WORKING NEDS
PAPERS

2

04/2003

Material Flow Analysis on the Regional Level: Questions, Problems, Solutions

Mark Hammer
Stefan Giljum
Silvia Bargigli
Friedrich Hinterberger

SÖF Sozial-ökologische Forschung
Hamburger Universität für Wirtschaft und Politik HWP
UHH Universität Hamburg
SERI Sustainable Europe Research Institute

Das vorliegende zweite Working Paper des Forschungsprojekts NEDS ist Ergebnis unserer intensiven Kooperation mit dem Sustainable Europe Research Institute (Wien). Die AutorInnen der folgenden Studie, Mark Hammer, Stefan Giljum, Silvia Bargigli und Friedrich Hinterberger, arbeiten am SERI zu verschiedenen Aspekten der Materialflussanalyse (MFA) und liefern mit dem Text eine wichtige Grundlage für die „Durchsatz-Dimension unserer Forschungsarbeit. Sie stellen in umfassender Weise einen spezifischen Ansatz zur Analyse der materiellen Aspekte nachhaltiger Entwicklung dar und verdeutlichen die möglichen regionalen Anwendungsbezüge. Die Methodik der Materialflussanalyse wird für die weitere Projektarbeit in doppelter Hinsicht von Bedeutung sein: Zum einen nutzen wir den MFA-Ansatz zur Analyse des Material- und Energiedurchsatzes der von uns untersuchten Regionen. Zum anderen ist die MFA als spezifische Bearbeitungsform materieller Veränderungen Gegenstand unserer kritischen Reflexion über Ansätze zur Messung und auch Steuerung materieller Prozesse vor dem Hintergrund der Zielsetzung einer nachhaltigen Entwicklung.
Hamburg, im April 2003

This second working paper of the NEDS research project is the result of our intensive cooperation with the Sustainable Europe Research Institute (Vienna). The authors of this study, Mark Hammer, Stefan Giljum, Silvia Bargigli and Friedrich Hinterberger, work at the SERI on different aspects of material flow analysis. With the present paper, they provide an important basis for the "throughput-dimension" of our research. They depict, in an extensive way, a particular approach for the analysis of the material aspects of sustainable development and elucidate possible regional applications. The methodology of material flow analysis will be of great importance for our further work on the project in a twofold manner: First, we use the technique for the analysis of the material-energy-throughput of the examined regions. Secondly, material flow analysis is an object of our critical reflection referring to methods of measurement and regulation of material processes in the context of the goal of sustainable development.
Hamburg, April 2003

Fred Luks

Das dem folgenden Text zugrunde liegende Vorhaben wird mit Mitteln des Bundesministeriums für Bildung und Forschung unter dem Förderkennzeichen 624-40007-07 NGS 11 gefördert. Die Verantwortung für den Inhalt dieser Veröffentlichung liegt bei den Autorinnen und Autoren.

The following paper draws on research funded by the German Ministry of Education and Research (# 624-40007-07 NGS 11). The responsibility for the content lies with the authors.

Forschungsprojekt NEDS, c/o HWP – Hamburger Universität für Wirtschaft und Politik
Von-Melle-Park 9, D-20146 Hamburg

ISSN 1610-0778 (Print-Ausgabe)
ISSN 1612-5150 (elektronische Ausgabe)

Zusammenfassung

Diese Arbeit zielt darauf ab, eine Methode für die Anwendung der Materialflussanalyse (MFA) auf regionaler Ebene zu entwickeln. Ausgehend von der Erörterung des gegenwärtigen Standes bei der MFA auf nationaler Ebene werden bereits veröffentlichte regionale Fallstudien untersucht und Einzelprobleme der unterschiedlichen methodologischen Ansätze diskutiert. Die Untersuchung zeigt, dass existierende Studien sich in Bezug auf die Größe der untersuchten Region, die angewandten Methoden und die erhobenen Daten deutlich unterscheiden. Auf diesen Betrachtungen basierend wird eine Methode für die Erstellung regionaler MFA entwickelt, die mit der Standardmethode für nationale MFA kompatibel ist. Besondere Aufmerksamkeit gilt der Beschreibung möglicher Schätzmethoden, mit deren Hilfe zu erwartende Datenlücken – insbesondere im Hinblick auf internationale und intranationale Handelsflüsse – geschlossen werden können. Schließlich werden Verkettungen zwischen MFA und Methoden der Flächennutzungsbilanzierung diskutiert.

Summary

This paper aims at developing a method for applying the framework of material flow accounting and analysis (MFA) on the regional level. Starting from a discussion on the state-of-the-art in MFA on the national level, already published regional case studies are reviewed and details concerning the different methodological approaches discussed. The review reveals that existing studies differ considerably with regard to the size of the investigated regions, the methods applied and the data generated. Based on this review, a method for compiling regional MFA accounts is derived, which is compatible with the standard method for national MFA. Special focus is put on the description of possible estimation methods to overcome expected data gaps, in particular with regard to international and intranational trade flows. Finally, interlinkages between material flow accounting and land use accounting are discussed.

1. Introduction

This working paper is part of the project "Nachhaltige Entwicklung zwischen Durchsatz und Symbolik" (NEDS) (Sustainable development between throughput and symbolism), funded by the German Ministry of Education and Research in the context of its program on socio-ecological research.[1] The main objective of NEDS is integrating approaches of ecological economics, environmental accounting (in particular material flow accounting - MFA), discourse analysis (for the aspect of interlinking MFA with discourse analysis see Luks and Hammer, 2003) and constructivist aspects, in order to explicitly take into account the complex relationship between science and policy. The analysis will be carried out in three case studies of regional development in Germany and Austria.[2]

The aim of this working paper is to develop a method for regional MFA for application in the NEDS project. After a short introduction to sustainability research on the regional level from a biophysical perspective (chapter 2), the method of material flow analysis is described, focusing on the standardised method for MFAs on the national level (chapter 3). On this basis we describe specific problems for MFA on a regional and local level, review existing local or regional MFA studies, compare their methodologies and develop a method that will be used in the NEDS project (chapter 4). Chapter 5 briefly describes the concrete tasks for the MFA part within the project. Finally, chapter 6 discusses possible links between MFA and land use, which is another focal point of research in the NEDS project.

2. Sustainability on the regional level

The concept of sustainability has been a focus point of the development discussion since the release of the Brundtland Commission Report in 1987 (WCED 1987). Until today a very large number of studies, statements and declarations have been published, dealing with sustainability issues from the local to the global level, stressing the importance of reducing environmental pressures stemming from human activities and proposing a culture of peace and equitable welfare distribution on the local, regional, national, and global scales.

Regions can play a crucial role in the process of implementing sustainable development, as at this level there often exists a strong linkage between physical functions (such as the use of materials, energy and land for production and consumption activities), social identity, economic units and political territories. Consequently, the regional level brings opportunities

[1] Contract number: SÖF (#624-40007-07 NGS 11). The responsibility for the contents lies with the authors.

[2] Further information on the project can be found in the internet at www.neds-project.de or www.seri.at.

to improve on the current state of fragmentation, offering new linkages for the sustainable development agenda at a level between local and national. At the regional level in many countries and on the level of the European Union, economic and environmental policy is often in a greater state of flux than at the national level, and there are new opportunities for increasing the 'connectivity' of sectors and actors (Ravetz, 2000).

As the economical disparities between the European regions are considerably large, the Regional Policy of the EU aims at reducing these differences. Financial instruments such as the Structural Funds, the Cohesion Fund for the Member States and the Pre-Accession Aid for the candidate countries in Central and Eastern Europe are supposed to support economic and social cohesion. The spending is usually directed by focussing on social and economic factors. Environmental concerns are not integrated with the same importance, even though sustainable development and the improvement of the environment is a declared goal of the European Union (European Commission, 2001). The narrow socio-economic focus of Regional Policy is in contrast to the objectives of the Union which are defined in Article 2 of the Amsterdam Treaty which directly refer to sustainable development in connection with the social and economic goals of the Union.

Especially for the formulation of such financial measures it is important to have indicators, according to which the appropriateness of the instrument can be judged. In the field of social and economic development, the gross domestic product (GDP) and the employment or unemployment rate are two widespread, generally known and accepted indicators. This also applies to the objectives to be achieved (continuous growth and a high level of employment). If we look for a general measure of environmental pressure that is capable of "competing" with these generally used indicators, particular significance should be given to biophysical indicators, such as derived from material flow accounting, because

- they provide a comprehensive representation of the impact of human activities on the ecosphere,
- a positive correlation can be assumed to exist between the material flows and many damages which are often difficult to capture, and
- decreasing material inputs are expected to result also in decreasing outputs of the economic cycles.

The present objective of regional policies is to create equal conditions of life in the regions. It is aimed at the alignment of the considerably diverging financial and material conditions through economic growth, transfer of funds and the supply of material goods. A different approach, focussing on the improvement of the quality of life while taking regional differences into account, has been introduced (Hinterberger, 2000; Hinterberger and Schneider, 2001). In this approach, the different regional potentials in societal, economical and ecological terms are taken into account, as well as the individual aspects of quality of life. That means that the existing potentials of a region should be developed (within ecological guard rails) in order to support a high quality of life. Under this guiding principle the region is regarded as an area to fulfil the basic needs of its inhabitants on a high and sustainable level.

The following principles are complementary to this guiding principle:

- Orientation of the demand for goods and services within the region,
- creation of job security (in the long term), and
- protection of the ecosphere.

One approach to reach this goal is a strategy of dematerialization, the reduction of the total material and energy flows contributing to a long-term protection of resources. If eco-efficiency strategies are pursued and a reduction of material flows can be reached, it will simultaneously lead to other positive effects: Lower costs of production, less emissions and waste, protection of the landscape, increasing tourist attraction, higher job security and social cohesion; just to name a few.

In the course of a dematerialization strategy, a regionalisation of the economy is both facilitated and required. This would result in a wide regionalisation of the material, energetic and informational processes (“In-ward orientation”). Together with the construction and fostering of co-operative relations between all parties involved it is possible to gain increased regional independence, competitiveness and stability. The activities of agriculture, firms, households and communities should aim at an increasing circulation of the regional economy. Furthermore, regional resources should be used taking into account their regional peculiarities. This would result in a reduction of the material and energy flows between the regions (through the increased circulation of the regional economy and the increased use of regional resources) and within a region (because of the increased resource efficiency of regional products and services).

It should be made clear that autarky is by no means a desired outcome. Regional economic forces and potentials should rather be mobilised without heavily relying on external forces. This aims at mobilising the regional potentials. There are, however, constraints to such a development, as a regional strategy for certain goods or services is economically or ecologically inefficient or simply not feasible.

A re-orientation of regional policy towards a more sustainable development path involves that by and large intraregional material circles and value-added chains are shortened through enhanced regional co-operation. The promotion, establishment and fostering of networks in the region between producers, consumers, public authorities, interest groups and other relevant actors are a decisive factor when pursuing an eco-efficiency strategy (ENCORE 2001).

3. MFA – General introduction to the methodology

In this chapter we present the method of MFA as it has been developed at the national level mainly during the last decade. In section 3.1., we introduce the concepts of environmental sustainability and carrying capacity and give a short review of the historical development of MFA. In section 3.2., we describe the method following the state of the art of a handbook published by the European Statistical Office (Eurostat). Section 3.3. shows which data sources are needed for the calculation of a MFA. Section 3.4. discusses limits and necessary improvements of the method. Finally, section 3.5. presents an overview of the state of the art of MFAs at the national level.

3.1. Context of MFA

3.1.1. Environmental sustainability and carrying capacity concepts

An economic system is environmentally-*sustainable* only as long as it is physically in a (dynamic) steady-state, i.e. the amount of resources utilised to generate welfare is permanently restricted to a size and a quality that does not overexploit the sources, or overburden the sinks, provided by the ecosphere.

Due to the technical skills of humankind and the material growth of the anthroposphere, an infinite number of - ever-changing - disruptive interactions can occur at the boundaries to the ecosphere. Moreover, these impacts are characterised by *non-linear relationships* between stresses and responses. An unknown quantity of these effects can neither be detected within human time horizons, nor could they be attributed to distinct causes. This precludes the observation or theoretical calculation - and thus quantification - of the totality of concrete consequences of human (economic) activities on ecosystems.

Since carrying capacity cannot be precisely determined, the political application of this natural science-based concept must necessarily take into account the *precautionary principle*. Decision-makers should adopt this approach and keep the economy within a sustainable frame. This highlights the need of proper tools of evaluation as a basis for political decisions.

The guiding theoretical concept for explaining the physical interrelation of society and nature is *socio-economic metabolism*, a concept applied to investigate the interactions between social and natural systems. It is the socio-economic metabolism (Fischer-Kowalski 1997) or industrial metabolism (Ayres and Simonis 1994) that exerts pressures upon the environment. The socio-economic metabolism comprises the extraction of materials and energy, their transformation in the processes of production, transport, and consumption and their release back to the environment.

There are several options to describe the environmental impacts of humankind, all of which may be helpful for specific purposes. In our opinion the chosen option should be of easy translation into policy action, in a non-ambiguous way. In this regards *material flows of resources* are of key importance for environmental deterioration evaluation, providing good estimates about the use of environmental space.

