Development of material use in the EU-15: 1970-2001.

Types of materials, cross-country comparison and indicator improvement

Draft report

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Introduction and Objectives

In the past years the physical dimension of economic processes, in particular the socio-economic use of materials, was increasingly recognized as key area for a sustainable development strategy in the European Union and in the OECD. In 2001 the Gothenburg Council adopted the Sustainable Development Strategy which has been reviewed and revised this year (Commission of the European Communities 2004, COM 2004 133-final). The 6th environmental action programme (OJC L241 1 2002) specifies the sustainable use of resources as one of six priority fields for the period 2002 to 2012. A communication towards a thematic strategy on sustainable use of resources was published by the European Commission in 2003 (Commission of the European Communities 2003) and the thematic strategy is currently in its final stage of preparation. These processes substantially increased the need for economy-wide, reliable and comparable time-series data and indicators for material use.

The backbone of an environmental reporting system which provides such information is economy-wide material flow accounting (MFA). Economy-wide material flow accounts are consistent compilations of the overall material inputs into national economies, the material accumulation within the economic system and the material outputs to other economies or to the environment. MFA covers all material inputs except for water and air, the unit of measurement is tonnes per year (Eurostat 2001a). Economy-wide MFA thereby complements the system of national accounts which describes production and consumption activities in monetary terms, by a compatible system of biophysical national accounts.

Since the mid-1990s Eurostat and an increasing number of national statistical offices have been compiling economy-wide MFAs (Schandl et al. 2000) (Pedersen 2002) (Mäenpää and Juutinen 2001), (Muukkonen 2000), (Statistisches Bundesamt 1995), (German Federal Statistical Office - Statistisches Bundesamt 2000), (Barbiero et al. 2003), (Isacsson et al. 2000), (DETR/ONS/WI 2001). The G-8 industrial nations recently recommended the implementation of economy-wide material flow accounting in all OECD countries (OECD 2004).

Two publications by the World Resources Institute pioneered the comparative empirical analysis of national economies in physical terms and the development of internationally comparable MFA indicators (Adriaanse et al. 1997) and (Matthews et al. 2000). A major step towards methodological harmonization was the publication of *Economy-wide material flow accounts and derived indicators: A methodological guide* (Eurostat 2001a).

The European Environmental Agency published first estimates of aggregate material indicators for the EU-15 in its indicator report *Environmental signals 2000* (EEA 2000) and in its 2001 report *Total material requirements of the European Union*, prepared by the Wuppertal Institute ((Bringezu and Schütz 2001)) and (Bringezu et al. 2001)

The Wuppertal Institute also prepared the first time-series of aggregate material use in the EU-15, 1980 to 1997 for Eurostat and the DG Environment, documented in the Eurostat report *Material use indicators for the European Union: 1980-1997* (Eurostat 2001b). The data set on which this study was based is referred to as *Eurostat/WI/2001 data set* in the following report.

In the same year Eurostat and the DG Environment commissioned a project aiming at updating, extending, and revising the Wuppertal Institut's 2001 estimate. The results for the period 1980 to 2000, including a systematic breakdown by all EU member states, dematerialization analysis, data sources, methods and recommendations are documented in *Material use in the European Union 1980-2000: Indicators and Analysis* ((Eurostat 2002), prepared by the IFF-Social Ecology. The data set underlying this study is referred to as the *Eurostat/IFF 2002 data set* in following report. The Eurostat/IFF 2002 data set put an emphasis on methodological harmonization, improvement of the comparability of the accounts, and a consistent integration of national MFAs (i.e. economy-wide material flow accounts compiled by national Statistical offices of the EU member states)

Later in 2002 the European Topic Centre on Waste and Material Flows published the study *Resource use in European Countries* (ETC-WMF (European topic centre on waste and material flows) 2003) prepared by the Wuppertal Institute, the so called "zero study". This report gives an overview of the material use in the EU-15 member states and 13 accession countries (now EU-25 plus Rumania, Bulgaria, and Turkey) using the Eurostat/IFF 2002 data set for DMC, DMI, and PTB, the Eurostat/Wuppertal 2001 data set for TMR, DPO and NAS accounts , and additional estimates for the 13 accession countries (only DMI).

The following report builds upon this previous work, from which it will picks up the following key messages. The level of overall domestic extraction in the EU-15 remained quite constant in the past two decades. The same holds true for EU wide domestic material consumption, which changed only slightly, following a pattern that closely resembles the economic cycles (phases of recession, low and high GDP growth). For a deeper understanding of the past development of material use and its determining factors an extension of the historical time-series as well as a more detailed breakdown by different types of materials would be necessary.

Physical imports and exports increased substantially. The structure of the physical imports shows a high reliance on the rest of the world as a source for metal ores and fossil fuels. The growth of physical exports was twice as high as the increase of imports in the period 1980 to 2000. Considering also that exports are mainly composed of highly processed commodities, these findings stress the need to develop reliable procedures to account for raw material equivalents (RMEs) of foreign trade flows.

The EU-15 member states are very different in terms of material use regarding, the level of use, the composition of materials used, the role of foreign trade and the development over the past decades. Identifying the driving forces and determinants of these differences is essential to specify potentials and limitations of possible political interventions towards a more sustainable use of resources.

Summarizing, the following report takes up the issues of: historical trends in material use, economic growth and material use, the role of foreign trade, the types of materials used in EU-15, patterns and determinants of cross-country variability, interpretation and further development of MFA derived indicators. In particular, the objectives of this report are:

- to present the main results of the extension of the *Eurostat/IFF 2002 data set* back to 1970 and an update for 2001, in the following referred to as *Eurostat/IFF 2004 data set.*
- to present and analyse the main results of a further break down of the times series of economy-wide material flows into 12 categories of materials.
- to take a first step to explain the different trends and patterns of material use in the EU-15.
- to explore methods for calculating raw material equivalents (RMEs) of exports and imports using monetary and physical input-output analysis and to present a first comparative estimate of new MFA/IO derived indicators based on RMEs, for one member state.
- to document all data sources and procedures applied or developed.

Indicators for material use and material categories

The compilation of the *Eurostat/IFF 2004 data set*, and the derived indicators which represent the empirical basis for this study, is consistent with the methodological guidelines published by Eurostat (2001a) and the further methodological specifications documented in Eurostat (2002). All additional procedures and data sources are documented in the technical part of this report.

Some of the aggregated indicators that are used in this analysis have been defined by Eurostat (2001a), others are newly developed. For reasons of readability we here define all indicators of material use which appear in this study.

System boundaries

“The focus of economy-wide MFA and balances is on the economy’s metabolism, i.e. on the flows between a given economy and the environment. Therefore, the system boundary is defined: 1. by the extraction of primary (i.e., raw, crude or virgin) materials from the national environment and the discharge of materials to the national environment; 2. by the political (administrative) borders that determine material flows to and from the rest of the world (imports and exports). Natural flows into and out of a geographical territory are excluded. [...]

Inputs from the environment refer to the extraction or movement of natural materials on purpose and by humans or human-controlled means of technology (i.e., involving labour). [...] Material flows within the economy are not presented in economy-wide MFA and balances. Therefore, inter-industry deliveries of products, for example, are not described. However, they are described in Physical Input-Output Tables (PIOT) (Eurostat 2001a).

Extensive material flow indicators

Domestic extraction (DE): The aggregate flow DE covers the annual amount of solid raw materials (i.e. all material except for water and air), extracted from the national territory in order to be used as material factor inputs to economic processing. The term “used” refers to acquiring value within the economic system, it signifies “an input for use in any economy, i.e. whether a material acquires the status of a product...” (Eurostat 2001a, p.20).

Physical imports and physical exports: All imported or exported commodities in tonnes. Traded commodities comprise goods at all stages of processing from raw materials to finals products.

Domestic material consumption (DMC) measures the annual amount of raw materials extracted from the domestic territory of the focal economic area, plus all physical imports minus all physical exports. It is important to note that the term "consumption" as used in DMC denotes "apparent consumption" and not "final consumption". DMC, thus, is defined in analogy to "total primary energy supply" - TPES (see (Haberl 2001). Conceptually DMC represents a "physical GDP equivalent" (Eurostat 2001a).

Physical trade balance (PTB) equals physical imports minus physical exports. This definition of the physical trade balance as being the reverse of the definition of the monetary trade balance (exports minus imports) recognizes that in economies, money and goods move in opposite direction. A physical trade surplus indicates a net import of materials, whereas a physical trade deficit indicates a net export.

Intensive material flow indicators

For cross-country comparisons intensive material flow indicators must be used. As common in environmental accounting we here use population as denominator, to compare the levels of economy-wide material use between nation states.

To indicate overall material efficiency of an economy we relate DMC to GDP (in const. 1995 Euros, for details see part II of this report).

Material intensity is defined as the DMC to GDP ratio.

Material productivity is the inverse of material intensity, thus the GDP to DMC ratio.

To compare the differences in the importance of foreign trade across countries and across time we introduce the following intensive MFA indicators.

DE to DMC ratio: The ratio of domestic extraction to domestic material consumption indicates the dependence of the physical economy on domestic raw material supply. We therefore denote the DE/DMC ratio as "**domestic resource dependency**".

Import to DE ratio and **export to DE ratio**: The ratios between imports and exports respectively to DMC indicate the import respectively export intensities of the physical economies. Together they can be addressed as "**trade intensity**" indicators.

Classification of material categories:

Aggregated economy-wide material flow indicators allow to monitor the material use of national economies in a comparable, transparent and comprehensive way. To identify driving forces of national material use patterns and to evaluate progress concerning dematerialisation and sustainable use of resources, however, detailed material flows rather than highly aggregated indictors must be examined (c.f. Commission of the European Communities 2003; Ayres and Ayres 1998).

Table 1: Classification and definition of twelve types of material flows

Main material categories	Subcategories	Aggregated items
Biomass	Food	All potentially edible biomass from cropland
	Feed	All biomass from grassland, by-products and crops exclusively used for feeding livestock
	Animals	DE of “wild” animals (in particular fish catch) and all traded livestock and animal products, incl. fish
	Wood	Wood and wood based products incl. paper, furniture etc.
	Other biomass	Commodities consisting predominantly of biomass which cannot be allocated to one of the above biomass categories (textiles, fibre crops etc.)
Fossil fuels	Coal	All types of coal and derived products
	Oil	All types of oil and derived products
	Natural gas	All types of natural gas and derived products
	Other fossils	Peat etc.
Industrial minerals	Industrial minerals	All non-metallic minerals used predominantly for industrial processes (excl. fossil fuels)
	Ores	All types of metallic ores and metal based products
Construction minerals	Construction minerals	All minerals used primarily in construction

A detailed analysis in turn needs to be based on a consistent classification. The classification of material categories and the level of detail according to which we carry out our analysis, follow specific guiding principles. First, the level of detail must be justified by the data quality (see Eurostat 2002 and part II of this report). Second, the level of detail should not impair the strength of material flow analysis in providing an overall picture of the economy-wide material flows. Third, the classification should be consistent and meaningful in terms of physical and chemical properties, economic use and environmental pressures associated with the primary production of the materials.

The application of these principles led to the classification shown in table 1 which distinguishes between four main material categories and twelve material subcategories. For each of the twelve subcategories, the material flow parameters DE, imports, exports, as well as the derived indicators DMI, DMC and PTB have been compiled for each of the European Union member states and for the EU as a whole, for the time period 1970 – 2001.

Classification of countries

When discussing country patterns of material use we apply the following classifications;

According to geographical position:

Mediterranean Countries: GR, IT, ES, PT

Northern European Countries: GB, IE, NL, BE/LU, DK

Scandinavian Countries: SE, FI

Central European Countries: AT, FR, GE

According to national income

Low income countries: PT, GR, ES, (IE) (real GDP/cap more than 20 % beyond EU average).

Medium income countries: IT, GB (real GDP/cap less that 20 % beyond EU average).

High income countries: DK, AT, SE, GE, BE/LU;FI, NL, FR, (IE) (real GDP/cap above EU average).

With the exception of Ireland all member states remained in the same relative income level throughout the whole period of time. Ireland experienced an unprecedented economic growth since the mid 1990s and thus turned from a low income country (1970 to 1994) to a medium income country (1995 to 1998). Since 1999 Ireland has an above average per capita income and may thus be classified as high income country.

Development and composition of material use in the EU-15 1970 to 2001

In the EU-15 the total amount of materials extracted from the domestic territories amounted to 4.3 billion tonnes in 1970 and to 4.8 billion tonnes in 2001. With 1 billion tonnes in 1970 and 1.4 billion tonnes in 2001, physical imports account for app. 20% of DMI in both 1970 and 2001. The level of physical exports is significantly lower compared to imports. They amounted to 0.2 billion tonnes in 1970 and to 0.4 billion tonnes in 2001. Thus, in the European Union, physical imports now exceed physical exports by a factor of four. Total change between 1970 and 2001 was 100 % for exports and 40% for imports. DMC amounted to 5 billion tonnes in 1970 compared to 5.9 billion tonnes in 2001 (Table 2).

