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IIASA Interim Report
November 2001

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Interim Report **IR-01-059**

International trade, material flows and land use: developing a physical trade balance for the European Union

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Land Use and Land Cover Change (LUC)

November 2001

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Abbreviations

Coordination of Information on the Environment	CORINE
Ecological footprint	EF
European Union	EU
European Union before 1995 (12 member countries)	EU-12
European Union after 1995 (15 member countries)	EU-15
Food and Agricultural Organisation of the United Nations	FAO
Material flow accounting and analysis	MFA
Monetary input-output table	MIOT
Physical input-output table	PIOT
Physical trade balance	PTB
Statistical Office of the European Union	EUROSTAT
Sustainable process index	SPI
System of National Accounts	SNA
System of Integrated Environmental and Economic Accounting	SEEA
United Nations (Organisation)	UN(O)
United Nations Conference on Trade and Development	UNCTAD

Abstract

The environmental impacts of globalisation and further liberalisation of international trade today are on the top of the policy agenda in a number of international organisations. While the trade relations between two countries or regions may be balanced in monetary terms, they may at the same time be characterised by a substantial inequality with regard to the flows of natural resources. Thus some regions may systematically exploit the ecological capacity of other regions by importing resource intensive products and exporting wastes.

In the last 10 to 15 years there has been extensive research on material flows mainly on the national level. However, empirical studies on material flows in international trade so far are very limited. In the last few years some studies have been presented, which link material flow accounting and input-output analysis (based on monetary input-output tables) for the calculation of indirect material flows through intermediate production. This procedure has also been applied for calculating direct and indirect land appropriation. The compilation of the first physical input-output tables for some western European countries in the 1990s opened new possibilities for linking physical accounting and input-output analysis. Physical input-output analysis has so far been applied only for selected materials in single-country studies. It has neither been used for assessments of material flows in international trade nor for any land-related studies.

In this report first steps towards the elaboration of a physical trade balance for the EU-15 are undertaken. Concerning the methodology of physical input-output analysis, three alternative approaches will be presented and discussed. In the empirical part, a physical trade balance for direct material flows of the EU is presented, disaggregated by world regions as well as product and material groups. In order to assess indirect resource requirements induced by imports and exports, a physical input-output model for the EU-15 is developed, based on physical input-output tables already published. This model then is used for assessing the overall resource requirements for the production of exports from EU-15 to the rest of the world. By applying physical input-output analysis, direct and indirect resource requirements will be calculated concerning both material flows and land appropriation.

Acknowledgements

We want to thank Aviott John and Eduard Löser from IIASA library for their engagement in providing literature and data for this report. We are also grateful to Günther Fischer, Fritz Hinterberger, Mark Hammer and Faye Dutchin for very helpful discussions and comments. Finally, we would like to thank Helmut Schütz from the Wuppertal Institute for providing essential material flow data for the European Union.

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International trade, material flows and land use: developing a physical trade balance for the European Union

Stefan Giljum and Klaus Hubacek

1 Introduction

1.1 Trade, environment and sustainable development

The environmental impacts of globalisation and further liberalisation of international trade today are on the top of the policy agenda in a number of international organisations (e.g. OECD 1997, 2000a; UNEP 1999; WTO 1999). One main characteristic of the globalisation process is the restructuring of the various stages of production chains on an international scale. The sectoral shift towards so-called service economies in developed countries has been and still is accompanied by increased outsourcing of manufacturing industry mainly to so-called "developing" countries (Altvater and Mahnkopf 1997/1996). The declining material use per unit GDP in countries of the western hemisphere (e.g. Adriaanse *et al.* 1997) does not automatically lead to lower overall consumption of material intensive goods, but results to some extent from higher imports of these products from "developing" countries (Muradian and Martinez-Alier 2001).

While the trade relations between two countries or regions may be balanced in monetary terms, they may at the same time be characterised by a substantial inequality with regard to the flows of natural resources (Proops *et al.* 1999). Thus some regions may systematically drain off ecological capacity from other regions by importing resource intensive products and exporting wastes (Andersson and Lindroth 2001). By doing so, a shift of environmental burden and a redistribution of environmental costs to the detriment of (mainly) "developing" countries can be observed (OECD 1993; Sachs 1999). The externalisation of environmental burden through international trade might be an effective strategy for industrialised countries to maintain high environmental quality within their own borders, while externalising the negative ecological consequences of their production and consumption processes to other parts of the world.

Taking into consideration the economic, social *and* environmental interrelations between all regions of the world has also been the central essence of the concept of sustainable development since its first introduction (World Commission on Environment and Development 1987). Sustainability concepts like the concept of environmental space (Spangenberg 1995; Weterings and Opschoor 1992) explicitly stress the global equity principle, demanding a fair distribution of resource use between the inhabitants of the different world regions and the maintenance of an intact global environment as the base for prospering economic development of future generations. Concerning sustainability in Europe, the European Council recently agreed on a European Strategy for Sustainable Development (European Commission 2001). Therein the European Council states explicitly that production and consumption activities within the EU borders increase the pressure on the environment in other parts of the world (particularly in so-called developing countries) by imports of natural resources and exports of waste. Thus the linkages between trade and environment have to be taken into account in order to guarantee that the goal of achieving sustainability within Europe fosters sustainability on a global scale at the same time.

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 sustainability (Schmidt-Bleek 1994). Resource-flow based indicators help monitoring progress towards this goal.

Material flow analysis (MFA) and land use accounting are regarded as the most appropriate tools 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. An evaluation of the economic activities of one country within a global context can only be carried out by extending the domestic material flow accounts and including indirect flows associated to imports and exports (Bringezu *et al.* 1994, 1998).

1.2 Main research questions and the structure of the report

In the last 10 to 15 years there has been extensive research on material flows mainly on the national level (see Fischer-Kowalski and Hüttler (1999) for a recent summary). However, empirical studies on material flows in international trade so far are very limited. In the last few years some studies have been presented, which link material flow accounting and input-output analysis (based on monetary input-output tables) for the calculation of indirect material flows through intermediate production (e.g. Hinterberger *et al.* 1998; Moll *et al.* 1998). This procedure has also been applied for calculating direct and indirect land appropriation (e.g. Ferng 2001; Hubacek and Sun 2000). The compilation of the first physical input-output tables for some countries of the EU (Germany, Denmark, Italy, and Finland) enables the derivation of multipliers based on the physical structure of the economy. Physical input-output analysis has so far been applied only for selected materials in one country study (Konijn *et al.* 1997). It has neither been used for assessments of material flows in international trade nor for any land related studies.

In this report we will make first steps towards the elaboration of a physical trade balance for the EU-15. Concerning the physical trade balance for direct material flows, we will present a time series of physical data for imports and exports of the EU, disaggregated by world regions as well as product and material groups. In order to assess indirect resource requirements induced by imports and exports, we will develop a physical input-output model for the EU-15, based on physical input-output tables already published. We will then use this model for assessing the overall resource requirements for the production of exports from the EU-15. By applying physical input-output analysis, direct and indirect resource requirements will be calculated concerning both material flows and land appropriation.

The following main research questions shall be addressed:

- What are the overall resource requirements for imports to the EU and export production in the EU, in terms of both material flows and land appropriation?
- Which methodology is suitable for this kind of assessment?
- Which differences between the categories of material flows and land use can be observed?
- What is the structure of imports to the EU-15 and exports of the EU-15, disaggregated by world regions and product/material groups?
- Which world regions are characterised by capital-intensive trade and where is resource intensive trade located?
- Are there divergent global trade patterns concerning the flows of money on the one hand and resource flows on the other hand?
- What are the likely environmental consequences (in terms of resource consumption) of further enhancement of international trade activities?
- What are possible contributions to the debate on “environmentally sustainable trade”?

The report is divided into two main parts. The methodological part comprises Section 2 to 5. First, Section 2 introduces the basic methodology of material flow accounting and analysis (MFA) and presents the concept of the physical trade balance. In Section 3 methodological foundations for the input-output analysis will be given and the differences between monetary and physical input-output tables explained. Four models of input-output analysis for international trade assessments will be discussed in Section 4. Section 5 focuses on land use and presents approaches for linking land appropriation to physical input-output models. With regard to the empirical part of this report, Section 6 presents a simple trade balance of direct material flows for the EU-12/15 region in a time series of 1989-1999. In Section 7 we will develop a physical input-output model for the EU-15 and calculate the direct and indirect material requirements of exports from the EU-15 for the year 1990. In Section 8 we will then apply the physical input-output model to assess the land intensity of international trade. Finally in Section 9, we will discuss strengths and shortcomings of the chosen approaches and examine some implications of the empirical study.

PART 1: METHODOLOGY

Among the representatives of ecological economics there is general agreement that it is not sufficient to quantify the relations between the natural and the socio-economic subsystem only in monetary terms. Ecological economists claim that pure economic analyses based solely on monetary evaluations and market decisions are "turning a blind eye on sustainability" (Rees and Wackernagel 1999, p. 47).

According to their opinion, a number of shortcomings of these pure monetary approaches can be listed (e.g. Faucheux and O'Connor 1998).

1. Monetary evaluation reduces the manifold services of nature (supply of natural resources, sink for residuals, conservation of biodiversity etc.) to a single monetary unit. Thus monetary evaluation cannot adequately take this natural complexity into account[1].
2. Furthermore no markets do exist for a number of life maintaining functions of nature, like climate stability, maintenance of the ozone layer or water and nutrient cycles. As these environmental functions are available without directly causing costs for the economy, pure financial accounting systems are not capable for adequately reflecting present or future environmental problems created by the use of these functions.
3. Market prices reflect opportunity costs and therefore do not include issues like intergenerational distribution or irreversibility.
4. Monetary indicators cover only a small fraction of natural capital losses (e.g. Bartelmus and Vesper 2000). Rising marginal costs of resources, which become scarce, can lead to constant market prices, although the resource basis is physically shrinking.
5. Market prices are characterised by permanent fluctuations. Monetary values therefore are not adequate for long-term planning. Short-term economic activities stand in sharp contrast to the long-term cycles in ecosystems.

For a comprehensive description of the economy-environment relationship and an evaluation of development processes with the goal of a sustainable development, approaches of physical accounting are irreplaceable (Rees 1999).

The demand for an extension of monetary accounting systems by physical accounts has been met by the United Nations, which presented a first draft for a handbook on integrated environmental and economic accounting, called „System of Environmental and Economic Accounts (SEEA)" at the UN Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992 (United Nations 1992), first complete version (United Nations 1993). Thus the UNO initiated a process of setting up satellite accounts, which are extending the framework of the conventional System of National Accounts (SNA) and able to incorporate a number of environmental problems. SEEA can therefore be described as a „…coherent, comprehensive accounting framework which allows the

[1] The same reductionism is often reproached the supporters of physical accounting, when aggregating all economic processes in a single *physical* unit (e.g. tons or joule) (see e.g. Gawel 1998).

contribution of the environment to the economy and the impact of the economy on the environment to be measured objectively and consistently“ (United Nations 2001, p. 1-1).

The systematic integration of information about the economy *and* the environment within a standardised framework is the main precondition for comprehensive analyses of the economy-environment inter-linkages and allows to predict the likely economic effects of environmental policy strategies on the one hand and of economic policy upon the environment on the other hand (Stahmer 1993).

The full set of physical flow accounts within SEEA comprises energy accounts as well as economy-wide material flow accounts (MFA) and a physical input-output-table (PIOT). Economy-wide material flow analysis is the standard methodology for assessing the size and structure of the biophysical metabolism of societies, calculating resources that cross the environment-economy border on the input side (raw materials, water, air) and, after having been processed and used within the economic system, leave the economy as waste. The economy itself is regarded as a black box. A physical input output table extends the MFA concept by not only accounting for the resource flows between nature and economy but also between the different sectors and actors within the economy. Thus a PIOT provides the most comprehensive information on the physical interrelations between economy and nature. Concerning the analysis of international trade relations, the physical trade balance (PTB) is explicitly mentioned as the most important physical indicator.

2 Material flow accounting and analysis (MFA)

2.1 Historical development of MFA[2]

Material flow analysis builds on earlier concepts of material and energy balancing, as presented e.g. by Ayres (1978; Ayres and Kneese 1968). 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 methodologies. 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, which are the state of the art in MFA.

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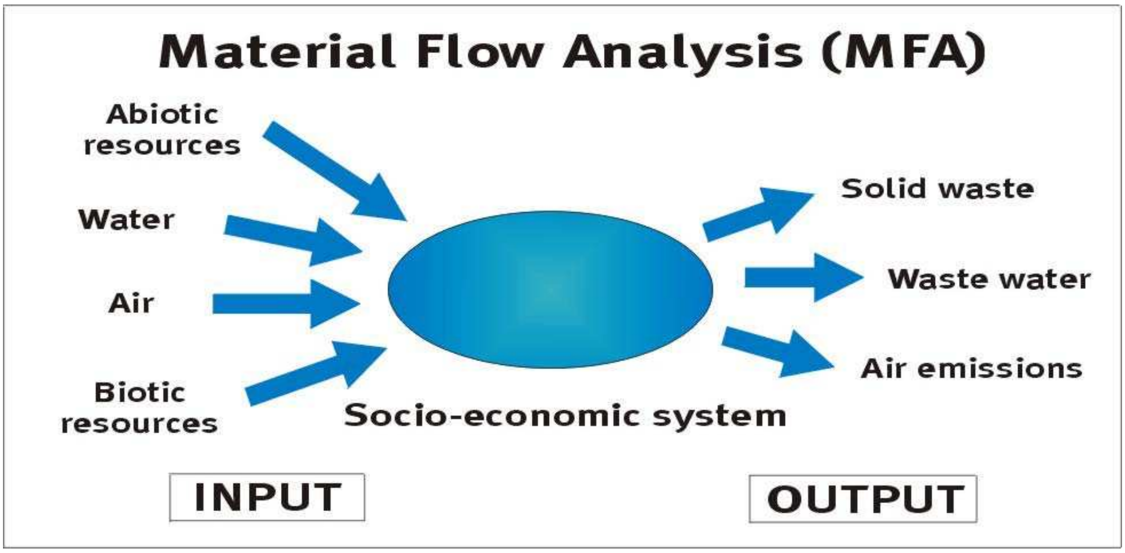
[2] For a comprehensive review on the history of the development of MFA see Fischer-Kowalski (1998b); Fischer-Kowalski and Hüttler (1999).

In an international working group on MFA, consisting of members of all important research teams in this field, an international standard for economy-wide material flow accounting has been agreed upon and published by the European Statistical Office (EUROSTAT 2001). This standard methodology and the set of derived resource indicators are presented in the following section.

2.2 Methodological foundations

The principle concept underlying the economy-wide MFA approach is a simple model of the interrelation between the economy and the environment, in which the economy is an embedded subsystem of the environment and – similar to living beings – dependent on a constant throughput of materials and energy. Raw materials, water and air are extracted from the natural system as inputs, then transformed into products and finally re-transferred to the natural system as outputs (waste) (see Figure 1). To highlight the similarity to natural metabolic processes, the terms “industrial” (Ayres 1989) or “societal” (Fischer-Kowalski 1998a) metabolism have been introduced.

Figure 1: The basic model of material flow accounting and analysis (MFA)



According to the first law of thermodynamics (the law of the conservation of mass), total inputs must by definition equal total outputs plus net accumulation of materials in the system. This material balance principle holds true for the economy as a whole as well as for any sub-system (an economic sector, a company, a household) (EUROSTAT 2001).

For a consistent compilation of an economy-wide material flow account, it is necessary to define exactly, where the boundary between the economic and the environmental system is to be set, as only resources crossing this border will be accounted for. As described in the System of Environmental and Economic Accounts (SEEA) (United Nations 1993, 2001), the economic sphere is defined in close relation to the flows covered by the conventional System of National Accounts (SNA). 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. On the other hand, the environmental sphere comprises all resources other than products traded within the market system.

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

2.3 Categories of material flows

2.3.1 According to origin and destination of the flows

Before outlining a comprehensive material balance scheme on the national level, we have to explain the differences between the different types of material flows. In its methodological guide EUROSTAT (2001) advises to distinguish the various types of material flows according to the following scheme[3]:

1. ***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 Section 2.8.

2. ***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.

3. ***Domestic versus Rest of the World (ROW)***

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

Combining these three dimensions to one table shows the 5 categories of material inputs relevant for economy-wide MFA (Table 1):

[3] For the categories of unused and indirect material flows, the terms „ecological rucksacks“ (Schmidt-Bleek 1994) or „hidden flows“ (Adriaanse *et al.* 1997) are also used in the literature.

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

Weight	Economic treatment	Origin	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	Used	Rest of the world	Indirect input flows associated to imports
Indirect	Unused	Rest of the world	

Source: modified from EUROSTAT 2001

2.3.2 According to different groups of materials

In its methodological guide, EUROSTAT provided a standard classification of materials, which should be applied in the preparation of material flow accounts on the national level. All physical material inputs of a socio-economic system can be attributed to three subgroups:

- Solid materials,
- Water and
- Air.

As water flows in most cases exceed all other material inputs by a factor of 10 or more (especially if water for cooling is also accounted for, 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.

A standard material flow account (see also next section) focuses on flows of solid materials. This group is further classified into 3 main subgroups:

- Minerals (metal ores and non-metallic minerals like stones, clays, etc.)
- Fossil energy carriers (coal, oil, gas)
- Biomass (from agriculture, forestry and fishery).

A very detailed list of materials can be found in the annex of the EUROSTAT manual (EUROSTAT 2001).