The concept of environmental space has been developed in the early 1990s (Weterings and Opschoor 1992). "Environmental space is a normative concept which takes into account the physical as well as the social and developmental aspects of sustainability. Physically environmental space is described as the capacity of the biosphere's environmental functions to support human economic activities, the upper limit given by the carrying capacity. The social dimension of environmental space is given by the 'global fair shares' or 'equity principle' derived from the definition of sustainable development" (Spangenberg et al. 1999, p. 9). By carrying out economic activities, humans use environmental space. Living within our environmental space would mean living in-between a floor of a minimum of necessary use of environmental space for satisfying human needs and a ceiling of a maximum use of environmental space given by the carrying capacity of the eco-systems (ibid., p.9). Environmental space constitutes itself of three core categories: materials, energy and land (ibid., p. 11). The throughput of resources, however, must be measured with well-defined conventions, definitions and system boundaries to permit the reproduction of data and international harmonisation.

We regard material flow analysis (MFA) (along with land use accounting) as the most appropriate tool to measure environmental space and resource use. MFA provides a comprehensive picture of the environmental pressures induced by and inter-linked with the production and consumption of one country by illustrating the relations between resource extraction, production and final consumption.

Monitoring the transition of modern societies towards a path of sustainable development requires comprehensive information on the relations between economic activities and their environmental impacts. Physical accounting systems fulfil these requirements by (a) describing these relations in biophysical terms and (b) being compatible with the standard system of national economic accounting. Resource use indicators derived from physical accounts play a major role in environmental and sustainability reporting (Spangenberg *et al.* 1998). A substantial reduction of the resource throughput of societies by a factor of 10 or more (also referred to as a strategy of „dematerialisation" (Hinterberger *et al.* 1996) is generally regarded as a requirement for achieving environmental sustainability (Schmidt-Bleek 1994). Resource-flow based indicators help monitoring progress towards this goal in the age of postmodern environmental policy (Luks 2000).

3.1.2. Historical Background of MFA

Material flow analysis builds on earlier concepts of material and energy balancing, as presented e.g. by Ayres and Kneese (1969). For a comprehensive overview of the application of MFA in social and natural sciences since 1860 see Fischer Kowalski (1998) and Fischer-Kowalski and Hüttler (1999).

The first material flow accounts on the national level have been presented at the beginning of the 1990s for Austria (Steurer 1992) and Japan (Environment Agency Japan 1992). Since then, MFA was a rapidly growing field of scientific interest and major efforts have been undertaken to harmonise the different methodological approaches developed by different research teams. The Concerted Action „ConAccount" (Bringezu *et al.* 1997; Kleijn *et al.* 1999), funded by the European Commission, was one of these milestones in the international harmonisation of MFA methods. The second important co-operation was guided by the World Resources Institute (WRI), bringing together MFA experts for 4 (5 for the second study) countries. In their first publication (Adriaanse *et al.* 1997) the material inputs of four industrial societies have been assessed and guidelines for resource input indicators have been defined. The second study (Matthews *et al.* 2000) focused on the material outflows and introduced emission indicators.

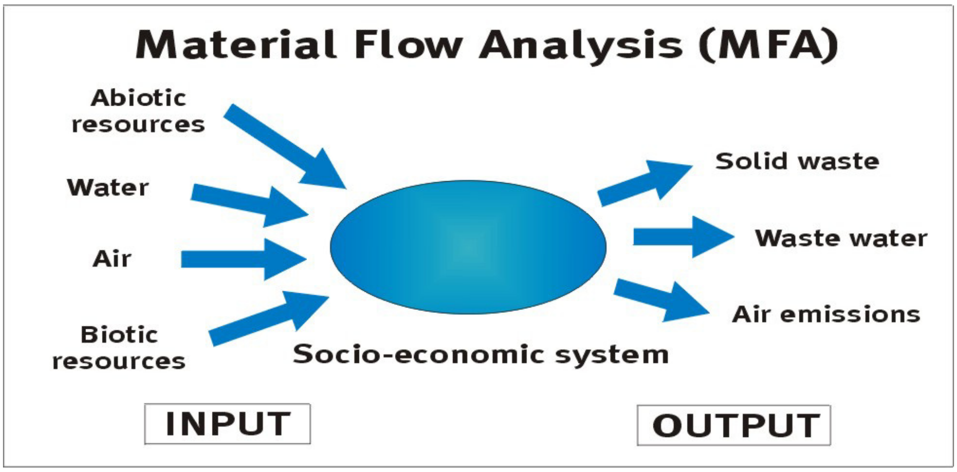
Finally, with the publication of a methodological guide “Economy-wide material flow accounts and derived indicators” by the European Statistical Office (Eurostat 2001), an officially approved harmonised standard was reached.

3.2. Methodology

3.2.1. The basic MFA model

The basic concept of MFA is that the economy is physically embedded sub-system of the environment, with the economy being an open system with regard to matter and energy (see Figure 1).

Figure 1. The basic model for MFA



Source: Own figure.

In economy-wide MFA, the whole economy including production and consumption activities is a single black box. Only flows that cross the system boundaries of the economy to nature or other economies are recorded but not flows within the economy itself.

3.2.2. The system boundaries and system stock

For MFA on the national level thus two main boundaries for resource flows have to be defined. The first one is the boundary between the economy and the domestic natural environment, from which resources (materials, water, air) are extracted and to which disposed after their use. The second one is the frontier to other economies with the imports and exports as accounted flows.

3.2.2.1. Boundary between the economy and the natural environment

For a consistent compilation of economy-wide material flow accounts, it is at first necessary to define exactly, where the boundary between the economic and the environmental system is to be set (i.e. which elements of the material world belong to society and which to nature) as only resources crossing this border are accounted for.

Every part of the material world that is produced by, or is periodically maintained by, human labour is part of the material components of society. This implies that *human bodies, livestock* and all the man-made infrastructures along with their complete metabolism has to be included in society's metabolism. As a consequence, products from livestock, like meat and milk, are not to be treated as inputs but as internal transfers within the socio-economic system.

However, experience suggests that these stocks are very small compared to other stocks such as buildings, machinery or consumer durables and also do not show significant changes over time. In practice, therefore, human bodies and livestock and their changes may be ignored unless there is evidence that these stocks change rapidly.

Same theoretical considerations could be raised about whether to include *plants* as a component of the socio-economic system, as they are maintained by labour in agriculture and forestry. For pragmatic reasons it is suggested not to consider plants as a component of the socio-economic system (Fischer-Kowalski 1997). Therefore, plant harvest can be seen as an input to the socio-economic system whereas manure and fertilisers are an output to nature. Eurostat (2001) recommends treating forests and agricultural plants as part of the environment in economy-wide MFA and the harvest of timber and other plants as material inputs. This corresponds to the economic logic of the System of National Accounts (SNA) and to economic statistics as described in the System of Environmental and Economic Accounts (SEEA) (United Nations 1993, 2001). Thus all flows related to the three types of economic activities included in the SNA (production, consumption and stock change) are referred to as part of the economic system.

Once these components are recognised (human bodies, livestock and artefacts) every material *flow* that produces or reproduces these components is considered to be an input of society's metabolism. These material flows are set in motion via society's activities to produce and maintain the material *stock*. Stocks of materials that belong to the economy are mainly man-made fixed assets as defined in the national accounts, such as infrastructures, buildings, vehicles and machinery as well as inventories of finished products. Durable goods purchased by households for final consumption are not considered fixed assets in the national accounts but should be included in economy-wide MFA and balances as flows (Eurostat 2001).

There are components of the material stock for which compilers have to determine whether they should be treated as part of the economy or of the environment. Cases in point are controlled landfills and cultivated forests. These decisions have an impact on the input and output flows that are recorded in the accounts. When controlled landfills are included within the system boundary, the emissions and leakages from landfills rather than the waste landfilled must be recorded as an output to the environment. For cultivated forests, the nutrients taken up by the trees rather than the timber harvested would be recorded as an input.

In Eurostat (2001), waste land filled is considered an output to the environment but compilers are free to choose the treatment they prefer. If controlled landfills are included within the system boundary, the classifications of outputs and stock changes must be adapted. It is recommended to indicate waste land filled as a separate category of stock changes in order to facilitate international comparison of data. (For a more detailed discussion on this topic see Eurostat, 2001.)

Clearly, there is a close link between stocks and flows and also a positive feedback. The bigger the material stocks are, the bigger the future material flows needed to reproduce the material stock.

3.2.2.2. Frontier to other economies (residence vs. territory principle)

Economy-wide material flow accounts and balances should be consistent with the national accounts. The national accounts define a national economy as the activities and transactions of producer and consumer units that are resident (i.e. have their centre of economic interest) on the economic territory of a country. Some activities and transactions of these units may occur outside the economic territory and some activities and transactions on the geographical territory of a country may involve non-residents. Standard examples for illustrating this difference are tourists or international transport by road, air or water. Due to such activities the environmental pressures generated by a national economy may differ from the environmental pressures generated on a nation's geographical territory. Trans-boundary flows of emissions through natural media (e.g., emissions to air or water generated in one country but which are carried by air or rivers and impact on another country) are not part of economy-wide MFA.

For physical accounts to be consistent with the national accounts, they have to apply the residence (rather than territory) principle. Hence, in principle, materials purchased (or extracted for use) by resident units abroad would have to be considered material inputs (and emissions abroad material outputs) of the economy for which the accounts are made. Likewise, materials extracted or purchased by non-residents on a nation's territory (and corresponding emissions and wastes) would have to be identified and excluded from that nation's economy-wide MFA and balances. Current knowledge suggests that the most important difference between residence and territory principle results from fuel use and corresponding air emissions related to international transport including bunkering of fuels and emissions by ships and international air transport as well as to fuel use and emissions of tourists.

For practical reasons, however, MFA follows the territory principle as do also national production and trade statistics

3.2.3. Classification of material flows

Various types of material flows are distinguished according to the following scheme (following Eurostat 2001).

- **Direct versus indirect**

Direct flows refer to the actual weight of the products and thus do not take into account the life-cycle dimension of production chains. Indirect flows, however, indicate all materials that have been required for manufacturing (up-stream resource requirements) and comprise both used and unused materials. For a detailed discussion on direct and indirect flows and their relevance for trade studies see Eurostat (2001).

- **Used versus unused**

The category of used materials is defined as the amount of extracted resources, which enters the economic system for further processing or direct consumption. All used materials become (part of) products exchanged within the economic system. Unused extraction refers to materials that never enter the economic system and thus can be described as physical market externalities (Hinterberger et al. 1999). This category comprises overburden and parting materials from mining, by-catch and wood harvesting losses from biomass extraction and soil excavation and dredged materials from construction activities.

- **Domestic versus rest of the world (ROW)**

This category refers to the origin and/or destination of the flows.

Combining the three dimensions leads to five categories of inputs relevant for economy-wide MFA. These categories are summarised in **Table 1** below.

Table 1. Categories of material inputs for economy-wide MFA

Product-Chain	"Economic Fate" (used/unused)	Origin (Domestic/ROW)	Term to be used
Direct	Used	Domestic	Domestic extraction (used)
(Not applied)	Unused	Domestic	Unused domestic extraction
Direct	Used	Rest of the world	Imports
Indirect (up stream)	Used	Rest of the world	Indirect input flows associated to imports
Indirect (up stream)	Unused	Rest of the world	

Source: modified from Eurostat 2001

For output flows the column 'used<–>unused' is called 'processed<–>non-processed', i.e. stemming from an economic use or not, and the distinction 'domestic<->ROW' refers to the destination (rather than the origin) of the flows.

The output categories relevant for economy-wide MFA are summarised in **Table 2**. A more detailed classification of the outputs based on their final environmental fate and harm is still to be developed (see also below).

Table 2. Categories of material outputs for economy-wide MFA

Product-Chain	"Economic Fate "Processed or not	Destination (Domestic/ROW)	Term to be used
Direct	Processed	Domestic	Domestic processed output to nature
(Not applied)	Unprocessed	Domestic	Disposal of unused domestic extraction
Direct	Processed	Rest of the world	Exports
Indirect (up stream)	Processed	Rest of the world	Indirect output flows associated to exports
Indirect (up stream)	Unprocessed	Rest of the world	

Source: modified from Eurostat 2001

3.2.4. Categories of materials

A standard classification of materials, which should be applied in the preparation of material flow accounts is summarised in **Table 3**. A very detailed material classification can be found in the annex of Eurostat (2001).

Table 3. Classification of input and output flows in economy-wide MFA, broad categories.