Table 2: Main material flow indicators EU-15: 1970 and 2001

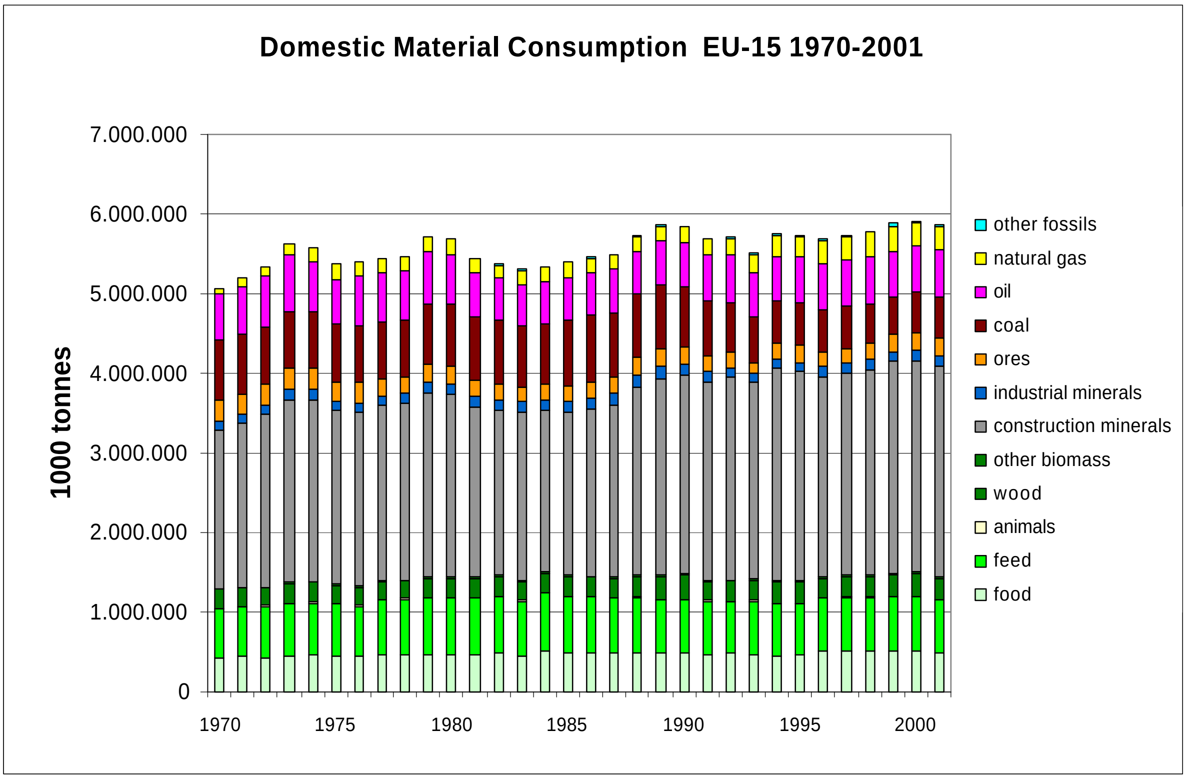
EU-15	**1970**	**2001**
[1 000 tonnes]		
DE	4.254.134	4.833.472
Imports	1.020.574	1.442.045
Exports	197.490	402.808
DMC	5.077.218	6.275.517

source: Eurostat/IFF 2004

Domestic Material Consumption

The material composition of DMC in the EU-15 is characterized by a dominance of construction minerals (45% in 2001). Over the whole period of time the use of construction minerals increased by 32%. The share of fossil fuels in DMC slightly declined from 28% in 1970 to 25% in 2001. This is due to a shift from the less energy intensive coal to natural gas (energy content of coal is only 30 to 50% of oil and gas).

Figure 1: Development and material composition of overall domestic material consumption in the EU 15 1970 to 2001

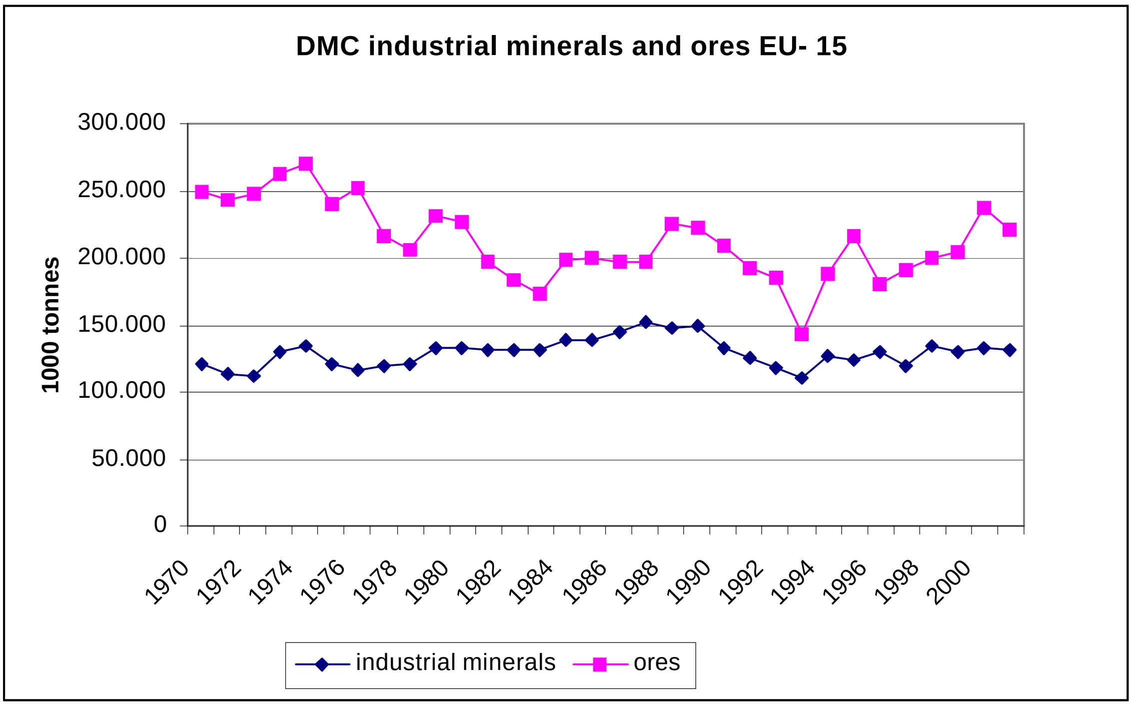


Source: Eurostat/IFF 2004

The use of coal declined by 33% over the whole period whereas consumption of natural gas increased by 300%. Domestic consumption of oil remained fairly constant in the past three decades (plus 5 %). Since 1970 the share of coal in total DMC declined from 15 to 9% while the share of natural gas increased from 1,5 to 5%. (see Figure 1). Currently the share of coal, oil, and natural gas in fossil fuel consumption is 37%, 42%, and 21% respectively. In 1970 fossil fuel consumption was composed of 54% coal, 41% oil, and 5% natural gas.

The share of biomass in total DMC was constantly at 25% over the whole period. Structurally, a slow shift towards animal fodder (feed) can be observed, indicating the growing importance of meat production in the EU. Likewise wood production increased by 10 % over the whole period.

Figure 2: Domestic material consumption of industrial minerals and ores in the EU –15



Source: Eurostat/IFF 2004

The trend for the domestic consumption of industrial minerals and ores is less homogenous (see Figure 2). In particular the consumption of ores fluctuated substantially. In the period of observation the domestic extraction of ores in the EU 15 dramatically declined and was more and more substituted by imports (see also Figure 3and Figure 7 below). By this, the domestic consumption of ores became more and more dependent on world market prices, which in turn are strongly affected by the economic cycles. From Figure 2 the years after the two oil crises of the 1970s and the 1993 recession can easily be depicted as phases of low domestic consumption of ores (see also the chapter on foreign trade). The ongoing economic boom in China and India, with its resulting accelerated demand for raw materials from the world market (above all metals and fossil fuels) and the subsequent rise in raw material prices, certainly will affect the future of metal ore consumption in the EU.

Foreign trade flows and physical trade balances

The EU-15 member states import from other EU member states and from the rest of the world in roughly the same orders of magnitude in terms of tonnes and money. In 2000 EU imports from the rest of the world (so called extra EU trade) amounted to 1.4 billion tonnes worth 1000 billion Ecu. EU exports to the rest of the world amounted to 900 billion Ecu and 0.4

billion tonnes. Logically the sum of intra-EU imports and exports must be the same, they amounted to 1.1 billion tonnes worth 1500 billion Ecu in 2000. If we compare the ton prices of extra EU imports and exports (Table 3) we see that the EU exports comparable small amounts of expensive products (which indicates a high state of processing and high know how intensity of the traded commodities) and imports large amounts of comparable cheap products, mainly raw materials and semi manufactured commodities, from the rest of the world. Intra EU trade is in between extra EU imports and exports in terms of overall volume and ton prices (Table 3).

Table 3: Foreign trade structure of the EU 15 in 2000

	Imports		Exports	
	intra EU	extra EU	intra EU	extra EU
1000 billion Ecu	1.5	1.1	1.5	0.9
billion tonnes	1.1	1.4	1.1	0.4
ton prices (Ecu/kg)	1.3	0.7	1.3	2.2

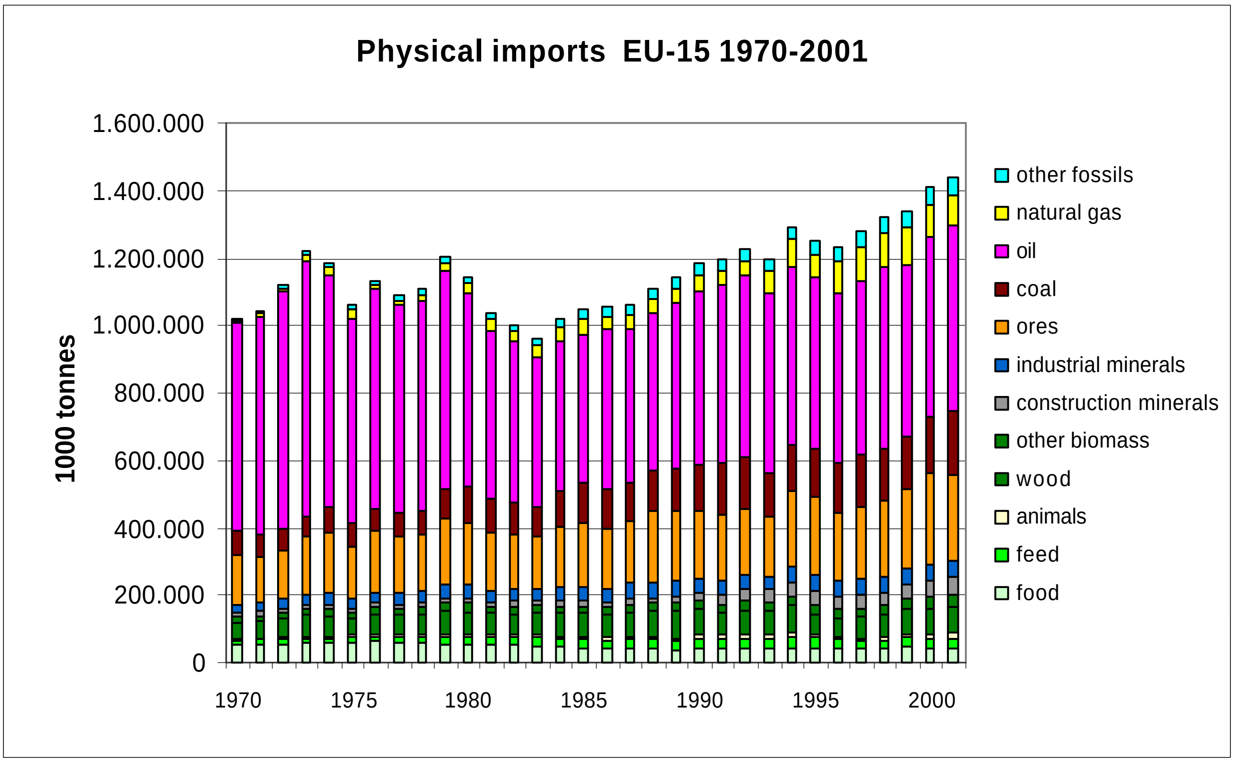
Source: Eurostat/IFF 2004 and Comext database, current prices

For the compilation of aggregated EU wide MFA indicators intra EU trade must of course be netted out. Figure 3 shows the development and material composition of the physical imports to the EU from the rest of the world between 1970 and 2001. The material composition clearly shows the high reliance on imported fossil fuels and ores. Currently (2001) these two commodity groups together make up 80% of the physical import volume of the EU-15. Fossil fuels amount to three fourth of this 80% and ores to one fourth.

The fossil fuel imports since 1970 are characterized by the dominance of oil. However, during the past decades this dominance slowly declined. The import volume of oil peaked in 1973, (the year of the first oil crises) when the EU-15 imported 760 million tonnes (or 91 % of all imported fossil fuels). From 1973 to 1984 the import volume dropped to 440 million tonnes. Since 1990 EU-15 oil imports are stable at around 520 million tonnes, or 70 % of all imported fossil fuels. In total oil imports declined by 11% from 1970 to 2001. This development is a consequence of the oil crises in the 1970s and the subsequent accelerated exploitation of North-Sea oil by the United Kingdom (since the mid 1970s) and later by Denmark (since the

1990s). The Netherlands, the third EU country with excess to the North Sea fossil fuel resources, exploits predominantly natural gas.