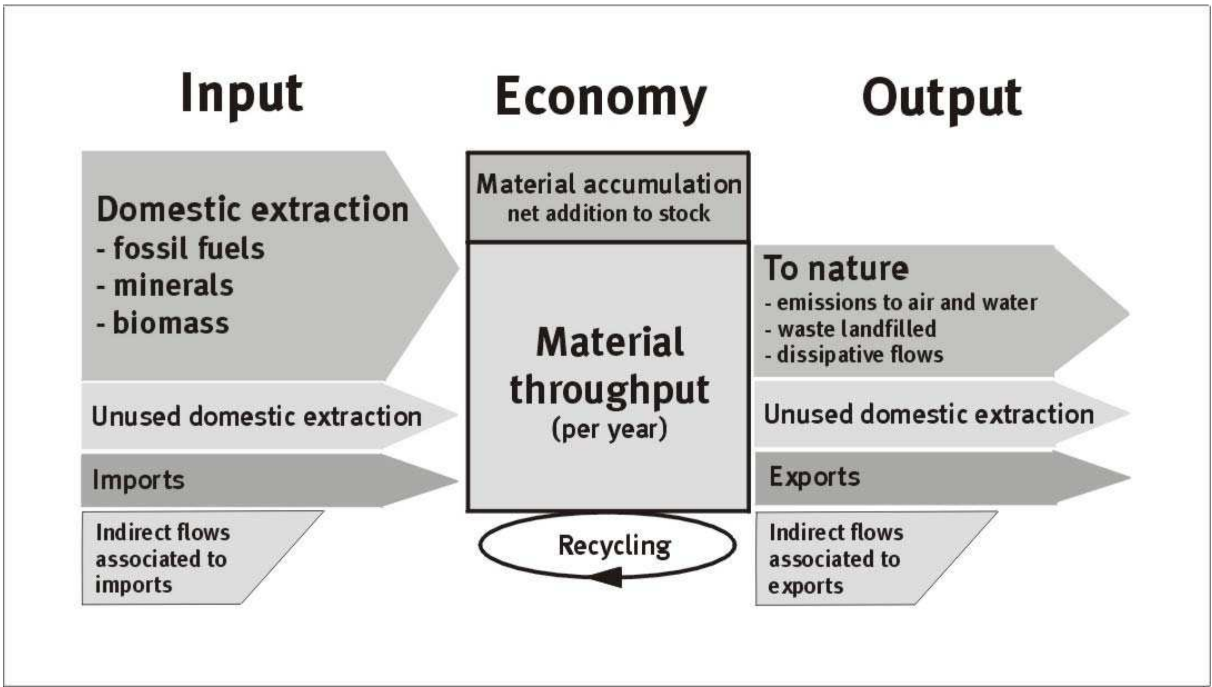
2.4 The material stock

From the viewpoint of physical accounting, the accumulation of a large physical stock is one main characteristic of modern industrialised societies. Stocks in the MFA framework are mainly made of man-made assets, comprising infrastructure and buildings on the one hand and durable consumption goods (like cars, household equipment) and investment goods (machinery) on the other hand. Forests and agricultural plants are considered part of the environmental system and are therefore not included in the physical stock, whereas harvests of timber and crops are accounted as inputs to the socio-economic system. EUROSTAT (2001) suggests to treat waste deposited in controlled landfills as outputs of the economy to the environment rather than a physical stock.

2.5 A general scheme for economy-wide MFA

After having explained the various categories of material flows and the importance of the physical stock, a general balance scheme including all relevant input and output flows can be presented (Figure 2). The material balance reveals the composition of the physical metabolism of an economy and shows the dependency on imports, the physical growth of its infrastructure as well as the amount of materials released back to nature.

Figure 2: General scheme for economy-wide MFA, excluding water and air flows



Source: EUROSTAT (2001)

Material inputs to the economic system comprise used domestic extraction of various material groups, unused domestic extraction (which does not enter the economic system), imports and indirect flows associated to imports. The material inputs are either accumulated within the socio-economic system (net addition to stock), consumed domestically within the time period of the analysis (in most cases one year) and crossing the system boundary as waste and residuals back to nature or are exported to other economies. Again, indirect flows of export production are associated to the exported goods.

2.6 Indicators derived from economy-wide MFA

Within the internationally harmonised classification systems for environmental indicators, like the pressure-state-response (PSR) framework of the OECD (1994a) or the extended Driving Forces-Pressures-State-Impact-Response (DPSIR) system of the European Union (EUROSTAT 1999), material-flow based indicators are part of the pressure indicator group. These indicators identify and describe socio-economic activities, which cause pressures on the environment. However, their ability to provide information on the actual environmental *impacts* is very limited. Thus they must be regarded as complements to other more detailed environmental data sets and indicators (like air and water emissions etc).

A large number of resource-use indicators can be derived from economy-wide material flow accounts as illustrated in Figure 2, providing a comprehensive description of the biophysical metabolism of societies. These indicators can be grouped into (a) input, (b) output and (c) consumption indicators and have been developed in international co-operations in the course of the last 5-10 years (see e.g. Adriaanse *et al.* 1997, Matthews *et al.* 2000).

The following section lists the main indicators of each indicator group and is based on the suggestions in the methodological guide, published by EUROSTAT (2001). Indicators, which so far have been most widely used in international studies, are expressed in bold letters.

Main input indicators:

- **Direct material input (DMI)** comprises all materials, which have economic values and are directly used in production and consumption activities. DMI equals the sum of domestic extraction plus imports.
- **Total material input (TMI)** is the DMI plus the unused domestic extraction.
- **Total material requirement (TMR)** includes - in addition to TMI - the indirect (used and unused) flows associated to the imports of an economy. TMR thus is the most comprehensive material input indicator, comprising all input flows illustrated in Figure 2.

Main output indicators:

- **Domestic processed output (DPO)** equals the flow „outputs to nature“ in Figure 2 and comprises all outflows of used materials from domestic or foreign origin. DPO includes emissions to air and water, wastes deposited in landfills and dissipative flows. Recycled materials are not included in the DPO indicator.
- Direct material output (DMO) is the sum of DPO plus exports and thus describes the total quantity of direct material outputs either to the domestic environment or other economies.
- **Total material output (TMO)** includes additionally to the DMO also the unused domestic extraction thus comprises all three categories of output flows shown in Figure 2.

Main consumption indicators:

- **Domestic material consumption (DMC)** measures the total quantity of materials used within an economic system, excluding indirect flows. Thus DMC is the closest equivalent to aggregate income in the conventional system of national accounts. DMC is calculated by subtracting exports from DMI.

- **Total material consumption (TMC)** includes, in addition to DMC, also the indirect flows associated to imports and exports and can only be calculated using input-output techniques. TMC equals TMR minus exports and their indirect flows.

Net addition to stock (NAS) describes the annual accumulation of materials within the economic system and thus could also be termed „physical growth of the economy". Materials forming the stock mainly consist of construction materials for new infrastructure and durable goods, such as cars and industrial machinery.

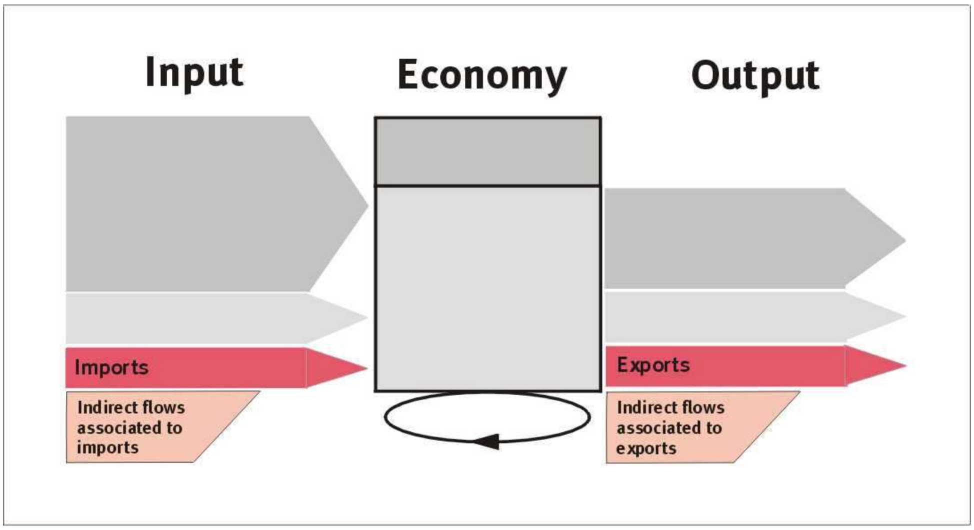
Furthermore, material flow-based indicators (input, output as well as consumption indicators) can be linked to monetary indicators like GDP per capita, thus providing information on the resource productivity (or eco-efficiency) of an economy (Spangenberg *et al.* 1998).

2.7 The physical trade balance (PTB)

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.

Referring to the general scheme of economy-wide MFA, Figure 3 shows the flows included in the physical trade balance.

Figure 3: The material flows included in a physical trade balance



Source: adapted from EUROSTAT (2001)

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.[4] In a second step, a PTB can also be calculated including indirect flows associated to imports and exports, which include both used resource flows and unused resource flows. The former refers to the intermediate products required to satisfy the export demand, the latter comprises e.g. overburden and excavation materials in the countries, where the resources are primarily extracted. In addition to a PTB covering the resource flows, a PTB can also be compiled for the calculation of appropriated land caused by import and export activities to provide a certain amount of import or export products (see the chapter on land use for more details). Finally, international balances could also be defined for the import of residuals to the domestic environment from other economies as well as from the domestic economy to the environment in the rest of the world (United Nations 2001).

Two main approaches for assessing the indirect flows associated to imports and exports can be identified: The first is based on a simplified life-cycle analysis (LCA) of products or product groups, accounting for the life-cycle wide resource inputs. The first approach shall be presented in the next section. The second uses input-output analysis on the sectoral level and will be discussed in Section 4.

2.7.1 The calculation of indirect flows with (simplified) life-cycle analysis

In its methodological guidelines, EUROSTAT (2001) suggests to mainly apply the LCA-based approach for the calculation of indirect flows associated to imports and exports. Accordingly, they consist of two main components (see also Table 1):

1. **Used Extraction**: This share is termed Raw Material Equivalents (RME) of the imported or exported products and comprises the used extraction that was needed to provide the product, less the weight of the product itself.
2. **Unused Extraction**: these are the indirect flows of unused extraction linked to the RME.

This methodology of calculating direct and indirect material flows required in the life-cycle of a product has been developed at the Wuppertal Institute in Germany[5]. The so-called Material Intensity Analysis (MAIA) (Schmidt-Bleek *et al.* 1998) is an analytical tool to assess the material inputs along the whole life-cycle, including direct material inputs and the so-called „ecological rucksack“ (Schmidt-Bleek 1992, 1994). The ecological rucksack can be defined as „the total sum of all materials which are not physically included in the economic output under consideration, but which were necessary for production, use, recycling and disposal. Thus, by definition, the ecological rucksack results from the life-cycle-wide material input (MI) minus the mass of the product itself.“ (Spangenberg *et al.* 1998, p. 15).

[4] The definition for physical trade balances thus differs from the definition of monetary trade balances in standard economics, which equals exports minus imports.

[5] In addition to product related studies, the methodology of Material Intensity Analysis (MAIA) has also been applied for the compilation of economy-wide material balances (see e.g. Bringezu 1993; Bringezu and Schütz 1995).

To use the terms proposed by EUROSTAT, the ecological rucksacks of imported products equal their indirect flows and consist of both used and unused materials – see also Table 1. The so-called „rucksack-factor“ is the ratio of the materials included in the ecological rucksack and the produced good (tons/tons).

2.7.2 Data availability and data restrictions

The Wuppertal Institute for Climate, Environment and Energy in Germany has been one of the central institutions in the development of a standardised methodology for MFA and today is one of the most important sources for material flow data. 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[6]. 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 methodology 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 methodology requires the collection of an enormous amount of data for every product under consideration. A more convenient methodology 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 will be described in Section 4.

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.

2.8 Main applications of economy-wide MFA

Economy-wide MFA is an instrument to provide aggregate information on the physical structure and the material metabolism of socio-economic systems. Due to its consistent and comprehensive data organisation, MFA can be directly affiliated to existing economic accounting schemes, like the system of national accounts (SNA) and is part of extended environmental and economic accounts, like the SEEA system of the United Nations (Weisz 2000b). In October 2000 the

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[6] The link is www.wupperinst.org/Projekte/mipsonline/download – document: MI-Werte.pdf.

OECD *Working Group on the State of the Environment* has dedicated a special session to MFA, which also reflects the increasing recognition of this concept in international organisations (OECD 2000b).

The main purposes of economy-wide material flow accounts and balances, of which some have already been mentioned in previous sections, are summarised in Box 1.

Box 1: Main purposes of economy-wide material flow accounts and balances:

- Providing insights into the structure and change over time of the physical metabolism of economies;
- Deriving a set of aggregated indicators for resource use, including for the EU-level initiative on Headline Indicators and the United Nations' initiative on Sustainable Development Indicators;
- Deriving indicators for resource productivity and eco-efficiency by relating aggregate resource use indicators to GDP and other economic and social indicators;
- Providing indicators for the material intensity of lifestyles, by relating aggregate resource use indicators to population size and other demographic indicators;
- Through their underlying data structure integrated with the national accounts contributing to organising, structuring and integrating available primary data and ensuring their consistency;
- Reacting flexibly and quickly to new policy demands (e.g., related to specific materials) through this data structure which can be adjusted easily and put to additional uses;
- Permitting analytical uses, including estimation of material flows and land use induced by imports and exports as well as decomposition analyses separating technological, structural and final demand changes.

Source: EUROSTAT (2001)

2.9 State of the art in economy-wide MFA

The number of countries, which already have compiled or currently are in the stage of compiling an economy-wide MFA according to the methodological guidelines presented above, is rapidly increasing. So far, full MFAs have been presented for the USA, Japan, Austria, Germany and the Netherlands within the framework of the two MFA projects co-ordinated by the World Resources Institute (WRI) (Adriaanse *et al.* 1997; Matthews *et al.* 2000, for calculations of material inputs for Austria see also Schandl 1998). In addition, MFAs for Italy (de Marco *et al.* 2001; Femia 2000), Denmark (Gravgaard Pedersen 2000), Finland (Muukkonen 2000), Sweden (Isacsson *et al.* 2000), the United Kingdom (Bringezu and Schütz 2001d; Schandl and Schulz 2000), France (Chabannes 1998) and China (Chen and Qiao 2001) exist. For Poland a study on the economy-wide material inputs has been presented (Mündl *et al.* 1999). The calculation of the indicator „Total Material Requirement (TMR)" for the European Union (EU-15) (Bringezu and Schütz 2001b) as well as the first material balance of the European Union (EU-15) (Bringezu and Schütz 2001a) have recently been published by the European Environmental Agency (EEA) and the European Statistical Office (EUROSTAT), respectively.

Within the framework of two research projects funded by the European Commission, MFAs for Brazil (Machado 2001), Venezuela (Castellano 2001), Thailand, Laos, Vietnam and the Philippines have been or are being compiled under methodological consultation of the Interdisciplinary Institute of Austrian Universities (IFF) / Department of Social Ecology.

3 Physical versus monetary input-output tables (PIOT vs. MIOT)

Monetary input-output tables (MIOTs) have been playing an important role in economic policy analysis and form the basis of national economic accounting systems. Today, MIOTs are available for all economically important countries of the world. In the 1990s, the statistical offices of some European countries have presented the first input-output tables in physical terms (in tons) The goal of these studies is to show the physical structure of the economy and provide scientists and policy-makers with a tool for a comprehensive analysis of the economy-environment relationship. In this section we will explain the methodological foundations of a PIOT and describe the similarities and differences with regard to the traditional monetary tables.

3.1 The basic methodological concept of a PIOT

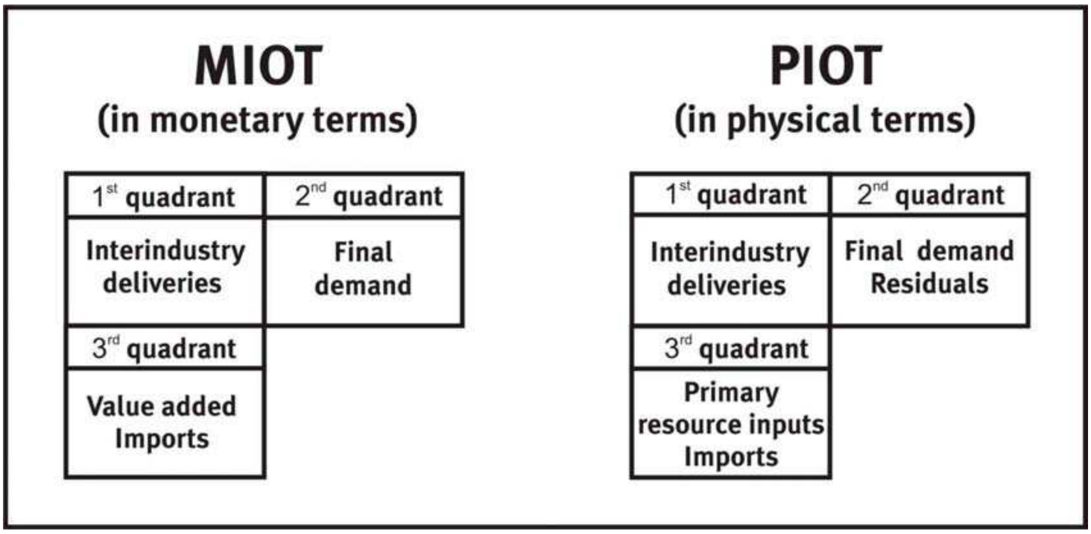
Physical input-output tables (PIOTs) provide the most comprehensive description of anthropogenic resource flows. A PIOT describes the material and energy flows between the socio-economic system and the environment (thus providing the same information as economy-wide material flow accounts described above) and in addition the flows between the different sectors within an economic system. Furthermore the net-accumulation of materials in the economic system is accounted for (EUROSTAT 2001).