INPUTS	OUTPUTS
Domestic extraction (used)	**Emissions and wastes**
Fossil fuels	Emissions to air
Minerals	Waste landfilled
Biomass	Emissions to water
	Dissipative use of products and dissipative losses
	Dissipative use of products
	Dissipative losses
Imports	**Exports**
Raw materials	Raw materials
Semi-manufactured products	Semi-manufactured products
Finished products	Finished products
Other products	Other products
Packaging material imported with products	Packaging material exported with products
Waste imported for final treatment and disposal	Waste exported for final treatment and disposal
Memorandum items for balancing	***Memorandum items for balancing***
O_2 for combustion (of C, H, S, N ...)	*Water vapour from combustion*
O_2 for respiration	*Water evaporation from products*
Nitrogen for emission from combustion	*Respiration of humans and livestock (CO_2 and water vapour)*
Air for other industrial processes (liquefied technical gases…)	
Unused domestic extraction	**Disposal of unused domestic extraction**
Unused extraction from mining and quarrying	Unused extraction from mining and quarrying
Unused biomass from harvest	Unused extraction from biomass harvest (discarding of by-catch, harvesting losses and wastes)
Soil excavation and dredging	Soil excavation and dredging
Indirect flows associated to imports	**Indirect flows associated to exports**

Source: modified from Eurostat 2001

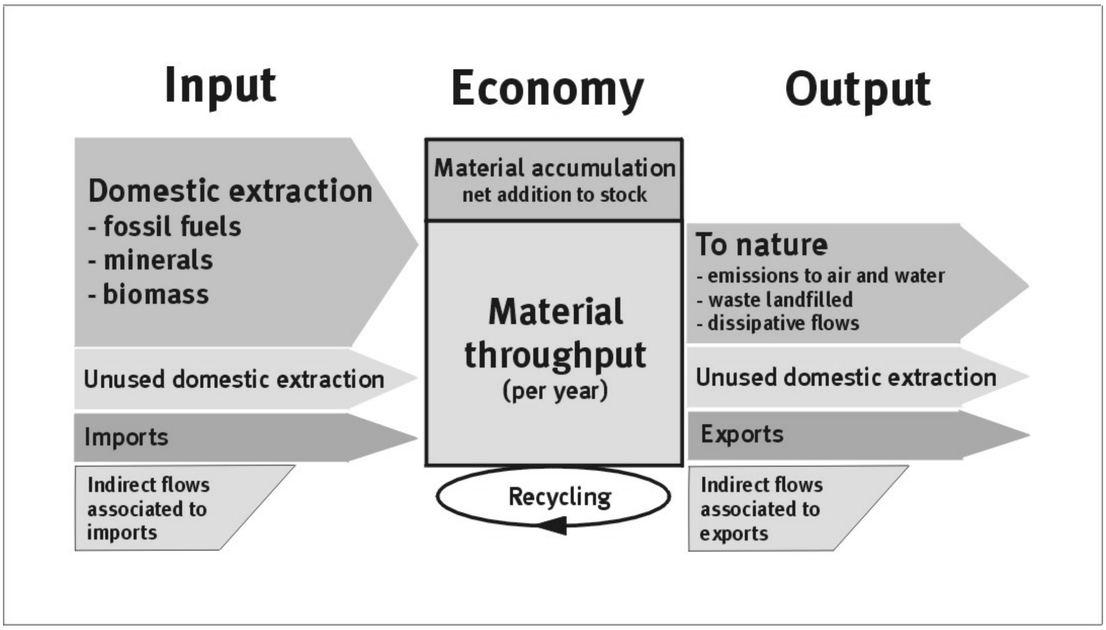
As water flows in most cases exceed all other material inputs by a factor of 10 or more (especially if water for cooling is taken into accounted, see e.g. Stahmer et al. 1997), Eurostat recommends presenting a water balance separately from solid materials. Thus in the standard accounts, water should only be included when becoming part of a product.

In order to close the overall material balance, the input of air has to be considered corresponding to air emissions on the output side. In this respect, the most relevant processes are the combustion of fossil energy carriers (O_2 on the input side as a balancing item corresponding to CO_2 emissions), air for other industrial processes and air for respiration of humans and livestock.

3.2.5. The final scheme and the material balance

Figure 2 presents the general balance scheme including all relevant input and output flows, but excluding water and air.

Figure 2. Summarizing scheme of the MFA system.



Source: modified from Eurostat 2001

The *law of conservation of matter* states that matter is neither created nor destroyed by any physical transformation (production or consumption) process.

This material balance principle provides a logical basis for the physical bookkeeping of the economy-environment relationship and for the consistent and comprehensive recording of inputs, outputs and material accumulation. The material balance principle can be applied from either a systems perspective or from a flow perspective.

For a given *system* such as production or consumption processes, companies, regions or national economies, the material balance principle leads to the following identity:

Total inputs = Total outputs + Net accumulation

This means that what goes into the system is either accumulated in the system or is leaving the system again as an output.

For a given physical *flow* the material balance identity can be expressed as:

origin = destination (other terms used are **supply = demand**, or **resources = uses**).

This refers to the fact that all flows have an origin and a destination, and a breakdown by origin must be exhaustive in the sense that the sum of masses by origin must be equal to the sum of masses by destination. Matter changes form during production and consumption processes. When this identity is used to establish economy-wide balances for specific material groups (e.g. fossil fuels or biomass), the raw materials must be related to e.g. the emissions or wastes that are the final destinations of these materials.

3.2.6. Indicators

The material balance also allows deriving several aggregate material-related indicators (see **Table 5** below). They can be classified into input, output and consumption indicators.

If foreign trade is not included with both imports *and* exports in the calculation but only with one of these trade flows (as in most input and output indicators) these indicator become not additive across countries. This is due an unavoidable double counting related to foreign trade statistics. For example, in order to calculate DMI of the EU as a whole, the intra-EU foreign trade flows must be netted out from the DMIs of Member States.

Table 5. Main material flow-based indicators.

INPUT INDICATORS
DMI (Direct Material Inputs) = Domestic Extraction + Imports ☹
TMI (Total Material Inputs) = DMI + Unused Domestic Extraction ☹
DOMESTIC TMR = TMI – Imports ☺
TMR (Total Material Requirements) = DMI + +Imports +Unused Domestic Extraction +Indirect Flows Associated to Imports ☹
OUTPUT INDICATORS
DPO (Domestic Processed Output to nature) = Emissions & Waste + Dissipative Use of Products & Losses ☺
DMO (Direct Material Output) = DPO + Exports ☹
TDO (Total Domestic Output to nature) = DPO + Disposal of Unused Domestic Extraction ☺
TMO (Total Material Output) = TDO + Exports ☹
CONSUMPTION INDICATORS
DMC (Domestic Material Consumption) = DMI – Exports ☺
TMC (Total Material Consumption) = TMR - Exports - Indirect Flows Associated to Exports ☺
NAS (Net Addition to Stock) = TMR – TMO ☺
PTB (Physical Trade Balance) = Imports –Exports ☺

Source: modified from Eurostat 2001

Notes:

Memorandum items for balancing are not to be included when compiling indicators.

☹ Not additive across countries.

☺ Additive across countries.

3.2.6.1. The physical trade balance

Concerning the trade and environment issue, the physical trade balance (PTB) is the most important indicator derivable from economy-wide MFA. The PTB expresses whether economies of countries or regions are dependent on resource inputs from other countries/regions and to what extent domestic material consumption is based on domestic resource extraction and on the imports of resources from abroad, respectively. With regard to regional analyses, the calculation of a PTB is a challenging task, as not only imports and exports between the region and the rest of the world have to be assessed, but also trade flows with other regions within the same country. Especially the latter task is accompanied with difficulties, as estimation methods have to be applied in order to calculate intra-country trade flows (see below for more details).

A physical trade balance is compiled in two steps: First, a PTB for direct material flows is calculated, which equals imports minus exports of a country or region. In a second step, a PTB can also be calculated including indirect flows associated to imports and exports, which include both used and unused resource flows.

For economy-wide MFA, two components of indirect flows are distinguished:

(a) up-stream indirect flows expressed as the Raw Material Equivalents (RME) of the imported or exported products (less the weight of the imported or exported product). The RME is the used extraction that was needed to provide the products;

(b) up-stream indirect flows of unused extraction (e.g. mining overburden) associated to this RME.

The first step is to compile the RME of imports or exports, i.e. the vector of raw materials needed to provide the product at the border. In a second step the unused extraction associated to this RME is estimated.

When imports and exports are converted into their RME, the weight of the RME includes the weight of the imports or exports. For the purpose of economy-wide MFA and balances, the indirect flows of type (a) (i.e., those based on the RME) are calculated by subtracting the weight of the imports or exports from the RME associated to these imports or exports in order to ensure additivity. This method of calculating direct and indirect material flows required in the life-cycle of a product has been developed at the Wuppertal Institute in Germany. In the NEDS project we will not calculate indirect flows by ourselves but will apply factors developed by the Wuppertal Institute.

Some of the indirect flows associated to exports may consist of the indirect flows associated to products previously imported. This effect would be particularly pronounced for countries with important harbours where a substantial part of imports is direct transit to other countries (the ‘Rotterdam effect’). It is recommended to show direct transit as a separate category of imports and exports in the accounts and to leave out direct transit when compiling indicators.

3.3. Data Sources

At the national level, the main data sources are production and trade statistics from national statistical offices, the United Nations (UN), the Food and Agriculture Organisation (FAO) or the Organisation for Economic Cooperation and Development (OECD). For the regional level data should be collected at regional statistical offices or at various regional institutions (administrative, political, economic, see also below).

The Wuppertal Institute for Climate, Environment and Energy in Germany has been one of the central institutions in the development of a standardised method for MFA and today is one of the most important sources for material flow data for unused and indirect material flows. At the website of the Wuppertal Institute, a spreadsheet with a number of „rucksack-factors", mostly for abiotic raw materials, building and construction materials and selected chemical substances can be downloaded. An extensive description of indirect flows for imported products can be obtained from the study „Total Material Requirement of the European Union" (Bringezu and Schütz 2001c). Detailed lists with „rucksack-factors" for minerals and metals as raw materials and semi-manufactured products as well as some factors for biotic resources are provided. Good summaries for the calculation of indirect flows with the LCA-based approach have also been published by Schütz (1999) and Bringezu (2000). The annexes in both publications present comprehensive compilations of all available "rucksack-factors", both for abiotic and biotic products, for domestic extraction as well as imports to Germany. This calculation method is mainly suitable for the calculation of indirect flows associated to biotic and abiotic raw materials and products with a low level of processing. To calculate indirect flows for semi-manufactured and finished products by applying this method requires the collection of an enormous amount of data for every product under consideration. A more convenient method for calculating the indirect flows on the macro level therefore is to apply input-output analysis. This allows quantifying the overall amount of material requirements stemming from inter-industry interrelations along the production chain (what is similar to the indirect effects in input-output-analysis). The input-output technique is presented briefly in Eurostat (2001) and discussed in detail in Rodrigues et al. (forthcoming).

Apart from the Wuppertal Institute, other research groups have investigated the material and energy requirements of resource extraction and processing. Especially the study series „Material flows and energy requirements in the extraction of selected mineral raw materials", published by the German Federal Geological Institute (see Kippenberger 1999 for an executive summary) provides detailed information on the resource inputs for the extraction, processing and transportation of eight of the most important mineral resources.

3.4. Limits and areas of Improvements

As stated above, MF-based indicators reflect environmental pressures stemming from societal metabolism. However, several theoretical shortcomings and limits to the current standard method can be identified (Eurostat, 2001).

- Big material flows dominate all indicators and bias interpretations of aggregated results. However, small material flows, which might be neglected in aggregated indicators, can have large environmental impacts. Changes in the composition of aggregated indicators due to substitution between different materials thus are of crucial importance;
- Unweighted (emission) indicators do not tell anything about actual environmental impacts, which are determined by the use of materials with different environmental effects (e.g. toxicity) and the risks associated to different technologies (e.g. atomic energy versus decentralized renewable energy). These facts significantly reduce the usefulness of MF indicators for policy use;
- The sole focus on the reduction of aggregated resource use is a necessary but not sufficient precondition for achieving environmental sustainability. The question remains of what exactly we have to reduce to achieve a sustainable resource throughput (see, Reijnders, 1998);
- Indicators relating material flows to economic data (e.g., material productivity, eco-efficiency indicators) have a strong economic component. Aggregation should therefore also reflect the economic usefulness of materials. Weight is no category to reflect economic values/decisions of end-users of materials (Cleveland and Ruth, 1999);

Although problems related to weight-based aggregation are in principal recognized by the MFA community, this procedure is being justified by the intention to create "value-neutral physical accounts that include all materials, regardless of their economic importance or environmental impacts" (Matthews et al., 2000, p. 2).

First suggestion for establishing a closer link between MFA and environmental problems has been suggested by Fröhlich *et al.* (2000), and Matthews *et al.* (2000). Ayres *et al.* (1998) proposed to evaluate the potential harm of outputs according to their residual eXergy content.

The World Resources Institute (WRI), when compiling the national physical accounts for the United States for 1975-96, developed methods to characterise material flows (see Annex 2 of Matthews et al. 2000). The characterisation is made on the basis of quantity, mode of first release, quality, and velocity (expressed as residence time). The method also allows estimating outflows to the environment and net additions to stock from input flows based on the velocity, in which material flows pass through the economic system. Nevertheless, an internationally standardised procedure for considering qualitative differences in the quantitative concept of MFA is so far still missing.

Another important aspect is the non-inclusion of environmental services provided by the environment in the MFA approach. Land use and territory exploitation may severely affect the ability of national environments to provide environmental services such as local microclimate maintenance, water cycling, soil buffering and filtering capacity, dispersion of pollutants, etc. A promising approach is to link MFA to other physical accounting methods (Bargigli et al., 2002; Ulgiati, 2002). The connection to land use accounting and land use change research is particularly important to integrate spatial aspects in interpretation of MFA results (see below for details). Another promising link is between MFA and other energy-based methods (for example, the eMergy concept, Odum 1996) for the evaluation of environmental services provided by national territories.

