to MFA and empirical works undertaken within the last decade several preliminary conclusions can be drawn.

Firstly, the research community heavily concentrated on methodological agreements to foster comparability. This is especially true for economy wide analysis. Nevertheless, this process resulted in two different solutions. One being the international agreement reached within the attempt to harmonise different approaches for economy wide MFA under the umbrella of the World Resources Institute (WRI). There, principal solutions both for inputs into and outputs from a macroeconomic system were found (Adriansee et al. 1997, Matthews et al. 2000).[49, 50]

A parallel effort has been undertaken at the German Statistical Office. Their work resulted in a physical input output table (PIOT) for the German economy that differentiates between 71 activities (Stahmer et al. 1998).[51] The table, which has been established for the year 1990 is very much similar to the methodological logic of economic input output tables (Leontief 1970).[52] Also recently, a PIOT for Denmark has been released (Pedersen 1999).[53]

Considering this two strands of research, we have to acknowledge that the process of methodological stringency actually led to two answers.

What are the main differences of the two approaches? WRI, on the one hand, provides accurate data for inputs and outputs in a time series approach for several countries. This data, which is rather easily to produce, gives a first overview of the physical dimension of a national economy. Clearly, in this approach, inputs and outputs stand rather loosely aside. Since the economic system is portrayed as a black box, there is no information available for intra economic processes. Hence, this approach focuses on the environmental performance at the boarder between society and the environment.

Opening up the black box economy is exactly the strength of the PIOT approach. The internal economic activities are the focus of the research. On the basis of this tables, we can exactly know, how materials are transformed within an economic system an hence discuss environmental problems related to these activities. At the same time, the research effort to establish such a table seems to be a massive one. It does not come as a surprise, that the most recent available data set is only for 1990. Therefore, we might have to accept, that the huge amount of information stored in this tables will not be very relevant for political decision making processes.

48. Paper prepared by Heinz Schandl and Helga Weisz, Institute for Interdisciplinary Studies of Austrian Universities (IFF), Vienna, Austria.

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

50. Matthews, E., C. Amann, S. Bringezu, M. Fischer-Kowalski, W. Hüttler, R. Kleijn, Y. Moriguchi, C. Ottke, E. Rodenburg, D. Rogich, H. Schandl, H. Schütz, E. Van der Voet, and H. Weisz. The Weight of Nations. Material Outflows from Industrial Economies. Washington, DC. World Resources Institute.

51. Stahmer, C., M. Kuhn, and N. Braun 1998. Physical Input-Output Tables for Germany, 1990. Report prepared for DG XI and EUROSTAT. Working paper No. 2/1998/B/1. Luxemburg: EUROSTAT.

52. Leontief, W. 1970. Environmental Repercussions and the Economic Structure. An Input-Output Approach, Review of Economics and Statistics, Vol. 52, pp. 262-271.

53. Pedersen, O. G. 1999. Physical Input-Output Tables for Denmark. Products and Materials 1990. Air Emissions 1990-92. Kopenhagen: Statistics Denmark.

We might think that these two approaches should only be linked to gain the advantages of both approaches at the same time. This would be a promising strategy but is undermined by methodological incompatibilities.

There are some differences in the two approaches on the very basic level of system definition. The PIOT first and most important, applies the economic input/output framework to MFA by referring to the law of conservation of mass as the physical equivalent to the basic equation (Leontief equation) of monetary input output analysis, which considers of the economic system as a closed system with input and output values necessarily to be equal at all levels of disaggregation. While this is quite compelling on a conceptual level, it quickly becomes difficult at a more operational level. The application of the law of conservation of mass to an input output framework, clearly demands additional conceptual decisions. In fact, recognising the physical openness of the economic system being the most important. Hence, defining the boundary between the economic system and the natural environment is probably the most difficult problem to solve. The two approaches brought forward by PIOT and WRI diverge in their conclusions with regard to two important aspects. PIOT's solution to the economy/nature boundary is to treat the production of plant biomass as a process taking place within the economic system. This clearly does not reflect an SNA logic, but the way this is done, indeed does reflect a strict and consistent application of the input output logic. WRI on the other hand considers agricultural crops as well as timber from managed forests as elements of nature, which enter the economy as harvested plant biomass. This is certainly closer to the SNA classification.

To put forward a second example, we might consider respiration of humans and livestock animals treated both in PIOT and WRI. Whereas PIOT treats this feature in a systemic logic, WRI fails to apply a consistent systems theory framework, and hence fails to provide comparable input and output data. We suggest to take both criteria, SNA compatibility and a consequent systems logic, as essential and to combine both within the conceptual framework of MFA. Still there will be some contradictions when operationalizing both criteria, (and there will be even more when operationalizing other criteria, such as policy relevance). However, there should be a methodological solution that represents an optimum combination.

Beside methodological efforts, the question of policy relevance of a bulk flow approach was the other major challenge within the discussion. Pretty soon indeed, this question was on the agenda. One answer given did come quiet naturally. The MFA concept was a political concept as such from the very beginning on, because it strongly questions the dominant approach which portrayed the environmental problem as a problem of toxic outputs. Without doubt, MFA could successfully show that environmental pressures stem from every step in the extraction - production – distribution - consumption chain. Being an overall approach based on a consistent concept MFA should serve as a guideline to anticipate future environmental problems that are connected to the huge amount of, at first glance, harmless materials. To put it in a nutshell, the CO_2 problem is a prominent example in this context.