The concept of PIOTs is based on the principles laid out in the „System of Integrated Environmental and Economic Accounts (SEEA)" of the United Nations (1993, 2001). Together with MFA and energy accounts it forms the methodological core of physical flow accounting systems within the SEEA framework.

Input-output analysis takes a meso-perspective to analyse the economy-environment relationship and disaggregates economic activities by sectors. Concerning the flows of intermediary products within the economy (1st quadrant), PIOTs are directly comparable to monetary input-output tables (MIOTs), but with the products of the intra-industry trade listed in physical units (tons) instead of monetary (value) terms (Figure 4).

The most wide-ranging extension of PIOTs compared to MIOTs is the inclusion of the environment as a source of raw materials on the input side (3rd quadrant) and as a sink for residuals (solid waste and emissions to air and water) on the output side of the economy (2nd quadrant) (Stahmer *et al.* 1996, 1997). Thus also the resource flows, which have no economic value, are integrated into the system of PIOTs.

Figure 4: MIOT and PIOT



It is important to note that the basic identities of monetary values on the one hand and physical terms on the other hand for each of the sectors are different (Konjin *et al.* 1995).

Whereas the identity

Total output = total input of goods and services + value added (all in monetary terms)

holds true for the MIOT, the identity concerning the total material inputs and outputs is not given, as - in the 1st quadrant - only inputs embodied in the output are accounted for. To enable a material balancing on the sectoral level, one thus has to add the waste arising form production (3rd quadrant). The material balance is then equal to

Total output = input of raw materials and intermediate products embodied in the output – waste (all in physical terms).[7]

Only the step including both resource inputs from nature and waste flows back to the environment allows a consequent application of the material balance principle in accordance with the first law of thermodynamics (the law of the conservation of mass). Thus the sum of all physical inputs and outputs has to be equal for each economic sector as well as for consumption activities of private households. Concerning the changes in fixed assets and the interrelations with the rest of the world, the accumulation of materials (net-addition to stock) and the physical trade balance give information on the net difference. By definition, physical accumulation plus physical trade surplus or deficits have to be zero (Stahmer *et al.* 1997).

[7] This difference has important consequences for the application of PIOTs in input-output analysis. Deriving an inverse multiplier matrix only from the interindustry deliveries listed in the 1st quadrant of the PIOT (as it is done with monetary multipliers), leaves aside the wastes produced in the production activities and thus does not cover the whole amount of material inputs involved. We will discuss this issue in Section 4 in greater detail.

A complete set of a PIOT comprises a number of sub-tables. The *physical input table* explains, which materials (raw materials, goods or residuals) serve as inputs to which economic activity (production, private consumption, stock changes and exchanges with the rest of the world). The outputs (products and residuals) of each of the economic activities are listed in the *physical output table*. Both physical input and output table are asymmetric, with the inputs or outputs listed on one axis and the different areas of economic activities on the other. The integration of these two sub-tables finally delivers the symmetric *physical input-output table*, in which the production branches, the consumption activities of private households, stock changes and imports/exports are the categories in both the rows and columns of the matrix. A full PIOT shows the material flows between different branches (industry by industry tables) or the materials required to transform other materials in the production process (materials by materials tables) (EUROSTAT 2001). The symmetric input-output table can again be composed of other sub-tables, which separately describe the flows of specific product groups, different materials or residuals (Gravgaard Pederson 1999; Stahmer *et al.* 1996).

A simplified version of a PIOT was developed at the *Institute for Interdisciplinary Studies of Austrian Universities (IFF)*, called „Operating Matrix form material interrelations between Economy and Environment (OMEN)“ (Weisz *et al.* 1999). OMEN combines approaches of MFA and PIOT, consisting of a highly aggregated input-output matrix with only 3–6 production branches, material accumulation and household consumption in the processing quadrant, an input quadrant, containing all physical inputs to the economy (domestic extraction plus imports) and an output quadrant showing emissions and exports. Table 2 shows an aggregated version of a symmetric PIOT with 3 production sectors.

Table 2: A simplified physical input-output table (PIOT)

	Primary production	Industry	Services	Total processed output	Private consumption	Accumulation	Emissions	Exports	Total systems output
Primary production									
Industry									
Services									
Total processed input									
Solid materials									
Water and air									
Total domestic extraction									
Imports									
Total primary inputs									

Source: adapted from Weisz (1999) and EUROSTAT (2001)

Aggregated PIOTs like OMEN are especially suitable for economy-wide or sectoral material balancing, consistency checks and the estimation of missing data in an economy-wide MFA (EUROSTAT 2001).

3.1.1 The problem of double-counting (primary and secondary materials)

As stated above, the compilation of PIOTs widely follows the procedure of the monetary tables. This methodological parallel gives rise to one central problem concerning the material balancing and the calculation of the total material inputs to the economic system.

The input quadrant (3rd quadrant) contains all *primary material inputs* to the economic system. These consist of primary domestic extraction on the one hand and imports on the other hand. These flows cross the border to the system that needs to be balanced (the national economy), either from the natural system or from other economies.

The processing quadrant (1st quadrant) of the PIOT lists the flows of the intermediate products in physical units (tons) and thus comprises all material flows within the economic system. For each of the sectors, the column shows the input of secondary or processed materials. But all products of the 1st quadrant are made of materials, which before had to be extracted from nature or being imported as primary inputs. If we assume that in general a production process (ranging from material extraction to the completion of the final product) takes less than a year and so the inputs to production are generally not taken from material stocks accumulated in the former reporting period (the last year), then total material input of the economic system as a whole equals total primary inputs. On the sectoral level, however, total material inputs are primary inputs plus secondary inputs from other sectors.

In the PIOTs published so far, this distinction is not clearly drawn. Both in the PIOT for Germany (Stahmer *et al.* 1997) and Denmark (Gravgaard Pederson 1999), primary and secondary inputs are misleadingly summed up to an aggregate, in the German PIOT called “total material use”. Whereas in the OMEN system the difference between sectoral and economy-wide material balances is most explicitly addressed (Weisz *et al.* 1999).

3.2 Main applications of PIOTs

Like economy-wide MFA, a PIOT lists the overall amount of materials flowing into and out of the socio-economic system. In addition, the sectoral disaggregation of data allows analyses of resource intensities of the different branches and highlights the correlation of material inputs, produced goods and residuals in each sector, thus providing information on the resource efficiency in production processes.

As the symmetric physical input-output table is directly comparable to the MIOT, various possibilities for parallel studies of material and monetary flows as well as the correlation of the physical and monetary data arise. Residuals, like air or water emissions can thus be directly connected to the MIOT and scenarios on the impacts of specific policy strategies can be developed and analysed (Stahmer *et al.* 1997).

Apart from the accounting of direct material inputs of economic activities, the application of input-output analysis enables the calculation of indirect material flows activated in the production chains. These indirect flows can then be attributed to categories of final demand (e.g. private consumption and exports). For a detailed description of this methodology see Section 4.

3.3 State of the art in the compilation of PIOTs

Since the compilation of a full set of a PIOT is a very work and time intensive task and requires the availability of highly disaggregated production and trade data as well as data on domestic material extractions and water use, only a few economy-wide PIOTs have been presented until today.

The first attempt to calculate a PIOT has been carried out for Austria with input-output data for the year 1983 (Kratterl and Kratena 1990; Kratena *et al.* 1992). Up to now, for Austria only preliminary results for a very aggregated PIOT exist (Weisz 2000a). Full PIOT have so far been elaborated for Germany (Stahmer *et al.* 1997) and Denmark (Gravgaard Pederson 1999), both for the year 1990. An updated German PIOT for 1995 will be published at the end of 2001 (Waldmüller 2001). Further, an aggregated PIOT for Italy for the year 1995 has been published (Nebbia 2000). Recently, first results for a PIOT have also been presented for Finland (Mäenpää and Muukkonen 2001). For the Netherlands, PIOT for selected material flows (cement, paper, steel etc.) have been compiled for 1995 (Konjin *et al.* 1995). PIOTs have also been calculated for specific sectors. For example, the Interdisciplinary Institute of Austrian Universities (IFF) presented a methodological framework, including an empirical case study of the Austrian chemical sector (Schandl and Weisz 1997).

3.4 Further considerations on methodology

The compilation of PIOTs and their application for input-output analysis is a very young research field (see also Section 4). The innovative character is also reflected by the fact that most of the existing studies have not yet been published in scientific journals, but are only available as reports or working papers from statistical offices and research institutions. The comprehensive collection of all existing literature therefore was a difficult task.

The major methodological weakness with regard to the PIOTs compiled so far is that – unlike economy-wide MFA – no standardised methodology has been agreed upon yet. This fact complicates international comparisons of existing PIOTs and has also strong implications for the development of aggregated physical input-output models.

The differences of the various PIOTs can be summarized as follows.

- First, differences occur with regard to the disaggregation level and the numbers of sectors reported. Whereas the German PIOT consists of 59 sectors, the Finish PIOT is based on 30 sectors, the Danish PIOT on 27 sectors, and the Italian PIOT on 12 sectors. In the German and Italian PIOT, the waste treatment sector, which is the sector with the highest material inputs from other sectors, is separated from the other service sectors.
- Concerning the disaggregation into material and products groups, the Danish PIOT is especially illustrative and valuable for environmental policy applications. In addition to an aggregate input-

output table it also comprises sub-tables for 10 material groups, such as agricultural products, wood and wood products, stones and building materials, metals, chemical products and plastics. The German PIOT is the only one to differentiate between several groups of primary inputs in domestic material extraction, such as energy carriers, minerals, stones, water and air. It also depicts the category of unused domestic extraction (e.g. overburden, excavation and cooling water).

- As already mentioned in the description of economy-wide MFA, it is a crucial factor, whether or not water and air are included in the tables, as these flows surpass all other (solid) materials by a factor of 10 or more. Whereas the Danish PIOT only takes into account water that is added and included in products, the German PIOT also considers waste water and water for cooling. In addition, air components (like oxygen) are calculated as inputs for combustion processes. The inclusion or exclusion of water and air leads to different physical technology matrices.[8]
- Finally, the reference years differ from study to study, with some being based on data from 1990 and others on data from 1995.

4 Input-output models and international trade analysis

As explained above, data restrictions so far limit the applicability of the LCA-based approach especially for studies of industrialised economies. The second possible approach is the application of input-output techniques, which allows the comprehensive accounting of indirect resource flows activated by imports and exports.

One of the most important applications of input-output analysis is the calculation of total input requirements for a unit of final demand. By doing so, one can assess not only the direct requirement in the production process of the analysed sector itself, but also all indirect requirements resulting from intermediate product deliveries from other sectors. Thus the total (direct and indirect) input necessary to satisfy final demand (e.g. private consumption, exports) can be determined (Miller and Blair 1985). Therefore, the recently published methodological handbook for economy-wide material flow accounting (EUROSTAT 2001) also demands for the further development of approaches for calculating indirect flows associated to imports and exports using input-output techniques.

Input-output analysis has been introduced by Leontief and carried out for monetary studies since the 1930s (Leontief 1936). Since the late 1960s input-output methods have also been used to describe and analyse the economy-environment relationship. This can be done by either extending a multiplier matrix derived from a MIOT by a resource intensity vector or by using a physical multiplier derived from a PIOT. We will present the calculation with a MIOT as well as three approaches for applying physical input-output analysis in the following section.

[8] This fact makes it especially difficult to use data from MFA for calculations with a PIOT, as in standard MFA, water is usually displayed in a separate balance.

4.1 I-O analysis based on a monetary input-output table (MIOT) (Model 1)

The framework of standard (monetary) input-output analysis can be extended in order to calculate direct and indirect resource requirements of economic sectors and to attribute resource inputs to the different categories of final demand. First attempts to link material flows to the economic input-output structure have been presented e.g. by Victor (1972). In the 1970s, the first hybrid input-output models have been introduced, which include both physical and monetary values. These models have been applied for energy studies (e.g. Bullard and Herendeen 1975) and for a number of other resources including water pollutants (Johnson and Bennet 1981), air pollutants, for example CO_2, SO_2, NO_x (Duchin and Lange 1994; Östblom 1998) or specific materials such as plastics (Duchin and Lange 1998). Recently there have been attempts to link input-output models with material flow calculations on the national level (Hinterberger *et al.* 1998; Moll *et al.* 1998). Examples of input-output analysis for the calculation of land appropriation will be given in Section 5.

The starting point for an explanation of the calculation procedure is the following illustration of a monetary input-output table (MIOT):

Table 3: Simplified monetary input-output table (MIOT) for calculation Model 1

Use / Supply	Sectors *(1,..,n)*	Final demand (*Y*)		Total output
		Domestic	Exports	
Sectors *(1,..,n)*	*Z*	*D*	*E*	*x*
Value Added	*VA*			
Imports	*I*			
Total input	*x'*			

Total inputs (x') sum up to

(1) $$x' = Z + VA + I$$

and total outputs (x) are

(2) $$x = Z + Y$$

with $Y = D + E$.

From this monetary flow tables, one can derive the matrix of (technical) input-output coefficients (A) by dividing the flow matrix of inter-industry deliveries (Z) with total output (x):

(3) $$A = Z(x)^{-1} \ .$$

The technical coefficients illustrate the share of inputs from each of the sectors necessary for the production of one unit of sectoral output. Subtracting this A matrix from the identity matrix *(I)* delivers the *(I-A)* matrix, which in its inverse form is generally referred to as the Leontief Inverse Matrix or monetary multiplier matrix (*M*).

(4) $$M = (I - A)^{-1}$$

The multiplier matrix shows, which additional intermediate products are indirectly required to fulfil the demand for one additional unit of final demand. The general equation for the static input-output model then is

(5) $$x = (I - A)^{-1} Y$$

with x: Total output,
$(I - A)^{-1}$: Leontief inverse matrix,
Y: Total final demand.

Adding biophysical data to this input-output model requires that the inputs in physical units (e.g. material, energy, or land) are expressed as a vector of direct inputs attributed to each production sectors. Dividing the physical inputs of each sector i (R_i) by the total output of each sector (x_i) leads to a vector of sectoral input coefficients (r_i). In the case of material flows, this vector shows the material input required to produce one unit of (monetary) output of this sector. In the case of land areas, this vector illustrates the appropriated land area necessary to deliver one unit of (monetary) output:

(6) $$r = R(x)^{-1}$$

with r: Vector of sectoral input coefficients,
R: Vector of physical inputs for all sectors,
x: Total output.

Substitution of total output (x) in Equation (6) by $(I - A)^{-1} Y$ results in the general formula for the extended input-output model:

(7) $$R = r(I - A)^{-1} Y \text{.}$$

The matrix of the extended Leontief inverse matrix or weighted multiplier matrix M_m is finally calculated by post-multiplying the diagonal matrix of the sectoral input coefficients ($\hat{r}$) with the Leontief inverse matrix. The diagonal matrix consists of zeros, except for the diagonal, where the sectoral input coefficients are listed. Hereby we get the multiplier matrix, weighted by physical units (e.g. material, energy, and land):

(8) $$M_m = \hat{r}(I - A)^{-1}$$

with M_m: weighted multiplier matrix,
$\hat{\mathrm{r}}$: diagonal vector of resource intensities.

In order to calculate all direct and indirect resources required to satisfy the different categories of final demand and to attribute these inputs to the different categories in a sectoral disaggregated form, one has to first calculate the sum of sectoral weighted multipliers for each of the sectors. Then this row of aggregated multipliers is post-multiplied with the diagonal matrix of final demand, ($\hat{Y}$). This can be carried out for the vector of domestic demand ($\hat{D}$) as well as for exports ($\hat{E}$). Equation (9) shows the multiplication with the export vector.

(9) $$R_e = M_m \hat{E}$$

with R_e: direct and indirect resource requirements for export production

$\hat{E}$: (monetary) diagonal vector of exports.

The resource requirement coefficient R_e finally illustrates, which absolute amount of biophysical resources (material, energy or land) was necessary as direct and indirect inputs to satisfy the export demand.

4.2 I-O Analysis based on a physical input-output table (PIOT)

The compilation of the first physical input-output tables for some western European countries in the 1990s opened new possibilities for linking physical accounting and input-output analysis. When taking a PIOT instead of using a MIOT with an additional resource intensity vector as a starting point for input-output calculations, two main advantages compared to the procedure as described above can be identified. These advantages are of particular relevance with regard to the calculation of direct and indirect *environmental* consequences of economic activities:

1. The flow tables of inter-industry deliveries (1st quadrant) for the same economy (country or region) look completely different in a MIOT as compared to a PIOT, as prices on the one hand and physical contents of the intermediate products on the other hand vary substantially between different sectors and product groups. In general it can be observed that the outputs of resource intensive sectors (agriculture, forestry, mining, energy supply) are characterised by relatively low monetary values, but high material flows. Whereas in the service sectors the monetary value per unit of output is substantially higher, but with lower resource intensity[9]. Table 4 illustrates this tendency showing the 1st quadrant of aggregate input-output tables for Germany in 1990.