There is an urgent need of careful investigation in the environmental fate and the eco-toxicological impact of the chemical compounds released by societal metabolism. This topic is particularly crucial if we consider that many materials used in industrialised countries are very material- and energy-intensive, and are based on the exploitation of raw materials, which often takes place in developing countries, where environmental protection norms are lacking or less strictly enforced. This consideration applies to some extent to all kinds of industrial processes, but is often disregarded, and calls for a careful assessment of the consequences that the technological choices of a country may have on other regions of the world (Ulgiati *et al.* 2002). This point should be carefully considered while observing dematerialization paths of modern societies.

The derivation of highly aggregated resource use indicators can lead to misinterpretations of results, as detailed information on developments of other material groups or sectors is submerged. For example, international comparison of aggregated MF indicators, such as material input per capita, should be treated with caution. Numerically identical DMIs can have very distinctive material compositions and thus cause very different actual environmental impacts (Giljum 2002). The collection and interpretation of MF data should therefore be carried out on a disaggregation level, which is distinguishing different economic sectors or material groups. The major potential of MFA for future policy use lies in particular in the parallel analysis of monetary and physical flows, preferably within a framework comprising both monetary and physical tables.

Finally, in most MFA studies carried out so far, the link to the actors responsible for the activation of material flows is not established. Consequently, it is not investigated, which groups of society (consumers, entrepreneurs, etc.) could contribute to what extent to a strategy of dematerialisation (Hinterberger et al. 1996). It is one of the concrete goals of the NEDS project to analyse the links between material flows, relevant actors and the discourse on dematerialisation in the investigated regions (see below for details on the work done in the NEDS project).

From the view of discourse analysis (or social sciences in general) one can criticise the concept of MFA for its strong focus on the physical world, pursuing an approach that "believes" on the existence or necessity of a scientific sound method of accounting. Following this view, which seems very common in natural sciences, environmental problems can be understood by accounting of physical interrelations. From the critique of social sciences this approach neglects important aspects that are – according to their nature – not accountable in quantitative terms (at least not with the methods of natural science). The combination of two very different approaches (material flow analysis and discourse analysis) within this project could therefore help to overcome this gap between two scientific domains (see also Luks and Hammer, unpublished).

So far MFA did not contribute sufficiently to practical or political conclusions to be drawn from its results. MFA so far focused to the methodological, mathematical accounting of balances and indicators and the presentation of these results. In most case studies presented so far it did not go a step further and reflect on the policy-related use of its results. This field should clearly be further developed within the MFA community in cooperation with society, economics and politics.

3.5. State of the art at the national level

Economy-wide material flow analyses have been published or are currently in progress for a number of countries: Germany, Japan, the Netherlands and the United States (Adriaanse *et al.* 1997, Matthews *et al.* 2000), Australia (Durney --), Austria (Gerhold and Petrovic 2000, Schandl *et al.* 2000, Eurostat 2000, Schandl 1998, Wolf *et al.* 1998, BMUJF 1996), China (Chen and Qiao 2000, in Chinese with English abstract; Chen and Qiao 2001), Finland (Muukkonen 2000, Ministry of the Environment 1999, Mäenpää and Juutinen 2000, Juutinen and Mäenpää 1999), Hungary (Hammer and Hubacek 2002, Hammer 2002), Italy (De Marco *et al.* 2001, Femia 2000), Japan (Moriguchi 2001), Poland (Mündl *et al.* 1999, Schütz and

Welfens 2000), Sweden (Isacsson *et al.* 2000), United Kingdom (Schandl and Schulz 2002, Schandl and Schulz 2000, Sheerin 2002, Bringezu and Schütz 2001d), France (Chabannes 1998), Brazil (Machado 2001, Amann *et al.* 2002), Venezuela (Castellano 2001, Amann *et al.* 2002), Bolivia (Amann *et al.* 2002), Chile (Giljum 2002), the Czech Republic (Scasny et al. forthcoming) and the European Union (Eurostat 2002, Eurostat 2001b, Bringezu and Schütz 2001 a, b, c). National material accounts exist further for Denmark and are in work for Egypt (mentioned in OECD 2000, p. 7).

Several countries have integrated material flow statistics into their official statistics or are planning to do so (Austria, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands and Sweden, according to Fischer-Kowalski and Hüttler 1999). The United Nations integrated physical flow accounts into its *System of Environmental and Economic Accounting* (SEEA) (UN 2001).

4. Regional MFA

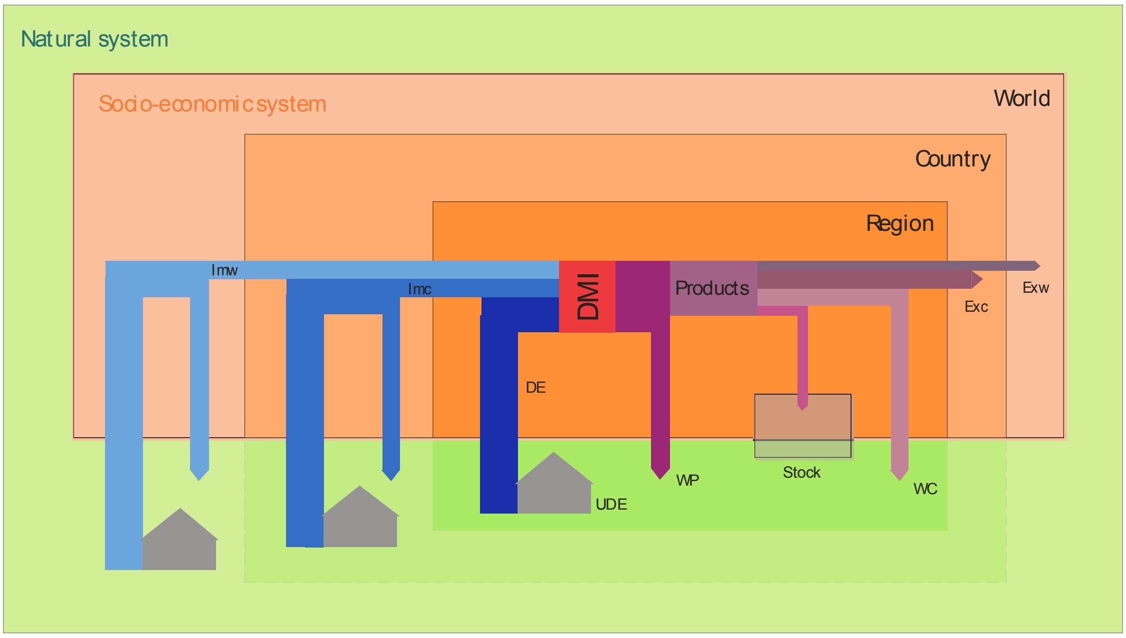
4.1. General introduction – Specific problems, methods and data

Issues of regional metabolism have already been discussed in the 1960s with a focus on water use and water and air pollution of cities, for example by Wolman (1965). The fact that cities are draining natural resources from their "Hinterland" has been discussed from an ecological footprint perspective by Rees and Wackernagel (1996) and Luck *et al.* (2001). On the one hand, they describe how Ecological Footprints are spatially distributed in a heterogeneous way between urban areas and their surrounding regions and that cities can not be sustainable within their boundaries. On the other hand they describe how the population density of cities can facilitate solutions for certain environmental problems (e.g. traffic or waste water treatment).

Several empirical MFA studies on regional or local levels have been carried out in the past (see the following section). However, compared to the large number of MFA studies on the national level, published studies on the regional or local level are still very limited and a standardised method such as presented by Eurostat (2001) for the national level does not exist yet.

Based on the Eurostat framework, Figure 3 illustrates material flows, which are linked to the physical metabolism of a region.

Figure 3: The material flows related to the physical metabolism of a region



Source: own figure.

Direct material input (DMI) of a region comprises materials extracted within the regional boundaries (domestic extraction, DE) plus imports. Imports either come from other regions within the country (intranational imports, Imc) or from the rest of the world (international imports, Imw). Associated with domestic extraction is the extraction of materials that are not economically used (unused domestic extraction, UDE or ecological rucksacks of extraction) and thus do not cross the boundary between the natural and the socio-economic system. In order to produce the imports, material extraction (used and unused components) is required outside the region and waste flows occur abroad during production of the imported goods.

Part of the material input of the region ends as waste of production (WP) in the course of production processes. The goods produced in or imported to the region comprise (a) durable consumer goods, which form part of the material stock of the region (such as cars, infrastructure etc.), (b) goods, which are consumed within the accounting period and end up as waste (waste of consumption, WC, including waste of durable goods) and (c) exports, which can either have other regions within the country (Exc) or other countries (Exw) as their destination.

A main difference between regional and national MFAs concerns the data sources. On the national level most of the data needed can be obtained from publications from statistical offices directly in published form. Almost all material input and trade data in physical units is accessible. On a regional level, data availability in general is much smaller. Data may have to be gathered in a more time consuming process as it may be dispersed among several institutions and not be available centralised (like on national levels at national statistical offices or from the United Nations). Furthermore, data may not be available in physical units at all for a number of material flows and therefore may have to be estimated from more general data. Two main methodological differences between the national and the regional level concern import (and export) flows and confidentiality of data. On national levels trade flows for the whole country are reported by official statistics. On a regional level trade flows have to be separated into interregional or intranational trade flows (physical flows between the region and the rest of the country) and international trade flows (physical flows between the region and the rest of the world outside the country); see also Figure 3 above. For both kinds of flows different statistical sources and methods of estimation may have to be used. Details on these estimation methods will be given in Section 5.

Confidentiality of data on a regional level could be a problem if the production structure in a certain branch within the region is dominated by a small number of firms. In that case data for the whole region could allow conclusions on the production quantities or technologies of single firms and could therefore be confidential.

4.2. Regional MFA: state of the art

So far only a few applications of MFA to regional areas exist. In this section we will present short abstracts of existing regional and local MFA (and ecological footprint, EF) studies. The descriptions will focus on the methods and data sources used for these studies and emphasise main problems and constraints of each of the studies. From this background we will extract implications for the empirical studies to be undertaken in the project. On the basis of the reviewed analyses a method for the regional MFAs carried out in this project shall be developed (see Section 5).

4.2.1. MFA of the Basque country

Within the MFA of the Basque Country, the Total Material Requirement (TMR) has been accounted for the years 1989-1998 (IHOBE, 2002). The applied method followed the method, which has been used for the accounting of TMR for the European Union (Bringezu and Schütz, 2001a, b). The method of the latter report has been changed in three major points concerning the calculation of erosion, excavation, and imports (IHOBE, 2002), p. 12) with regard to the specific characteristics of the Basque country. The report does not express in further detail how the original method had been changed or which method finally had been used to calculate these three items.

The authors state that the data collection process was a "laborious" one as the data has been widely dispersed, in some cases has not been expressed in conventional weight units, and lack of data made it necessary to estimate some material flows. Data for domestic extraction has been available at the Ministry of Agriculture, Fisheries and Food (the report does not specify, whether this is a national or a regional ministry) and the Spanish Geological and Mining Institute. Data on imports from the rest of Spain had to be calculated by own estimations whereas data on imports from the rest of the world has been available at the Institute for Foreign Trade and the Basque Institute of Statistics. The report does not explain in detail whether at these institutions data on physical flows has been available directly (either in published form or through personal communication) or if the material flows have been estimated using sources from this institutions (ibid, pp. 13).

For estimating imports from the rest of Spain, and taking into account data availability, two methods were applied: i) the first one was based on data of transport statistics between Spain and the Basque Country. These statistics include the transport in tonnes for the different branches of activity, but only for road transport and since 1994. ii). The second one was to use data of imports from Spain, obtained via Monetary Input Output Tables. The only problem for this option was to convert monetary data into physical data. For the study prices of Spanish exports (excluding Basque Country exports) to the rest of the world have been used (personal communication).

The points of main interest for the NEDS-project would be how much and what data has been available directly in the sources cited in the report and which methods have been used for the estimation of material flows for which data has not been available directly. Concerning the three main methodological differences mentioned above the main important for the project is the import issue as erosion will not be accounted for in the project and for the calculation of excavation the method of (Bringezu and Schütz, 2001b) could be used.

4.2.2. Local MFA of Amsterdam

A local MFA has been carried out by Gorree et al. (2000) but is available in Dutch only and was therefore not accessible for a full review. In the study a full bulk MFA has been carried out for the municipality of Amsterdam plus a little "hinterland". Amsterdam has its own statistical office and environmental office and a lot of data came from there. On the side of products and other material flows the authors had to make quite some assumptions and extrapolations from national data (personal communication).

4.2.3. Local MFA in Amazonia

Three local MFAs have been carried out in Bolivia, Columbia and Brazil. All three studies do not follow a method similar to bulk MFA on national levels. The studies focused on single important input and stocks categories and therefore do not account overall indicators like DMI or TMR. The main categories analysed were: food consumption, fossil fuels consumed by households, biomass extracted from domestic environment, materials used in the households and imported consumer goods (Amann et al., 2002, p. 17).

The characteristics and system boundaries of the analysed groups and areas varied widely within the three studies. In Bolivia material flows have been accounted for 8 farming families (58 persons) from 4 communities in El Chore. In Columbia the object of the study has been the municipality of Puerto Nariño. In Brazil three local communities on the Island of Marajo have been analysed. The studies focussed on the analyses of the degree of subsistence (mainly of food) and the energy sources consumed) (ibid., p. 18).