The MFA approach could also claim to be the only integrated approach, both with respect to the theoretical foundations, the methodological solutions and the arrangement of large sets of data. Differently form traditional environmental indicators, MFA provides a framework which allows for answers to a variety of questions, but still being able to integrate the answers into a common and consistent framework.

The main question still not sufficiently answered is the one concerning the political strategies. It often has been asked, at which level of disaggregation policy intervention towards environmentally sound economic behaviour could take place. Questions, such as if the picture provided by an economy wide MFA is more than a retrospective indicator of political success, are very justified.

One prerequisite for political intervention, independently at which level it should take place, is disaggregated information. Whether it is the local or regional level, the level of the companies, the economic sectors, or even groups of materials where political efforts would be worth to be undertaken is not excessively clear. But consequently, each level of interest would be reflected in a level of indicator availability. Subsequently, this results in the discussion about the relation of the different levels. This has often been addressed as a need to link the macro, meso, and micro level.

Though we perfectly know that a sectoral economic and environmental policy is not part of current economic or environmental policy practice within OECD countries, we notwithstanding think that the economic sector, representing an important level of integration and system differentiation should be an important factor in this discussion.

2. Methodological preconditions for a sectoral approach

Above, we have argued that the process of development of MFA methods has actually resulted in two different products, the WRI approach and the PIOT approach. Here, we will suggest that these two strands could successfully be linked within an aggregated input/output framework. We will argue that getting things ordered at this level would enable us to more successfully establish a sectoral account. This might also be true for all other levels of disaggregation.

A guiding principal for structuring our discussion will be the principal of policy relevance. If we accept that MFA first of all needs to be a political relevant concept several decisions are made at the same time.

Firstly, data sets must be provided at a regular basis in order to provide indicators of sufficient actuality. This can only be achieved, if we strictly follow a top-down approach. Doing indicators “quick and dirty” might not be desirable for a scientist but certainly is for the political system.

Secondly, indicators must successfully reduce complexity. This can be fostered, if our decisions of the system under observation is theoretical sound and plausible for all levels of disaggregation. What is part of the economy/society and what is part of nature has to be decided on grounds of theoretical decision and has to be true for the overall system as well as for its parts and components (for a detailed discussion see Fischer-Kowalski 1997, Schandl and Schulz 2000).[54, 55]

Thirdly, it is definitely not enough to only understand the interrelationship between a system and its natural and social environment.[56] Policy making also needs a picture of internal systems dynamics. On the other hand, it is not convincing to argue for an approach that delivers data with a delay of a decade. Consequently, we have to open up the system by linking inputs to outputs within an overall understanding of internal interlocking. To be able to do this, one should start with a rather superficial picture of internal complexity, as provided by a three sector model of an economy. This model necessarily should be established within an input/output framework (see Weisz et al. 1999).[57]

Having understood the systematic of this, we might think of a more complex sector model at least including eight to ten sectors but not more than that. In such a model, we still can analyse data on a top-down basis ensuring readiness and actuality. In a next step, we can think of the relation of a certain economic sector to the overall structure. On the one hand, data for a sector can be organised in the same way as data for the whole economy. On the other hand we can zoom out one sector from the overall table and also link it back again.

Let us just briefly explain the logic of a rather simple input output model and mention where the data to fill such a model might stem from.

54. Fischer-Kowalski, M. 1997. Society’s Metabolism. On the Childhood and Adolescence of a Rising Conceptual Star. The International Handbook of Environmental Sociology. Redclift, M. and G. Woodgate. Cheltenham: Edward Elgar. Pp 119-137.

55. Schandl, H. and N. Schulz 2000. Using Material Flow Accounting to Operationalize the Concept of Society’s Metabolism. A Preliminary MFA for the United Kingdom. ISER Working Papers 2000 (3). Colchester: University of Essex.

56. A macro-economic system interacts with its natural environment represented by the domestic nature and with other social units represented by other macro-economies.

57. Weisz, H., H. Schandl, and M. Fischer-Kowalski 1999. OMEN – An Operating Matrix for Material Interactions Between the Economy and Nature. How to make Material Balances Consistent. Kleijn, R., S. Bringezu, M. Fischer-Kowalski, and V. Palm, eds. Ecologizing Societal Metabolism: Designing Scenarios for Sustainable Materials Management. CML report 148. Leiden: CML.

The aggregated physical Input Output Table (aggregated PIOT) as well as any sub-table consists of three quadrants, the input quadrant (left below), the processing quadrant (left above) and the output quadrant (right above). Additional rows or even whole quadrants, which allow to estimate additional items of interest, such as unused extraction and indirect flows associated to imports (for terminology see EUROSTAT 2000)[58] might be provided. 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.

The input quadrant contains all inputs into the system. We call these inputs primary inputs to emphasise that they cross the border of the system to be balanced. For an aggregated PIOT calculation on the economy-wide 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 material input (DMI).