Figure 3: Material composition and development of physical imports to the EU-15 (extra EU trade only)



Source: Eurostat/IFF 2004

Coal is the second largest fraction of imported fossil fuels, the overall import volume increased continuously during the past decades. (total increase between 1970 and 2001 was 180 %). The increasing imports of coal developed in parallel with the decline of domestic exploitation of coal, predominantly caused by the closure of lignite sites in the former GDR after the German reunion (see also below Figure 7). The increases in coal imports did not fully compensate for the decline in domestic extraction leading to a total reduction of domestic consumption of coal by 33% since 1970 (see above).

As can be seen from Figure 3 imports of natural gas were marginal in the early 1970s, they amounted to less than one tenth of the domestic production inside the EU, which was at app. 100 millions tonnes in the early 1970s. Imports of natural gas levelled off in three phases starting 1974, 1984, and 1993, in clear correspondence to the oil crises and the economic development. Natural gas imports peaked in 1999 with a volume of 108 million tonnes, which is half of the domestic production in that year. In total natural gas imports increased by 1200% over the whole period.

Products from fossil fuels which comprise highly manufactured consumer goods raised since the mid 1980s now reaching a share of 4% of total import volume.

The share of metal ores in total import volume of the EU-15 increased from 14% in 1970 to 18% in 2001. In total imports grew by 75% from 147 million tonnes in 1970 to 257 million tonnes in 2001. In parallel to this trend the domestic extraction of metals ores declined by 70% since 197. This shift from domestic production to imports from outside the European Union is the most pronounced among all material groups distinguished in this study. Less dominant in total volume but likewise increasing are imports of industrial minerals (plus 90% since 1970). Construction minerals played no significant role in the import structure of the EU-15 during the first two decades. Since 1990, however, imports of construction minerals have been rising and amount to 51 million tonnes or 4% of total import volume in 2001. Compared to the level of the domestic consumption of construction minerals this is still a negligible quantity.

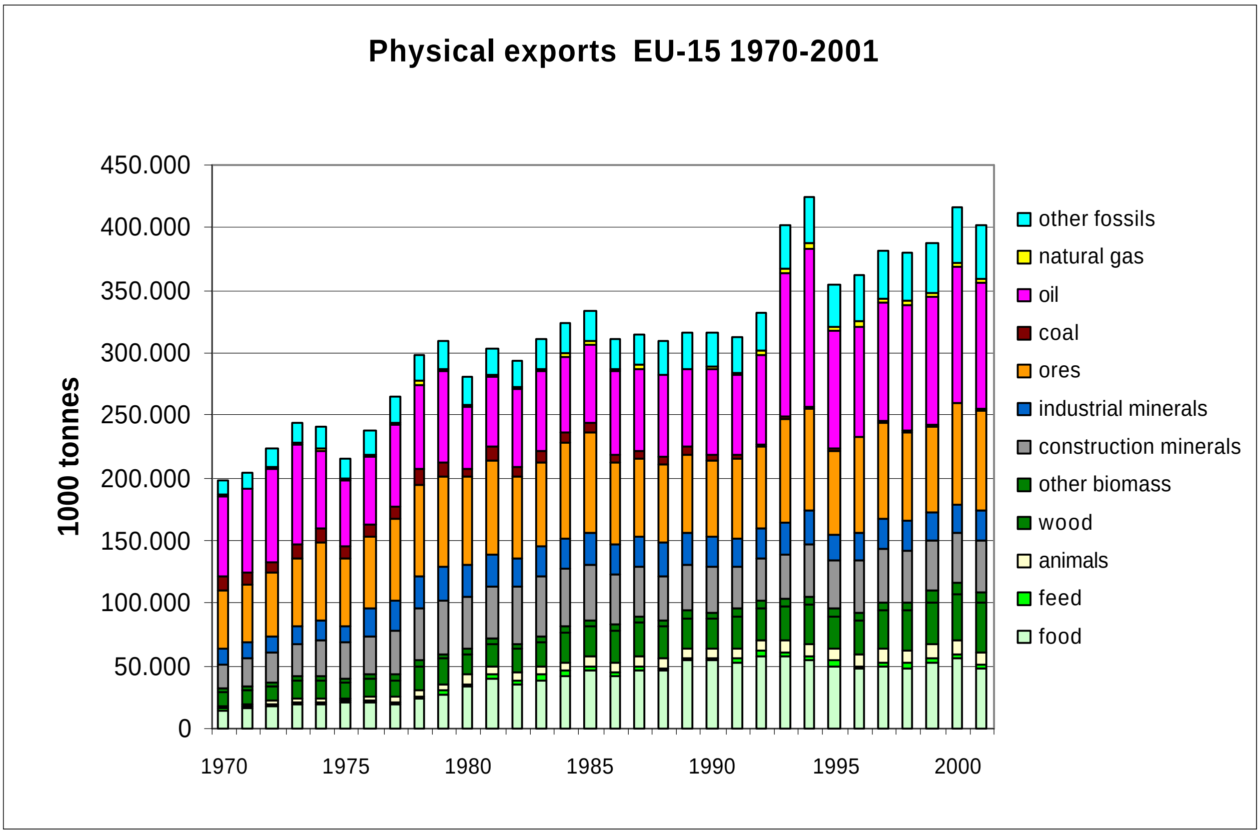
Wood and wood products have been dominating biomass imports throughout the whole period. They continuously contributed 5% to the total import volume of the EU-15. Imports of feed and animals make up a small but heavily increasing fraction (plus 140 and 180% respectively since 1970), whereas imports of food have declined by 16% since 1970.

The volume and physical composition of EU-15 exports are quite different from the import structure (Figure 4). With 200 million tonnes in 1970 and 400 million tonnes in 2001 the physical export volume doubled during the past three decades and now amounts to one third of the import volume. In 1970 physical exports amounted to one fifth of physical imports. The trend shows a fluctuating but overall continuous upward direction. The negative peaks in the physical export curve predominantly occurred in years which immediately followed phases of economic turndown.

Compared to the import structure the composition of exports is not dominated by just one material category. Export categories of quantitative importance are fossil fuels, construction minerals, ores, wood, and food. As illustrated in Table 3, exported commodities are generally in a higher stage of processing than imported commodities. For export commodities made from fossil fuels and metal ores the amount of domestic extraction in the EU-15 cannot fully supply the raw materials needed to produce these commodities. These commodities clearly are to a large part produced from imported raw materials. In all categories distinguished in

Figure 4 exports increased substantially over the whole period, with the only exception of coal exports, which had dropped to half of the volume of 1970 in the year 2001.

Figure 4; Material composition and development of physical export from the EU-15 (extra EU trade only)

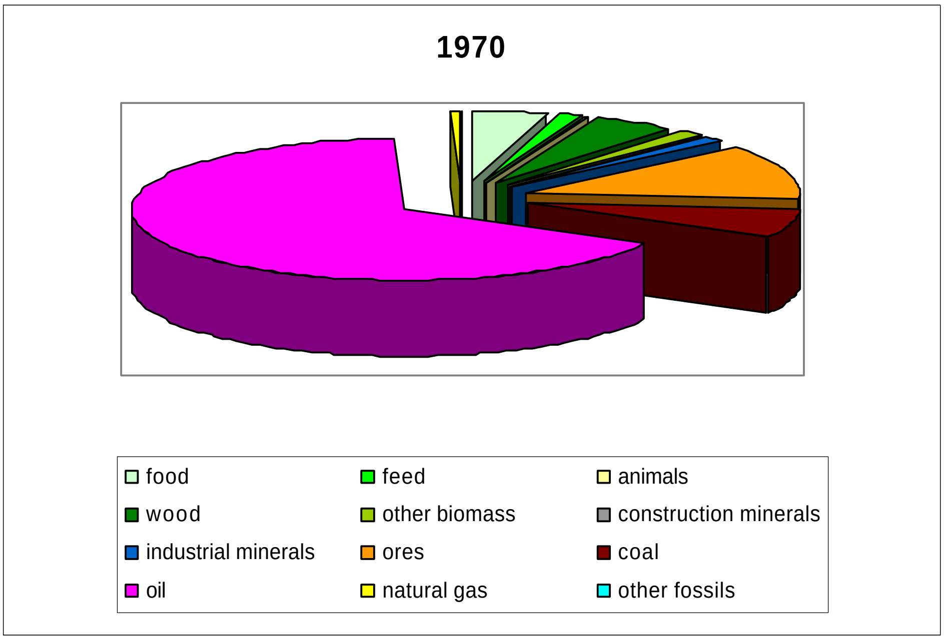


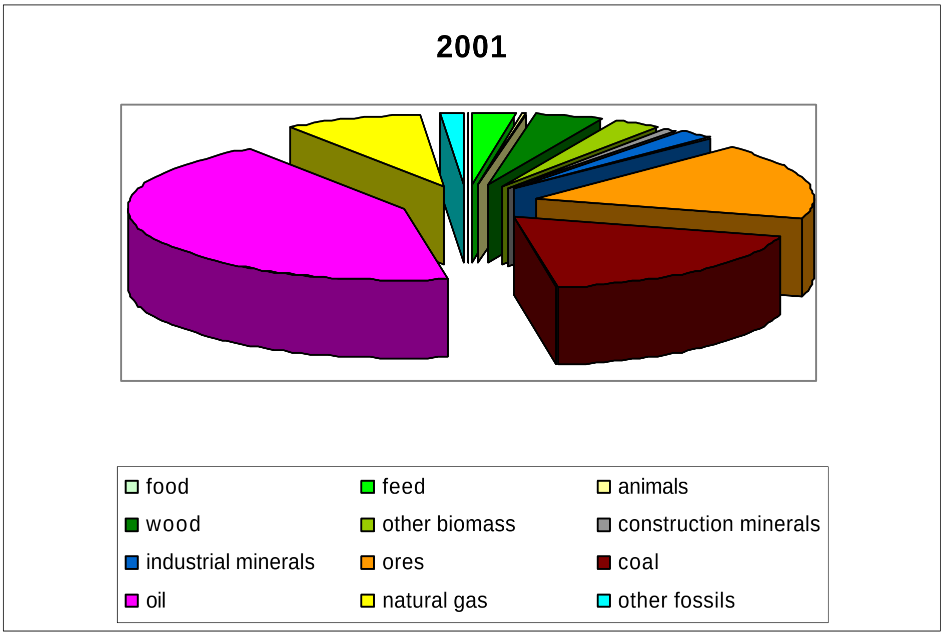
Source: Eurostat/IFF 2004

Subtracting exports from imports leads to the physical trade balance (PTB). The physical trade balance of the EU-15 shows a continuously high, slightly increasing surplus for the whole period of observation (0.8 billion tonnes in 1970 and 1 billion tonnes in 2001).

The material composition of the physical trade balance shifted between 1970 and 2001 as illustrated in Figure 5. The share of oil in the EU-15 trade surplus declined (from 66 to 42% of the total surplus), whereas coal, metal ores and natural gas increased their share. In 1970 net imports of agricultural products for nutrition ("food") represented the fifth largest net import category, corresponding to 4% of the trade surplus. Since 1985 the EU-15 had turned into a net exporter, of currently 5 million tonnes of food. A contrary development can be observed for construction minerals and products from fossil fuels, which showed a physical trade deficit (or net exports) until 1991 and 1984 respectively. Net imports of wood remained constant whereas net imports of animal fodder ("feed") and other biomass more than doubled since 1970. The largest increase in net imports and in relative share can be observed for natural gas. Net imports increased by an order of magnitude from 5 million tonnes in 1970 to 83 million tonnes in 2001, which corresponds to 8% of the physical net import volume, as compared to 1% in 1970.