The only study out of these three using a method similar to the one intended to be used in the NEDS-project is the study on the municipality of Puerto Nariño. The method and data sources used are not described in detail in the report but the authors state that “a good wealth of MFA data” could be gathered or should be accessible (ibid., p. 19).

4.2.4. Local MFA Trinket Island

In this study (Singh et al 2001) a local MFA has been performed. Trinket Island belongs to the Nicobar archipelago in the Indian Ocean, with an area of about 3600 hectares and a population of about 400 people living in 43 households in three main villages. The society lives from horticulture and hunting and gathering with elements of industrialisation and market economy. The method for the MFA used in this study follows the methodology of economy-wide bulk MFA and uses the same indicators (DMI, DMC). But as data is not available from statistical offices data collection had to follow a significantly different way than on a national level. Data for the analysis has been gathered through interviews and direct analysis of processes and samples during two field trips. The method of data generation is described in good detail and would allow a reproduction but seems not to be applicable to a region of the size of the regions that are intended to be analysed within this project (metropolitan regions or larger countryside regions).

4.2.5. MFA of the Ruhr Area and North Rhine Westphalia

Within the framework of a project entitled “New strategies for old industrial regions”, the Wuppertal Institute for Climate, Environment and Energy calculated a material balance for the “Ruhr Area” (Bringezu and Schütz 1996 a,b), which forms part of the German province of North-Rhine-Westphalia. Aggregated regional MFA indicators, like DMI and TMR were calculated for the Ruhr Area and compared with results from North-Rhine-Westphalia and Germany.

Bringezu and Schütz emphasize that in particular for regions the inclusion of “ecological rucksacks” of imports and exports (in the Eurostat convention called indirect flows associated to imports and exports) is imperative in the evaluation of progress or setbacks towards sustainable development on the regional level. They divide the material balance of the “Ruhr Area” in two subsections, one comprising materials extracted and used in the region, the other listing imports and exports from/to other German provinces and from/to the rest of the world.

Critical for the authors is the problem of “missing borders” in MFA studies on the regional level. As imports and exports from other German regions are not listed in any trade statistics, they have to be calculated indirectly. Imports from the rest of the world are attributed to the “Ruhr Area” according to the regional share in total economic activity for each of the economic sectors in Germany. However, they neither give details on the attribution procedure nor on the statistical sources used. Imports from other German provinces are estimated as the difference of total production (including the generation of waste and emissions) in the region minus regional material extraction minus imports from other countries.

4.2.6. MFA of two regions in Switzerland

MFA studies have been carried out for two regions in Switzerland (Brunner et al. 1994; Hendriks et al. 2000). As the authors emphasise, regional material balances are an important management tool, as they allow identifying the most effective measures for the control of biophysical flows in a region. However, as they regret, standardized procedures for MFAs on the regional level have not been agreed upon so far. The fact is stressed that cooperation with actors in the region is an important precondition for the compilation of regional MFAs. In these studies, data were to a large part collected through personal interviews with enterprises and households in the region.

The methodological approach differs from the Eurostat method in so far, as also material flows within the region are accounted for. Five main so-called “processes” are identified to be important for a regional MFA (Brunner et al. 1994): private households, service sector, production sector, public services and agriculture. Another major difference in the approach is the fact that focus is put on single elements like lead or phosphorus, or single sectors (like the timber sector). No comprehensive accounting is done, as, according to the authors, the limited data situation does so far not allow an analysis of all processes in the region under investigation. Imports from outside the regional boundaries to the production sector in the region are assessed. However, no details are given, which data sources and methods have been used for this calculation. Another major difference to the Eurostat convention is the definition of the system boundaries, which are not set at the frontier between the socio-economic system and nature, but also include natural components, like soil and forests.

Material balances are established only for regional imports and exports (including waste flows) of materials. In addition, internal flows within the region are listed.

4.2.7. MFA and EF calculation of Vienna

The urban metabolism of Vienna for the year 1991 was assessed by Daxbeck et al. (1996) and Obernosterer et al. (1998) by applying so-called material flow and stock analysis (MFSA), which in principal is similar to the EUROSTAT approach. The overall objective was the identification and quantification of the key material flows and stocks within the city of Vienna and to investigate dependencies of the city on resources provided by the “Hinterland”, the surroundings of Vienna. The method closely resembled the one applied in the Swiss case studies (see above). Thus, not only inflows and outflows, but also flows within the city of Vienna have been assessed with the city being divided into 3 main compartments: supply (production and distribution of goods), consumption (private households) and disposal (waste management and waste water treatment). Material balances were compiled for both the total number of goods imported to and exported from the anthroposphere of Vienna (including water and air) and the flows of several elements (such as carbon, nitrogen, lead, iron, etc.).

Results showed that in 1991, each inhabitant of Vienna consumed around 150 tons of water, 2 tons of fossil fuels and 12-18 tons of construction materials and consumer products. Apart from 4-10 tons per capita of construction minerals, which were accumulated as infrastructure in the physical stock, and 3 tons per capita of exported products, material inputs were transformed into outflows of waste and emissions within the same year. Therefore, the city of Vienna has been described as a typical “throughflow” system (Obernosterer et al. 1998).

The links of the material metabolism of Vienna with its “Hinterland” have been assessed by several case studies. One focused on “Hinterland” carbon flows related to transport activities, showing that more than 60% of Carbon emitted in the “Hinterland” could be attributed to activities of Viennese inhabitants. Another study revealed the emission of high amounts of lead in the “Hinterland” caused by the use of car batteries within Vienna. For all MFSA studies, only already existing data available in the literature has been used.

The evaluation of current levels of material flows and stocks with regard to environmental sustainability was done by comparing anthropogenic flows and stocks with the “geogenic” conditions prior to settlement conditions. The authors emphasize the suitability of these reference levels for deriving directionally safe targets for the reduction of anthropogenic material flows and stocks.

In addition to the MFA study, also the ecological footprint of Vienna has been calculated (Daxbeck et al. 2001). Data sources and Vienna-specific experiences described in both the MFA and the EF study will provide a good starting point for the MFA of Vienna, which will be compiled in the course of the NEDS project.

4.2.8. Regional MFA and ecological footprint studies in Great Britain

In Great Britain there have recently been several studies trying to evaluate both the state of the local environment and the consumption patterns by means of MFA and the “ecological footprint” of small territorial entities such as cities (York and Liverpool) or counties (North West England).

In some cases these analyses focus more the life cycle of materials in one sector, i.e. construction minerals in the building sector, but covered a wider territory (McEvoy, et al., 2001). In other cases (Barrett *et al.,* 2002; Barrett and Scott 2001) the studies are framed within the city limit but try to evaluate the whole amount of goods moving in and out of the system due to the local societal metabolism.

In all cases data availability and consistency are crucial issues. Moreover, the majority of these studies are based on personal communications with local authorities and the remaining part is down-scaled from national and regional figures. Sometime a mismatch of data coming from different sources is highlighted (McEvoy et al., 2001). However, the majority of data is from local sources (85% in York and Liverpool studies) and provides a very detailed picture of the local consumption patterns.

The general approach is mostly based on the calculation of the ecological footprint, where the energy required for production and disposal of the purchased item (calculated over its whole life cycle and expressed in primary energy) is subsequently converted into the relative energy land equivalent and then into an ecological footprint figure (in hectares).

Both in the case of ecological footprint and MFA calculations, mass/energy multipliers are applied to local consumption data in order to include indirect energy/mass flows and provide an LCA viewpoint. The disposal phase is also taken into account. Often multipliers are taken from literature data.

In all the analyses, results show unsustainable consumption patterns of the three investigated areas and this calls for a change in societal behaviour both at the citizen and at the policy-maker levels.

4.3. Methodological conclusions from existing studies

The summary of existing material flow studies on the regional level reveals that all studies share some common features, but differ considerably with regard to the methods applied.

The main common feature are the difficulties in obtaining all necessary data for the material flow (or footprint) calculations, as official statistical sources in general publish physical flow data for regional identities only for a small number of material flow categories. Therefore, in many of the studies, official data had to be completed either by data obtained through personal communication and interviews with actors (e.g. enterprises, households) in the region or through the application of estimation methods. For practical reasons of data collection it seems to be of advantage, if the studied region corresponds to administrative boundaries (especially to NUTS[3] classifications within the European Union). The availability of data is expected to be better in that case as statistical offices may publish their data for administrative entities or national statistical offices may run regional offices for well defined administrative regions. Furthermore, also the existence of actors (e.g. business organisations) may correspond to administrative regions.

[3] Nomenclature des unités territoriales statistiques.

The studies differ considerably with regard to their methodological approach. Some of the regional studies (Great Britain, EF of Vienna) apply a life-cycle oriented approach starting from consumption data of different actors and calculating the overall material requirements along the life-cycle of a product by multiplying final consumption with specific factors (mass/energy multipliers).

The majority of the studies takes a systemic perspective analysing material inflows and outflows at the border between the socio-economic system and the natural system and between the region and other economies, respectively. Following the approach of economy-wide material flow analysis proposed by Eurostat, some studies (Ruhr Area, Basque Country) consider the regional socio-economic system as a black box. Other studies in addition consider intraregional flows (Swiss regions, Vienna), thus providing simplified physical input-output tables for the regions, which give insights into the material interrelations of different economic sectors (e.g. agriculture, manufacturing, services) and between production sectors and final demand of goods (e.g. private consumption, government expenditures, etc.). In general, this approach is very promising, as the material flows between the different actors in the region are also quantified and therefore policy recommendations can be defined and the effectiveness of policy measures monitored on a more disaggregated level. However, the assessment of intraregional flows requires significantly more data and makes data collection more difficult and time consuming. The regional MFAs carried out in the NEDS project will apply the black box approach, as time and financial resources do not allow a consideration of intraregional flows.

Another crucial difference between the reviewed studies refers to the consideration of different material groups. Some methodological approaches focus on flows of single materials (such as lead, phosphorus and nitrogen in the studies on Switzerland and Vienna), presenting very detailed indicators with regard to specific environmental problems. Other studies (Basque Country, Ruhr Area) take a comprehensive view and account for all materials involved in the physical metabolism of the region, providing higher aggregated indicators for total domestic extraction and imports. To our understanding, the latter approach is to be favoured from the viewpoint of sustainable development, as comprehensive accounting and indicators should be taken as a basis for the evaluation of improvements or set-backs towards the goal of dematerialisation, which is acknowledged as one central precondition for achieving sustainability both by researchers (Hinterberger et al. 1996) and politicians (European Commission, 2001). Only the comprehensive view can reveal shifting of environmental problems from one material group to another (e.g. reducing waste dumped into landfills through increased capacity of garbage incinerators instead of reducing the absolute amount of waste).

5. The NEDS project: MFA methodology and concrete tasks

In the NEDS project, 3 European regions are selected as case studies for regional MFAs. The regions are: the metropolitan region of Hamburg (the city of Hamburg and 14 NUTS 3 regions surrounding the city), the metropolitan region of Vienna (the city of Vienna and two NUTS 3 regions) and the metropolitan region of Leipzig (including one NUTS 3 region of surrounding area). The regions have been selected from a database of 73 European regions, which have been classified as active promoters of regional sustainable development (BBR 2001). In the course of the project, parallel analyses of the biophysical metabolism (assessed with an MFA approach) and the discourse on sustainability are carried out in each of the selected regions, in order to identify their linkages and to formulate possible paths towards a more efficient use of natural resources on the regional level.

The 3 regional MFA accounts compiled in the course of the project will as close as possible be compiled in accordance with the standardized method of the Eurostat guide for economy-wide material flow accounts (Eurostat, 2001). This is of importance, as, on the one hand, regional MFAs can only enable the cross-checking with and completion of national MFAs, when following the same methodological procedure. On the other hand, when regional MFA data is not available and estimation methods have to be applied, national MFA data can only serve as a starting point for estimations, when using the same classification of material flows.

As already discussed in the last section, the material flow accounts on the regional level have to be extended by intra-country trade data, in order to account for material exchanges with other regions within the same country. Given sufficient data availability, the regional material flow accounts will also include unused domestic extraction and indirect flows associated to imports. If data concerning unused domestic extraction (mainly overburden from mining activities) is not available from official statistical sources, a first estimation of overburden should be obtained through personal communication with the most important mining co-operations in the regions.

Indirect flows associated to imports will be estimated by applying “rucksack factors” for the German economy, which have been calculated by the Wuppertal Institute and are so far the most detailed data for indirect flows available world-wide (for example, Bringezu 2001). For the 2 regions located in Germany this procedure should deliver reliable results. For the third region in another European country, the estimation is based on the assumption of an identical import structure of the region compared to Germany. This procedure has been used for a number of other MFA studies on the regional and national level (for example, Hammer 2002, IHOBE 2002, Juutinen and Mäenpää 1999). However, one should be aware of deviations from results based on country- or region-specific rucksack factors for imports.

Provided a sufficient availability of data, the 3 regional MFAs will be compiled in a time series from 1992-2001. We choose this period of 10 years, as, on the one hand, we can expect that data availability will be the higher the more recent the time period of our investigation is set. This is of particular importance, as data availability will be one of the crucial points for the success of the regional MFA studies. On the other hand, a period of 10 years is long enough to capture recent changes in the metabolic profile of the regions and to analyse impacts of changed political / discursive frameworks on regional material flows.