The processing quadrant contains all material flows within the economic system. Rows and columns are equally differentiated into three aggregated economic sectors, the primary production sector (agriculture and mining), the industry sector (including construction) and the service sector (including, besides other activities the public and private households). For these sectors the sectoral input has to equal the sectoral output. Stock changes, independently where they occur, are treated as a separate sector. Here inputs do not have to equal outputs.

Table 6. Table 7. **The general structure of an aggregated PIOT table**

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

Source: Weisz et al. (1999)

58. EUROSTAT 2000. Economy-wide Material Flow Accounts and Balances with derived Resource Use Indicators. A Methodological Guide. Draft for Public Review. Luxembourg: EUROSTAT.

The cross line in the processing quadrant contains intra-sectoral flows, referring to 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 (here, intra-sectoral 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 leave the economic system to be balanced. Preferably, here it should be distinguished between exports, emissions (to land, air and water) and dissipative use and loss of materials (such as fertilisers, seeds, pesticides, but also abrasion and leakages, etc.). All flows in the output quadrant can be summed up to make the direct output.[59]

For the total consistency check the calculation of the aggregated PIOT 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.

This kind of table directly represent a flow chart and vice versa. An aggregated economy-wide material balance as presented here is still too complex to be calculated in one step. For this reason material flows might be divided into five groups and the balances would be calculated separately for each group, using sub-tables. Sub-tables clearly have to be structured in a way that allows for aggregation to an overall table by summing up. The difficulty with this approach is, that both double counting's must be avoided and completeness must be achieved.[60]

It has to be stated, that the suggestion to consider material categories as a starting point for sub-tables is not the only opportunity to take. Especially for a sectoral approach, a functional differentiation along raw materials, semi-manufactured materials and final goods might be more promising. Nevertheless, for raw materials the difference between biomass, mineral materials and energy carriers might make sense again. Actually, this solution has been favoured by the input/output approach (Stahmer et al. 1998).[61]

The input/output approach as represented in the aggregated PIOT might also help to structure available data sources. Data to fill the input quadrant stems from Agricultural, Forestry, Fishing and Mining Statistics, and from Foreign Trade Statistics. Data to fill the intermediary quadrant can be obtained from Industry and Trade Statistics and Monetary Input Output Tables. Finally, data to fill the output quadrant is available in Foreign Trade Statistics and Waste Statistics, Emission Monitoring Statistics, respectively.

59. Matthews et al. (2000) successfully tries to set a standard for indicator classification both for inputs and outputs. One major indicator for outputs there, namely DPO (Domestic Processed Output) does not subsume exports. The argument established there is, that exports will contribute to waste and emissions in other countries.

60. Of course double counting is a general problem of any MFA. The decision for sub-tables, however, adds additional traps for double counting.

61. A definition of sub-tables according to five major groups of input materials, namely water , air, biomass, fossil fuels and mineral materials as a consequence introduces a substance logic into the structure of the aggregated PIOT, which generates some consistency problems. This can easily be illustrated by considering the sub-table for fossil fuels.

The input quadrant contains the gateways from which fossil fuels enter the economy. These gateways are domestic extraction and imports. Difficulties emerge if the materials are not raw materials but semi-manufactured materials or final goods. These groups of materials usually represent a mix of different raw material categories and cannot easily be related to either one of the main categories (fossils, minerals or biomass). On the input side this is the case for imports. One decision could be to integrate imported products according to their main component into the different sub-tables. This would indeed help to avoid overlaps between different sub-tables, which would have to be considered when summing up.

The aggregated PIOT approach mainly offers two prerequisites for a sectoral approach. It offers a framework to define a specific economic system and to organise data accordingly. This enormously supports consistency. On the basis of this systems approach every level of interest (from macro to micro level) can be structured alike. Secondly, the aggregated PIOT is a first step to reduce the system complexity on which the sectoral balance can build upon. Hence, we regard the aggregated PIOT as a necessary intermediate step of investigation.

3. Problems witch mainly occur at the sectoral level

Economy wide MFA on principle relies on data periodically available at official statistical bodies or international data compendia (such as the OECD or FAO data base). Similarly, sectoral MFA can be established using the same data sources but additionally taking industry and trade statistics into account. These additional statistics traditionally cover material inputs into a sector (input lists) and the production of a sector (production lists). Preliminary estimates for wastes may be derived from environmental and waste statistics, but unfortunately not always disaggregated for economic sectors. Once again, other data compilations and frameworks, such as the NAMEA framework could provide useful data.

Data concerning sectoral origin and destination of commodities are provided in the conventional Input/Output Statistics. These are usually provided periodically, but record monetary values only. Clearly, the statistical sources mentioned here differ from one another with respect to data collection procedures, terminological usage and levels of aggregation; this, in turn, causes methodological problems when it comes to attributing data sets to the specific categories.

As said before, also a sectoral material balance accumulates data at an aggregated level, with at least the following aggregates listed separately: On the input side, one should distinct quantities of water, air, raw materials as well as semi-manufactured and auxiliary materials used in production.[62] On the output side, the balance should record goods produced (exports as well as domestically used goods), wastes and emissions (differentiated by gateways).

Looking at the individual aggregates one cannot fail to notice that they normally differ with respect to the extent to which they are documented in the official statistics.

The sum total of water used often is estimated by means of reference to the industry and trade statistics. In order to map outputs as a function of inputs one would have to differentiate between water used in production and water used as a cooling medium or for transport. The statistical sources available, however, simply do not differentiate among these different forms of using water. No statistical data are available for the quantity of air used.