Figure 5: Material composition of the physical net imports 1970 and 2001 (in % of net imports)



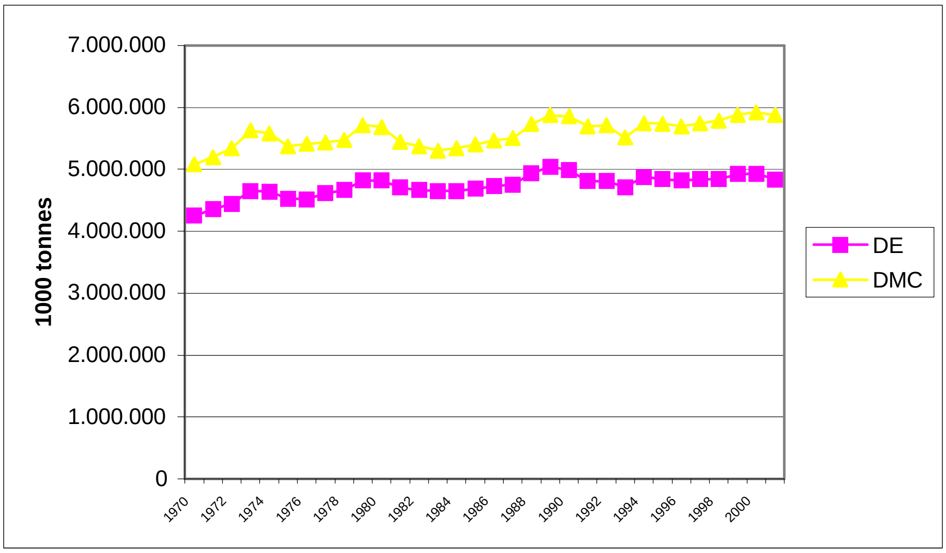


Source: Eurostat/IFF 2004

Domestic extraction of raw materials and domestic resource dependency

The territory of the EU-15 continuously provided 80% of all domestically consumed materials, thus overall domestic resource dependency (measured as DE/DMC ratio) was constantly at 0.8. The trend for domestic extraction closely resembles the DMC trend throughout the whole period (see Figure 6)

Figure 6: Development of domestic extraction and domestic material consumption, EU-15 1970 to 2001



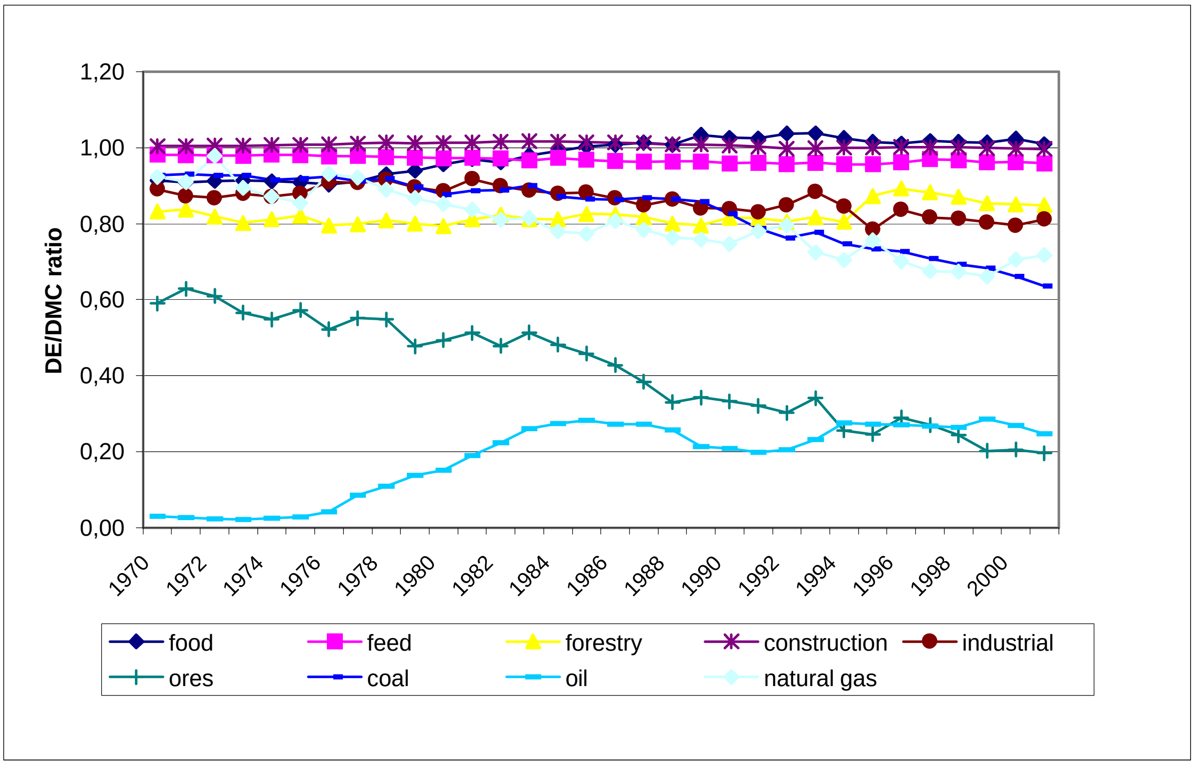
Source: Eurostat/IFF 2004

If we look at the relation between DE and DMC, by categories of raw materials, we see that the stable overall trend is composed of quite different sub-trends. Domestic resource dependency differs greatly between the various types of raw materials. Some groups of raw materials show a stable trend over the past decades regarding domestic resource dependency. Some groups, however, significantly changed their DE/DMC ratio.

Figure 7 shows the annual DE/DMC ratios for nine categories of raw materials from 1970 to 2001. A domestic resource dependency of 1 corresponds to 100% self sufficiency, or more precisely, 100 % of the domestically consumed raw materials can be provided by domestic production. Of course these materials may still be traded in considerable quantities, but the trade balance is close to zero. Contrary to that, a domestic resource dependency of zero indicates that the supply of this type of raw material is completely provided by imports, and most probably not produced within the EU-15. A declining domestic resource dependency, thus, indicates a gradual externalisation of the primary production to countries outside the EU-15.

Construction minerals show a domestic resource dependency close to 1 throughout the time period. Also very stable at 1 or 0.8 respectively were feed and wood DE/DMC ratios. The domestic resource dependency of food production slowly grew from 0.9 in 1970 to 1.01 in 2001, indicating a shift from a slight import dependency to a equally slight domestic production surplus. Industrial minerals show a modest decline in DE to DMC ratio from 0.9 to 0.8.

Figure 7: Change in EU-15 domestic resource dependency (DE/DMC) for different types of raw materials



Source: Eurostat/IFF 2004

A more pronounced decrease in domestic resource dependency can be observed for coal (0.9 to 0.6) and natural gas (0.9 to 0.7). The coal trend predominantly reflects the decline of German lignite production after the reunion in 1990. Throughout the 1970s and 1980s Germany, in particular Eastern Germany, (the former GDR) was the largest coal producer in the EU-15, with annual production volumes around 500 million tonnes. After the reunion many production sites in the former GDR were closed and within a few years coal production dropped to half of its late 1980s volume. The United Kingdom, the second largest coal producer in the EU-15 (early 1970s production amounted to 100 million tonnes), substantially reduced its coal production also since the early 1990s. In parallel coal imports increased (Figure 3).

Contrary to that the domestic production of natural gas doubled from 1970 to 2001. In the same period of time, however, imports of natural gas grew by an order of magnitude (Figure 3), thus in total reducing the DE/DMC ratio.

A substantial shift in the opposite direction occurred regarding the domestic resource dependency on oil. Starting from close to zero in 1970 the DE to DMC ratio of oil levelled off since 1976. This was a consequence of the beginning exploitation of North-Sea oil by the United Kingdom in the aftermath of the first oil crises. Domestic resource dependency of oil peaked in 1986 at 0.3 and has since then fluctuated around 0.25, indicating a sustained contribution of domestic production to EU-15 domestic consumption of oil of about 25% since 1986.

The most pronounced shift from domestic production to imports applies to metal ores. Domestic resource dependency declined from 0.6 in 1970 to 0.2 in 2001. This means that mining of metal ores virtually stopped in most of the EU 15 member states, and was substituted by imports.

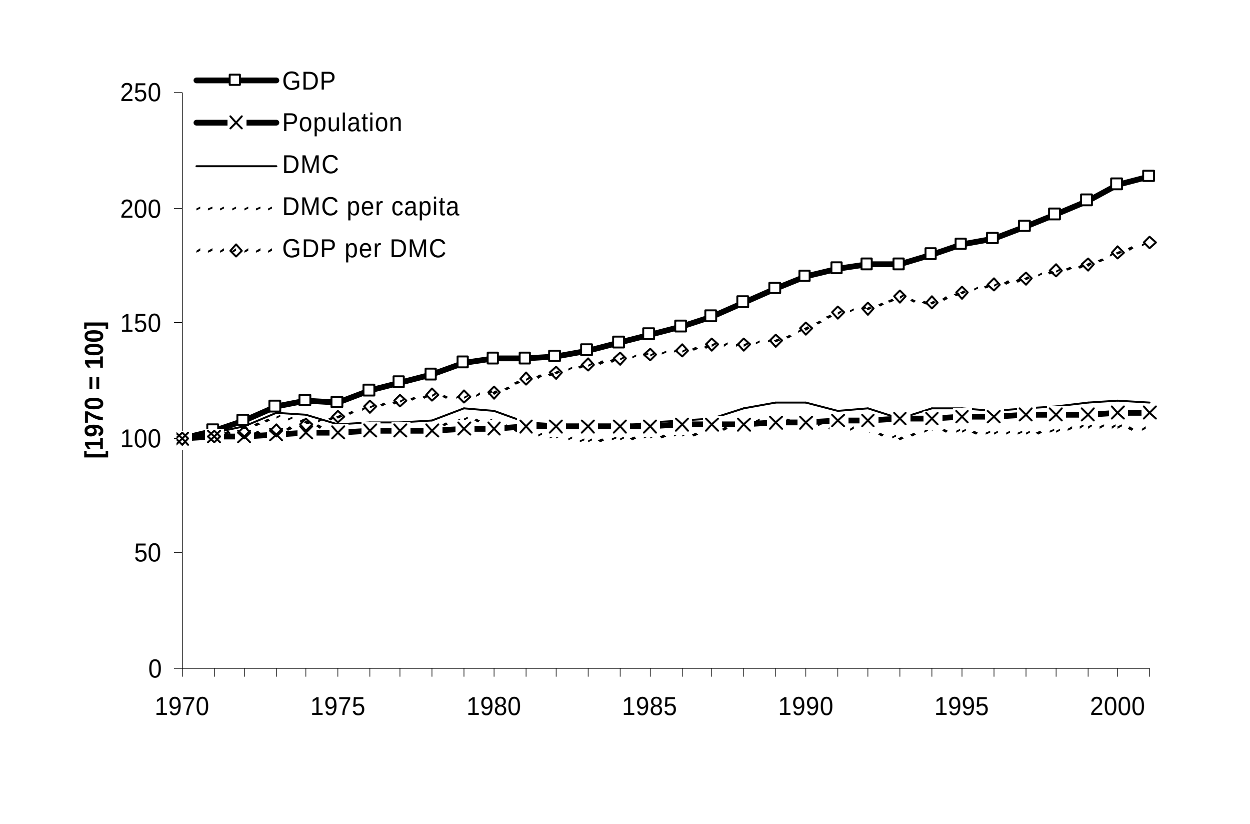
Domestic material consumption and economic development

The development of real GDP, material productivity, domestic material consumption, domestic material consumption per capita, and population from 1970 to 2000 for the EU 15 is shown in Figure 8. Among these indicators DMC/cap changed least. Total growth was highest for real GDP (92%), material productivity, measured as real GDP/DMC enhanced by 77%, DMC grew by 16 %, population by 11%, and DMC per capita by 4%.

Real GDP shows a continuous upward trend interrupted only by the three recession years 1975, 1981, and 1993. 1975 and 1981 can be attributed to the first and second oil crises. 1993 was the year of the most pronounced recession in the EU-15 in the past three decades. The 1993 recession was a consequence of three main causes: (1) the world recession of 1991, (2) the German recession which started in mid 1992 as a consequence of the difficult economic situation in the aftermath of the German reunion, and (3) the turmoil in European currency markets, which put a pressure on the newly established European exchange-rate mechanism.

Overall material productivity increased in parallel with real GDP but at a slightly lower rate. As a result EU-15 DMC in 2000 was only 16% above the level of 1970.

Figure 8: Development of population, GDP, DMC, DMC per capita and GDP per capita for the EU 15 1970-2000. 1970=100



Sources: DMC Eurostat/IFF 2004, population: New Cronos, GDP in const. 1995 Euro, ES95, own calculation based on data supplied by Eurostat C2 and New Cronos.

The DMC trend is not homogenous but rather fluctuating. A characteristic repeated change between phases of growth and phases of decline in domestic material consumption is evident from Figure 8. Our previous analysis of the 1980 to 2000 MFA EU-15 time series suggested a specific relation between GDP and DMC trend, namely that increasing DMC only occurred in phases where annual GDP growth was constantly above 2% (see Eurostat 2002). The extended MFA time series allows us to re-examine the relationship between GDP and DMC development on a broader empirical basis. Contrary to our previous analysis the definition of the phases which are distinguished in Table 4 follows the GDP trend and not the DMC trend.

Table 4: Phases of development of GDP and DMC in the EU-15 1970 to 2000

phase	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
	70-73	**73-75**	**75-79**	**79-83**	**83-91**	**91-96**	**96-00**
average annual chance per period in %							
GDP	4.5	**0.7**	3.4	**1.0**	2.9	**1.5**	3.0
DMC	3.5	**-2.3**	1.6	**-1.8**	0.9	**0.0**	1.0
range of annual change rate in %							
GDP	3.4 to 5.8	-0.5 to 2.0	2.6 to 4.4	0.1 to 1.7	2.0 to 4.1	-0.5 to 2.7	2.5 to 3.6
DMC	2.3 to 5.4	-3.8 to 0.8	0.5 to 4.4	-4,3 to -0.5	-2.7 to 4.2	-3.4 to 0.8	0.7 to 1.6

Sources: DMC: Eurostat/IFF 2004, GDP in const. 1995 Euro, ES95, own calculation based on data supplied by Eurostat C2 and New Cronos

If we look at annual GDP growth rates in the EU-15 two types of phases can be distinguished. Phases where annual GDP growth was on average above 2% and phases where GDP growth was on average beyond 2%. The application of this criterion to the 1970 –2000 period leads to the seven phases defined Table 4. Interestingly, not only average annual growth rates but also actual annual growth rates were constantly above or beyond the 2% threshold in all phases with the only exception of phase VI. The period 1991 to 1996 comprises the years which immediately preceded and followed the 1993 recession, and is characterized by more or less annual fluctuations in GDP (and also DMC) change rates.

For each of the above GDP defined phases, also for DMC average annual growth rates and the range of annual growth rates were calculated. The comparison of average annual growth rates of GDP and DMC in each of the defined phases reveals a clear pattern (Table 4). In the past three decades DMC repeatedly declined in periods where annual GDP growth was beyond 2% and increased in periods where annual GDP growth was above 2%. This points to a persistent, non linear but discontinuous threshold relation between GDP and DMC in the EU-15.