[9] This holds true for most of the service sectors. An exception to this general rule is the waste treatment sector, which receives huge amounts of resources (waste water, solid waste) as inputs from other sectors and, as a consequence, has also large output flows of treated waste back to the nature (Stahmer et al. 1997). Illustrating the tendency of lower resource use per unit of output in the service sector thus requires a separation of the waste treatment sector from the other service sectors.

Table 4: Inter-industry flow matrix in MIOT and PIOT, Germany 1990

MIOT, in billion DM	Primary sector	Secondary sector	Tertiary sector
Primary sector	40	89	80
Secondary sector	33	654	427
Tertiary sector	28	363	2327

PIOT, in million tons	Primary sector	Secondary sector	Tertiary sector
Primary sector	2248	1442	336
Secondary sector	27	1045	206
Tertiary sector	5	69	51

Source: adopted from Stahmer (2000)

Using a multiplier matrix based on the monetary structure of the economy therefore causes distortions of results, which can be avoided by carrying out input-output analyses with data from a PIOT.

2. From a PIOT it is possible to directly derive physical technology and multiplier matrices, since the flow table already contains the physical information.

In the following sections, we will introduce three alternative approaches for the calculation of physical multipliers. The first is an input-output model with primary material inputs on the input side integrated into the inter-industry table (Model 2). The second physical model (Model 3) separates primary and secondary materials and is based on a methodology presented by Konijn and colleagues from Statistics Netherlands (Konijn *et al.* 1997). To our knowledge, this study so far is the only one, in which a physical multiplier matrix has been applied to calculate direct and indirect resource requirements and to attribute material inputs to final demand. Model 4 extends the vector of final demand in order to consider materials, which do not become part of the products themselves. Until now, physical multipliers have not been used for studies related to land use (the calculation of direct and indirect land requirements of final demand).

4.2.1 Closing the model for primary inputs (Model 2)

As mentioned above, primary inputs have to be integrated in the multiplier matrix, in order to avoid underestimation of overall resource requirements. In this section we will present an approach of directly including these resource flows in the input-output model.

In standard input-output analysis this procedure is referred to as „closing the input-output model" and including exogenous sectors (e.g. the household sector) into the interrelated table (1st quadrant) (Miller and Blair 1985). In the case of the PIOT, this would result in closing the input-output model for both primary inputs on the input side *and* disposals to nature (wastes and emissions) on the output side. Table 5 gives this hypothetically flow table.

Table 5: PIOT closed for primary inputs and disposals to nature, calculation Model 2

Use Supply	Sectors *(1,..,n)*	Disposal to nature	Final demand (Y)		Total output
			domestic	exports	
Sectors *(1,..,n)*	F_s	W	D	E	x
Primary inputs	m_p	*			
Total input	x'				

F_r

* In this box flows from nature to nature would be listed. These flows are not of interest for our calculations.

$F_{s,}$ m_p and W together form the new interrelated flow table (F_r), comprising inter-industry flows as well as primary inputs from nature to economy and flows of residuals from economy back to nature. In the logic of input-output calculations, "Disposal to nature" would thus be regarded as an economic sector. But the inputs into this sector are in fact flows *out* from the economy into the environment (landfills, sewage treatment, rivers, and air; depending on aggregate state of the material flow in question). Treating residuals as part of the inter-industry (production) matrix implies that the production of residuals itself is generating material flows, which is accounted for in higher values in the multiplier matrix. The model is therefore comprehensive in terms of the accounting of primary inputs and residuals or disposal, on the other hand, there seems to be a considerable amount of double counting. Materials are accounted for as primary inputs in the economic system, during the transformation process, and finally again as flows into the environment.

Therefore, we suggest a model, where the inter-industry table is only closed for primary inputs by adding them as a row. The column for primary inputs is all 0, as no material inputs are needed to produce primary inputs. The column for "Disposal to nature" remains as an end use sector (but not a final demand sector). Table 6 shows the new flow table for our calculation.

Table 6: PIOT closed for primary inputs, calculation Model 2

Use Supply	Sectors *(1,..,n)*	Primary inputs	Disposal to nature	Final demand (Y)		Total output
				domestic	exports	
Sectors *(1,..,n)*	F_s	*0*	W	D	E	x
Primary inputs	m_p	*0*				
Total input	x'					

F_r

We then get the extended physical A matrix (A_P) by dividing the new flow table (F_r) by total output (x):

(10) $$Ap = F_r(x)^{-1} .$$

By subtracting the physical A matrix (A_p) from the identity matrix (I) and calculating its inverse, we directly have the total physical multiplier matrix $(I\text{-}A_p)^{-1}$, named M_p. We then post-multiply M_p with the diagonal matrix of final demand categories ($\hat{Y}$) in order to calculate direct and indirect requirements (R_e). Again we show the equation for the diagonal export vector ($\hat{E}$):

(11) $$R_e = M_p\hat{E}\,.$$

R_e then is the sum of all direct and indirect material requirements for export production.

4.2.2 Separating primary and secondary inputs (Model 3)

To explain the calculation procedure introduced by Konijn *et al.* (1997), we again start from a simplified flow table, with the flows denoted in physical units (tons) (Table 7).

Table 7: Simplified PIOT with separate quotation of primary and secondary materials, calculation Model 3

Use Supply	Sectors *(1,..,n)*	Sum of sec. outputs	Final demand (*Y*)		Disposal to nature	Total output
			domestic	exports		
Sectors *(1,..,n)*	F_s	x_s	D	E	W	x
Sum of secondary inputs	m_s					
Primary inputs	m_p					
Total input	x'					

Source: adapted from Konijn *et al.* (1997)

Total physical inputs (x') sum up to

(12) $$x' = m_p + m_s$$

with m_p = sum of primary inputs (primary materials) of sectors *1,..,n,*
m_s = sum of secondary inputs (secondary materials) of sectors *1,..,n*.

Total outputs (x) are

(13) $$x = x_s + Y + W$$

with x_s = sum of secondary outputs of sectors *1,..,n,*
$Y = D + E$.

The first step towards the derivation of the physical multiplier, the calculation of a physical A matrix (A_p), is similar to the procedure using a MIOT: the intra-industry flow matrix (F_s) is divided by total output (x).

(14) $$A_p = F_s(x)^{-1}$$

The physical multiplier for secondary outputs (M_s) can then be gained by subtracting A_p from the identity matrix (I) and forming its inverse:

(15) $$M_s = (I - A_p)^{-1}.$$

As already pointed out in a previous section, this multiplier matrix (M_s) only comprises secondary materials, which are embodied in intermediate products, but does not account for unused material inputs, which become waste of inter-industry production. Applying this multiplier of secondary products for the calculation of direct and indirect resource requirements of final demand thus underestimates the overall resource inputs.

To extend this multiplier by the dimension of primary inputs, Konijn and colleagues suggest the following procedure. First, a coefficient for the amount of primary inputs per secondary output for each of the sectors is calculated (C_p):

(16) $$C_p = m_p(x_s)^{-1}$$

with m_p = sum of primary inputs of sectors *1,..,n*,
x_s = sum of secondary outputs of sectors *1,..,n*.

In a second step, the diagonal matrix of the coefficient ($\hat{C}_p$) is multiplied with the multiplier matrix for secondary materials (M_s), to receive the extended physical multiplier (M_e):

(17) $$M_e = \hat{C}_p M_s.$$

The calculation of direct and indirect resource requirements (R_e) of different final demand categories is then again parallel to the MIOT procedure: post-multiplying M_e with the diagonal matrix of final demand ($\hat{Y}$). As an example we show the identity for the export vector ($\hat{E}$).

(18) $$\mathrm{R}_e = M_e \hat{E}x.$$

R_e shows all direct and indirect material requirements for export production.

4.2.3 Extending the export vector by share of "unused" inputs (Model 4)

The third approach for performing PIOT-based input-output analysis in order to calculate direct and indirect material requirements for the production of exports also starts from a simplified PIOT (Table 8).

Table 8: Simplified PIOT for calculation Model 4

Use / Supply	Sectors (1,..,n)	Final demand (Y)		Disposal to nature	Total output
		domestic	exports		
Sectors *(1,..,n)*	F_s	D	E	W	x
Primary inputs	m_p				
Total input	x'				

The first steps in calculation Model 4 are parallel to Model 3 for obtaining the physical multiplier for secondary materials (M_s). As argued before, this multiplier has to be extended in order to assess also material inputs, which do not become part of the products, but end as wastes and thus are not reflected in the 1st quadrant of the PIOT. Model 3 integrates primary inputs by multiplying the inverse matrix for secondary materials with a coefficient of primary inputs per secondary outputs.

Here we present another approach to take into account the amount of materials not included in economic outputs by attributing shares of "unused" inputs to final demand. Disposal to nature (W) differs from the final demand categories (Y) in so far, as it is only an unavoidable *by-product* of production. Unlike all other categories of final deliveries, waste is not directly demanded, but rather "tolerated" (Leontief 1986, p. 251). The category of disposal to nature reflects, which amount of material inputs does not become part of durable goods (stock exchange) or exports. Disposals arise both directly as wastes from production processes and indirectly from the consumption of non-durable goods. Assuming that primary inputs are in a fixed ratio to the other final demand categories, we can calculate a coefficient (C_w) of waste generation per unit of primary input by dividing W by m_p. We then multiply the sectoral primary inputs by C_w in order to receive the disposal of "unused" materials per sector with the distribution according to the input structure (W_I). For each of the sectors, W_I tells us, which amount of primary inputs of this sector has not become part of the economic output of this sector. Thus, primary inputs are included in the calculation over the detour of final demand. If we further assume identical technology in production for stock exchange and exports in each of the sectors, a constant amount of W_I per unit of economically used output arises. This assumption enables us to extend the vector of final demand by the shares of the materials included in W_I.

We first calculate the shares of domestic consumption (S_D) and exports (S_E) in final demand.

(19) $$S_D = D/(D+E) \text{ and } S_E = E/(D+E)$$

with $S_D + S_E = 1$.

Dividing W by m_p delivers the coefficient C_w, which is then multiplied by the primary inputs of each of the sectors in order to receive the vector of "unused" materials with the input structure (W_I).

In the next step this new vector (W_I) is split up according to the shares calculated above and added to the categories of final demand. Thus we get the extended vector for domestic consumption (D_{ext}) and exports (E_{ext}).

(20) $D_{ext} = D + (W_I * S_D)$ and $E_{ext} = E + (W_I * S_E)$

The total amount of direct and indirect material requirements for satisfying final demand then is obtained by post-multiplying the diagonal matrix of final demand ($\hat{D}_{ext}$ and $\hat{E}_{ext}$) with the original physical multiplier obtained from the 1st quadrant of the PIOT, as shown in Equation (15). Again, we show this calculation for the export vector.

(21) $\mathrm{Re} = M_s * \hat{E}_{ext}$,

with R_e being total direct and indirect materials induced by export demand.

4.3 Discussion of the four models

In this section we will present and discuss the results of numerical examples for each of the approaches described above. The examples are based on highly aggregated input-output tables for Germany for the year 1990. In order to keep the calculation simple and illustrative, aggregates with three production sectors have been derived from the 12 sector tables given by Stahmer (2000). The detailed calculations can be found in the Annex of this report. We start the discussion with a summary of the direct and indirect material flows activated by exports according to the four input-output models (Table 9):

Table 9: Direct and indirect material flows activated by exports, results of calculations with the four models (in million tons)

	Primary sector	Secondary sector	Tertiary sector	**Sum**
Model 1 (MIOT)	239.2	1,087.0	116.7	**1,482.8**
Model 2 (PIOT)	93.5	609.7	61.1	**764.4**
Model 3 (PIOT)	59.6	291.4	112.2	**463.2**
Model 4 (PIOT)	2,468.4	602.9	579.4	**3,650.6**

Clearly it can be seen that the results of the four models differ substantially. Model 3 delivers the lowest material requirements, whereas Model 4 shows by far the highest numbers. The main reason is that Model 4 is the only one, in which the primary inputs, not included in the outputs of final demand, are directly considered in the calculation. In Models 2 and 3, disposal to nature remains a separate category of final use. Analytically this means that this category is also generating direct and indirect input requirements. But as residuals are not willingly produced, but rather accepted “by-products” of economic production, we suggest to treat the dimension of disposals to nature not as a separate end-use sector, but instead link it to the categories of final demand, as it is suggested in Model 4.

The distribution of material flows between the three sectors is different in all of the approaches. Notably, Model 4 is the only one, in which the material requirements for exports of the primary sector exceed those for the secondary sector. This is the case, as the primary sector necessitates the highest material inputs and "produces" the largest amount of residuals per unit of output. As in Model 4 the amounts of primary inputs, which leave the economic system as unused residuals, are considered in the form of the extended export vector, these substantial waste flows are also reflected in the calculation results. In Models 2 and 3, the (original) export vector is dominated by the secondary sector and consequently is the sector with the highest material requirements.

Surprisingly, the results from the three PIOT models show no unambiguous difference compared to the results gained from the MIOT model, although the underlying (monetary and physical) structures of the input-output tables differ substantially (see Table 4). Model 4 delivers higher material requirements than the MIOT, whereas Models 2 and 3 show lower results than the MIOT. Despite the substantial variation of the results obtained from the three PIOT models, we will apply an input-output methodology based on the physical structure of the economy for the calculation of the comprehensive physical trade balance in this report. As (a) Model 4 is the most comprehensive model in terms of inclusion of materials, which are not physically part of the produced goods, and (b) data restrictions do not allow an application of Models 2 or 3 at the moment, we will apply this model for further calculation of the physical trade balance in Section 7.

5 Land use accounting and trade balance calculations

In addition to the physical trade balance in terms of material flows, EUROSTAT (2001) suggests to compile trade balances for land use (in hectares) as an additional resource use indicator in international trade. The land-based trade balance illustrates the land area appropriated by export production abroad as well as the domestic land area needed to produce the goods and services exported to the rest of the world.

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 e.g. Spangenberg and Bonnoit 1998). Thus land use and land cover accounts are one of the core natural resource accounts in the Integrated System of Environmental and Economic Accounts of the United Nations (2001).

Land use and land cover changes have also been increasingly recognised as key issues of environmental policy in the European Union. The establishment of the European Spatial Development Perspective (ESDP) initiative by the European Council in 1993 was the first step towards an integrative land use policy of the EU. As the European Environment Agency (1999) stresses, more than 80 % of the EU territory has already been converted into land for "productive" use, like agriculture, forestry, transport, industry and urban settlement. Due to increasing pressures mainly for urban expansion a real threat to the conservation of natural and fertile land for future generations can be observed.

5.1 The ecological footprint

The most influential physical accounting methodology 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)[10]. 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. Since today, EF calculations have been carried out for almost all countries of the world (for the latest comprehensive country data set see WWF *et al.* 2000). Data for the EF calculations on the national level is usually adopted from internationally available statistics, such as United Nations and its sub-organisations (FAO, UNCTAD etc.). Recently, the EF methodology has been specifically applied to illustrate the unequal exchange of natural resources in international trade (Andersson and Lindroth 2001; Wackernagel and Giljum 2001).

Concerning the methodology, 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. The five categories of consumption goods are food, housing, transport, consumer goods and services. Each of these five categories covers land areas in one or several of the 5 land categories, which are build-up land, agricultural land, pasture, forest and land for CO_2 sequestration.

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 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.

EFs are presented both disaggregated by land use categories as well as aggregated as a single indicator (see e.g. WWF *et al.* 2000). The aggregation of actual appropriated land with hypothetical

[10] Another land-based approach was presented by Krotscheck and Narodoslavsky (1996) under the term Sustainable Process Index (SPI). Since the SPI gained much less resonance in the scientific community compared to the ecological footprint, it will not be dealt in detail in this report.

land to the total EF of a country has been one major source for critique of this concept (see e.g.van den Bergh and Verbruggen 1999).

One could think of providing an equivalent to the physical trade balance of direct material flows in hectares according to the methodology described above. For example, the *direct* land appropriation within the EU-15 for exports to the rest of the world could be determined as well as the land area appropriated in the rest of the world to produce exports to the EU-15. In this report we will not carry out this calculation. The reason is that the conversion of mass units into land areas is only feasible for biotic products (agricultural, forestry or fishery products), as productivity data is available for all countries of the world.[11] 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 exports of these goods is not yet available.[12] We therefore suggest obtaining the land intensities of export production by performing input-output analysis with actual land cover data. We will explain this procedure stepwise in the next two sections.

5.2 The CORINE land cover data base

The initiative for establishing a Europe-wide consistent land cover database was initiated in 1985 by the European Commission within the framework of the "CORINE (Coordination of Information on the Environment) Programme". Based on GIS (Geographical Information System) data, CORINE provides information on a number of issues with explicit spatial reference, such as biotopes, soil and coastal erosion, air emissions and transportation infrastructure. Concerning land cover data, CORINE uses a raster scale of 250 by 250 meters and classifies European land cover into 43 categories, comprising the major categories of artificial areas, agricultural areas, forest and seminatural areas, wetlands and water bodies. A detailed description of each of the classes and the methodological details concerning the attribution of each of the grids to one class has been presented by Bossard *et al.* (1999). The complete list of the CORINE categories can be found in Table 21. At the end of 1999, CORINE covered 14 EU members and 10 accession countries. Sweden will provide its data in the course of the 2000 revision programme, which will be published in 2003 (Krynitz 2000).

CORINE land cover data can be obtained from the European Environment Agency (EEA) from the NATLAP (Nature-land cover information package) CD-ROM (European Environment Agency 2000).