All other materials are recorded in the input lists monitoring the use of raw and auxiliary materials, as well as in foreign trade statistics. Final goods produced within a sector are registered in the production lists of the industry and trade statistics.

Waste statistics or environmental statistics list the amount of waste and emissions produced for several years. However, the quality of waste data is often weak, since it documents actual amounts of waste but also waste potentials. It also leaves important quantities out. These different approaches cannot easily be distinguished.

Several methodological problems seem to be characteristically for a sectoral approach, despite some of these are also relevant at the economy-wide level. These problems are (a) conversion of data reported in different units to metric units, (b) handling of secret or protected data, which more frequently appear on a sectoral level, (c) handling of flows, which are not reported within statistical data bodies, (d) intra-sectoral double counts, and (e) a high number of data of which big parts might be of minor relevance.

62. The definition of these aggregates largely follows the systematics in which data are presented in the statistical sources.

Not underestimating the seriousness of all of these problems, we will only discuss intra-sectoral double counts as a specific problem of sectoral balances here. Industrial and trade statistics are computed on the basis of company surveys. Empirical monetary and physical data gained in these surveys are ultimately summed up to estimate total aggregates. In this case, each substance used by a firm is counted as an input. For a sectoral material balance, however, only those materials are considered as inputs which are bought from other sectors viz. other economies, or extracted from nature. From the point of view of a consistent sectoral material balance, materials which are supplied from another firm within the same sector – i.e. materials traded intra-sectoral – must not be considered inputs of the sector in question.

This implies that simple summation of the positions included in the lists of raw and auxiliary materials leads to an overestimation of sectoral inputs. Hence, adjusting these lists for intra-sectoral double counts is, in our view, one of the crucial methodological challenges when establishing a material balance for an economic sector. That this challenge can successfully be met we have shown in a case study for the chemical sector in Austria (Schandl and Zangerl Weisz 1997).[63] We will not go into further detail here. It should just be mentioned, that the methodological solution is a mathematical one, which combines all available data (including monetary IOT) in a certain way.

4. Discussion

What we have suggested here is to structure the material dimension of economic processes within a consistent aggregated Input Output framework. This framework is based on criteria such as theoretical soundness, methodological clarity, policy relevance and feasibility.

This framework of an aggregated PIOT brings together the positive achievements of the currently two most prominent approaches, represented in the two WRI reports and the German (and Danish) PIOT. From the first it acknowledges the system definitions and the top-down approach as well as its feasibility. From the latter it acknowledges the SNA compatibility and the attempt to open up the black box of the economic system.

These advantages should be brought together to not only add a new feature to the economy-wide approach but to also serve as a structural device for disaggregation at any level. The system definitions, the difference between stocks and flows, the recognition of physical components of the economy/society, to mention some of the relevant principles, guide the arrangement of MFA datasets, on the economy-wide, the sectoral, the regional and also the company level.

Once empirical work at different levels keeps going in the same direction, results can be related to one another.

It has often been argued, that consumption is a driving force within the economic system, maybe even the dominant one. This understanding implicitly guides large parts of the efficiency and dematerialization debate. A prominent example of such an understanding is the MIPS concept (Schmidt-Bleek 1994).[64] There, symbolic responsibility is attributed to the agents (the consumers), who, by buying a good also decide to "buy" the material rucksack. The same approach can be found within life cycle analysis (LCA) approaches, despite being useful political concepts, they overestimate the potential of the consumer.

The aggregated PIOT approach and the related suggestion for sectoral investigations can be seen as a descriptive method. The method mainly concentrates on the question, which amounts of material are processed by an agent (be it an individual consumer or a company or an economic sector, etc.) and how efficiently these materials are used.

63. Schandl, H. and H. Zangerl-Weisz 1997. Materialbilanz Chemie. Methodik sektoraler Materialbilanzen. Schriftenreihe Soziale Ökologie. Vol. 47. Wien: IFF.

64. Schmidt-Bleek, F. 1994. Revolution in Resource Productivity for a Sustainable Economy – a new Research Agenda. Fresenius Environmental Bulletin 2. pp. 245-490.

Clearly, this focuses on certain steps in the production-consumption-chain, where different actors occur and contribute to the environmental soundness of an economic system or expand environmental pressures. Within this economic process, the monetary logic and the material logic is quite contradictory. While materials gain value within this process (added value) they, at the same time, lose weight ("lost weight" or "added waste"). The material analogue to value added of a company or economic sector is the difference between the mass of material input and the mass of produced outputs, i.e. the amount of waste and emissions.

Sectoral material balances can document this relation of input to output (as an material to material efficiency indicator) but can also relate the material performance of a sector to its economic performance. These results can be linked back to the economy-wide picture but also to the performance of certain companies that are part of a sector. Benchmarking could only be one consequence of these information systems. We certainly regard this information as highly relevant for policy decision making.

The systems approach discussed here does not only offer a comprehensive understanding how to link the macro – meso and micro level. It furthermore fosters congruence with the economic tradition since Leontief and with the principals of SNA. In the context of sustainability, where economic and ecological understanding should be linked, this congruency is of major importance.