Concerning the time schedule for the three regional MFA studies, two main approaches can be identified: a parallel and a consecutive approach. The latter approach would allow accumulating experiences with the applied method from study to study, thus carrying out the first MFA as a test of the method and then adapting it for the other studies were necessary (e.g. due to data limitations). The positive learning effect would probably help to advance the method and to provide a well designed and tested methodological tool for regional MFA as one main deliverable at the end of the project. However, this approach could lead to a situation, where final results of the 3 case studies are no longer comparable due to further developments of the method.

Given the well-defined methodological framework (see above) it is likely that final results will more depend on available data than on methodological considerations. Non-comparability of results will likely be rather due to data restrictions than methodological changes. Therefore, to our view, a consecutive approach would be preferable for the compilation of the regional MFAs in the NEDS project.

5.1. Detailed description of the methodology

The following methodological procedures shall be applied for the MFA calculations carried out in the NEDS project. We will describe several approaches for the calculations of both domestic material extraction and material flows related to trade activities. If possible, at least two approaches shall be used in parallel, in order to enable a cross-checking of results and to minimize estimation errors. The approach to be chosen for application in the NEDS project finally depends on data availability, which cannot be specified at this stage of the project.

5.1.1. Domestic extraction

According to the experiences of other regional MFA studies (see above), data on regional domestic extraction should be directly available from statistical sources.

For the case that data is not available, estimation methods have to be applied. A rough estimation would be the allocation of national extraction data to sectors in the region according to the shares of economic activities in the region in relation to the national economy. Domestic extraction consists only of a small number of materials (for example fossil fuels, oil, gas, ores, minerals, wood, agricultural products) that can be allocated easily to the small number of extracting sectors (mining, forestry, agriculture). Problems arise concerning the homogeneity of domestic extraction and the distribution of sectors between different regions. For example, one cannot easily distribute national extraction of a single metal according to the share of the mining sector in a region as the sector in the region may consist only of one firm extracting one specific metal. Therefore, information on the structure of extracting sectors nationally and in the regions is crucial for the analysis and the applicability of these methods depends on the levels of (dis)agreggation both for the sectoral and the extraction data.

5.1.2. International imports

Five different methods for calculating international imports to a region can theoretically be identified:

1. In the best of all cases, regional trade statistics, quantifying flows of goods between the region and the rest of the world, are directly available in physical terms. However, indirect flows of imports can only be calculated accurately, if these statistics are disaggregated by products or, at least, product groups.
2. If regional trade statistics disaggregated by products or product groups are available, but only in monetary terms, they can be converted into physical units with the use of national trade statistics. National trade statistics provide import data for all products in both monetary and physical units and therefore allow the calculation of a ratio between weight and value for the various imported

products. This ratios can then be used to convert regional monetary import data into physical data on the assumption that regional imports for each product group consist of the same commodities like those on the national level (for example, if we calculate an aggregated price/weight ratio for the pulp, paper and paper products sector based on disaggregated data from the national trade statistics, we would have to assume that one unit of monetary imports to the region consists of the same shares of pulp, paper and paper products like one unit of monetary imports on the national level).

3. A third approach would be based on a national physical-input-output-table (PIOT), as it has been published for example for Germany (Statistisches Bundesamt, 2001a). The import row of the national PIOT delivers information on the total weight of physical imports of each production sector. Using the shares of a sector's economic activity in the region to the sector's activity on the national level, one can calculate the total physical imports for each sector within the region assuming that the import structure of each sector within the region is the same as of the same sector nationally (for example, that an average paper producer in the region purchases the same material inputs from abroad as the average paper producer in the country as a whole). As this method delivers only one aggregated number of total imports for each sector, the calculation of indirect flows associated to imports is not possible, as the 'rucksack factors' vary in a broad range for different commodities. An allocation of indirect flows therefore requires import data dissaggregated by products or, at least, product groups.

4. Another approach uses the import matrix of a national monetary-input-output-table (MIOT). The import matrix shows the imports of various commodities by different economic sectors (commodity times sector-table). In a first step, physical imports taken from the national trade statistic have to be allocated to the commodity groups of the import matrix. In the ideal case the categories of the trade statistics and the categories of the import matrix correspond or conversion tables exist which allow an exact allocation. In all other cases, imports have to be allocated according to estimations of the belonging of different products to commodity groups of the matrix (for example, imports of pulp, paper and paper products, listed separately in the national trade statistics, are allocated to the corresponding commodity group in the import matrix of the IO table). In a

second step, the national physical imports by commodity groups are allocated to the national sectors according to the shares specified in the import matrix. Here we have to assume that the share of a sector in imports of a specific commodity is the same in monetary and physical terms which means that the composition of one unit of imports is the same in all of the sectors (for example, that the food sector imports the same shares of pulp, paper and paper products as the machinery sector[4]). In a third step the imports by each sector are distributed to the region according to the regional share of each sector on the total national sector. This is based on the assumption that the imports of a sector in a region have the same structure as the imports of the whole sector on the national level (see above).

5. The last method is using transportation data. If transportation data is available in tons for cross-border trade it can be used as an estimate for the imports of goods from other countries into the region. Transportation data may be disaggregated either by countries or by product categories. However, data may not be available for all means of transport (road, train, ship, plane, "transport" by pipelines). If indirect flows associated to imports (ecological rucksacks of imports) are to be calculated, then disaggregation by product categories is a necessary precondition.

The first case would be the preferred optimum, as no estimations would be necessary. However, as the review of existing regional MFA studies revealed this case seems to be very unlikely. Monetary trade statistics on the regional level do exist for a number of regions and cities, so it is likely that approach 2 can be applied to at least one of the selected regions. For the use of method three a comprehensive PIOT is available for Germany for the year 1995 (Statistisches Bundesamt 2001a). Thus, for regions located in Germany, the method using a PIOT could be used to cross-check results gained with other approaches. Method 4 is based on various assumptions (as mentioned above) and would therefore deliver the less exact results. However, data needed for this method (trade statistics in physical terms, MIOT for single years) is available for all European countries and therefore this approach can be applied, if no other approach is applicable. Method 5 may only be possible for larger regions, which are defined administrative entities.

[4] This assumption can also be illustrated at the product level, stating that each unit of imports consists of the same composition of all products, as we can split "pulp", "paper" and "paper products" into single products each of them having its characteristic price/weight ratio.

5.1.3. Intranational imports

Several estimation methods for the calculation of imports from other regions within the same country can be distinguished.

1. Using production data: As Bringezu and Schütz (1996 a,b) explain in their study on the Ruhr area, imports from the rest of the country can be estimated roughly as a residue number of total production in the region minus imports from the rest of the world, minus domestic extraction and intermediary production of the region. However, the authors do not give any details on the methodological procedure (for example, what the term "total production" includes and which data has been available in physical and monetary terms, respectively) and further methodological descriptions are not available from the authors of the study (Helmut Schütz, Wuppertal Institute, personal communication, 29.1.2003).
2. Using regional and national IO tables: the national monetary IO table lists deliveries of intermediate products between all production sectors (industries) of an economy (for example the iron sector in Germany delivering crude iron to the steel sector for 100 million EURO). If a region holds a share of 10% of total steel producing activities of the country (this information can be taken from common regional statistics, see above), we can estimate that also 10% of these deliveries (here, 10 million EURO) have the region as their destination. From the regional IO tables we get the absolute number of deliveries from the iron in the steel sector within the region (for example, 3 million EURO) and therefore can calculate the intranational deliveries as the difference between national and regional deliveries (7 million EURO in our example). The final conversion from monetary into physical data is then carried out with weight to value ratios calculated from a national MIOT and PIOT, respectively. Problems with this approach could arise due to different levels of aggregation in the regional and national IO tables. It is likely that the regional tables are higher aggregated than the national tables and thus sectors in the national tables would have to be aggregated in order to harmonize with the regional tables. In addition, this approach is only applicable for countries, for which a PIOT is

available (for example, Germany), in order to allow the calculation of weight/value ratios.

3. Using transport data: If transportation data is available for intra-national trade by regions it can be used as an estimate for the imports of goods from other regions of the country. Transportation data may be disaggregated either by regions or by product categories. As described above for the national level, it may not be available for all means of transport (road, train, ship, plane, "transport" by pipelines).

6. MFA and land use

6.1. The ecological footprint

It is generally agreed among scientists that – together with energy and material flows - land use is the third important resource input category for economic activities (see, for example, Spangenberg and Bonnoit, 1998). The most influential physical accounting method focusing on land appropriation has been introduced by Rees and Wackernagel at the beginning of the 1990s (Rees and Wackernagel, 1992) and is generally referred to as the ecological footprint (EF). The EF can be defined as the total land and water area required to support a population with a specific lifestyle and given technology with all necessary natural resources and to absorb all their wastes and emissions for an indefinite length of time (Wackernagel and Rees, 1996). Thus the EF is an instrument to perform natural capital assessments on the national level (Wackernagel et al., 1999). By comparing the land appropriation of the population of a country with the ecological capacity available within the national territory, sustainability deficits or surpluses can be quantified. The EF therefore is often used as a rough indicator for the sustainability of countries. EF calculations have been carried out for almost all countries of the world (for the latest comprehensive country data set see WWF 2002).

Concerning the method, the calculation of the EF is in general not based on actual land use or land cover data, but starts from the resource consumption of a specific population in terms of mass units. The first step is to develop a matrix with the categories of consumption on the one axis and the categories of land use on the other. In a second step, the weight of the consumed product is converted into its land equivalents. In the case of food, productivity data (yield/hectare) is used to calculate appropriated land areas from mass units. Concerning the category of housing, the EF takes into account the actual build-up land area (as far as it is available from international statistics) as well as the land area to produce all household articles (e.g. the furniture made of wood). Transport accounts for the land area for transport infrastructure as well as the fossil fuels needed to produce and operate the vehicles.

For all OECD and many of the newly industrialising countries (NICs), the largest share of the EF is made up by the land areas "reserved" for CO_2 sequestration. This category illustrates the hypothetical land that would be required to absorb the CO_2 emitted from the combustion of fossil energy carriers or to produce an energy carrier of the same energy content from renewable resources.

6.2. Land use accounting based on land use and land cover data

The ecological footprint is regarded as one of the most influential approaches for the communication of the concept of environmental sustainability and uses the limited availability of biologically productive areas on the planet as a symbol for the limited carrying capacity for anthropogenic environmental stress. However, a number of critical points concerning the calculation procedure of EFs have been raised (see, for example, Ayres, 2000; van den Bergh and Verbruggen, 1999). The aggregation of actual appropriated land areas with hypothetical land areas to the total EF of a country has been one major source for critique. Due to this aggregation, problems related to scarcity of actual used land remain hidden and cannot be analysed.

Another critical point is the assumption that present patterns of land use are sustainable (e.g. in agriculture and forestry), which in many countries can be disproved, considering, for example, high rates of erosion and loss of fertile soil due to intensive production or use of inappropriate production patterns.

The comparison of available bio-capacity within each country with the level of consumption of the country's population in order to quantify ecological surpluses or deficits has also been criticised as being biased against small and densely populated nations or nations with low ecosystem productivities. Due to their richness in natural resources, Canada and Australia have substantial ecological surpluses per capita despite very high consumption levels, whereas many sub-Saharan countries have ecological deficits, although the consumption levels are far below levels of a humane way of life.

Furthermore, the method of converting mass units into land areas is only feasible for biotic products (agricultural, forestry or fishery products), as for these categories productivity data is easily available. But there is no possibility for directly converting other products, like abiotic raw materials or semi-manufactured and manufactured products into land equivalents, as data on the land intensity of production of these goods is not yet available. Furthermore, the land appropriation of the service sector cannot be included in this kind of calculation.

Finally, the EF approach does not take the same system boundaries as the MFA concept, and thus cannot be directly related to other economic and social indicators derived from the System of National Accounts.

For all these reasons, in our opinion, a more suitable approach for including land use aspects in physical accounts is to use land cover data, available from land use statistics (for example, Statistisches Bundesamt, 2001b) or from Geographical Information Systems (GIS) (for example, EEA 2000). A parallel but separate analysis of the two categories of material flows and land use reduces the communicability of information by increasing complexity. However, problems connected to the conversion of one category into the other and the related loss of information are avoided, which significantly increases scientific transparency and credibility of the approach (Spangenberg et al. 1999).

On the product (micro) level, the definition of an indicator, which relates the intensity of land use to the service provided has been discussed (Schmidt-Bleek 1994). This procedure would follow the approach of “MIPS” (material intensity per service unit) developed for the category of material use.

In order to allow calculations of sectoral land intensities, land use data can be disaggregated by economic sectors and provide a differentiation between land used by industry, services and private households. Sectorally disaggregated data has been used to model economy-environment relationships within integrated input-output frameworks and to calculate overall land requirements of final demand (Hubacek and Giljum, 2003; Hubacek and Sun, 2001). This framework of extended input-output analysis allows to model in parallel material flows and land use of a region or a country. The recently started EU-funded project “MOSUS” (Modelling opportunities and limits for restructuring Europe towards sustainability) links material input and land use data to a global system of input-output models, which for the first time allows to calculate - in a sectorally disaggregated manner - the overall (direct and indirect) amount of resources activated by Europe’s demand for products and services. Thereby, ecological rucksacks of imports to Europe can be determined both in terms of material flows and land use. In the MOSUS project, five categories of land cover types will be distinguished: agricultural areas, forestry areas, built up area, natural areas and water areas. Each category is further specified in several sub-categories.