Cross-country comparison

Indicators per capita in 1970 and 2001

A comparison of the indicators DMC, and PTB between the years 1970 and 2001 is shown in Table 5. For the EU as a whole DMC increased by 1 ton to 15.5 tonnes per capita. The physical trade surplus grew from 2.4 to 2.7 tonnes per capita. A comparison of DMC per capita in 1970 to 2001 for each member state reveals that several countries did absolutely reduce their per capita material consumption. This applies to France, Denmark, Germany, The Netherlands, Sweden and the United Kingdom. The current level of per capita DMC in these member states ranges between 22 tonnes in Sweden and 12 tonnes in the United Kingdom.

Table 5: MFA indicators per capita 1970 and 2001

	DMC		DMI		PTB	
[tonnes]	**1970**	**2001**	**1970**	**2001**	**1970**	**2001**
EU-15	14.9	15.5	15.5	16.6	2.4	2.7
Austria	14.5	17.9	15.7	22.8	2.0	3.3
Belgium/Luxembourg	16.9	17.1	23.3	34.9	6.2	6.4
Denmark	24.0	23.1	26.3	30.8	5.1	0.9
Finland	36.3	38.0	39.2	45.2	2.8	4.4
France	14.8	14.4	16.7	17.6	1.9	1.9
Germany	21.8	17.7	23.4	21.1	2.7	2.8
Greece	7.3	21.8	7.9	24.0	0.7	4.3
Ireland	17.6	23.7	18.6	26.8	2.3	4.9
Italy	8.9	11.4	10.0	13.5	2.5	3.6
Netherlands	14.7	13.7	21.7	31.3	5.8	2.9
Portugal	5.8	14.8	6.3	16.3	0.6	3.7
Spain	8.5	15.6	9.0	17.9	1.1	3.2
Sweden	23.0	21.5	29.3	29.3	-1.5	-0.3
United Kingdom	13.6	11.8	14.5	15.0	2.7	0.7

source: Eurostat/IFF 2004, population New Cronos

All other member states increased their per capita DMC. The rate of change, however, is substantially different. The highest growth of DMC and DMI per capita can be observed for Greece (from 7.3 to 21.8 tonnes for DMC per capita and from 7.9 to 24.0 tonnes for DMI), Portugal (from 5.8 to 14.8 for DMC and 6.3 to 16.3 for DMI) and Spain (from 8.5 to 15.6 for

DMC and 9.0 to 17.9 for DMI). The high growth in DMC coincides with the fact, that these countries had the lowest per capita income of the EU-15 (in terms of real GDP per capita) throughout the whole period of time.

In 1970 PTB per capita ranged between 6.2 tonnes in Belgium/Luxembourg and -1.5 tonnes in Sweden. In 2001 the range was quite similar between 6.4 in Belgium/Luxembourg and -0,3 in Sweden. All countries with access to the North Sea oil and gas fields did decrease their PTB between 1970 and 2001. The most substantial decrease in per capita PTB took place in Denmark (from 5.1 to 0,9 tonnes per capita). Except for Belgium/Luxembourg (which had the highest PTB per capita in 1970 and 2001) all other countries increased their physical trade surplus in the past two decades (Table 5).

Changes in DMC, GDP, and material intensity

On the level of individual countries three types of development of DMC during the three decades can be distinguished (Table 6):

a) The 70s are the decade with the most significant growth in DMC in the countries Austria, France, Italy, and The Netherlands. In the 1980s and 90s growth of DMC slows down or even decreases in these countries.

b) In Sweden, the United Kingdom, and Finland the decade with the most pronounced growth in DMC are the 1980s, while in the 70s and 90s DMC decreased (or hardly showed any growth). The growth during the 80s in these countries is related to a more or less significant slump in DMC, predominantly in DMC of construction minerals, in the mid- to end 70s and a consecutive recovery and growth similar to the development on the level of the EU15.

c) The low income countries Greece, Portugal, Spain – and, however, less pronounced also Ireland – are characterized by a significant growth of DMC of most material categories throughout all three decades.

In Germany DMC hardly incresed in the 70s (0.3%) and decreased in the 80s and 90s. This unique development can be attributed to the drastic reduction in domestic extraction of lignite after the reunion. In Belgium and Denmark DMC changed only slightly throughout the whole period.

Table 6: Percentage change of DMC per decade and total

	DMC growth			
	70-80	**80-90**	**90-00**	**70-00**
EU-15	12.6%	2.5%	1.6%	17.2%
Austria	32.3%	1.1%	1.1%	35.2%
Belgium/Luxembourg	8.2%	2.3%	-6.6%	3.5%
Denmark	-4.2%	6.3%	5.0%	6.9%
Finland	2.0%	17.8%	-3.8%	15.5%
France	27.2%	-2.6%	-0.7%	23.0%
Germany	0.3%	-7.6%	-6.6%	-13.4%
Greece	46.8%	51.6%	46.4%	226.4%
Ireland	35.4%	6.0%	23.5%	77.3%
Italy	36.7%	-3.1%	5.7%	39.9%
Netherlands	35.0%	7.7%	-17.4%	20.2%
Portugal	38.1%	35.5%	64.4%	207.5%
Spain	36.1%	28.1%	26.5%	120.5%
Sweden	-5.7%	6.9%	-1.6%	-0.7%
United Kingdom	-7.6%	12.3%	-11.9%	-8.6%

source: Eurostat/IFF 2004

Despite the limited differentiation which a periodisation by decades allows for, it reveals that development of DMC is by no means homogenous over time but is subject to - sometimes considerable - fluctuations. The development of total DMC is often dominated by construction minerals, but in many cases it is a result of changes in the DMC of different materials counter balancing or aggravating each other.

The slumps in DMC, and particularly in DMC of construction materials, ostentatiously coincide with the so called “oil-crises”, i.e., the surges in oil-price related to the political crises in the near east in the mid and end 1970s and also in the early 90s to the world recession.

Table 7 presents data on the level and the development of material intensity (DMC per unit GDP) between 1970 and 2000. The member states are ranked by their material intensities in 2000, which ranged between 0.6 kg/Euro in the Netherlands and 2 kg/Euro in Greece. The EU-15 average was 0.8 kg/Euro in 2000, compared to 1.4 kg/Euro in 1970. In most member states material intensity has improved considerably since 1970.

Table 7: Material intensity (DMC/GDP): level and total chance 1970 to 2000

	1970	1980	1990	2000	total change 1970-2000
	[kg/Euro]				[%]
Netherlands	1.10	1.12	0.97	0.60	-46
France	1.17	1.08	0.82	0.66	-43
Belgium/Luxembourg	1.40	1.09	0.90	0.68	-51
United Kingdom	1.49	1.14	0.98	0.68	-54
Austria	1.20	1.12	0.89	0.71	-41
Germany	1.66	1.26	0.94	0.72	-56
Italy	1.09	1.04	0.81	0.73	-33
EU-15	1.42	1.18	0.96	0.79	-44
Denmark	1.33	1.05	0.96	0.80	-40
Sweden	1.52	1.12	1.04	0.86	-43
Ireland	2.88	2.46	1.84	1.13	-61
Spain	1.29	1.24	1.19	1.16	-10
Portugal	1.44	1.26	1.24	1.54	7
Finland	3.17	2.22	1.94	1.55	-51
Greece	1.28	1.20	1.78	1.99	55

source: Eurostat/IFF 2004, GDP in const. 1995 Euro, own calculation based on Eurostat 2003 and New Cronos

Total decline in material intensity was highest in Ireland (minus 61 %) due to its exceptional increase in GDP over the past three decades (total growth in GDP from 1970 to 2000 was 350%, the highest increase in the EU-15) and Germany (minus 56 %), the country with the most significant overall reduction in DMC (minus 13%, see Table 7). Average improvement of overall material intensity in the EU-15 was at 45%. The low income countries Portugal and Greece are exception from this general pattern. Their material intensity increased over the past three decade (plus 7% in Portugal and plus 55% in Greece) indicating that in these countries DMC outgrew GDP in the decades since 1970.

Imports and exports

One of the results of the Eurostat/IFF 2002 data set was, that in the European Union as a whole, and also in most member states, DE more or less has stabilized (exceptions are the low income countries Greece, Portugal and Spain) whereas imports as well as exports rapidly increased. Table 8 summarizes total change in physical imports and exports for the extended time period 1970 to 2001. In general growth rates are significantly higher for exports than for imports. The level, however, is lower for exports (app. 20% of imports, see Table 2).

Greece and Spain).

Table 8: Percentage change of Imports and Exports per decade and total

	Imports total change of the physical volume				**Exports** total change of the physical volume			
	70 to 80	**80 to 90**	**90 to 00**	**70 to 00**	**70 to 80**	**80 to 90**	**90 to 00**	**70 to 00**
EU-15	12.3%	3.4%	19.1%	38.3%	42.2%	12.7%	31.5%	110.6%
Austria	55.3%	18.7%	49.6%	175.8%	66.8%	47.6%	71.4%	321.7%
Belgium/Luxembourg	25.5%	16.7%	36.4%	99.7%	34.2%	29.0%	70.2%	194.6%
Denmark	10.3%	-4.4%	17.8%	24.2%	14.3%	70.5%	96.9%	283.7%
Finland	38.7%	12.5%	37.0%	113.7%	53.9%	3.5%	73.3%	176.1%
France	47.2%	-0.9%	11.7%	62.9%	36.6%	22.5%	21.8%	103.8%
Germany	14.3%	1.4%	28.3%	48.7%	28.5%	21.6%	27.5%	99.1%
Greece	61.5%	76.7%	80.4%	414.5%	248.8%	9.6%	29.6%	395.5%
Ireland	64.5%	29.2%	48.9%	216.5%	72.1%	76.7%	26.7%	285.5%
Italy	21.1%	7.1%	35.0%	75.1%	0.0%	29.0%	65.6%	113.5%
Netherlands	16.3%	41.1%	7.8%	76.8%	56.8%	29.2%	22.9%	149.0%
Portugal	104.9%	73.5%	53.9%	447.2%	33.4%	99.6%	32.8%	253.6%
Spain	80.3%	31.2%	74.2%	312.2%	112.5%	47.3%	67.3%	423.6%
Sweden	7.5%	9.8%	55.1%	83.1%	-0.3%	3.0%	40.2%	43.9%
United Kingdom	-28.9%	33.6%	11.2%	5.5%	114.1%	16.0%	67.1%	315.2%

Source: Eurostat/IFF 2004

For imports the predominant pattern is that total growth in the 1970s was high and app. in the same order of magnitude as it was in the 1990s. In the decade between 1980 and 1990 physical import volume grew considerably less compared to the 1970s and 1990s (this applies to Austria, Belgium/Luxembourg, Finland, Greece, Ireland, Italy, Spain) or even declined (this applies to Denmark, France, Germany, Sweden). A development distinct from this general pattern took place in three member states: The United Kingdom reduced imports in the 1970s by 30 % (due to the beginning exploitation of the North-Sea oil and gas fields). In Portugal imports grew by app. 100 % in the 1970s, by app. 70% in the 1980s and by app. 50 % in the 1990s. The high growth in the early years can be attributed to the fact that Portugal's imports were extremely low in 1970, actually the lowest in the whole EU (1 t per capita in 1970). It also indicates that Portugal started to connect to EU standards of trade integration during the 1970s. The Netherlands show a reverse trend, with highest total growth in the 1980s. Overall, those countries experienced the highest total growth in the physical import volume during the past three decades, which had the lowest import volume in 1970 (Portugal,

Physical exports experienced high growth in the 1970s and 1990s and comparable less growth in the 1980s in some of the member states (Austria, Finland, France, Germany, Spain, United Kingdom). In Denmark, Italy, and Sweden total increase in exports was highest in the 1990s and lowest in 1970s. The volume of exports was the same in 1970 and in 1980 in Italy and Sweden. Exceptional high increases (100% or more in one decade) can be observed in the in Greece and Spain for the 1970s, and in the 1980s in Portugal, again the countries which had very low foreign trade flows in 1970. The acceleration of North Sea oil and gas extraction by the United Kingdom in the 1970s and by Denmark in the 1990s is reflected in substantial increases in exports of fossil fuels in the corresponding decades (Table 8).

Trade intensity

Over the whole period of time all countries increased the size of imports and exports in relation to DE. i.e. their trade intensity. Table 9 compares imports and exports intensities between 1970 and 2001 for all member states and the EU-15 as a whole.

The average import/DE ratio of the EU member states (except Belgium/Luxembourg and The Netherlands) was at 23 in 1970 and at 36 in 2000. This means that app. one fifth of the direct material input was imported in 1970, whereas in 2000 it was already one fourth. For the EU as a whole the corresponding ratio remained almost constant at app. one fifth, indicating that the increase in imports is mainly due to intra EU trade. The corresponding export/DE ratios are 10 in 1970 and 20 in 2000, thus exports are at considerably lower level compared to DE but increased faster in the past three decades.