LINKS WITH NATURAL RESOURCE ACCOUNTS AND RELATED INCIDATORS: THE CASE OF WATER RESOURCE & USES ACCOUNTS
Presentation by France[65]

1. Objectives of water Resource & Uses accounts

Water resource and uses accounts are part of environmental accounts in the domain of water. Two approaches of water accounts can be considered. The first one is media oriented. It aims at describing the origin and quantity of the resource and the quality of the water. The second approach is social-economic oriented and deals with the uses of the water resource (by sectors), the polluting discharges (by sectors), the protection and operation expenditures and costs and the value of the assets.

The expected output of water resource and use accounts is indicators related to :

- Resource Availability: e.g. Groundwater replenishment rate, Natural inflows, Annual available resource (net…)..)
- Resource Use: e.g. Intensity of abstraction by sectors, Total consumption of water, Returns of waste water)
- Resource Depletion: e.g. Evapotranspiration inducted by irrigation, Depletion of groundwater (net accumulation…)…)

2. History

Water resource and uses accounts have been currently produced by hydrologists, agronomists, water or energy companies or urban managers since centuries… However, they have been developed in a structured format a few years ago in France in the context of the so-called Natural Patrimony Accounts project. In 1990, OECD proposed to experiment work on Natural resource accounting in two domains : forests and inland water. It was decided that the "Pilot study on inland water accounts" would consist in a test of the French methodology. Several countries started to collect statistics in this framework (Netherlands, Finland…). The most complete set of accounts (quantity, quality and expenditure) was produced in Spain.

3. Selected recent developments in the continuation of the OECD exercise

Although the subsequent history may seem hectic (no decision has been made so far considering its implementation), it is remarkable to note that the basic model as examined at OECD has continued being tested in pilot projects, but also as the foundation of the development of data base on water.

In France, a second generation of accounts was tested by IFEN, and results presented to the new "Committee of environmental accounts and economics" chaired by the Minister of Environment. First simplified accounts of the quality of rivers (1999) have been computed; a prototype of a model for calculation of the emissions to rivers has been successfully tested on a large drainage basin (the Loire river) and will be generalised next year to all of France, accounts of protection expenditure and of costs of production of the resource are produced on a yearly basis. As compared to the early times, three points can

65 . Paper prepared by Mr. Jean-Louis Weber, IFEN, France.

characterise this new generation of accounts : breakdown by catchments, breakdown by quarters, use of physical modelling for integrating the data delivered by the monitoring stations.

Pilot studies were worked out during the period in Indonesia (in the context of the implementation of a water agency in the catchment of River Brantas) and in Columbia (in parallel with the implementation of the law on water).

One of the most recent achievements as taken place in the Republic of Moldova with the establishment in 2000 of preliminary accounts for the years 1994 and 1998. Consideration is now given to the possibility of using the water accounts for streamlining the information system on water and as a reference in the "national water strategy".

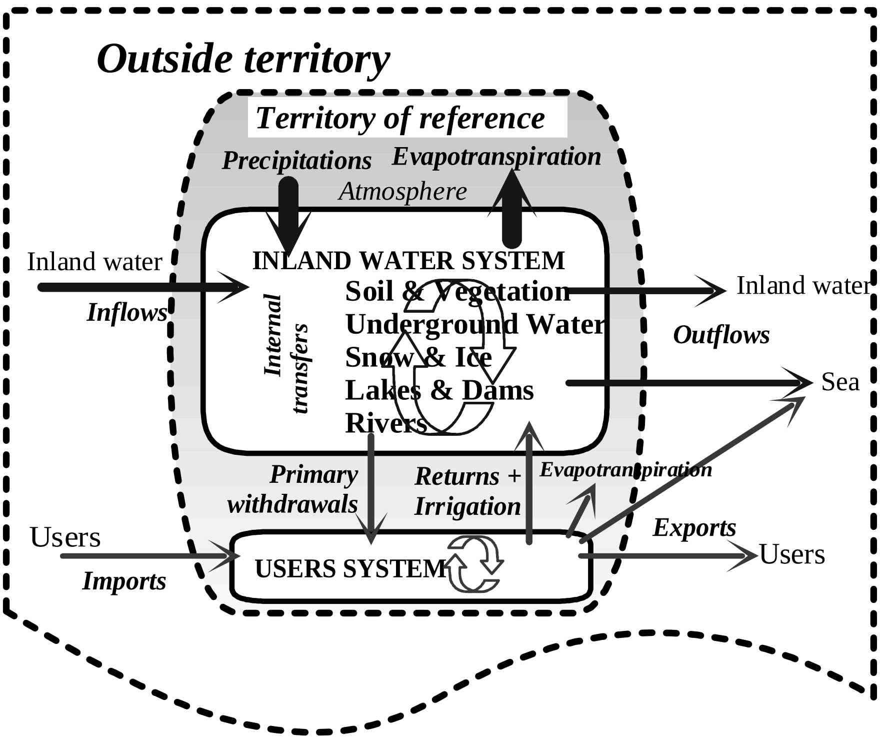
Another pilot study has been recently published for a catchment in Chile (River Aconcagua). It is based on the Spanish exercise and the time series cover Resource & Use (1992-97), Quality of rivers (1986-1997), Production & Expenditure (1997).