Concerning the land use data collected in the NEDS project, a similar classification to the one applied in the MOSUS project would be useful in order to guarantee consistency of data between the national and the regional level and allow comparisons of results.

If material flow and land use data can be allocated to economic sectors in the region (for example, within the framework of regional input-output tables), parallel analysis of resource intensities and land intensities of different economic activities could be carried out. This type of analysis could clarify the relation between material flows and land use and provide answers to the question, whether the most material intensive sectors are also the sectors with the highest intensity of land use. To our knowledge, no empirical study has been published so far addressing questions of the spatial distribution of material flows and the implications of changes in the metabolic profile of regions for regional land use changes. In the NEDS project, first steps towards the parallel assessment of material flows and land use shall be undertaken in the 3 selected case studies. Possible trade-offs between reductions of material intensity and land intensity, respectively, shall be identified. Furthermore, it shall be clarified, whether land intensity could be one possible criterion to evaluate different types of material flows. One focal point in this research shall be the analysis of sub-urbanisation processes from the perspective of both material flows and land cover change.

7. Conclusions

Only a small number of MFA studies on the regional level exists so far. The studies reviewed in this paper differ considerably with regard to the size of the investigated regions (geographically and in terms of population numbers), the methods used (for example, the definition of system boundaries, or bulk MFA versus focus on certain material flows) and data generation (by using regional or national statistical offices, or direct estimations through field work, or questionnaires). Most studies give only very brief descriptions of the methods applied. Therefore, the description and elaboration of methods to be used in the NEDS project had to be based on this small literature basis, on personal communication with the authors of existing regional MFA studies and on a first overview of available statistics which data can be used either directly or for estimation methods. Our conclusion is that the calculation of regional MFAs will to a good extent have to be based on estimation methods, as direct data for material flows may be available only for a very limited number of categories. This holds especially true for material flows related to trade activities. In this paper, we presented several approaches for estimating different material flows, which should be applied in parallel in order to gain comparable results. The one selected finally will depend on the specific data availability, which will only be clarified when the field-work in the regions actually starts.

Acknowledgments

We would like to thank the following persons for providing important information and for fruitful discussions and comments on earlier versions of this paper: Aldo Femia, Rene Kleijn, Fred Luks, Samuel Niza, Iñaki Arto Olaizola, Francois Schneider, Helmut Schütz, and Matthias Winkler.

References

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: World Resource Institute.

Amann, C., M. Fischer-Kowalski, W. Hüttler, H. Schandl, H. Weisz (2000). Material Flows: Austria. In: Matthews *et al.* (2000). The Weight of Nations. Material Outflows from Industrial Economies. Washington D.C.: World Resources Institute. pp. 48-65.

Amann, C., W. Bruckner, M. Fischer-Kowalski, and C. M. Grünbühel (2002). Material Flow Accounting in Amazonia. A Tool for Sustainable Development. Social Ecology Working Paper. 63. Vienna: Institute for Interdisciplinary Studies of Austrian Universities (IFF).

Ayres, R.U. (2000). Commentary on the utility of the ecological footprint concept. Ecological Economics. Vol. 32, pp. 347 - 349

Ayres, R.U. and A.V. Kneese (1969). Production, Consumption and Externalities. American Economic Review, 59:3, pp. 282-97.

Ayres R.U. and Masini A., (1998). Waste Exergy as a Measure of Potential Harm. In: Advances in Energy Studies. Energy Flow in Ecology and Economy. Ulgiati S., Brown M.T., Giampietro M., Herendeen R.A., and Mayumi K. (Eds). Musis Publisher, Roma, Italy; pp. 113-128.

Ayres, R. U. and Simonis, E. (1994) Industrial Metabolism. Restructuring for Sustainable Development. United Nations University Press. Tokyo, New York, Paris.

Bargigli S., Raugei M. and Ulgiati S. (2002). Thermodynamic and environmental profile of selected gaseous energy carriers. Comparing natural gas, syngas and hydrogen. Proceedings of the International Conference ECOS 2002, 3-5 July 2002, Berlin, pp.604 – 612.

Barrett J., A. Scott (2001). An Ecological Footprint of Liverpool. Developing Sustainable Scenarios. A Detailed Examination of Ecological Sustainability. Stockholm Environment Institute – York, Sustainable Steps Consultants.

Barrett J., H. Vallack, A. Jones and G. Haq (2002). A Material Flow Analysis and Ecological Footprint of York. Stockholm Environment Institute (York).

BBR (Bundesamt für Bauwesen und Raumordnung) (2001). Europe’s Regions on their Way to Sustainable Development. CD-ROM.

BMUJF (1996). Materialflußrechnung Österreich. Gesellschaftlicher Stoffwechsel und nachhaltige Entwicklung. Schriftenreihe des BMUJF Band 1/96. Vienna: Bundesministerium für Umwelt, Jugend und Familie

Bringezu, S. (2000). Ressourcennutzung in Wirtschaftsräumen. Stoffstromanalysen für eine nachhaltige Raumentwicklung. Berlin: Springer, Heidelberg, New York.

Bringezu, S. and H. Schütz (1996a). Der ökologische Rucksack des Ruhrgebiets, Rep. No. 61. Wuppertal Institute, Wuppertal.

Bringezu, S. & Schütz, H. (1996b) Die stoffliche Basis des Wirtschaftsraumes Ruhr. Ein Vergleich mit Nordrhein-Westfalen und der Bundesrepublik Deutschland. RuR, 6.

Bringezu, S., Fischer-Kowalski, M., Klein, R., and Palm, V. (1997). Regional and National Material Flow Accounting: From Paradigm to Practice of Sustainability., Leiden.

Bringezu, S. and H. Schütz (2001a). The Material Requirement of the European Union. Technical Report No 55. Copenhagen: EEA (European Environment Agency).

Bringezu, S. and H. Schütz (2001b). Material Use Indicators for the European Union, 1980-1997. Eurostat Working Papers 2/2001/B/2: Eurostat.

Bringezu, S. and H. Schütz (2001c). Total Material Requirement of the European Union. Technical Part. Technical Report No 56. Copenhagen: EEA (European Environment Agency).

Bringezu, S. and H. Schütz (2001d). Total Material Resource Flows of the United Kingdom. Wuppertal: Wuppertal Institute for Climate, Environment, Energy.

Brunner, P., Daxbeck, H., and Baccini, P. (1994). Industrial metabolism at the regional and local level: A case-study on a Swiss region, in Ayres, R.U. and Simonis, U.E. (eds) Industrial Metabolism: Restructuring for Sustainable Development, United Nations University Press, Tokyo.

Castellano, H. (2001). Material Flow Analysis in Venezuela. Internal Report (unpublished). Caracas.

Chabannes, G. (1998). Material Flows Analysis for France. unpublished manuscript.

Chen, X. and L. Qiao (2000). Material Flow Analysis of the Chinese Economic-Environmental System. Journal of Natural Resources, 15:1, pp. 17-23.

Chen, X. and L. Qiao (2001). A Preliminary Material Input Analyses of China. Population and Environment, 23:1, pp. 117-26.

Cleveland, C.J., Ruth, M. (1999). Indicators of Dematerialization and the Materials Intensity of Use. Journal of Industrial Ecology 2 (3), 15-50.

Daly, H. E. (1990). "Towards Some Operational Principles of Sustainable Development." Ecological Economics 2: 1-5.

Daxbeck, H., Lampert, C., Morf, L., Obernosterer, R., Rechberger, H., Reiner, I., and Brunner, P. (1996) Der anthropogene Stoffhaushalt der Stadt Wien, Technical University of Vienna, Wien.

Daxbeck, H., Kisliakova, A., and R. Obernosterer, R. (2001). Der ökologische Fußabdruck der Stadt Wien. Ressourcen Management Agentur, Wien.

De Marco, O., G. Lagioia, and E. Pizzoli Mazzacane (2001). Materials Flow Analysis of the Italian Economy. Journal of Industrial Ecology, 4:2, pp. 55-70.

Durney, A. (--). Industrial Metabolism. Extended Definition. Possible Instruments and an Australian Case Study. Berlin: Wissenschaftszentrum Berlin für Sozialforschung.

EEA (2000). NATLAN (Nature/land cover information package), CD-ROM. European Environment Agency, Copenhagen.

ENCORE (2001). Villach Resolution. The 5th Environment Conference of the Regions of Europe, Villach.

European Commission (2001) A Sustainable Europe for a Better World: A European Union Strategy for Sustainable Development. The Commission's proposal to the Gothenburg European Council, European Commission, Brussels.

Eurostat (2000). Material Flow Accounts - Material Balance and Indicators, Austria 1960-1998. Eurostat Working Papers 2/2000/B/7: Eurostat.

Eurostat (2001). Economy-wide Material Flow Accounts and Derived Indicators. A Methodological Guide. Luxembourg: European Communities.

Eurostat (2001b). Material Use Indicators for the European Union 1980-2000. Luxembourg: Eurostat.

Eurostat (2002). Material Use in the European Union 1980-2000. Indicators and Analysis. Luxembourg: Eurostat.

Femia, A. (2000). A Material Flow Account for Italy, 1988. Eurostat Working Papers 2/2000/B/8: Eurostat.

Fischer-Kowalski, M. (1997). Methodische Grundsatzfragen. In: Gesellschaftlicher Stoffwechsel und Kolonisierung von Natur. Fischer-Kowalski, M., H. Haberl, W. Hüttler, H. Payer, H. Schandl, V. Winiwarter and H. Zangerl- Weisz eds). Amstedam: G+B Verlag Facultas, pp. 57-66.

Fischer-Kowalski, Marina (1998). Society's Metabolism. The Intellectual History of Materials Flow Analysis, Part I, 1860-1970. Journal of Industrial Ecology, 2:1, pp. 61-78.

Fischer-Kowalski, M. and W. Hüttler (1999). Society's Metabolism. The Intellectual History of Materials Flow Analysis, Part II, 1970-1998. Journal of Industrial Ecology, 2:4, pp. 107-36.

Fischer-Kowalski, M. and C. Amann (2001). Beyond IPAT and Kuznets Curves:Globalization as a Vital Factor in Analysing the Environmental Impact of Socio- Economic Metabolism. Population and Environment, 23:1, pp. 7-47.

Fröhlich, M., F. Hinterberger, N. Rosinski, and A. Wiek (2000). Wieviel wiegt Nachhaltigkeit? Möglichkeiten und Grenzen einer Beachtung qualitativer Aspekte im MIPS-Konzept. Wuppertal Paper (Entwurf). Wuppertal: Wuppertal Institut für Klima, Umwelt, Energie.

Georgescu-Roegen, N. (1976). Energy and Economic Myths: Institutional and analytical economic essays. New York, Pergamon.

Gutes Maite, C. (1996). "Commentary: The Concept of Weak Sustainability." Ecological Economics 17 (1996): 147-156.

Gerhold, S. and B. Petrovic (2000). Materialflußrechnung: Bilanzen 1997 und abgeleitete Indikatoren 1960-1997. Statistische Nachrichten, 4:2000, pp. 298-305.

Giljum, S. (2002). Trade, material flows and economic development in the South: the example of Chile. Paper submitted to the Journal of Industrial Ecology.

Giljum, S. and K. Hubacek (2001). International trade, material flows and land use: developing a physical trade balance for the European Union. Interim Report. IR-01-059. Laxenburg: International Institute for Applied Systems Analysis (IIASA).

Gorree, M., R. Kleijn and E. van der Voet (2000). Materiaalstromen door Amsterdam. Amsterdam, CML.

Hammer (2002). Material Flows and Economic Development - Material Flow Analysis of the Hungarian Economy. Master thesis at the Institute for Anthropology, University of Vienna.

Hammer, M., and K. Hubacek (2002). Material Flows and Economic Development - Material Flow Analysis of the Hungarian Economy. Interim Report No. IR-02-057. International Institute for Applied Systems Analysis, Laxenburg.

Hendriks, C., Obernosterer, R., Müller, D., Kytzia, S., Baccini, P., and P. Brunner (2000). Material flow analysis: a tool to support environmental policy decision making. Two case studies on the city of Vienna and the Swiss lowlands. Local Environment, 5, pp. 311-328.

Hinterberger, F. (2000). Eco-efficiency of regions. How to improve competitiveness and create jobs by reducing environmental pressure. With contributions from: K.

Bamberger, C. Manstein, P. Schepelmann, F. Schneider and J. Spangenberg. Commissioned by the government of Carinthia, supportet by the Austrian ministry of agriculture, forestry, environment and water. Vienna.

Hinterberger, F., F. Luks, and M. Stewen (1996). Ökologische Wirtschaftspolitik. Zwischen Ökodiktatur und Umweltkatastrophe. Berlin: Birkhäuser.

Hinterberger, F., S. Renn, and H. Schütz (1999). Arbeit - Wirtschaft - Umwelt. Wuppertal Papers. 89. Wuppertal: Wuppertal Institut für Klima, Umwelt, Energie.