5.3 Land use accounting and input-output analysis

Recently, several studies relating input-output analysis to land use accounting have been presented (Bicknell *et al.* 1998; Eder and Narodoslawsky 1999; Ferng 2001; Hubacek and Sun 2000; Proops *et al.* 1999). This methodology proved to be a useful tool for the calculation of directly and indirectly appropriated land areas of production and consumption processes.

[11] See for example the data base of the Food and Agricultural Organisation (FAO) of the United Nations at http://apps.fao.org.
[12] Furthermore, the land appropriation of the service sector can not be included in this kind of calculation.

As land is no inherent quality of a product (such as value or physical component), this category can only be linked to input-output tables (whether monetary or physical) as an additional row of resource input. Input-output analysis is then performed in the same way as it has been described in Model 1 for material flows (see also Section 4.1): we first calculate the land intensity coefficients for each of the sectors by dividing the land appropriation of each sector by total output of that sector. Then we post-multiply the diagonal matrix of the coefficients with the multiplier matrix to obtain the multiplier weighted by land coefficients. Post-multiplying this weighted inverse matrix with the diagonal matrix of final demand delivers the direct and indirect land requirements.

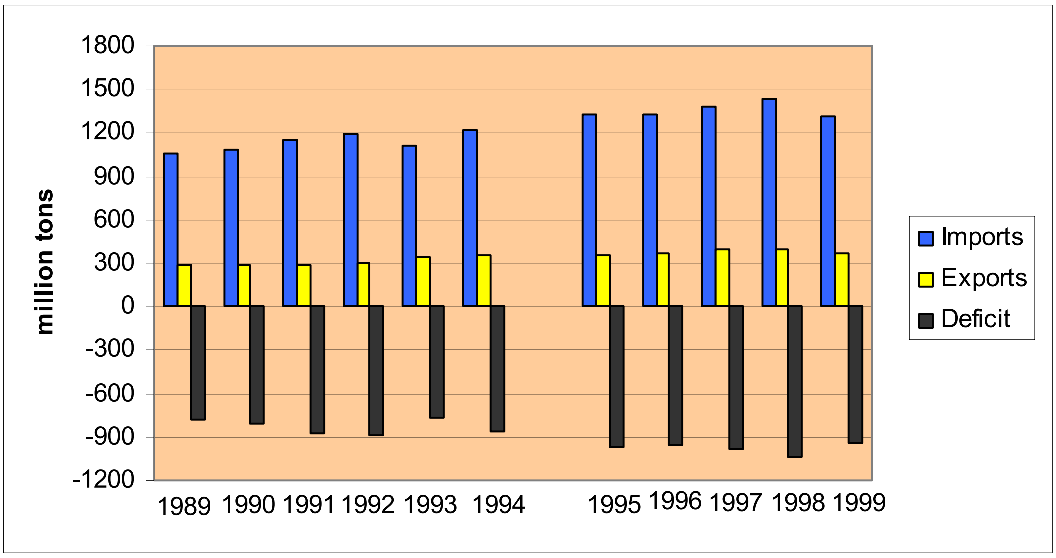
All land-related studies presented so far used monetary input-output tables (MIOTs) for attributing land to the different categories of final demand. In our case study on the EU-15 we will integrate the CORINE land use data into a physical input-output table (PIOT) in order to calculate land intensities of exports (see Section 8 for the empirical part). Using a physical multiplier for this kind of calculation is more appropriate, as the most land intensive sectors are also the sectors with the highest amounts of material flows (see Tables 15 and 16). Physical input-output analysis illustrates land appropriation in relation to the material flows of each of the sectors, which is more significant from the point of view of environmental pressures than the land appropriation in relation to the monetary flows of a MIOT.

Part 2: Case Study

6 A physical trade balance of direct material flows for the European Union

As explained in Section 2.8, physical trade balances (PTBs) are compiled in two steps. The simple version only includes material flows, which cross the border of the area under investigation. In this section we will present a simple PTB for the European Union in a time series of 1989 to 1999 and disaggregate the physical trade data for world regions and product/material groups.[13] All figures are split in two sections, covering EU-12 from 1989-1994 and EU-15 from 1995-1999. To emphasize that the data series represent different aggregates of EU member countries (12 and 15), a gap has been included in the tables between the years 1994 and 1995. Data has been extracted from COMEXT CD-ROM, which is published by EUROSTAT and provides data on trade flows between the European Union and the rest of the world in both monetary and physical terms. Figure 5 presents an overview of total physical imports, exports and the trade deficit for the EU-12 and EU-15.

Figure 5: Physical imports, exports and trade deficit for the EU-12/15 (1989-1999), (in million tons)



Data source: EUROSTAT (2000)

According to Figure 5, physical imports into the European Union rose from around 1,000 million tons in 1989 to more than 1,400 million tons in 1998 and showed a slight decline to around 1,300 million tons in 1999. Exports from the EU to all other world regions amounted to 250 million tons in 1989, reached their maximum with more than 400 million tons in 1997/98 and declined to 375 million tons in 1999. As imports exceeded exports by far during the whole time period, a substantial

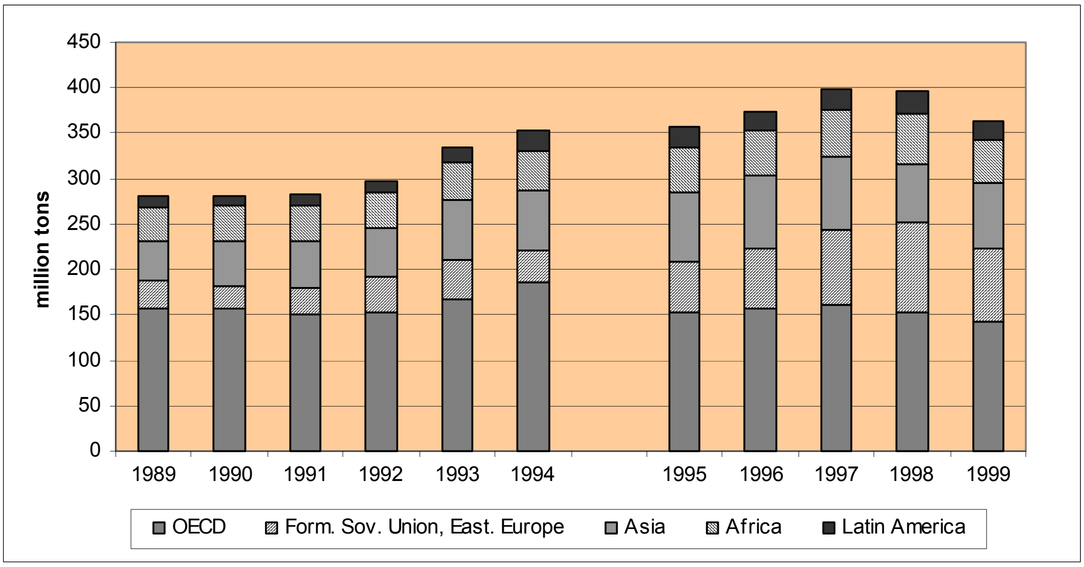
[13] In their publication on the material balance of the EU-15, Bringezu and Schütz (2001d) have also calculated a simple physical trade balance for the EU-15. However, they do not disaggregate imports and exports by regions, which is especially important with regard to the objective of this study.

trade deficit in physical terms can be observed. The deficit totalled 750 million tons in 1989, then increased to more than 1,000 million tons in 1998 and fell to 940 million tons in 1999. At the end of the 1990s, the European Union thus had a net import of almost 1 billion tons of materials per year from outside its territory.

6.1 Disaggregation by regions (1989-1999)

We gain more detailed information concerning the spatial structure of the EU external trade by disaggregating imports, exports and balance by world regions. For that we define five major country aggregates: OECD countries, countries of the former Soviet Union and Eastern European countries, Asia (excluding Japan), Africa and Latin America. Figure 6 shows the EU-12/15 imports in the time period of 1989-1999.

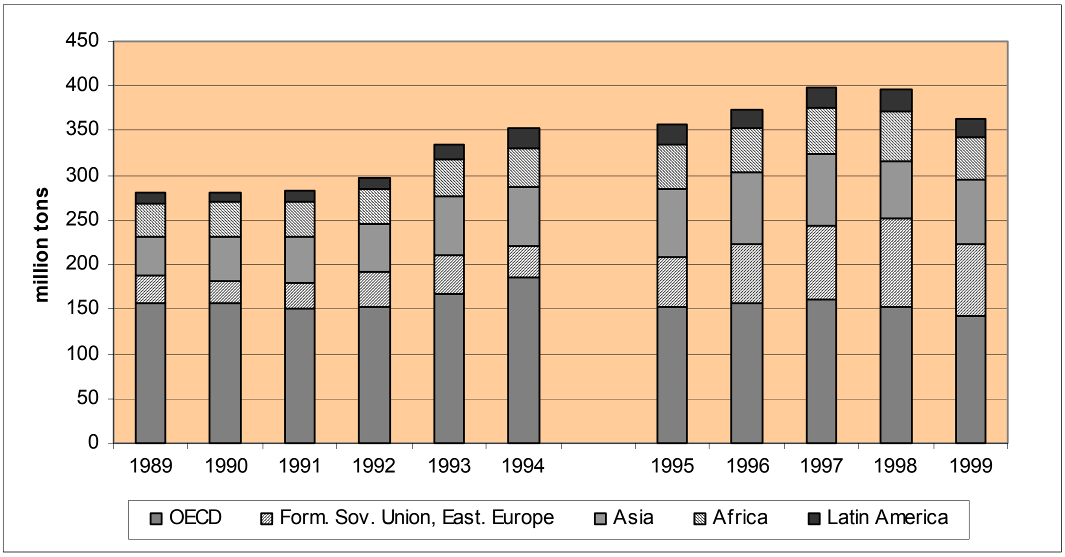
Figure 6: EU-12/15 imports 1989-1999 by world regions (in million tons)



Data source: EUROSTAT (2000)

Figure 6 reveals that in the last 10 years no major changes in the structural composition of the EU external trade could be observed. Note that the share of OECD countries is not increasing, as the trade between former EU-12 and Sweden, Finland and Austria is no longer reported as EU external trade and thus is not included in the figure for the years 1995-1999. Absolute increase in total material imports was mainly caused by intensified trade between the EU and the Eastern European countries and Russia. The share of the so-called developing and emerging countries (Asia, Africa, Latin America) fell from 58 % in 1989 to 49 % in 1999. The same disaggregation is carried out for EU exports (Figure 7).

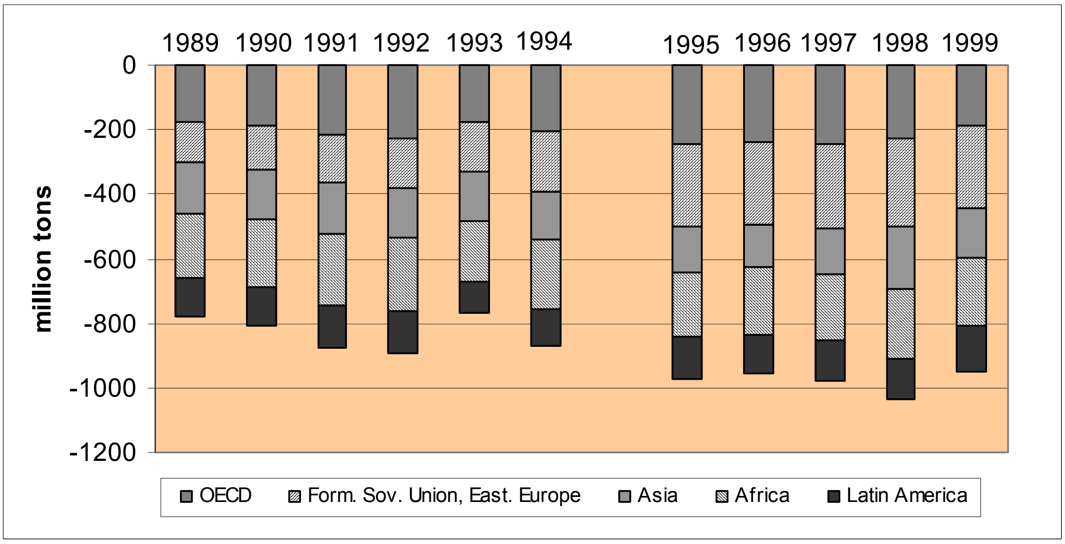
Figure 7: EU-12/15 exports 1989-1999 by world regions (in million tons)



Data source: EUROSTAT (2000)

Apart from the fact that the absolute numbers are significantly lower for physical exports, we observe that also exports to the Eastern European countries and Russia have increased to the largest extend in the period under investigation. This reflects the strengthened integration of Eastern Europe in the course of the enlargement process of the European Union. The share of the OECD countries is lower for the period of 1995-1999 compared to 1994, as Sweden, Finland and Austria were no longer counted as extra EU countries. Concerning developing and emerging countries, exports to Asia play the most important role. In Figure 8 the trade deficit is also disaggregated by the five world regions.

Figure 8: EU-12/15 trade deficit 1989-1999 by world regions (in million tons)



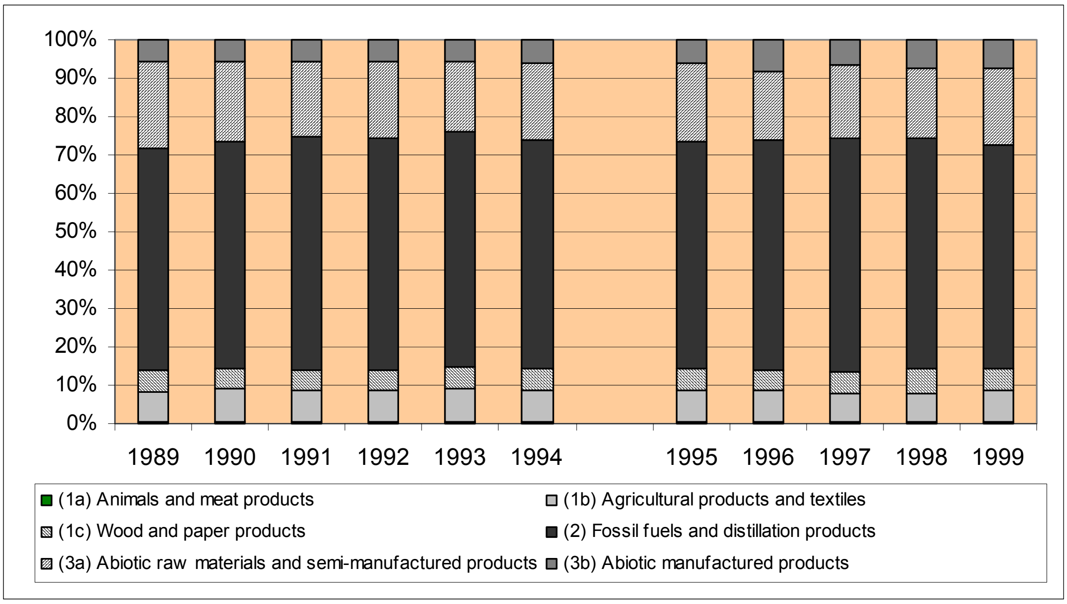
Data source: EUROSTAT (2000)

Interestingly, we find that the European Union has physical trade deficits with regard to all other world regions. Via international trade, the EU appropriates material resources from all over the world without reciprocally re-exporting physical resources. In terms of material flows, the trade relations between the EU and the other world regions can thus be characterised as ecologically unequal (Andersson and Lindroth 2001). Figure 8 also shows that the European economy has been increasingly depending on material inputs from outside its territory in the course of the 1990s. This result complements the findings of Bringezu and Schütz (2001b), who assessed that the total material requirements of the European Union are increasingly satisfied by imports instead of domestic material extraction.

6.2 Disaggregation by product/material groups (1989-1999)

Additional information can be gained by the disaggregation of imports and exports by groups of materials and products. According to the methodological guide for material flow accounting (EUROSTAT 2001), we organise materials in three main groups: (1) biotic materials, (2) fossil fuels and (3) abiotic materials. Group (1) is further classified into (1a) animals and meat products, (1b) agricultural products and textiles and (1c) wood and paper products. Group (3) is divided into (3a) abiotic raw materials and semi-manufactured products and (3b) abiotic manufactured products. Figure 9 depicts the shares of the different material groups in EU imports.

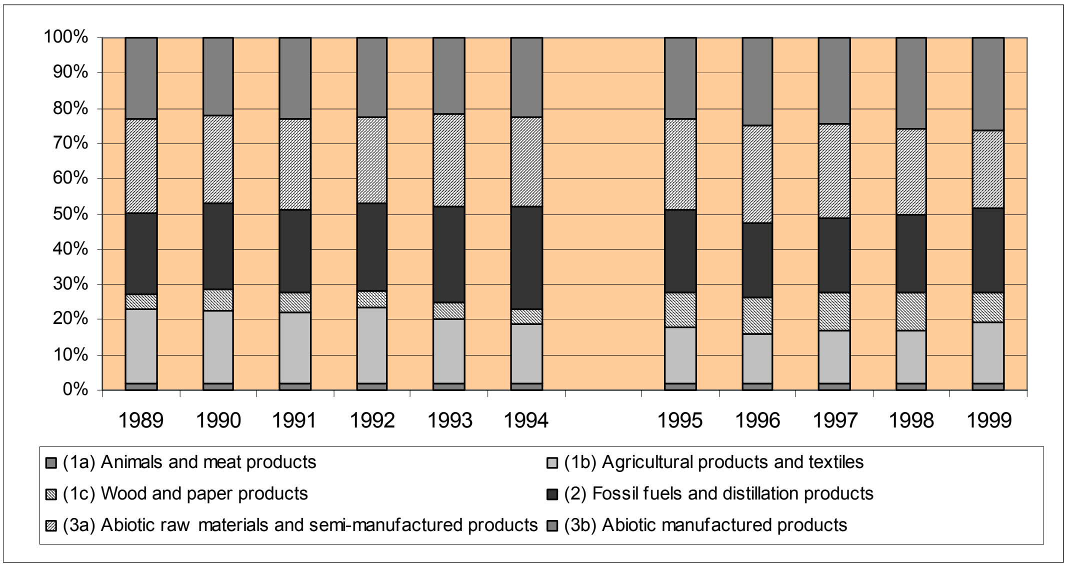
Figure 9: EU-12/15 imports 1989-1999 by material/product groups (in million tons)



Data source: EUROSTAT (2000)

The absolute dominance of material group 2 (fossil fuels and their distillation products) is striking: fossil energy carriers accounted for 58 to 65 % of total material imports during the time period of 1989 to 1999. Biotic materials in total did not exceed 15 %. The remaining share of around 25 % is made up by abiotic materials, with raw materials largely dominating over manufactured products. Figure 10 shows the material composition of EU exports.