Table 9: Trade intensities 1970 and 2000

	1970	2001	70-01	1970	2001	70-01
	imports/DE		**total diff. imp/DE**	**exports/DE**		**total diff. exp/DE**
EU-15	24%	30%	24%	5%	8%	80%
Austria	25%	57%	126%	10%	34%	255%
Belgium/Luxembourg	118%	228%	92%	60%	167%	177%
Denmark	39%	38%	-2%	12%	34%	184%
Finland	17%	34%	99%	9%	21%	143%
France	30%	40%	35%	15%	26%	71%
Germany	23%	41%	81%	9%	23%	159%
Greece	18%	37%	105%	8%	12%	53%
Ireland	22%	43%	98%	7%	17%	153%
Italy	54%	74%	36%	16%	27%	75%
Netherlands	144%	190%	33%	79%	163%	107%
Portugal	20%	47%	129%	10%	14%	44%
Spain	22%	45%	109%	7%	19%	162%
Sweden	20%	35%	74%	26%	36%	40%
United Kingdom	32%	35%	8%	8%	29%	275%

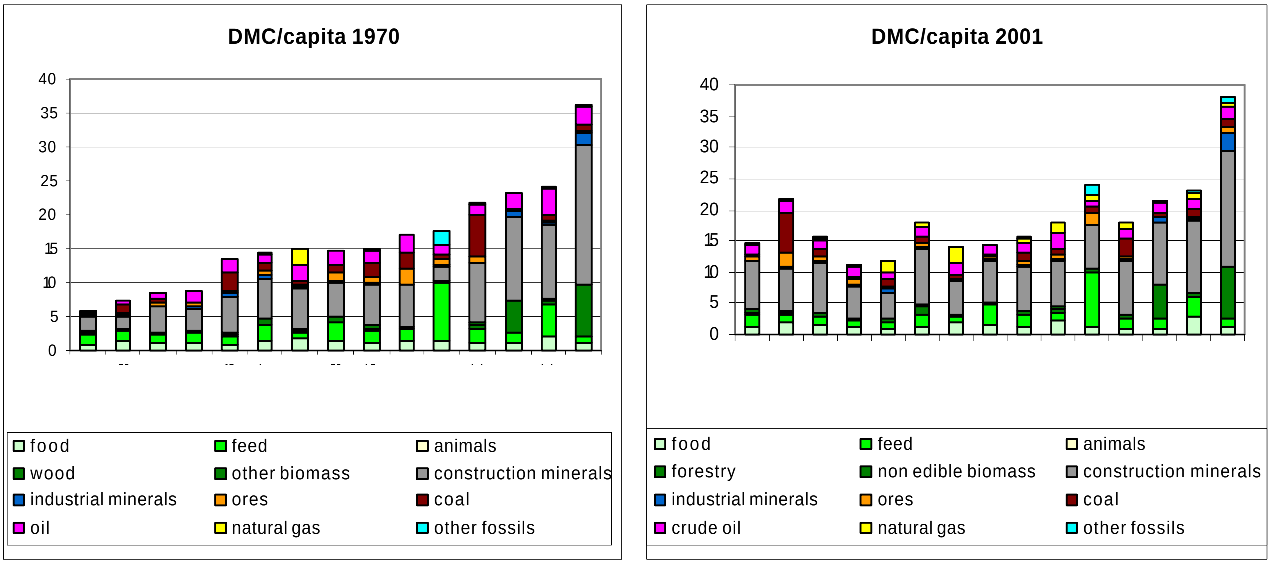
Source: Eurostat/IFF 2004

For both Belgium/Luxembourg and in The Netherlands the "Rotterdam" effect can be clearly distinguished in the trade intensity figures. In both countries physical imports surpassed DE already in 1970. In Belgium/Luxembourg imports reached a level twice as high as DE by 2001. The Netherlands is close to follow. Physical exports were below DE in 1970 in both countries and are at a level of 1.6 times the amount of DE in 2001. For the European Union as a whole all trade intensity figures are substantially lower. Exceptionally high total growth of the exports/DE ratio occurred in the United Kingdom (275%) and in Austria (255%). Total increase in import/DE ratio was highest in Austria (126%) Portugal (129%) and Spain (109%).

Analysing cross-country variations in DMC

In 2001 domestic material consumption per capita among EU-15 member states ranged between 11.6 tonnes in the United Kingdom and 37.3 tonnes in Finland. Four countries with an exceptionally high DMC (above 20 t/cap) and three with an exceptionally low DMC (less than 15 t/cap) stand out, while half of the EU15 countries can be found in the middle range of 15-20 t/cap (Figure 9).

Figure 9: Material composition of per capita DMC across EU-15 member states: 1970 and 2001



Source: Eurostat/IFF 2004

The variability of DMC was higher in 1970 (coefficient of variation 0.5) than in 2001 (0.34). Obviously, economic development during this 30 year period has not only reduced income disparities but also the disparities in DMC among the European Union countries.

The sparsely populated countries Finland, Sweden and Ireland are among the countries with the highest level of DMC, owing mainly to high DMC of construction minerals and/or biomass. The fourth country in this group is Denmark with an average population density but high values of biomass DMC as a consequence of its intensive livestock based agriculture and a DMC of construction minerals above average.

Densely populated countries like the Netherlands, Belgium/Luxembourg, the United Kingdom and Italy are among the countries with outstanding low or average (Belgium/Luxembourg) per capita DMC. Except for the United Kingdom, these countries are also characterized by high net imports and the lowest DE to DMC ratios (0.65-0.71).

In the case of Belgium/Luxembourg and the Netherlands both imports and exports are extremely high and by far exceed the size of DE (factor of 1.4 to 2.2). These countries are among the largest trading nations in the world in terms of the weight of their imports and exports. Statistically, the structure of the physical economy of these countries determined by what has been termed “Rotterdam effect”. The notion refers to the role of the huge harbours (Rotterdam and Antwerp) located in these countries, which serve as European entry ports for international trade. The United Kingdom has since 1970 decreased its DMC due to the reduction of materially intensive heavy industry and could reduce net imports by accelerated exploitation of North Sea oil.

The DMC of the Mediterranean low-income countries Greece, Portugal and Spain ranged around the European average in 2000. However, in 1970 these countries showed by far the lowest values of per capita DMC (6-8 t/cap). With their rapid economic development (total growth in GDP 1970-2000 was 112, 188, and 146 %, above the EU average of 110 %) also DMC increased, in Portugal and Greece even over-proportionally (total growth of DMC 1970-2000 was between 100 and 200%). Especially DMC of construction minerals has increased dramatically and became a dominant flow in the physical economies of Portugal, Greece and Spain. The high DMC of Greece is also related to the high domestic consumption of coal, mainly low quality lignite, from domestic production. The large Central European Countries France and Germany are in the European midfield. Due to their absolute size these two countries also largely determine overall EU-15 material flow indicators.

For a more in-depth analysis of the differences in level and composition of domestic material consumption between EU-15 member states, we now discuss country patterns of DMC by types of materials.

Biomass

Regarding its function for social metabolism, biomass, in providing food to sustain the human population, is the most fundamental of all socio-economic material flows. Biomass as raw material for food is virtually irreplaceable, and even in the most advanced economies biomass DE and DMC significantly depend on natural conditions.

In the EU biomass accounts for 25% of total DMC. In most EU member states the share of biomass in overall DMC is between 20-30% exceptions being Finland, France, Sweden, and Ireland where the contributions of biomass to overall DMC are between 40-50%. Per capita consumption of biomass amounts to 4.0 tonnes in the EU as a whole. Across member states, per capita DMC of biomass varies by a factor of 4, extremes being observed for the United Kingdom (2.5 t/cap) and Finland (10.6 t/cap). DMC of biomass is highly correlated to DE of biomass ($r^2 = 0.97$), and the domestic resource dependency (measured as DE to DMC ratio, see above) is close to one for most countries (see Table 10).

Still the physical trade volume (imports or exports) of biomass is considerable in some member states (extremes being 4.9 t/cap of imports in Belgium/Luxembourg, 4.2 t/cap of exports in Finland). In the Netherlands and in Belgium/Luxembourg, biomass imports even exceed biomass domestic extraction in terms of mass. Physical trade balances for biomass are generally positive and amount to less than 1 tonne per capita, which means that the EU-15 countries import more biomass (or biomass products) than they export, with the exceptions of Finland (net exports of 1.5 tonnes biomass per capita in 2000), France and Sweden (net exports of 0.6 and 0.5 respectively in 2000).

In general the level of per capita biomass use in an economy depends on a number of factors. Above all these are (1) the per capita availability of land area, (2) the applied techniques to increase area productivity, (3) the relation between competitive and non competitive uses of biomass, in particular the relation between agricultural biomass and wood, (4) the size of the livestock, and (5) the physical volume of trade. There is no reason to expect the effects of these factors to be mutually independent, so in the end there may be a complex network of effects hard to disentangle.

Table 10: MFA parameters and indicators for biomass for European Union countries (2000).

Biomass (2000)	DE per capita	Import per capita	Export per capita	DMC per capita	DMI per capita	PTB per capita	DMC/km²	DE/DMC
	[t/cap]	[t/cap]	[t/cap]	[t/cap]	[t/cap]	[t/cap]	[t/km²]	
EU-15	3.8	0.5	0.3	4.0	4.3	0.2	465	0.9
Austria	4.3	2.2	2.0	4.5	6.5	0.2	434	1.0
Belgium/Luxembourg	3.2	4.9	3.6	4.5	8.1	1.3	1 579	0.7
Denmark	6.3	2.5	2.1	6.7	8.9	0.4	834	0.9
Finland	12.5	2.7	4.2	11.0	15.2	- 1.5	168	1.1
France	6.1	0.9	1.5	5.6	7.0	- 0.6	592	1.1
Germany	3.3	1.0	1.0	3.3	4.3	- 0.0	757	1.0
Greece	3.3	1.1	0.4	4.0	4.4	0.7	317	0.8
Ireland	10.0	1.7	1.1	10.6	11.7	0.6	567	0.9
Italy	2.5	0.9	0.5	2.9	3.4	0.4	550	0.9
Netherlands	2.6	3.3	2.6	3.3	5.9	0.7	1 267	0.8
Portugal	3.6	1.2	0.6	4.2	4.8	0.6	470	0.9
Spain	3.5	1.0	0.6	3.9	4.5	0.4	306	0.9
Sweden	8.7	2.3	2.8	8.3	11.0	- 0.5	163	1.1
United Kingdom	2.0	0.9	0.4	2.5	2.9	0.5	620	0.8
Minimum	2.0	0.9	0.4	2.5	2.9	- 1.5	163	0.7
Maximum	12.5	4.9	4.2	11.0	15.2	1.3	1 579	1.1
Average	5.1	1.9	1.7	5.4	7.0	0.2	606	0.9
Standard deviation	3.1	1.1	1.2	2.7	3.4	0.7	374	0.1
Coefficient of variation	0.60	0.59	0.72	0.49	0.49	2.86	0.62	0.13

Source: Eurostat/IFF 2004, population New Cronos, land area FAO 2002

However, in the EU-15, even nowadays, under industrial conditions, 70-90% of the territory is used for agriculture and forestry (FAO 2002). Biomass flows, thus, are the most important cause for competitive land occupation, competitive in particular for most non human species Tilmann 2002, (Haberl et al. 2004).

Finland, Sweden and Ireland are the countries with the lowest population densities (15.3-53.7 cap/km² compared to 116.2 for the EU-15) and have the highest levels of DE and DMC of biomass (8.7-12.5 t/cap and 8.3-11.0 t/cap respectively. In the case of Finland and Sweden, the size of DE is determined by forestry and in the case of Ireland by grassland based agriculture. On the contrary, the countries with the highest population densities are among the countries with the lowest values of per capita DE: Population densities in the United Kingdom, Belgium and the Netherlands are the highest in the EU, ranging from 246 to 382 cap/km² whereas DE of biomass is between 2.0 and 3.2 t/cap (see Table 10). This indicates that population density and thus per capita availability of land area definitely functions as a limiting factor for the domestic extraction of biomass in these countries, whereas in Ireland and in the Scandinavian countries the lack of such a limitation allows for exceptionally high levels of per capita biomass extraction. In countries with medium population densities, the existence or lack of an area limitation seemingly is not a decisive factor for per capita levels of biomass DE or DMC (see Table 10).

(2) Biomass yields per area are determined by climatic conditions, technological factors and population density. All of these factors vary significantly across EU countries. Biomass DE is comparatively low in Mediterranean Countries (2.5-3.6 t/cap) where the natural area productivity as well as the agricultural area yields are typically below the European average (FAO 2002). Under the climatic conditions in the Mediterranean countries, hydric stress in summer is likely to act as a limiting factor to biological productivity, despite irrigation. Intensification of the agricultural production– defined as higher levels of inputs and increased output of cultivated or reared products per unit area and time - is less pronounced in the Mediterranean countries.

In contrast, the extremely densely populated Northern European countries are characterized by climatic conditions allowing for high natural productivity In combination with the most intensive agricultural production systems of the European Union this results in the highest agricultural yields in the EU (Table 11). In the less densely populated countries Ireland (54 cap/km^2) and Denmark (124 cap/km^2) high yields are accompanied by equally high amounts of domestically extracted biomass per capita. The Netherlands, Belgium/Luxembourg and the United Kingdom, however, show lower per capita biomass extraction despite their high natural productivity and advanced agricultural industrialization, seemingly for lack of land, a consequence of their high population densities.

Table 11: Selected biomass related indicators (2000).