A similar work has been done in Australia (with publication in 2000). It covers Resource & Uses accounts by catchments, details for sectors. The report introduces the concept of divertible resource (the part of the overall available resource which can be use in acceptable environmental conditions).

Last but not least, the SEEA under revision will incorporate some elements of the water accounts.

4. The accounting framework of water R & U

As all accounting framework Water R&U Accounts are based on a system analysis. It can be illuminated by the following scheme which describes all the flows. Some key point have to be underlined: accounts are established for a territory (a country, a region, a river basin,…); this territory exchanges water



with other territories and the sea. The overall system is split in two subsystems, the hydrological system and the users systems; they are connected by withdrawal of water (on the one hand) and returns of water, including wastewater (on the other hand). The water cycle starts with the precipitation and finished with the evapo-transpiration and the flowing out to the sea. Within each subsystem, breakdowns are produced to show in which way the water resource is available (humidity of soil, groundwater, snow, lake, river,…) and who are the users. Accordingly, matrixes describe how the initial input (precipitation, withdrawal,…) is distributed to final resource (through internal transfers) and to final users (through supply and purchase).

From this scheme is derived the water resource and uses accounting framework. The presentation will be illustrated by the water accounts of Moldova. (Please, note that the results, being provisional, cannot be quoted).

Basically, the R & U water accounts are made of 3 sets of accounts :

- The tables of the users system : uses by sectors and transactions between sectors
- The account of the hydrological system : origin, transfers between natural subsystems and making of the water resource
- The synthesis balance sheet (where the flows are given a + or a -, according to the way they are going)

The users are sectors or activities of the National Accounts; for analytical purposes, key sectors in the domain of water are highlighted (water supply of irrigation water and of drink water, sewerage, fisheries, agriculture and energy). Industry is aggregated here but some breakdowns could be relevant at the regional level where a particular industry is a key user. Specific operations of the users deal with water extraction and imports, distribution, irrigation, returns of wastewater, exports. Leaks and losses are considered as a use. In situ uses (bathing in rivers, navigation) are not taken into account here. Import and export means that water enters or flows out of the territory in an artificial feature (pipe or channel).

The accounts of the hydrological system calculate the total input (precipitation, outside natural influents, returns of water (incl. wastewater and irrigation, spontaneous internal transfers) and the total output (spontaneous internal transfers, primary withdrawals, evapo-transpiration, natural outflows to other territories and the sea). The accounting balance between input and output is the Net Accumulation of Water (change in stocks). The spontaneous internal transfers between subsystems are described in a matrix.

The Synthesis Balance Sheet presents side by side the flows accounts of the hydrological and of the users systems. These flows are given a + or a - according to the fact they are an inflow or an outflow. In addition, the Balance Sheet integrates the stock account of the various components.

5. Examples of indicators of material flows derived from the water resource & uses accounts

Indicators can be easily extracted from the accounts and give useful information. Below, comparisons are made between Moldova in 1994 and 1998, France in 1981 and Spain (average year for resource, 1992 for uses).

A first information is given on the respective hydrological profiles (e.g. m3 per hectares). Considering the rain, Moldova is closer to Spain (with an average level of precipitation even lower) than France. Due to hot summers and evapo-transpiration, there is a recurrent deficit of water in Moldova, a country where agriculture is a key activity. At the same time, Moldova can rely on an external resource, the River Prut and the River Nistru or Dniestr, which is not the case for Spain. But they are international rivers which operation is limited by international conventions.

If we consider the uses (m3 per ha. or per capita) we can see that in spite of similar climate conditions and existing irrigation schemes, the intensity of use water by agriculture is much lower in Moldova than in Spain. Even though we consider the very high level of evaporation generated by irrigation in Spain, the gap between Moldova (339 m3/ha in 94) and Spain (1196 m3/ha) suggests that there are margins for developing the irrigation in the latter country. We can also observe the impact on water of the economic crisis in Moldova in the sectors of energy and agriculture (although, in the latter case, the high level of precipitation in 1998 has to be taken into account).

6. Next steps (very incomplete panorama)

In general terms, one can say that the original model of water accounting for R&U as well as for the quality of the rivers is robust. Solutions have been identified and implemented for producing such accounts starting from the existing databases and improving the quality of the numbers step by step. These solutions encompass physical modelling, sampling techniques and geo-statistics.

As they are now, the water accounts prove to be very useful for securing the best possible comparability over time and in space (between catchments or countries). This is generally not guaranteed with the current statistics based on the aggregation of results from monitoring stations when the monitoring networks have not been designed with sampling preoccupation. Accounts also facilitate the cross checking of the statistics and help in identifying gaps or inconsistencies.

The main improvements which are required and foreseen are the following :

- a more operational definition of the "annual available resource" to take into account the physical limitations (the minimum to keep in the ecosystems and the purely physical constraints) as well as the quality of the resource; interesting proposals have been made in this way by Eurostat (Water accounts task force) and by the ABS in its recent publication.
- A full development of the rivers quality accounts for the causes of changes of quality, which constitute a gateway to economic activities.
- The development of a methodology to account for the quality of groundwater.
- The development of accounts of emissions to water. In this domain, a reasonable balance has to be found between the detail of accounting by activities (NAMEA type, similar detail in the ABS accounts) required for macro-economic analysis and the breakdown by catchment areas required for the physical modelling of the leakage from non point sources (now) and the relation between emissions of pollutants and the quality of the water (in the future).
- The development of costs calculations of the resource (asset and product) and of the maintenance of its quality.