Figure 10: EU-12/15 exports 1989-1999 by material/product groups (in million tons)



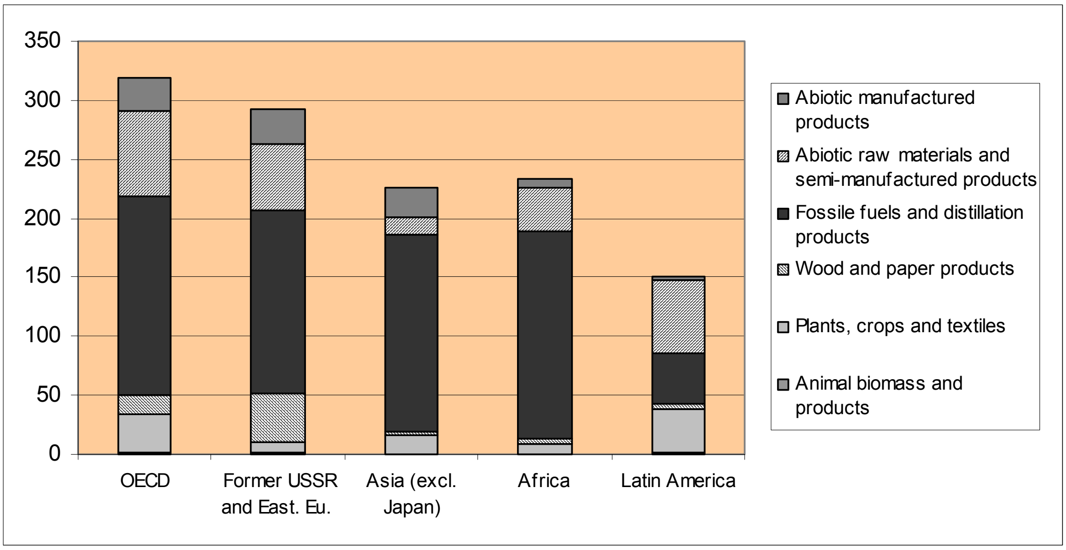
Data source: EUROSTAT (2000)

As can be seen from Figure 10, the structural composition of EU exports significantly differs from the import structure. As could be expected, fossil fuels and distillation products only hold a share of 20 – 30 % of total exports. Considering the lower level of absolute material flows in exports, it becomes obvious that the EU member countries are consuming around 90 % of the fossil fuel imports within their territory and export only 10 %, mostly in form of refined fuels. The share of biotic products is remarkably higher for the exports and counts for up to 30 %. Evidently, the accession of Sweden, Finland and Austria raised the share of wood and paper products since 1995. With up to 52%, abiotic materials hold the largest share of the three main material groups. One half of the abiotic materials are exported in the form of raw materials and semi-manufactured products, the other half in the form of manufactured goods.

6.3 Disaggregation by regions and product/material groups (1999)

The most detailed information can be gained by disaggregating the physical trade data by both world regions and products groups. Figure 11 shows the absolute numbers of EU imports for the year 1999. Again, we can clearly take from the figure that fossil fuels are the main product group for imports from four of the five world regions. Concerning fossil fuel imports from OECD countries, Norway is by far the largest trading partner, delivering more than 100 million tons of oil to the EU in 1999. Additionally, the EU is also importing fossils from all other major oil extracting regions of the world, including Russia and Central Asia, the Middle East and North Africa. Apart from fossil fuels, South America mainly serves as an exporter of abiotic raw materials as well as crops. Manufactured products are imported from the OECD region, Russia and Eastern Europe as well as Asia at an amount of 25 to 30 million tons. Russia and the Eastern European countries are also the main providers of wood and wood products.

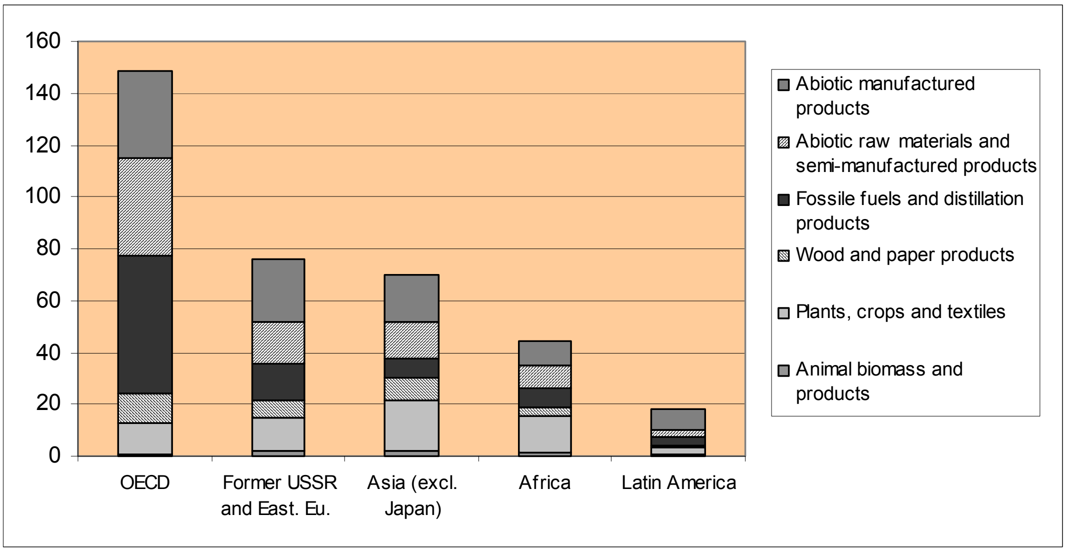
Figure 11: EU-15 imports 1999 by world regions and product/material groups (in million tons)



Data source: EUROSTAT (2000)

In Figure 12 we show EU exports in detailed form.

Figure 12: EU-15 exports 1999 by world regions and product/material groups (in million tons)



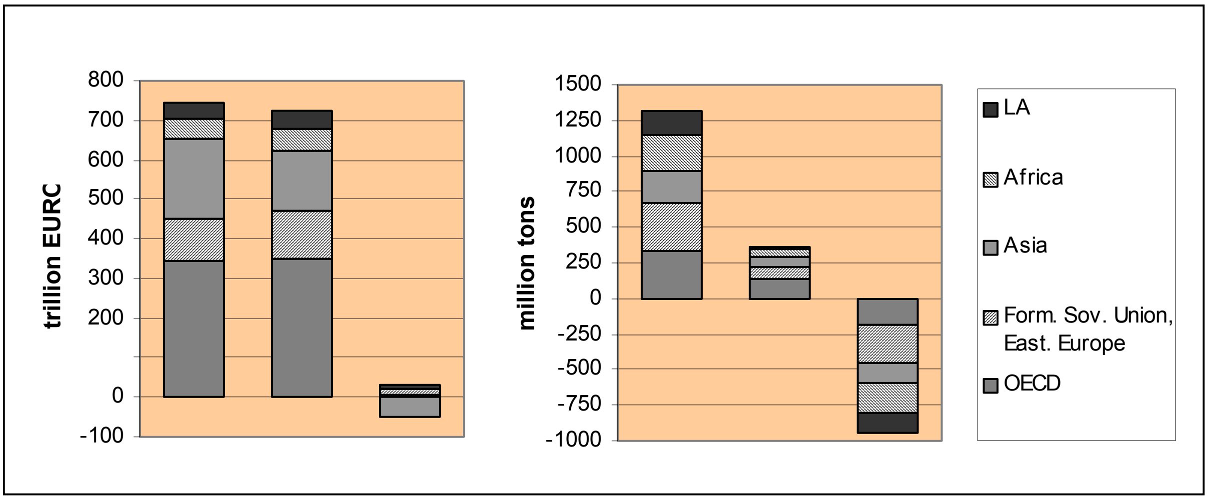
Data source: EUROSTAT (2000)

Apart from trade with the OECD countries, fossil fuels play a minor role in EU exports. Semi-manufactured and manufactured products are the largest group with regard to the trade with the former Soviet Union countries and Eastern Europe as well as Latin America. The share of crops in EU exports is significantly higher than in imports, especially with regard to trade relations with Asia and Africa.

6.4 Comparing monetary and physical trade balances

Reporting the numbers for monetary trade balances has traditionally been part of standard economic accounting. The parallel analysis of monetary flows on the one hand and their underlying physical flows delivers interesting insights into the regional structure of capital intensive trade on the one hand and resource intensive trade on the other hand. Figure 13 depicts imports, exports and trade balance for the EU-15 in 1999 in both EURO and tons.

Figure 13: EU-15 imports, exports and balance in monetary and physical terms, 1999 (in trillion EURO and million tons)



Data source: EUROSTAT (2000)

The figure reveals that trade relations between the EU and all other world regions are almost balanced in monetary units. Only a slight deficit arises due to the high amount of imports from Asia. We also see that almost half of the monetary flows are concentrated within the OECD region. Turning to the physical table on the right side of Figure 13, the same trade flows deliver a completely different picture when analysed from the viewpoint of material content. Trade between the OECD region is much less important with only about one fourth of the imports and two fifth of the exports. The region of the former Soviet Union and Eastern Europe as well as the so-called developing countries are by far more essential as providers of material inputs to the EU than as recipients of EU exports. Whereas trade is more or less balanced in monetary units, a large physical deficit can be observed, as has already been explained in detail in previous sections. If the monetary flows are balanced, but a large physical deficit arises, prices of imports and exports must as well differ substantially. Table 10 shows the average value per ton of EU imports and exports, disaggregated by the five world regions.

Table 10: Value in EURO per ton of imports and exports of EU-15 (in 1999)

	Imports	Exports
OECD	1080	2360
Former Soviet Union and Eastern Europe	380	2010
Asia	840	2130
Africa	230	1240
Latin America	240	2100
Total trade	**580**	**1920**

Data source: EUROSTAT (2000)

We see that the average value of total imports amounts 580 EURO per ton, whereas the value of total exports is almost four times higher. To some extent, this general numbers also reflect the position of the EU in the world economy and the international division of labour. Relatively cheap fossil fuels, raw materials and semi-manufactured products are imported form other world regions, from which the largest share is consumed within the territory of the Community. Products that are exported leave the EU with a substantial added value. The relatively cheapest imports origin from Africa and Latin America. The large share of countries with a relatively high level of economic development in Asia (newly industrialised countries) leads to the high value of 840 EURO per ton of imports. As expected, the average value of imported products is highest for the OECD countries. With the exception of Africa, the average value of EU exports lies between 2,010 and 2,360 EURO per ton.

7 A comprehensive physical trade balance for the European Union

After having presented the results for the simple trade balance of the EU-12/15, we will now turn to the calculation of the comprehensive physical trade balance. In addition to the physical trade balance for direct material flows (see above), the comprehensive balance also accounts for indirect resource requirements necessary to produce the exported (or imported) goods. For that purpose we will develop a physical input-output model for the EU and apply physical input-output analysis in order to calculate direct *and* indirect material flows.[14]

7.1 Data restrictions and shortcomings of the model

As already mentioned earlier, physical input-output analysis is a very young research field. With only one publication introducing an approach on how to use a physical multiplier (Konijn *et al.* 1997), the methodology for physical input-output analysis is far from being standardised and internationally accepted. In Section 4 we presented two alternative approaches for performing physical

[14] As explained earlier, indirect flows associated to imports and exports comprise both used and unused components. In the calculation carried out in this section we will only consider materials, which are used and actually cross the boundary between the natural and the socio-economic system. Thus substantial flows of unused components, such as overburden from mining or soil excavation for construction activities are not included here, but should be considered in an extension of this calculation example.

input-output analysis. Further clarification of the analytical foundations of the three models as well as comparative calculations are needed to test the appropriateness of the different methods. For the calculations undertaken in this section we will apply Model 4, which is based on a PIOT where the vector of final demand is extended by the shares of material inputs not included in the produced goods. The reason is that (a) Model 4 is the most comprehensive of the three alternative methods of using a PIOT and (b) the other two models would have required data that is not yet available (for both Model 2 and 3 the physical inter-industry flow table of the EU-15 would be the starting point, which has not yet been compiled).

As by now data restrictions allow only very rough estimations of the material intensities of traded products (see below), we will only calculate the material requirements of the EU-15 exports as an example for performing physical input-output analysis. Therefore the calculations carried out below should be regarded as a first numerical illustration of the methodological procedure described above. For the compilation of a complete physical trade balance, including direct and indirect flows of both imports and exports, more detailed data on the physical structure of the EU-15 trading partners would be imperative.

7.2 Development of a physical input-output model of the EU-15

Our input-output model of the EU-15 will comprise the following 7 sectors (Table 11):[15]

Table 11: The 7 sectors of the physical input-output model of the EU-15

1	Agriculture, Forestry, Fishing (AFF)
2	Electricity Generation and Water Supply (EGWS)
3	Resource extraction (fossil fuels, ores, minerals)
4	Manufacturing
5	Construction
6	Transport
7	Services

As a PIOT for the EU-15 does not yet exist, we have to develop a model from already published national studies. Thus we will combine data from physical input-output tables with material flow data for the EU-15. Table 12 gives an overview of currently available data. As explained in Section 3.4, PIOTs for European countries published so far differ significantly in terms of sectoral disaggregation as well as material categories considered (in particular whether or not water and air are included). Detailed PIOTs so far exist only for Germany and Denmark. As Germany is the largest economy within the European Union, the most realistic procedure would be to assume an identical physical structure of the EU as a whole. The main obstacle to this procedure is that water is included in the inter-industry table in the German PIOT and is dominating all other material categories by a factor of 10 or more in some of the sectors. As we are interested in solid materials activated by the production for satisfying final demand, the application of the German technology matrix would not be

[15] This sectoral differentiation is derived from the eight-sector framework, which is applied in the Statistical Yearbooks of the United Nations (e.g. United Nations 2000).

usefull. Therefore we have to base our calculation on the physical input-output relations for Denmark, being aware that the economic structure of a small country like Denmark significantly differs from the structure of the EU-15 and that the results are heavily influenced by this underlying physical structure.

Table 12: Data availability for the physical input-output model of the EU-15

Sectors	AFF	EGWS	Resource extraction	Manufacturing	Construction	Transport	Services	Total processed outputs	Stock exchange**	Exports	Disposal to nature***	Total systems output	Total output
AFF	Dk	Dk	Dk	Dk	Dk	Dk	Dk	X	D	EU	D		X
EGWS	Dk	Dk	Dk	Dk	Dk	Dk	Dk	X	D	EU	D		X
Resource extraction	Dk	Dk	Dk	Dk	Dk	Dk	Dk	X	D	EU	D		X
Manufacturing	Dk	Dk	Dk	Dk	Dk	Dk	Dk	X	D	EU	D		X
Construction	Dk	Dk	Dk	Dk	Dk	Dk	Dk	X	D	EU	D		X
Transport	Dk	Dk	Dk	Dk	Dk	Dk	Dk	X	D	EU	D		X
Services	Dk	Dk	Dk	Dk	Dk	Dk	Dk	X	D	D	D		X
Total processed inputs	X	X	X	X	X	X	X	X	EU-15	EU-15	EU-15		X
Domestic extraction*	D	D	D	D	D	D	D	EU-15					
Imports**	D	D	D	D	D	D	D	EU-15					
Total primary inputs													
Total inputs	X	X	X	X	X	X	X	X					

Dk: physical structure of Denmark (Gravgaard Pederson 1999)
D: physical structure of Germany (Stahmer et al. 1997)
EU: export structure taken from EUROSTAT COMEXT Trade data (2000)
EU-15: Data taken from Bringezu and Schütz (2001): Material use indicators for the European Union, 1980-1997, EUROSTAT Working Paper, Luxembourg
* Excluding water, unused extraction and erosion, incl. air; shares based on Tables 1.1.2 and 1.1.4 in Stahmer et al. (1997)
** Shares based on Table 3.3.1 in Stahmer et al. (1997)
*** Shares based on Table 2.2.2 and 2.2.4 in Stahmer et al. (1997)

Concerning the sectoral shares of inputs (3rd quadrant) and outputs (2nd quadrant), we will refer to the physical structure of Germany, as detailed tables *excluding* water *are* available in the PIOT publication (Stahmer et al. 1997). As both the German and Danish PIOT are based on 1990 data, we will also select this year as the reference year for our model. Table 13 gives the numbers of the EU-15 model, which are technical coefficients in the 1st quadrant and absolute numbers in the 2nd and 3rd quadrant.