	Livestock	Cereal yield	Fertilizer	Meat consumption
	[LU/cap]	[t/ha]	[kg/km²]	[GJ/cap.a]
EU-15	0.31	5.6	54	0.65
Austria	0.35	5.7	28	0.76
Belgium/Luxembourg	0.40	7.8	97	0.49
Denmark	0.68	6.1	103	0.70
Finland	0.26	3.1	9	0.73
France	0.41	7.1	92	0.83
Germany	0.24	6.7	80	0.55
Greece	0.20	3.7	38	0.52
Ireland	2.01	7.5	96	0.64
Italy	0.17	5.0	61	0.62
Netherlands	0.41	7.4	121	0.66
Portugal	0.23	2.8	26	0.62
Spain	0.32	3.0	41	0.72
Sweden	0.24	4.5	7	0.47
United Kingdom	0.28	6.8	87	0.67
Minimum	0.17	2.8	7	0.47
Maximum	2.01	7.8	121	0.83
Average	0.44	5.5	63	0.64
Stabw	0.45	1.8	36	0.10
Vc	1.02	0.32	0.58	0.16

Sources: own calculations based on FAO (FAO 2002) (livestock, meat consumption, cereal yield) and Statistics Austria (Statistics Austria 2002) (fertilizers)

(3) Agricultural biomass on the one hand, wood and wood products on the other show very different patterns across countries and follow different dynamics. Per capita DE of agricultural biomass (especially of food) is significantly less variable across countries than per capita DE of wood (variance coefficient of DE of food: 0.38; agricultural biomass: 0.54 and

wood 1.49, see Table 10). In most EU countries, agricultural biomass accounts for at least 75% of biomass DE. The two exceptions are Sweden and Finland where wood contributes by over 70% to DE of biomass. The importance of wood extraction for the Swedish and Finnish physical economies can be illustrated by the fact that those two countries together contribute 4% to the overall EU population, 5% to total EU GDP, but 44% of the domestic extraction of wood in the EU (the other major contributors of wood being Germany (17%) and France (15%). In all non Scandinavian EU countries per capita amounts of wood domestic extraction are significantly lower, ranging from 1.4 t/cap in Austria and 0.1 t/cap in the Netherlands. Values for DMC of wood are roughly in the same order of magnitude in all countries as DE, indicating that not the raw material is traded but highly processed wood products.

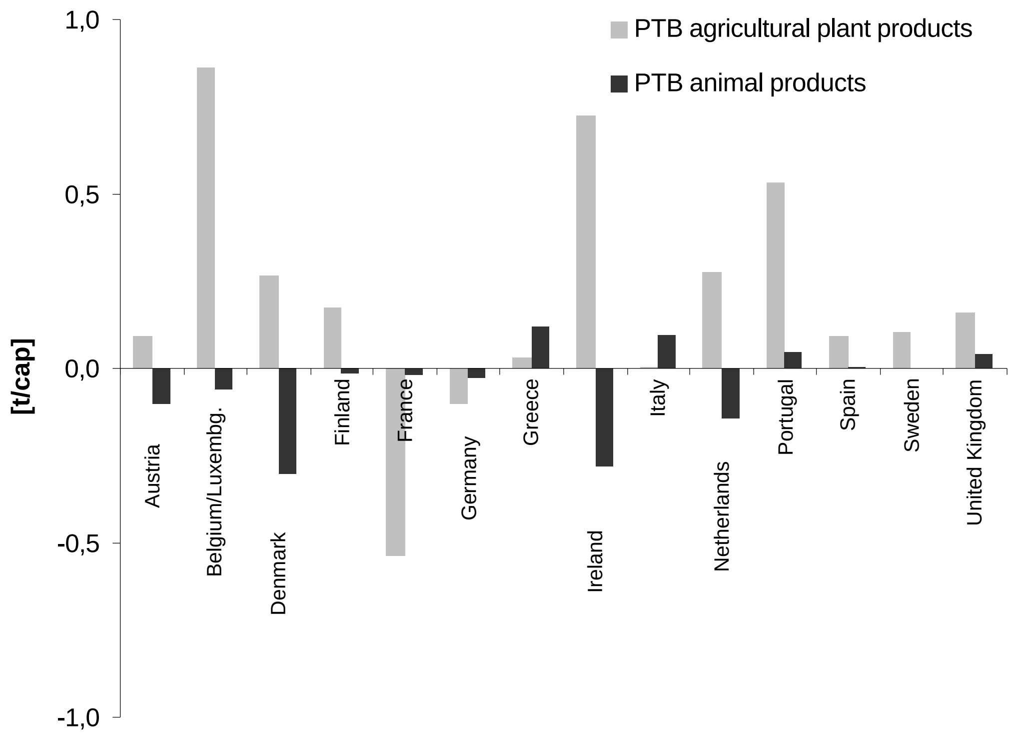
(4) Countries with an emphasis on livestock farming in the agricultural sector usually have high per capita values of biomass DE. This immediately becomes understandable if we consider the biomass-intensity of livestock production systems: One mass unit of animal products (e.g. meat or milk) is associated with up to ten mass units upstream primary material inputs. In the European Union, Ireland and Denmark have the largest per capita livestock (2.0 LU/cap and 0.7 LU/cap respectively, compared to 0.3 LU/cap for the EU-15, see Table 11). These two countries have the highest DE of agricultural biomass (9.4 t/cap and 5.9 t/cap) EU-15 wide, and the highest DE of fodder biomass in particular (see Table 10).

(5) However, this simple causal relation between population, livestock size, and domestic extraction of agricultural biomass may be counteracted by foreign trade. Although imports and exports of biomass are quite balanced in the EU-15 and net trade with biomass (PTB) is low (less than 0.3 t/cap EU-15 average) compared to DE or DMC (see Table 10), trade has a significant impact on the level of DMC for agricultural biomass. As already noted, the agricultural sector and the downstream food producing sectors are characterized by a large discrepancy between gross biomass inputs and net output in terms of final products. In Austria for example biomass turnover in the agricultural sector is by a factor 3-4 larger than the net output of food products. If we now consider that imports and exports are included in DMC with their weight as they cross the border, it immediately becomes obvious that with increasing volumes of final biomass products in the foreign trade flows, the level for DMC becomes affected. This applies in particular to livestock production but also to sectors processing wood or ores. Earlier stages of the animal production chain (which starts with the harvest of plant fodder and leads to meat and meat products) may take place in third countries. Products may be imported at later stages of processing, thus reducing the factual weight of

primary material inputs into a national economy and leading to a lower domestic material consumption than would be expected from the size of the livestock.

It follows, and the data support this, that particularly high amounts of domestic extraction of agricultural biomass (under European conditions this would be above 4 t/cap) definitely indicate a huge livestock production sector. The highest per capita DE of food and feed are observed for Ireland (9.4 t/cap), Denmark (5.7 t/cap) and France (5.5 t/cap), the very countries with the highest livestock units per capita (Ireland 2 LU/cap, Denmark 0.7 LU/cap, and France 0.4 LU/cap) see Table 10 and Table 11.

Figure 10: Physical trade balances for plant and animal products in European Countries (2000).



Source: Eurostat/IFF 2004

The reverse line of reasoning, however, is not applicable. A large livestock not necessarily implies high per capita DE of agricultural biomass, as highly processed fodder can also be imported. This clearly is the case in Belgium/Luxembourg and the Netherlands which have the same livestock densities as France (0.4 LU/cap), but comparably smaller amounts of domestic extraction of agricultural biomass (Belgium/Luxembourg: 2.9, the Netherlands: 2.6 t/cap, and France 5.5 t/cap).

Most European countries appear as net importers of plant agricultural products (exceptions are France and Germany), while quite some are net exporters of animal products: Austria, Belgium/Luxembourg, Denmark, Ireland and the Netherlands have net exports of animal products of more than 0.1 t/capita (Figure 10). The only EU-15 countries relying significantly on net imports of overall agricultural biomass (DE to DMC ratio less than 0.9) are Belgium/Luxembourg, Portugal and the United Kingdom.

Lifestyle related patterns, such meat consumption, or per capita national income play no role empirically for any of the biomass flow indicators. This becomes immediately understandable, if we consider that the same level of meat consumption may be satisfied either by domestic livestock production or by imported meat. In the former case the biomass intensity of the livestock production system is fully reflected in biomass DMC, in the latter case the materially most extensive stages of meat production are externalised.

Overall, the pattern of domestic material consumption of biomass across EU member states reveals that countries with the lowest per capita values of biomass extraction and domestic consumption have the most intensive land use systems, associated with comparatively high environmental pressures (e.g. measured in terms of pesticide and fertilizer application see Table 11) and vice versa. This seemingly paradox pattern diminishes if we relate DE or DMC of biomass to the territory (Table 10). The countries with the highest values for per capita DMC and DE of biomass show the lowest values per km^2. For example, Finland's and Sweden's domestic material consumption of biomass amounts to 160-170 t/km^2. At the same time the densely populated countries Belgium/Luxembourg and the Netherlands with low per capita values of biomass DMC, show the highest per area values, amounting to roughly 1 500 t/km^2. This means that the extraction of raw materials is already in the order of magnitude of the natural productivity (measured as net primary productivity per km^2, which is app. 1000 tonnes dry weight per km^2 for Central Europe (see (Haberl et al. 2001)). The per area levels of biomass DMC also relate well to other indicators for the intensity of land use, such as the application of artificial fertilizer (see Table 11). We may thus consider the land related biomass flow to be a better indicator for environmental pressure than the per capita amounts.

Construction minerals

The material consumption (DMC) in the EU-15 as a whole and in most of its member states is dominated by construction minerals (see Figure 1). In ten of the 14 EU countries construction minerals account for more than 40% of total DMC. Per capita amounts range from 4.3 t/cap in the United Kingdom to 18.4 t/cap in Finland, a variation by factor 4 (Table 12). Despite their quantitative importance, there remains considerable uncertainty, regarding the quality of the data (see Eurostat 2002). The low data quality hampers an in-depth analysis of the DMC of construction minerals. Also a further breakdown into different kinds of construction materials is not justified by the data quality. Still, the overall aggregate of construction minerals for the EU-15 member states seems sufficiently reliable now to warrant some structural descriptions.

One paramount feature of the use of construction minerals is its localism, the locations of its production and consumption are not far apart. In the material flow data this is mirrored by the high domestic resource dependency of construction minerals. Their DE to DMC ratio is close to one in all countries except for the small (in terms of area) and densely populated Netherlands, which depend on significant net imports of construction minerals (Table 12). Contrary to biomass flows also the trade intensity of construction minerals is low, actually the smallest of all material categories. Import to DE ratios for construction minerals range between 0.02 and 0.6 and export to DE ratios between 0.02 and 0.4. Ubiquitous high volume and low-price commodities are predominantly sold locally, as transport costs are high compared to production costs. In addition availability of construction minerals is hardly a limiting factor for DE and DMC. Sand, gravel and crushed stone, the bulk materials determining DE and DMC, are generally abundant. In densely populated areas though, where mining causes prohibitive disturbances for residents, access to construction minerals is becoming difficult. An indication for this tendency is that the Netherlands and Belgium increasingly rely on imports of construction materials.

The highest per capita DMC of construction minerals can be found in the Scandinavian countries (Finland 18.4 t/cap, Denmark 12.1 t/cap). Low population density leads to a higher per capita requirement of built infrastructure. According to data from the European Environmental Agency, per capita land requirement for transport infrastructure amounts to 200-350 m² in Finland and Sweden compared to 60 and 75 in densely populated countries like the United Kingdom and the Netherlands ((European Commission and European Environment Agency 2000)).

Contrary, the lowest values of DMC construction minerals can be found in densely populated countries with mild climatic conditions such as the UK (4.3 t/cap) or the Netherlands (4.8 t/cap), but also in the Mediterranean countries with medium population densities like Italy (5.0 t/cap) or Greece (6.7 t/cap). These countries also show low per capita values of transport area (EEA, 2000).

Table 12: Material flows of construction minerals in the European Union countries (2000).

Construction minerals (2000)	DE per capita	Import per capita	Export per capita	DMC per capita	DMI per capita	PTB per capita	DMC/km²	DE/DMC
	[t/cap]	[t/cap]	[t/cap]	[t/cap]	[t/cap]	[t/cap]	[t/km²]	
EU-15	7.0	0.1	0.1	7.0	7.1	- 0.0	817	1.00
Austria	9.4	0.5	0.4	9.4	9.8	0.1	912	0.99
Belgium/Luxembourg	7.5	2.9	3.0	7.4	10.5	- 0.1	2 595	1.02
Denmark	12.2	0.8	0.9	12.1	13.0	- 0.0	1 502	1.00
Finland	17.8	0.9	0.3	18.4	18.7	0.6	282	0.97
France	6.8	0.4	0.3	6.9	7.2	0.0	731	1.00
Germany	8.8	0.5	0.4	8.8	9.3	0.0	2 036	1.00
Greece	7.1	0.1	0.6	6.7	7.2	- 0.4	533	1.06
Ireland	6.6	0.7	0.2	7.2	7.3	0.5	384	0.92
Italy	5.1	0.3	0.3	5.0	5.3	- 0.0	961	1.01
Netherlands	3.4	2.1	0.7	4.8	5.5	1.4	1 832	0.70
Portugal	7.9	0.4	0.2	8.0	8.2	0.2	891	0.98
Spain	7.9	0.2	0.5	7.7	8.2	- 0.2	605	1.03
Sweden	10.3	0.4	0.7	9.9	10.6	- 0.3	195	1.03
United Kingdom	4.5	0.1	0.3	4.3	4.6	- 0.2	1045	1.05
Minimum	3.4	0.1	0.2	4.3	4.6	- 0.4	195	0.7
Maximum	17.8	2.9	3.0	18.4	18.7	1.4	2 595	1.1
Average	8.2	0.7	0.6	8.3	9.0	0.1	1 021	1.0
Standard deviation	3.5	0.8	0.7	3.5	3.5	0.5	663	0.1
Coefficient of variation	0.42	1.07	1.11	0.42	0.39	4.37	0.65	0.09

Source: Eurostat/IFF 2004, population New Cronos, land area FAO 2002

Another distinguishing characteristic of DMC of construction minerals is its volatility with economic growth. The trend of DMC of construction minerals over the past three decades corresponds better with economic growth than the domestic material consumption trends of any other material type (Pearson correlations of GDP trend and DMC construction trend is 0.8 for the EU a whole, the corresponding coefficients for biomass, industrial minerals/ores and fossil fuels are: 0.7-0.4 and -0.5 respectively). Correlation with the growth of value added in the construction sector is even closer. Periods of accelerated economic growth often result in enhanced construction activities. During these periods high amounts of construction minerals are used to build up stocks while during periods of “average” growth or in recession phases, investment in physical infrastructure and thus the use of construction minerals usually declines.