INLAND WATER ACCOUNTS / RESOURCE ACCOUNTS IN RAW QUANTITIES

T1 - ACCOUNT OF THE USES OF THE WATER RESOURCE

YEAR : 1998 - COUNTRY : REPUBLIC OF MOLDOVA - UNIT : Mm³

T1A - WATER RESOURCE AND USE BY USERS

				u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	
			Users	Agriculture	Fisheries	Energy (hydopower and cooling)	Mining	Manufacturing industry	Distribution of water for irrigation	Distribution of drink water (incl. communal services)	Sewerage	Other government services (incl. urban cleaning, canals)	Households	TOTAL
f14	Import of water													
f34	Primary withdrawals (extraction...)	f34a	Extraction from groundwater	26,5	0,0	2,1	5,3	15,0	0,0	102,0		19,8	25,4	196,0
		f34b	Withdrawal from surface water	42,6	36,1	722,1		15,2	69,9	186,2		0,0		1072,1
f351	Supply of water FROM other agents/sectors			51,3	0,0	17,2		10,2	0,1	7,3	213,2	7,0	199,2	505,5
A	**TOTAL WATER RESOURCE BY USERS**			**120,4**	**36,1**	**741,4**	**5,3**	**40,5**	**70,1**	**295,4**	**213,2**	**26,7**	**224,6**	**1773,6**
f352	Supply of water TO other agents/sectors			0,2		8,0		28,3	50,5	226,0		33,2	159,4	505,5
f15	Export of water	f151	Export of water for delivery											
		f152b	Export of waste water to the sea											
f16	Evapo-transpiration					24,6								24,6
f31	Backflows (Returns of water)	f311	Returns of lost water (incl. leaks)	16,5	7,8	0,3			19,6	69,5		0,0		113,7
		f312	Returns of waste water	11,8	28,3	708,5	5,3	12,3			213,2	2,1	65,2	1046,6
f321	Irrigation			91,9										91,9
B	**TOTAL USE OF WATER BY USERS**			**120,4**	**36,1**	**741,4**	**5,3**	**40,5**	**70,1**	**295,4**	**213,2**	**35,4**	**224,6**	**1782,3**
C	*NET USES = (B - f352)*			*120,2*	*36,1*	*733,4*	*5,3*	*12,3*	*19,6*	*69,5*	*213,2*	*2,1*	*65,2*	*1276,8*

T1B - MATRIX OF TRANSFERS (SUPPLY) BETWEEN SECTORS

		u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	**TOTAL**
from origin	***to recipient***	Agriculture	Fisheries	Energy (hydopower and cooling)	Mining	Manufacturing industry	Distribution of water for irrigation	Distribution of drink water (incl. communal services)	Sewerage	Other government services (incl. urban cleaning, canals)	Households	**f352 : Supply of water TO other agents/sectors**
u1	Agriculture	0,1	0,0				0,1					0,2
u2	Fisheries											
u3	Energy (hydopower and cooling)			0,7				7,3				8,0
u4	Mining											
u5	Manufacturing industry					6,5			21,8			28,3
u6	Distribution of water for irrigation	50,5										50,5
u7	Distribution of drink water (incl. communal services)			16,5		3,8				6,5	199,2	226,0
u8	Sewerage											
u9	Other government services (incl. urban cleaning, canals)	0,8							32,0	0,5		33,2
u10	Households								159,4			159,4
TOTAL	**f351 : Supply of water FROM other agents/sectors**	51,3	0,0	17,2		10,2	0,1	7,3	213,2	7,0	199,2	505,5

(provisional results, not to be quoted)

INLAND WATER ACCOUNTS / RESOURCE ACCOUNTS IN RAW QUANTITIES

T2 - HYDROLOGICAL SYSTEM FLOWS ACCOUNT (INPUT-OUTPUT TABLE)

YEAR : 1998 - COUNTRY : REPUBLIC OF MOLDOVA - UNIT : Mm³

T2A - TOTAL INPUT AND OUTPUT TO THE (FROM THE) HYDROLOGICAL SYSTEM

		w1	w2	w3	w4	w5	TOTAL
		Soil & vegetation	Groundwater	Snow & ice	Lakes & reservoirs	Rivers	
f11	Precipitation	23516,3		"	362,5	290,0	24168,9
f12	Outside natural influents		1100,0			17750,0	18850,0
f311	Returns of lost water (incl. leaks)		113,7				113,7
f312	Returns of waste water		73,5			973,2	1046,6
f321	Irrigation						
f23 A	SPONTANEOUS INTERNAL INPUT		310,0			2123,0	2453,0
D	**TOTAL INPUT TO THE HYDROLOGICAL SYSTEM**	**23516,3**	**1597,1**		**362,5**	**21136,2**	**46632,2**
f23B	SPONTANEOUS INTERNAL OUTPUT	2299,0	134,0			20,0	2453,0
f34	Primary withdrawals (extraction…)		196,0				196,0
f16	Evapo-transpiration	21277,6			415,9	332,8	22026,3
f131	Natural outflows towards territories (regions, basins…)		1267,1			19420,0	20687,1
f132	Natural outflows towards the sea						
E	*WITHDRAWALS AND FINAL OUTPUT*	*21277,6*	*1463,2*		*415,9*	*19752,8*	*42909,5*
F	*CHANGES IN STOCKS (NET ACCUMULATION OF WATER) = (H - E)*	*-60,3*			*-53,4*	*1363,4*	*1269,7*
G	**TOTAL OUTPUT FROM THE WATER SYSTEM AND NET ACCUMULATION = (f23B + E + F)**	**23516,3**	**1597,1**		**362,5**	**21136,2**	**46632,2**