Table 13: Technical coefficients (1st quadrant) and absolute numbers of EU-15 inputs (3rd quadrant) and outputs (2nd quadrant), in million tons, 1990

Sectors	AFF	EGWS	Resource extraction	Manufacturing	Construction	Transport	Services	Total processed outpu	Stock exchange	Exports	Disposal to nature	Total systems output	Total output
AFF	*0,097*	*0,027*	*0,000*	*0,228*	*0,001*	*0,000*	*0,037*	X	102185	29288	1792075	1923548	X
EGWS	*0,002*	*0,026*	*0,000*	*0,008*	*0,000*	*0,001*	*0,020*	X	21574	12642	2078170	2112386	X
Resource extraction	*0,059*	*0,128*	*0,036*	*0,237*	*0,367*	*0,000*	*0,076*	X	40121	55562	666884	762566	X
Manufacturing	*0,168*	*0,022*	*0,003*	*0,180*	*0,232*	*0,471*	*0,465*	X	210517	199115	1695154	2104786	X
Construction	*0,001*	*0,001*	*0,000*	*0,001*	*0,000*	*0,009*	*0,129*	X	3158111	35	1209801	4367948	X
Transport	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	X	1865	0	323702	325567	X
Services	*0,000*	*0,000*	*0,000*	*0,001*	*0,000*	*0,000*	*0,000*	X	119574	18963	518871	657409	X
al processed input	X	X	X	X	X	X	X	X	3653947	316055	8284657	12254660	X
Domestic extraction	2252051	1629428	5566477	921039	52983	317498	365915	11105391					
Imports	71591	214	751587	309980	205	0	15692	1149269					
Total primary inputs	2323642	1629642	6318064	1231019	53188	317498	381607	12254660					
Total inputs	X	X	X	X	X	X	X	X					

Table 13 is the starting point for the calculation of the direct and indirect material requirements of EU-15 exports.

7.3 Calculation of direct and indirect flows of EU-15 exports

Following the methodological procedure of Model 4 (Section 4.2.3), we get the following results (Table 14). The detailed calculation can be found in the Annex of this report (Section 11.2).

Table 14: Direct and indirect material requirements of EU-15 export production, 1990 (in 1000 tons)

	Direct	Indirect	Total	Factors indirect/ direct
Agriculture, forestry, fishing	29.288	557.134	586.422	19
ity and water	12.642	513.567	526.209	41
esource extraction	55.562	2.592.602	2.648.163	47
Manufacturing	199.115	989.167	1.188.282	5
Construction	35	30	66	1
Transport	0	0	0	0
Services	18.963	106.746	125.710	6
	315.605	4.759.247	5.074.852	15

As can be seen from Table 14, the direct export flows of about 315 million tons activate additional 4.7 million tons as indirect material requirements. In average, the factor of direct to indirect flows is 15, illustrating that for each ton exported to the rest of the world, another 15 tons of materials are required within the European Union for producing the exported good. The sectors with the highest material inputs (sectors 1-3) are also those with the highest amounts of induced indirect flows. With factors higher than 40, electricity generation and water supply and resource extraction are the most material intensive sectors in terms of the activation of indirect flows.

8 Calculation of land appropriation of EU-15 exports

In this section, we will use the physical input-output model developed in Section 7 to calculate land appropriation of EU-15 exports. For that, we will first aggregate land cover data to the 7 sectors of the model and than apply physical input-output analysis to assess the direct and indirect land requirements.

8.1 Sectoral land appropriation in the EU-15

For the application of CORINE data (see Section 5.2) in our model of the EU-15, we have to aggregate the 44 categories to the 7-sectors of the model. Table 15 lists the land areas in hectares for the different land use categories and the categories of the 7-sector model, to which the land use data is aggregated.

Table 15: Land area (in hectares) of the 44 CORINE categories for the EU-14 (excl. Sweden) and aggregation to the 7 sectors of the input-output model

COUNT (ha)	NAME	Number of sector in 7-sector model
929,800	1.1.1 Continuous urban fabric	4
6,666,850	1.1.2 Discontinuous urban fabric	x
960,719	1.2.1 Industrial or commercial units	4
87,775	1.2.2 Road and rail networks and associated land	6
51,856	1.2.3 Port Areas	6
197,819	1.2.4 Airports	6
368,644	1.3.1 Mineral extraction sites	3
43,794	1.3.2 Dump sites	7
69,525	1.3.3 Construction sites	5
138,144	1.4.1 Green urban areas	7
375,331	1.4.2 Sport and leisure facilities	7
62,531,263	2.1.1 Non-irrigated arable land	1
3,467,813	2.1.2 Permanently irrigated land	1
402,494	2.1.3 Rice fields	1
3,144,550	2.2.1 Vineyards	1
1,611,181	2.2.2 Fruit trees and berry plantations	1
3,605,075	2.2.3 Olive groves	1
28,200,425	2.3.1 Pastures	1
1,356,600	2.4.1 Annual crops associated with permanent crops	1
20,027,713	2.4.2 Complex cultivation patterns	1
11,208,725	2.4.3 Land principally occupied by agriculture	1
3,220,544	2.4.4 Agro-forestry areas	1
22,542,238	3.1.1 Broad-leaved forest	1
33,476,875	3.1.2 Coniferous forest	1
17,214,094	3.1.3 Mixed forest	1
10,515,594	3.2.1 Natural grassland	x
8,052,950	3.2.2 Moors and heathland	x
8,626,394	3.2.3 Sclerophyllous vegetation	x

11,862,819	3.2.4 Transitional woodland-scrub	x
184,594	3.3.1 Beaches, dunes, sands	x
2,091,244	3.3.2 Bare rocks	x
2,758,900	3.3.3 Sparsely vegetated areas	x
227,231	3.3.4 Burnt areas	x
154,256	3.3.5 Glaciers and perpetual snow	x
282,675	4.1.1 Inland marshes	x
2,315,513	4.1.2 Peat bogs	x
172,338	4.2.1 Salt marshes	x
61,488	4.2.2 Salines	x
175,556	4.2.3 Intertidal flats	x
377,088	5.1.1 Water courses	x
4,343,888	5.1.2 Water bodies	x
361,306	5.2.1 Coastal lagoons	x
190,556	5.2.2 Estuaries	x
274,654,231	**Total**	

x….Land use categories not economically used and therefore not considered in the 7-sector model

Data source: European Environment Agency (2000)

In the CORINE data system, no separate numbers for electricity generation or water supply are listed. Although we are aware of the discrepancy between the model and reality, we have to set the land area appropriated by sector 2 at zero. Sector 4 (manufacturing) is made of the category of industrial commercial units plus continuous urban fabric. Whereas category 1.1.2 (discontinuous urban fabric), which mainly comprises private housing areas, is not included in our model, as it represents no commercially used land areas. Furthermore, we assume that all forest areas are economically used, which probably overestimates the land appropriation of sector 1. Another problematic aspect is the service sector, for which no explicit numbers are given. We only added the numbers for green urban areas and sport and leisure facilities to this sector, therefore underestimating the total land area appropriated by the service sector. The land categories used in our model sum up to 78 % of the total land area, which goes in line with the estimates of total "productive land area" in the EU, published by the European Environment Agency (European Environment Agency 1999), the remaining 22% of land not included in our model comprise land categories such as grasslands, marshes and water courses (see Table 15).

As data for Sweden has not yet been published, we assume an identical land use structure for Sweden as compared to the other 14 EU member countries in order to generate data for the whole EU-15 region. Table 16 shows the total land areas for the 7 sectors of the model, the shares of the several sectors and the total "productive" land area for the EU-15, including Sweden.

Table 16: 7-sector model: total land areas for EU-15 (in hectares)

7 sectors	EU-14	Shares	Sweden	Total area EU-15
1 Agriculture, forestry, fishing	212,009,588	0,9850	34,574,330	246,583,917
2 Electricity generation and water supply	0	0,0000	0	0
3 Resource extraction	368,644	0,0017	60,118	428,762
4 Manufacturing	1,890,519	0,0088	308,304	2,198,823
5 Construction	69,525	0,0003	11,338	80,863
6 Transport	337,450	0,0016	55,031	392,481
7 Services	557,269	0,0026	90,879	648,148
Total "productive" land area	215,232,994	1	35,100,000	250,332,994

The agricultural sector is by far dominating the economically used land areas in the EU-15, accounting for not less than 212 million hectares (or 98,5 per cent of total land areas). As stated above, this might include a slight overestimation of the land areas used by the forestry sector. The manufacturing sector ranks second, with a total land appropriation of 1,8 million hectares, followed by the service sector, resource extraction and transport.

8.2 Overall land appropriation by export production

The methodology for calculating land appropriation of export production has already been explained in Section 5.3. We have to remark that in this calculation the sectoral land intensities can only be calculated by dividing the sectoral land inputs by total final use (final demand plus disposal to nature) and not by total output, as data for secondary output for the EU-15 is not yet available. Calculation details are again given in the Annex (Section 11.3). Table 17 summarises the results.

Table 17: Direct and indirect land appropriation of EU-15 exports

	Total land areas	Physical exports (t)	Total dir./indir. land	Hectares / ton of exports
Agr. For. Fish.	**246.583.917**	**29.288**	**2.367.200**	**81**
Electricity & Water	**0**	**12.642**	**63.486**	**5**
Resource extraction	**428.762**	**55.562**	**79.481**	**1**
Manufacturing	**2.198.823**	**199.115**	**6.725.133**	**34**
	80.863	**35**	**373**	**11**
Transport	**392.481**	**0**	**0**	**0**
Services	**648.148**	**18.963**	**567.175**	**30**
	250.332.994	**315.605**	**9.802.848**	**31**

The manufacturing sector, amounting for almost two thirds of the EU-15 exports, also appropriates the largest land areas (6,7 million hectares) and requires direct and indirect land inputs of 34 hectares per ton of exports. The exports from sector 1, which only account for 29 million tons or less than 10 % of total exports, correspond to more than 2,3 million hectares of land inputs with a factor of 81 hectares per ton of exports. This surprisingly high number can be explained by the absolute dominance of sector 1 in total land use, which causes a very high land intensity coefficient per unit of output and consequently also high multipliers (see Equation 43 in the Annex).

9 Conclusions

This report is divided into two main parts, the first focusing on methodological approaches for analysing international trade from the perspective of resource requirements and the second giving empirical examples for the European Union. We maintain this two-fold perspective also in this conclusions section.

9.1 Concerning methodologies

Investigating material flows and land appropriation in international trade is a new and challenging research topic, in which only a few exemplary studies have been presented so far. Whereas the methodology for accounting direct material flows is already internationally standardised within the framework of economy-wide material flow accounting and analysis (MFA) (EUROSTAT 2001), this standardisation is so far completely missing with regard to methodologies assessing direct *and* indirect resource requirements (in terms of both material flows and land use) by applying input-output analysis.

As has been illustrated using the example of Germany, the monetary economic structure on the one hand and the physical structure on the other hand show characteristic and substantial differences, as the price per volume ratio of the outputs of the several economic sectors differ significantly. For the quantification of direct and indirect resource requirements, we therefore suggested to apply input-output analysis based on physical input-output tables. Thereby distortions of results arising from the monetary structure can be avoided. The main obstacle to the application of this approach is the very limited and restrictive data situation. Physical input-output tables have so far been compiled only for a very small number of countries. Furthermore, these already published input-output tables differ completely with regard to the level of sectoral aggregation as well as the consideration of different material groups. Especially the inclusion (or exclusion) of water and air dramatically changes the structure of the inter-industry table and as a consequence also the results of input-output analysis based on these tables.

Further developments of physical input-output tables, especially within the UN initiative of establishing a "System of Integrated Environmental and Economic Accounts (SEEA)" (United Nations 2001) should focus on the definition of a standardised methodological procedure for setting up physical accounts on the national as well as supranational level. The most promising approach would be to compile in parallel both aggregate tables, providing an overall picture of the physical flows within the socio-economic system, as well as sub-tables for different material groups, as has been done in the Danish PIOT (Gravgaard Pederson 1999). The sub-tables (e.g. for water, for heavy metals, for plastics, for biotic materials) would be of particular relevance with regard to formulating environmental policy suggestions.

To our knowledge only one study dealing with input-output analysis based on physical tables has been published yet (Konijn *et al.* 1997). In this report we presented two alternative approaches on how to use a physical multiplier and performed a numerical example of the direct and indirect resource input requirements of export production in the European Union by using one of the input-output models. As data limitations turned out to be very restrictive, the results can only be regarded as a first and very rough estimation. Still, much more empirical work is needed to clarify, which of the possible approaches proves to be the most adequate for analysing environmental pressures of economic activities.

9.2 Concerning the trade, environment and sustainable development issue

The external trade relations of the EU-15 region are almost balanced in monetary terms, with the OECD countries being the origin and destination of around 50 % of the traded products. However, analyses of the physical trade balance of the European Union carried out in this report revealed that the economy of the EU faces a substantial trade deficit in physical terms with all other major world regions (including the non-EU OECD countries) and is heavily depending on resource inputs provided by other countries, especially in Asia, Africa and Latin America. The significant trade deficit in physical terms is mainly caused by the import of large amounts of fossil fuels (around 60 % of all imports) as well as abiotic raw materials and semi-manufactured products (around 20 % of all imports).

The physical trade deficit clearly illustrates that the socio-economic system of the EU is indeed to some extent draining off ecological capacity from other world regions. From the point of view of biophysical flows, the trade relations between the EU and the rest of the world can therefore be characterised as "ecologically unequal" (for a definition of ecologically unequal trade see e.g. Andersson and Lindroth 2001; Cabeza-Gutés and Martinez-Alier 1998; Hornborg 1998). Especially within the context of north-south relations, these results raise important questions – their answer require a lot more empirical research in the future:

- How important was and is the role of physical inputs from other world regions for the competitive development of the EU economy? In the age of the IT-revolution, is it still one main characteristic of countries and regions in the core of the world economy to ensure a constant inflow of physical resources from the periphery (see e.g. Bunker 1985)?
- Is this inflow of physical resources (mainly from so-called developing countries) through international trade one of the main mechanisms to ensure that the developed countries keep their leading position in the world economic system (see e.g. Altvater and Mahnkopf 1997/1996)?
- What are the actual consequences of ecologically unequal trade for those countries and regions providing natural resources in terms of both economic development potentials and actual environmental impacts? Have countries, which are net-exporters of natural resources, in general faced a lower economic performance? [16]
- What are the implications for the transformation towards an (environmentally) sustainable development especially in the so-called developing regions from the loss of natural resources through international trade?

Concerning the ongoing debate on "sustainable trade", the analysis undertaken in this report highlights the fact that environmental pressures (in terms of activated material flows) caused by international

[16] Evidently, some countries (like some of the OPEC nations in the Middle East) managed to follow a successful development path, despite the fact of being a net-exporter of resources (fossil fuels), whereas others (in sub-saharian Africa or Latin America) did not. Therefore, other factors obviously significantly influence the development perspectives as well.

trade are increasing with further trade liberalisation. The additional inclusion of resource requirements for transport and transport infrastructure would even reinforce this trend. MFA-based assessments of international trade put the aspect of the positive scale effect (see e.g. OECD 1994b) of trade liberalisation in the centre of the debate. The discussion about the transformation to a more sustainable international trade regime should also consider the absolute amounts of materials (and land) activated by trade demand and should not be reduced to questions of harmonising international standards or the internalisation of external costs.

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Annex

Numerical examples for input-output models 1 – 4

In this section we will present numerical examples for each of the approaches presented in Section 4. The examples are based on highly aggregated input-output tables for Germany for the year 1990. In order to keep the calculation simple and illustrative, aggregates with three production sectors have been derived from the 12 sector tables given by Stahmer (2000).

Calculation with MIOT (Model 1)

The starting point for the calculation with Model 1 is the monetary flow table:

Table 18: Three-sector MIOT for Germany 1990 (in billion DM)

	Primary sector	Secondary sector	Tertiary sector	Final demand		**Total output**
				Domestic	Exports	
Primary sector	40.2	89.0	79.5	2.1	10.0	220.8
Secondary sector	32.5	654.4	426.9	463.1	592.2	2,169.1
Tertiary sector	27.5	363.4	2,326.8	2,658.3	113.4	5,489.4
Value added	100.3	814.7	2,421.1			
Imports	20.4	247.8	234.6			
Total input	220.9	2,169.3	5,488.9			

Data source: Stahmer (2000)

The A matrix, calculated according to Equation (3), reads as follows:

(22)
$$A = \begin{bmatrix} 0.182 & 0.041 & 0.014 \\ 0.147 & 0.302 & 0.078 \\ 0.124 & 0.168 & 0.424 \end{bmatrix}$$

We then get the monetary multiplier (M) by subtracting this matrix from the identity matrix (I) and forming its inverse.

(23)
$$M = \left\{ \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} - \begin{bmatrix} 0.182 & 0.041 & 0.014 \\ 0.147 & 0.302 & 0.078 \\ 0.124 & 0.168 & 0.424 \end{bmatrix} \right\}^{-1} = \begin{bmatrix} 1.244 & 0.083 & 0.043 \\ 0.302 & 1.500 & 0.210 \\ 0.357 & 0.454 & 1.806 \end{bmatrix}$$

In order to link biophysical data to this monetary multiplier, we need to calculate the sectoral resource intensity. In this example we took material input data from the German PIOT of the same year.