Hinterberger, F. and F. Schmidt-Bleek (1999). Dematerialisation, MIPS and Factor 10. Physical Sustainability Indicators as a Social Device. Ecological Economics, 29, pp. 53-56.

Hinterberger, F. and F. Schneider (2001). Eco-Efficiency of Regions: Toward Reducing Total Material Input. 7th European Roundtable on Cleaner Production, Lund (Sweden).

Hubacek, K. and S. Giljum (2003). Applying physical input-output analysis to estimate land appropriation (ecological footprints) for international trade activities. Ecological Economics, 44, pp. 137-151.

Hubacek, K. and L. Sun (2001). A scenario analysis of China´s land use and land cover change: incorporating biophysical information into input-output modelling. Structural Change and Economic Dynamics, 12, 367-397.

IHOBE (2002). Total Material Requirement of the Basque Country, IHOBE.

Isacsson, A., Jonsson, K., Linder, I., Palm, V., and Wadeskog, A. (2000). Material Flow Accounts, DMI and DMC for Sweden 1987-1997, Eurostat Working Papers, No. 2/2000/B/2. Statistics Sweden.

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

Juutinen, A. and I. Mäenpää (1999). Time Series for the Total Material Requirement of the Finnish Economy. Summary. Interim Report 15 August 1999. Oulu: University of Oulu. Thule Institute.

Kippenberger, C. (1999). Stoffmengenflüsse und Energiebedarf bei der Gewinnung ausgewählter ineralischer Rohstoffe. Auswertende Zusammenfassung, No. Heft SH 10. Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover.

Kleijn, R., Bringezu, S., Fischer-Kowalski, M., and Palm, V. (1999). Ecologizing Societal Metabolism. Designing Scenarios for Sustainable Materials Management, CML Report 148, Leiden.

Luck, M.A., G. D. Jenerette, J. Wu and N.B. Grimm (2001). The Urban Funnel Model and the Spatially Heterogenous Ecological Footprint. In Ecosystems, 4, 782-796.

Luks, F. (2000). Postmoderne Umweltpolitik? Sustainable Development, Steady-State und die "Entmachtung der Ökonomik". Marburg: Metropolis.

Luks, F., and M. Hammer (2003). Material Flow Analysis, Discourse Analysis and the Rhetorics of (Ecological) Economics. NEDS Working Paper # 1. Hamburg

Machado, J. A. (2001). Material Flow Analysis in Brazil. Internal Report (unpublished). Manaus.

Mäenpää, I. and A. Juutinen (2000). Explaining the Material Intensity in the Dynamics of Economic Growth: The Case of Finland. ISEE Conference, 5-8 July 2000, Canberra, Australia.

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 (2000). The Weight of Nations. Material Outflows from Industrial Economies. Washington D.C.: World Resources Institute.

McEvoy D., J. Ravetz and J. Handley (2001). 4 sight: Resource flow audit for sustainability. A framework strategy for the North West, Centre for Urban and Regional Ecology, University of Manchester.

Meadows, D. et. al. (1992). Beyond the Limits, Post Mills, Vermont: Chelsea Green Publishing Company.

Ministry of the Environment (1999). Material Flow Accounting as a Measure of the Total Consumption of Natural Resources. The Finnish Environment 287. Helsinki.

Moriguchi, Y. (2001). Rapid Socio-Economic Transition and Material Flows in Japan. Population and Environment, 23:1, pp. 105-15.

Mündl, A., H. Schütz, W. Stodulski, J. Sleszynski, and M. J. Welfens (1999). Sustainable Development by Dematerialisation in Production and Consumption. Strategy for the New Environmental Policy in Poland. Warsaw: Institute for Sustainable Development.

Muukkonen, J. (2000). Material Flow Accounts. TMR, DMI and Material Balances, Finland 1980-1997. Eurostat Working Papers 2/2000/B/1. Eurostat.

Obernosterer, R., Brunner, P., Daxbeck, H., Gagan, T., Glenck, E., Hendriks, C., Morf, L., Paumann, R., and Reiner, I. (1998). Materials accounting as a tool for decision making in environmental policy. Urban metabolism of Vienna, Technical University of Vienna, Vienna.

Odum H.T. (1984). Systems Ecology: An Introduction. Wiley, New York, pp.644.Odum H.T., 2000. The Prosperous Way Down". The University Press of Colorado, Boulder, Colorado.

Odum H.T. (1996). Environmental Accounting: Emergy and Environmental Decision Making. John Wiley & Sons, N.Y.

OECD (2000). Working Group on the State of the Environment 30th Meeting. Special Session on Material Flow Accounting. History and Overview. Room Document - MFA 1. Agenda Item 2a. Paris: Organisation for Economic Co-operation and Development.

Ravetz, J. (2000) Integrated assessment for sustainability appraisal in cities and regions, Environmental Impact Assessment Review, Vol. 20, pp. 31-64.

Rees, W. and M. Wackernagel (1992). Ecological Footprints and Appropriated Carrying Capacity: Measuring the Natural Capital Requirements of the Human Economy. In Second Meeting of the International Society for Ecological Economics, Stockholm.

Rees, W. and M. Wackernagel (1996). Urban Ecological Footprints: Why Cities cannot be Sustainable – and why they are a Key to Sustainability. In: Environmental Impact Assessment Review 16, 223-248.

Reijnders, L. (1998). The Factor X Debate: Setting Targets for Eco-Efficiency. Journal of Industrial Ecology 2 (1), 13-22.

Rodrigues, J., Giljum, S., and F. Schneider (forthcoming). The material requirements of economic and monetary flows. Linking micro and macro approaches in material flow analysis, SERI Working Paper.

Scasny, M., Kovanda, J., Hak, T. (forthcoming). Material flow accounts, balances and derived indicators the Czech Republic during the 1990s: results and recommendations for methodological improvements. Ecological Economics.

Schandl, H., C. M. Grünbühel, H. Haberl, and H. Weisz (2002). Handbook of Physical Accounting. Measuring Biophysical Dimensions of Socio-economic activities. MFA-EFA-HANPP. Version 1.0. Social Ecology Working Paper. 67. Vienna: Institute for Interdisciplinary Studies of Austrian Universities (IFF).

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 for the Period of 1937-1997. ISER Working Papers. 2000-3. Colchester: University of Essex.

Schandl, H. and N. Schulz (2002). Changes in the United Kingdom's Natural Relations in Terms of Society's Metabolism and Land-use from 1850 to the present day. Ecological Economics, 41, pp. 203-21.

Schandl, H., H. Weisz, and B. Petrovic (2000). Materialflussrechnung für Österreich 1960 bis 1997. Statistische Nachrichten, 2:2000, pp. 128-37.

Schmidt-Bleek, F. (1994). Wieviel Umwelt braucht der Mensch? MIPS - Das Maß für ökologisches Wirtschaften. Berlin, Basel, Boston: Birkäuser.

Schütz, H. (1999). Technical Details of NMFA (Inputside) for Germany. Wuppertal Institute, Wuppertal.

Schütz, H. and M.J. Welfens (2000). Sustainable Development by Dematerialisation in Production and Consumption - Strategy for the New Environmental Policy in Poland. Wuppertal Papers No. 103. Wuppertal: Wuppertal Institut für Klima, Umwelt, Energie.

Sheerin, C. (2002). UK Material Flow Accounting. Economic Trends, 583, pp. 53-61. Simonis, Udo E. (1994). Industrial Restructuring in Industrial Countries. In Industrial Metabolism. Restructuring for Sustainable Development. Ayres, R. U. and U.E. Simonis (eds). Tokyo, New York, Paris: United Nations University Press.

Singh, S.J., C.M. Grünbühel, H. Schandl, and N. Schulz (2001). Social Metabolism and Labour in a Local Context: Changing Environmental Relations on Trinket Island. In: Population and Environment Vol. 23, No. 1, 71-104.

Spangenberg, J. and O. Bonnoit (1998). Sustainability Indicators - A Compass on the Road towards Sustainability, Rep. No. 81, February 1998, Wuppertal.

Spangenberg, J.H., A. Femia, F. Hinterberger, and H. Schütz (1999). Material Flow-based Indicators in Environmental Reporting. Environmental Issues Series. No 14. Copenhagen: European Environment Agency (EEA).

Stahmer, C., M. Kuhn, and N. Braun (1997). Physische Input-Output-Tabellen 1990. Wiesbaden: Statistisches Bundesamt.

Statistisches Bundesamt (2001a). A Physical Input-Output Table for Germany 1995, Statistisches Bundesamt Deutschland, Wiesbaden.

Statistisches Bundesamt (2001b). Bodenfläche nach Art der tatsächlichen Nutzung. Statistisches Bundesamt, Wiesbaden.

Steurer, A. (1992). Stoffstrombilanz Österreich, 1988, Schriftenreihe Soziale Ökologie, No. Band 26. IFF/Abteilung Soziale Ökologie.

Ulgiati S. (2002). Energy Flows in ecology and in the economy. Encyclopedia of Physical Science and Technology, Third Edition, Vol. 5, pp.441-460. Academy Press, New York.

Ulgiati S., Bargigli S., Raugei M., and Tabacco A.M. (2002). Analisi Energetica e Valutazione di Impatto Ambientale della Produzione ed Uso di Celle a Combustibile a Carbonati Fusi. Report to ENEA (in Italian), Contract 1033/TEA.

United Nations (1993). Handbook of National Accounting: Integrated Environmental and Economic Accounting. Studies in Methods United Nations, New York.

United Nations (2000a). Energy Statistics Yearbook 1997. New York: United Nations. Department of Economic and Social Affairs. Statistics Division.

United Nations (2000b). Statistical Yearbook 1997. New York: United Nations. Department of Economic and Social Affairs. Statistics Division.

United Nations (2001). System of Environmental and Economic Accounting. SEEA 2000 Revision United Nations, New York.

van den Bergh, J.C.J.M. and H. Verbruggen (1999) Spatial sustainability, trade and indicators: an evaluation of the 'ecological footprint'. Ecological Economics, 29, 61-72.

Wackernagel, M., Onisto, L., Bello, P., Linares, A.C., Falfan, I.S.L., Garcia, J.M., Guerrero, A.I.S., and Guerrero, M.G.S. (1999) National Natural Capital Accounting with the Ecological Footprint Concept. Ecological Economics, 29, 375-390.

Wackernagel, M. and W. Rees (1996) Our Ecological Footprint: Reducing Human Impact on the Earth New Society Publishers, Gabriola Island, British Columbia.

WCED (World Commission on Environment and Development) (1987). Our Common Future. Oxford University Press, Oxford.

Weterings, R. and H. Opschoor (1992). The Ecocapacity as a Challenge to Technological Development. RMNO. 74a. Rijswijk.

Wolf, M., B. Petrovic, and H. Payer (1998). Materialflußrechnung Österreich 1996. Statistische Nachrichten 11/1998, pp. 939-48.

Wolman, A. (1965). The Metabolism of Cities. In: Scientific American, Vol. 213, no. 3, 178-193.

WWF, UNEP, Redefining Progress, and Centre for Sustainability Studies (2002). Living Planet Report 2002. WWF, Gland, Switzerland.

In der Reihe *NEDS Working Papers* werden Beiträge aus dem Kontext des Forschungsprojekts „Nachhaltige Entwicklung zwischen Durchsatz und Symbolik. Leitbilder der ökonomischen Konstruktion ökologischer Wirklichkeit in europäischen Regionen" veröffentlicht. Die NEDS Working Papers dienen dazu, vorläufige Ergebnisse unserer Arbeitsprozesse in die wissenschaftliche und gesellschaftliche Diskussion einzubringen. Sie sind im Regelfall projektintern diskutiert worden, spiegeln aber lediglich Zwischenergebnisse wider. Die Beiträge geben die Auffassungen der AutorInnen wieder, nicht notwendigerweise diejenigen des Gesamtprojekts. Kritische Kommentare zu den hier veröffentlichten Texten sind ausdrücklich erwünscht.

In the series *NEDS Working Papers* we publish contributions arising from the context of the research project "Sustainable development between throughput and symbolism. Visions of the economic construction of ecological reality in European regions". NEDS working papers serve to present intermediate results of our work to the scientific and general public. Even though the texts have usually been discussed within the project, they reflect preliminary results. The opinions expressed are those of the authors, not necessarily those of the project as a whole. Critical comments on the published texts are invited and appreciated.

Die bisher erschienenen NEDS Working Papers können per E-Mail bestellt werden:
NEDS Working Papers can be ordered by e-mail:
Gorrissen-SalazarS@hwp-hamburg.de

Luks, Fred / Höhler, Sabine / Bauriedl, Sybille / Schindler, Delia / Winkler, Matthias: Nachhaltige Entwicklung zwischen Durchsatz und Symbolik: Analyse wissenschaftlicher Evidenzproduktion und regionale Bezüge. NEDS Working Paper # 3 (05/2003).

Hammer, Mark / Giljum, Stefan / Bargigli, Silvia / Hinterberger, Friedrich: Material Flow Analysis on the Regional Level: Questions, Problems, Solutions. NEDS Working Paper # 2 (04/2003).

Luks, Fred / Hammer, Mark: Material Flow Analysis, Discourse Analysis and the Rhetorics of (Ecological) Economics. NEDS Working Paper # 1 (03/2003).