H	*GLOBAL AVAILABLE ANNUAL RESOURCE = (D - f23B)*	*21217,3*	*1463,2*		*362,5*	*21116,2*	*44179,2*

T2B - INTERNAL TRANFERS BETWEEN HYDROLOGICAL SUB-SYSTEMS

	to recipient / ***from origin***	w1	w2	w3	w4	w5	f23B
		Soil & vegetation	Groundwater	Snow & ice	Lakes & reservoirs	Rivers	SPONTANEOUS INTERNAL OUTPUT
w1	Soil & vegetation		310,0			1989,0	2299,0
w2	Groundwater				"	134,0	134,0
w3	Snow & ice						
w4	Lakes & reservoirs	"	"				
w5	Rivers	"	20,0				20,0
f23 A	SPONTANEOUS INTERNAL INPUT		330,0			2123,0	2453,0

(provisional results, not to be quoted)

INLAND WATER ACCOUNTS / RESOURCE ACCOUNTS IN RAW QUANTITIES

T3 - SYNTHESIS BALANCE SHEET

YEAR : 1998 - COUNTRY : REPUBLIC OF MOLDOVA - UNIT : Mm³

			w1 Soil & vegetation	w2 Groundwater	w3 Snow & ice	w4 Lakes & reservoirs	w5 Rivers	TOTAL (1) WATER RESOURCE SYSTEM	TOTAL (2) WATER UTILISATION SYSTEM	GENERAL TOTAL
S1		**INITIAL STOCK**	**5000,0**	**150000,0**		**2743,5**	**500,0**	**158243,5**	"	**158243,5**
PRIMARY INPUT	f11	Precipitation	23516,3		"	362,5	290,0	24168,9	"	24168,9
	f12	Outside natural influents		1100,0			17750,0	18850,0		18850,0
	f14	Import of water								
NET BALANCE OF INTERNAL TRANSFERS = (f23 A - f23B)			-2299,0	196,0			2103,0			
RETURNS AND IRRIGATION	f311	Returns of lost water (incl. leaks)		113,7				113,7	-113,7	
	f312	Returns of waste water		73,5			973,2	1046,6	-1046,6	
	f321	Irrigation							-91,9	-91,9
PRIMARY WITHDRAWALS AND FINAL OUTPUT(-)	f34	Primary withdrawals (extraction…)		-196,0			-1072,1	-1268,1	1268,1	
	f16	Evapo-transpiration	-21277,6			-415,9	-332,8	-22026,3	-24,6	-22050,9
	f131	Natural outflows towards territories (regions, basins…)		-1267,1			-19420,0	-20687,1		-20687,1
	f132	Natural outflows towards the sea								
	f15	Export of water								
F		CHANGES IN STOCKS (NET ACCUMULATION OF WATER) = (S2 - S1)	-60,3	20,0		-53,4	291,4	197,7	-8,7	189,0
S2		**FINAL STOCK**	**4939,7**	**150020,0**		**2690,1**	**791,4**	**158441,2**	"	**158432,5**

COMPARISON PER HECTARE OF WATER RESOURCE AND USES (UNIT : m³/ha)

	MOLDOVA 1994	MOLDOVA 1998	FRANCE 1981	SPAIN 1992
STOCK/UNDERGROUND WATER	44313	44313	40000	28162
STOCK/RESERVOIRS	630	630	164	435
PRECIPITATIONS	4140	7140	10455	6719
EXTERNAL INFLOW (TOTAL)	2984	5569	691	0
EVAPOTRANSPIRATION GENERATED BY IRRIGATION	288	54	237	1057
EFFECTIVE REAL EVAPOTRANSPIRATION	3990	6514	5552	4866
NET INTERNAL AVAILABILITY (= EFFICIENT RAIN)	348	668	4985	2277
NET ANNUAL AVAILABLE RESOURCE	3331	6237	5676	2277
USES/AGRICULTURE (INCL. TOTAL RESOURCE FOR IRRIGATION)	339	64	239	1196
USES/ENERGY (HYDROPOWER & COOLING)	438	219	355	447
USES/INDUSTRY	19	14	39	37
USES/HOUSEHOLDS	71	66	45	61

COMPARISON PER CAPITA OF WATER RESOURCE AND USES (UNIT : m³/capita)

USES/AGRICULTURE (INCL. TOTAL RESOURCE FOR IRRIGATION)	174	33	84	623
USES/ENERGY (HYDROPOWER & COOLING)	345	172	362	579
USES/INDUSTRY	15	11	40	48
USES/HOUSEHOLDS	56	52	46	79

(provisional results, not to be quoted)

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