Table 19: Primary material inputs (R_i) for German three-sector model

	Primary sector	Secondary sector	Tertiary sector
Total primary inputs (in million tons)	4234.2	277.9	567.9

Data source: Stahmer (2000)

The sectoral material intensities (r_i) can then be calculated by dividing the material inputs for each sector by the diagonal matrix of its monetary value of output ($\hat{x}$).

$$(24) \qquad r_i = \begin{bmatrix} 4234.2 & 277.9 & 567.9 \end{bmatrix} \begin{bmatrix} 221 & 0 & 0 \\ 0 & 2169 & 0 \\ 0 & 0 & 5489 \end{bmatrix} = \begin{bmatrix} 19.168 & 0.128 & 0.103 \end{bmatrix}$$

The weighted multiplier matrix (M_m) can then be obtained by post-multiplying the diagonal materix of r_i with the Leontief inverse matrix, shown in Equation (??).

$$(25) \qquad M_m = \begin{bmatrix} 19.168 & 0 & 0 \\ 0 & 0.128 & 0 \\ 0 & 0 & 0.103 \end{bmatrix} \begin{bmatrix} 1.244 & 0.083 & 0.043 \\ 0.302 & 1.500 & 0.210 \\ 0.357 & 0.454 & 1.806 \end{bmatrix} = \begin{bmatrix} 23.84 & 1.60 & 0.81 \\ 0.04 & 0.19 & 0.03 \\ 0.04 & 0.05 & 0.19 \end{bmatrix}$$

By adding up along the columns the vertical sum for each of the sectors can be received:

$$(26) \qquad M_{sum} = \begin{bmatrix} 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} 23.84 & 1.60 & 0.81 \\ 0.04 & 0.19 & 0.03 \\ 0.04 & 0.05 & 0.19 \end{bmatrix} = \begin{bmatrix} 23.919 & 1.835 & 1.029 \end{bmatrix}.$$

We finally get the sum of direct and indirect materials activated by export demand (R_E) by post-multiplying this vector with the diagonal matrix of exports (in monetary terms) ($\hat{E}$).

$$(27) \; R_e = \begin{bmatrix} 23.919 & 1.835 & 1.029 \end{bmatrix} \begin{bmatrix} 10.00 & 0 & 0 \\ 0 & 592.20 & 0 \\ 0 & 0 & 113.40 \end{bmatrix} = \begin{bmatrix} 239.189 & 1086.955 & 116.660 \end{bmatrix}.$$

According to the results provided by Model 1, the absolute resource requirements activated by German exports in 1990 thus are 239,2 million tons for the primary sector, 1087,0 tons for the secondary and 116,7 tons for the tertiary sector.

Calculation with a PIOT closed for primary inputs (Model 2)

Model 2 is based on a physical input-output table, which is closed for primary inputs (Tab. 20).[17]

Table 20: Three-sector PIOT for Germany 1990, closed model (in million tons)

	Primary sector	Secondary sector	Tertiary sector	Primary inputs	Residuals	Final demand		**Total output**
						Domestic	Exports	
Primary sector	2,247.7	1,442.2	336.2	0	2,404.5	46.8	36.7	6,514.1
Secondary sector	27.4	1,045.4	206.2	0	846.8	552.5	155.9	2,834.2
Tertiary sector	5.1	68.5	50.9	0	1,000.5	16.3	20.0	1,161.3
Primary inputs	4,234.2	277.9	567.9	0				
Total input	6,514.4	2,834.0	1,161.2					

Data source: Stahmer (2000)

The physical A matrix (A_P) is obtained by dividing the extended flow table (F_r) by the diagonal matrix of total output (x):

(28)
$$A_P = \begin{bmatrix} 0.345 & 0,509 & 0,290 & 0,000 \\ 0.004 & 0,369 & 0,178 & 0,000 \\ 0.001 & 0,024 & 0,044 & 0,000 \\ 0.650 & 0,098 & 0,489 & 0,000 \end{bmatrix}$$

We obtain the physical multiplier matrix (M_p) by subtracting the physical A matrix (A_p) form the identity matrix (I) and forming its inverse. The physical multiplier matrix is shown in Equation 29:

[17] For better illustration, the inputs of the other sectors to the waste treatment sector (e.g. solid wastes, waste water, etc.), which is indicated as a tertiary (service) sector in the original publication, has been directly added to the residuals in both Model 2 and 3. Otherwise the service sector would have been the sector with the highest material inputs.

(29) $$M_P = \begin{bmatrix} 1,536 & 1,265 & 0,700 & 0,000 \\ 0,011 & 1,605 & 0,301 & 0,000 \\ 0,002 & 0,042 & 1,054 & 0,000 \\ 1,000 & 1,000 & 1,000 & 1,000 \end{bmatrix}$$

The aggregate multiplier (M_{sum}) for each of the sectors is:

(30)
$$M_{sum} = \begin{bmatrix} 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} 1,536 & 1,265 & 0,700 & 0,000 \\ 0,011 & 1,605 & 0,301 & 0,000 \\ 0,002 & 0,042 & 1,054 & 0,000 \\ 1,000 & 1,000 & 1,000 & 1,000 \end{bmatrix} = \begin{bmatrix} 2,548 & 3,911 & 3,055 & 1,000 \end{bmatrix}$$

The direct and indirect material requirements can then be obtained by post-multiplying the diagonal matrix of the exports (in tons) with the aggregated multiplier:

(31) $$R_e = \begin{bmatrix} 2,548 & 3,911 & 3,055 & 1,000 \end{bmatrix} \begin{bmatrix} 36,7 & 0 & 0 & 0 \\ 0 & 155,9 & 0 & 0 \\ 0 & 0 & 20 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 93,514 & 609,741 & 61,101 \end{bmatrix}$$

According to the calculations in Model 2, the total material requirements for export production are 93.5 million tons for the primary sector, 609.7 million tons for the secondary sector and 61.1 million tons for the tertiary sector.

Calculation with a PIOT distinguishing between primary and secondary inputs (Model 3)

Model 3 again has the aggregated PIOT as the starting point, but separates primary and secondary material inputs (Table 21).

Table 21: Three-sector PIOT for Germany 1990, open model (in million tons)

	Primary sector	Secondary sector	Tertiary sector	Sum secondary material outputs	Residuals	Final demand		**Total output**
						Domestic	Exports	
Primary sector	2,247.7	1,442.2	336.2	4026.1	2,404.5	46.8	36.7	6,514.1
Secondary sector	27.4	1,045.4	206.2	1279.0	846.8	552.5	155.9	2,834.2
Tertiary sector	5.1	68.5	50.9	124.5	1,000.5	16.3	20.0	1,161.3
Sum secondary material inputs	2280.2	2556.1	593.3					
Primary material inputs	4,234.2	277.9	567.9					
Total input	6,514.4	2,834.0	1,161.2					

Data source: Stahmer (2000)

The matrix of physical technical coefficients (A_p) is calculated by dividing the inter-industry matrix by the diagonal matrix of total output (x). Equation 27 shows the A matrix based on the above flow table (Table 19) in physical units:

$$(32) \qquad A_p = \begin{bmatrix} 0.345 & 0.509 & 0.290 \\ 0.004 & 0.369 & 0.178 \\ 0.001 & 0.024 & 0.044 \end{bmatrix}.$$

In the next step, the physical multiplier for secondary materials (M_s) can be obtained by subtracting this physical A matrix from the identity matrix and forming its inverse:

$$(33) \qquad M_s = \left\{ \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} - \begin{bmatrix} 0.345 & 0.509 & 0.290 \\ 0.004 & 0.369 & 0.178 \\ 0.001 & 0.024 & 0.044 \end{bmatrix} \right\}^{-1} = \begin{bmatrix} 1.536 & 1.265 & 0.700 \\ 0.011 & 1.605 & 0.301 \\ 0.002 & 0.042 & 1.054 \end{bmatrix}.$$

To integrate primary material inputs, we have to calculate a coefficient of primary material input per secondary material output (C_p) for each sector. The row of coefficients of primary inputs looks as follows:

$$(34) \qquad C_p = \begin{bmatrix} 1.052 & 0.217 & 4.561 \end{bmatrix}.$$

By post-multiplying the diagonal matrix of this coefficient with the multiplier for secondary materials (M_s), we get the extended physical multiplier (M_e):

$$(35)\qquad M_e = \begin{bmatrix} 1.052 & 0 & 0 \\ 0 & 0.271 & 0 \\ 0 & 0 & 4.561 \end{bmatrix} \begin{bmatrix} 1.536 & 1.265 & 0.700 \\ 0.011 & 1.605 & 0.301 \\ 0.002 & 0.042 & 1.054 \end{bmatrix} = \begin{bmatrix} 1.615 & 1.331 & 0.736 \\ 0.002 & 0.349 & 0.065 \\ 0.007 & 0.190 & 4.808 \end{bmatrix}.$$

The column sum of the multipliers for each sectors is

$$(36)\qquad M_{sum} = [1.624 \quad 1.869 \quad 5.610].$$

We finally get the direct and indirect material requirements for export production by post-multiplying this vector with the diagonal matrix of exports (in tons).

$$(37)\qquad \mathrm{R_e} = [1.624 \quad 1.869 \quad 5.610] \begin{bmatrix} 36.7 & 0 & 0 \\ 0 & 155.9 & 0 \\ 0 & 0 & 20.0 \end{bmatrix} = [59{,}616 \quad 291{,}366 \quad 112{,}190].$$

The absolute amount of material requirements caused by export demand thus is 59.6 million tons for the primary sector, 291.4 million tons for the secondary sector and 112.2 million tons for the tertiary sector.

Calculation with a PIOT with final demand extended for waste (Model 4)

For the calculation of direct and indirect material requirements, which are to be attributed to exports, with Model 4, we need (a) a physical multiplier of secondary materials (M_s) and (b) an export vector, extended by the share of "unused materials" according to the input structure. The physical multiplier has already been calculated in Equation (33). Summing up the multipliers vertically for each of the sectors leads to

$$(38)\qquad M_{sum} = [1{,}548 \quad 2{,}911 \quad 2{,}055].$$

For the extension of the export vector, we refer to the output quadrant of the German PIOT (Table 22).

Table 22: Final demand and residuals in German PIOT 1990 (in million tons)

Sectors	Residuals	Final demand	
		Domestic	Exports
Primary sector	2,404.5	46.8	36.7
Secondary sector	846.8	552.5	155.9
Tertiary sector	1,000.5	16.3	20.0

Source: Stahmer (2000)

In the first step, we calculate the shares of domestic consumption (S_D) and exports (S_E) in final demand for each of the sectors according to Equation (19). The shares are presented in the following table:

Table 23: Shares of domestic consumption and exports in final demand

	Final demand	
	Domestic	Exports
Primary sector	0.56	0.44
Secondary sector	0.78	0.22
Tertiary sector	0.45	0.55

In the second step we transform the vector of disposals to nature according to the structure of material inputs. For this, we have to calculate a coefficient of disposals to nature per primary input. From Table 20 we get the total material input as 5080 million tons and total waste as 4251.8 million tons. The coefficient of waste generation per unit of primary input then is 0,84. The new vector of "unused" materials (W_I) is derived by multiplying the primary input of each sector with the coefficient. Table 24 gives the absolute numbers of "unused" materials with the input structure as well as the shares of the two final demand categories according to Table 23.

Table 24: New vector of residuals (W_I) attributed to domestic consumption and exports (in million tons)

	"Unused materials" (with input structure)	Shares of residuals (in absolute numbers)	
		Domestic	Exports
Primary sector	3543.9	1986.00	1557.89
Secondary sector	232.6	181.42	51.17
Tertiary sector	475.3	213.42	261.90
Total	5080.0	2380.84	1870.96

We then add the share of residuals to the vector of domestic consumption and exports to obtain the extended vectors (D_{ext} and E_{ext}).

Table 25: Extended vectors for domestic consumption and exports

	Final demand	
	Domestic	Exports
Primary sector	2032,8	1594,6
Secondary sector	733,9	207,1
Tertiary sector	229,7	281,9

By post-multiplying the diagonal matrix of these extended vectors with the multiplier matrix (M_{sum}) we finally get the direct and indirect material requirements. Equation (39) shows the numbers for exports.

$$(39) \qquad R_e = \begin{bmatrix} 1.548 & 2.911 & 2.055 \end{bmatrix} \begin{bmatrix} 1594.6 & 0 & 0 \\ 0 & 207.1 & 0 \\ 0 & 0 & 281.9 \end{bmatrix} = \begin{bmatrix} 2468.4 & 602.9 & 579.4 \end{bmatrix}$$

Using Model 4 for the calculation of material requirements we receive 2.468 million tons for sector 1, 602.9 million tons for sector 2 and 579.4 million tons for sector 3.

Detailed calculation of direct and indirect material requirements of EU-15 exports

According to calculation Model 4, we first have to calculate the physical multiplier matrix. For this, the technology matrix (A matrix)

(40) A =

0,097	0,027	0,000	0,228	0,001	0,000	0,037
0,002	0,026	0,000	0,008	0,000	0,001	0,020
0,059	0,128	0,036	0,237	0,367	0,000	0,076
0,168	0,022	0,003	0,180	0,232	0,471	0,465
0,001	0,001	0,000	0,001	0,000	0,009	0,129
0,000	0,000	0,000	0,000	0,000	0,000	0,000
0,000	0,000	0,000	0,001	0,000	0,000	0,000

is subtracted from the identity matrix (I) and its inverse is formed to obtain the physical multiplier of secondary materials (M_s):

(41) M_s =

1,168	0,041	0,001	0,326	0,077	0,154	0,206
0,004	1,027	0,000	0,011	0,003	0,006	0,027
0,132	0,149	1,039	0,340	0,460	0,164	0,305
0,241	0,037	0,005	1,289	0,301	0,610	0,648
0,001	0,001	0,000	0,001	1,000	0,009	0,130
0,000	0,000	0,000	0,000	0,000	1,000	0,000
0,000	0,000	0,000	0,001	0,000	0,000	1,001

Then the numbers are summed up by columns to get the aggregate multiplier M_{sum} (Equation 42):

(42) M_{sum} =

1,546	1,254	1,044	1,969	1,841	1,944	2,316

Second, we have to derive the extended export vector. For this, we calculate the shares of stock exchange and exports in final demand (Table 26).

Table 26: Shares of stock exchange and exports in the 7 sectors of the EU-15 model

	Stock exchange	Exports
Agriculture, forestry, fishing	0,78	0,22
Electricity and water	0,63	0,37
Resource extraction	0,42	0,58
Manufacturing	0,51	0,49
Construction	1,00	0,00
Transport	1,00	0,00
Services	0,86	0,14

Next, we calculate a coefficient of total disposal to nature per total primary input (C_w), based on the numbers given in Table 13. C_w equals 0,676. The multiplication of the original numbers listed in the row of primary inputs with the coefficient performs the transformation into the corresponding input structure. The total numbers stay unchanged (Table 27).

Table 27: Original Disposal to nature per sector and numbers adjusted by input structure (in 1000 tons)

	Disposal to nature (original)	Disposal adjusted by input structure
Agriculture, forestry, fishing	1.792.075	1.570.878
Electricity and water	2.078.170	1.101.705
Resource extraction	666.884	4.271.273
Manufacturing	1.695.154	832.220
Construction	1.209.801	35.957
Transport	323.702	214.642
Services	518.871	257.982
	8.284.657	8.284.657

The new vector with the input structure (W_I) then is distributed to the two categories of stock exchange and exports according to the shares listed in Table 25. Adding these numbers to the original export vector delivers the extended vector, which is displayed in Table 28.

Table 28: The extended export vector in the EU-15 model (in 1000 tons)

Agriculture, forestry, fishing	379.225
Electricity and water	419.698
Resource extraction	2.535.840
Manufacturing	603.642
Construction	36
Transport	0
Services	54.276

Post-multiplying the diagonal matrix of the extended export vector with the aggregated multiplier shown in Equation 42 delivers the direct and indirect material requirements of export production, which can be taken from Table 14 in Section 7.2.

Detailed calculation of land appropriation of EU-15 exports

For the calculation of the sectoral land appropriation of exports from the EU-15 to the rest of the world, we start with the calculation of the sectoral land intensities. For this, we divide the land use data for each of the sectors by total final use (final demand plus disposal to nature). Table 29 gives the land intensities *(l)*.

Table 29: Land intensities of total final use in the 7-sector model

	Total land areas	Total final use	Land intensity coefficient (l)
Agriculture, forestry, fishing	246.583.917	1.909.921	129,11
Electricity and water	0	2.111.610	0,00
Resource extraction	428.762	821.657	0,52
Manufacturing	2.198.823	2.059.530	1,07
Construction	80.863	4.367.948	0,02
Transport	392.481	325.567	1,21
Services	648.148	658.427	0,98
All sectors	250.332.994	12.254.660	20,43

Then we pre-multiply the diagonal matrix of the land intensity coefficient with the original physical multiplier (Equation 41) in order to obtain the multiplier weighted by the land intensity (M_l).

(43) $M_l =$

150,834	5,233	0,148	42,153	9,951	19,942	26,549
0,000	0,000	0,000	0,000	0,000	0,000	0,000
0,069	0,077	0,540	0,177	0,239	0,085	0,158
0,258	0,040	0,005	1,380	0,322	0,653	0,694
0,000	0,000	0,000	0,000	0,020	0,000	0,003
0,000	0,000	0,000	0,000	0,000	1,210	0,000
0,000	0,000	0,000	0,001	0,000	0,000	0,981

The direct and indirect land appropriations by exports are then calculated by summing up the multiplier by columns (M_{sum}) and post-multiplying the diagonal matrix of the physical exports with M_{sum}. The results are found in Table 17 in Section 8.2.