From 1970-2000, DMC of construction minerals increased in many medium and high income countries (overall growth between 12% and 64%, see Table 13), remained more or less the same in Germany and Finland and decreased in Sweden and the UK by 11 and 12% respectively.

Table 13: Total change in domestic consumption (DMC) of construction minerals 1970-2000.

	total change in %
	1970-2000
EU-15	32%
Austria	64%
Belgium/Luxembourg	31%
Denmark	12%
Finland	0%
France	51%
Germany	3%
Greece	358%
Ireland	354%
Italy	73%
Netherlands	16%
Portugal	385%
Spain	161%
Sweden	- 11%
United Kingdom	- 12%

Source: Eurostat/IFF 2004

A special case are the low income countries Greece, Ireland, Portugal, and Spain, where the increase in the domestic consumption of construction minerals from 1970-2000 was spectacular. Total increase over the whole period was 161% in Spain and 385% in Portugal, 354% in Ireland, and 358% in Greece. In 1970, these countries had values for per capita DMC of construction minerals (1.8-3.7 t/cap) far below EU average, in 2000 they had reached EU average (6.7- 8.0 t/cap).

Similar to biomass flows an area related perspective of construction minerals contrasts to the per capita amounts. Sweden, Finland and Ireland, the countries with the highest per capita DMC, have by far the lowest DMC of construction minerals per km² while Belgium, Netherlands, Denmark and UK show the highest values of DMC/km² (factor 5-10 above the values for Sweden and Finland). A relatively higher value of DE or DMC of construction minerals per area indicates a relatively higher pressure on terrestrial ecosystems due to resource extraction, and in particular to increased soil sealing.

Industrial minerals and ores

Industrial minerals and ores are a heterogeneous group of materials comprising various types of ores and non-metallic minerals and derived products. DMC of industrial minerals and ores is low in terms of weight compared to overall DMC in the EU-15 countries. Per capita DMC of industrial minerals and ores ranges between 0.5 t/cap and 3.3 t/cap (EU average 1.0 t/cap) and its contribution to total DMC varies between 2 to 13% (Table 14).

Technically and economically, however, industrial minerals and ores are the most important materials for industrial production. These material flows have also long been a focal area for environmental policies, because of the high environmental pressures associated to extraction, processing, consumption and final disposal of these materials. In European countries, the mining of industrial minerals and ores has long been under national governmental control. The governmental influence has been reduced considerably in the past decades mainly due to EU liberalization politics.

This effected in particular the domestic extraction of ores, which declined sharply in EU in the past 30 years (minus 67 % for the EU as a whole), as a result of high operation costs, decreasing ores grades, international competition, and increased efforts for environmental protection. An opposite trend in the extraction of ores can only be observed for three countries. Portugal (total change in per capita DE of ores from 1970-2000 was -57 %)

increased its domestic extraction in the 1990s due to the discovery of new copper and tin deposits. Greece continues to exploit large amounts of bauxite and is now the only considerable bauxite producer in the EU (total change in per capita DE of ores from 1970-2000 was +4.6 %). Ireland continues to open new mines (for gold, lead, and zinc) and maintained a more or less constant level of ores extraction throughout the past three decades (total change in per capita DE of ores from 1970 to 2000 was -1.0 %).

Table 14: Material flows of industrial minerals and ores in the European countries (2000)

Industrial minerals and ores (2000)	**DE per capita**	**Import per capita**	**Export per capita**	**DMC per capita**	**DMI per capita**	**PTB per capita**	**DMC/km^2**	**DE/DMC**
	[t/cap]	[t/cap]	[t/cap]	[t/cap]	[t/cap]	[t/cap]	[t/km^2]	
EU-15	0.4	0.8	0.3	1.0	1.3	0.6	114	0.42
Austria	0.6	2.0	1.5	1.1	2.6	0.5	110	0.53
Belgium/Luxembourg	0.0	6.0	5.2	0.7	6.0	0.7	258	0.00
Denmark	0.1	1.6	1.2	0.5	1.7	0.4	67	0.21
Finland	2.3	2.3	1.4	3.3	4.7	1.0	50	0.71
France	0.2	1.4	0.8	0.8	1.6	0.6	82	0.24
Germany	0.3	1.5	1.0	0.8	1.8	0.4	176	0.43
Greece	0.7	1.1	0.4	1.4	1.8	0.7	114	0.52
Ireland	0.9	2.2	1.1	2.0	3.1	1.1	109	0.44
Italy	0.2	1.9	0.6	1.5	2.1	1.3	281	0.10
Netherlands	0.3	4.0	2.8	1.5	4.3	1.2	565	0.21
Portugal	0.2	0.8	0.3	0.7	1.0	0.4	73	0.35
Spain	0.5	1.2	0.6	1.2	1.7	0.6	90	0.46
Sweden	2.7	1.4	3.1	1.0	4.1	- 1.7	20	2.67
United Kingdom	0.4	0.8	0.4	0.8	1.3	0.4	208	0.53
Minimum	0.0	0.8	0.3	0.5	1.0	- 1.7	20	0.0
Maximum	2.7	6.0	5.2	3.3	6.0	1.3	565	2.7
Average	0.7	2.0	1.5	1.2	2.7	0.6	154	0.5
Standard deviation	0.8	1.3	1.3	0.7	1.4	0.7	131	0.6
Coefficient of variation	1.14	0.67	0.91	0.56	0.54	1.23	0.85	1.17

Source: Eurostat/IFF 2004, population New Cronos, land area FAO 2002

Due to the combined influences of the natural availability of deposits, world market prices and national regulations, DE of industrial minerals and ores is extremely variable across the European Union member states (0.0 to 2.7 t/cap, variance coefficient 1.14). In most EU member states, DE does not exceed 1 t/cap. The only countries with significant per capita DE of industrial minerals and ores are Sweden which exploits predominantly iron ores at still high but decreasing rates (2.7 t/cap) and Finland which increasingly exploits industrial minerals (2.6 tonnes per capita, mainly limestone) and ores (0.4 tonnes per capita, mainly copper).

At the same time, domestic consumption is considerably higher than DE and still rising in most EU member states. DE to DMC ratio in 2000 was 0.8 for industrial minerals and 0.2 for ores in the EU as a whole. Net imports of industrial materials and derived products increased since 1970 by 105 %, net imports of ores and derived products by 85%.

This shows that the extraction of these important industrial raw materials, and to some degree also the related heavy industries which further process the purified raw materials, increasingly are being re-allocated to countries outside the European Union. The domestic resource dependency of ores in the EU as a whole is now at the low level of 0.2 8see also Figure 7).

Similar to the livestock production system, the primary production of industrial minerals and even more so of ores is characterized by enormous differences between the mass of the extracted gross ore and the mass of the final products (see e.g. (Giljum 2004)for copper production in Chile). We thus may expect considerable upstream flows of these materials left behind as wastes and emissions in the economies that extract them.

Fossil fuels

DMC of fossil fuels per capita ranges from 2.1 t/cap (France) to 8.0 t/cap (Greece), with an EU average of 3.7 t/cap Table 15). The variability of fossil fuel consumption across countries (coefficient of variation 0.39) is almost as low as with food (coefficient of variation 0.31). Contrary, the domestic extraction of fossils is extremely variable (coefficient of variation 1.08), a variability that is typical for point resources.

Most EU-15 countries extract only small amounts of fossil fuels per capita (less than 1 t/cap) compared to their domestic material consumption of fossil fuels. Exceptions with a significant domestic extraction of fossil fuels are Greece (exploiting lignite deposits at increasing rates, 6.0 t/cap in 2000) and the countries with access to North Sea oil and gas deposits, i.e. Denmark (4.7 t/cap), United Kingdom (4.5 t/cap) and the Netherlands (3.9 t/cap). Germany has reduced the extraction of coal (especially poor quality lignite) by almost 60% since the reunion in 1990 and now has a DE of fossils of 2.7 t/cap in 2000. In fact the closure of lignite production sites in the former GDR after the German reunion in 1991 is the most important single cause for the observed absolute dematerialisation of Germany from 1980-2000 (Eurostat 2002).

Table 15: Aggregated material flows of fossil fuels in European Union countries (2000)

Fossil fuels (2000)	DE per capita	Import per capita	Export per capita	DMC per capita	DMI per capita	PTB per capita	DMC/km^2	DE/DMC
	[t/cap]	[t/cap]	[t/cap]	[t/cap]	[t/cap]	[t/cap]	[t/km^2]	
EU-15	1.9	2.3	0.4	3.7	4.1	1.8	432	0.50
Austria	0.5	3.4	0.8	3.0	3.8	2.5	289	0.15
Belgium/Luxembourg	0.0	9.9	5.9	4.0	9.9	4.0	1 398	0.01
Denmark	4.7	3.5	4.0	4.2	8.1	- 0.5	515	1.12
Finland	0.9	5.1	1.4	4.6	6.0	3.7	71	0.20
France	0.1	2.7	0.7	2.1	2.8	2.0	225	0.06
Germany	2.7	3.3	0.7	5.2	5.9	2.5	1 202	0.51
Greece	6.0	2.9	0.9	8.0	8.9	2.0	640	0.75
Ireland	1.7	3.5	0.6	4.6	5.2	2.9	247	0.38
Italy	0.3	2.6	0.6	2.3	2.9	2.0	449	0.14
Netherlands	3.9	9.1	8.1	4.9	13.0	0.9	1 857	0.81
Portugal	0.0	2.7	0.4	2.2	2.7	2.2	246	0.00
Spain	0.6	3.1	0.7	3.1	3.7	2.5	240	0.20
Sweden	0.2	4.0	1.7	2.4	4.1	2.3	48	0.06
United Kingdom	4.5	1.7	2.2	4.0	6.2	- 0.5	977	1.12
Minimum	0.0	1.7	0.4	2.1	2.7	- 0.5	48	0.0
Maximum	6.0	9.9	8.1	8.0	13.0	4.0	1 857	1.1
Average	1.9	4.1	2.1	3.9	6.0	2.0	589	0.4
Standard deviation	2.0	2.3	2.3	1.5	3.0	1.3	515	0.4
Coefficient of variation	1.08	0.57	1.10	0.39	0.50	0.62	0.87	0.98

Source: Eurostat/IFF 2004, population New Cronos, land area FAO 2002

No EU-15 country is a significant net exporter of fossil fuels. In all countries (even in those with high DE of fossil fuels), fossil fuel imports account for 10-55% of total imports.

In general, DMC of fossil fuels reflects the variations in the composition of the primary energy supply: DMC of fossil fuels is highest in countries with a high share of coal (energy content of coal is only 30-50% of that of oil and gas) and lowest in countries with a high share of immaterial or renewable types of primary energy supply. Germany and Greece, the countries with the highest per capita DMC of fossils, exploit domestic coal deposits and have a high per capita DMC of coal. In these two countries, coal has an exceptionally large share of total DMC fossils (Germany 54%, Greece 76%, EU-15 35%). In countries where immaterial energy forms, such as hydropower, nuclear energy, electricity imports or renewable energy forms, such as biomass and wastes, substantially contribute to the energy supply, DMC for fossil fuels is low. For instance, Sweden, Finland and Belgium/Luxembourg have the highest energy consumption per capita in Europe due to energy intensive industries and high household and transport demand. Their per capita DMC of fossil fuels, however, is in the middle range Table 15) due to their low share of coal and comparatively high share of nuclear power and renewable energy. Within the EU, France has the lowest per capita DMC of fossils, followed by Italy and Portugal. While the low level for France is due to the extremely high share of nuclear power in French energy supply (40% of TPES), Portugal and Italy have rather low levels of energy consumption due to less heavy industry and residential energy demand. Per capita levels of DMC of fossil fuels, thus, indicate the combined effects of the material structure of the energy supply system and the energy intensity of the production and consumption system.

Interpreting and improving MFA indicators

Statistical measures of macro-characteristics of countries, be they economic, social or environmental, all face the same fundamental problems. (1) Finding ways to aggregate many elements of observed phenomena. These elements are not only highly divers and non-comparable at one point but also change over time. (2) Finding a common denominator for cross-country comparisons. As we know from the discussions about GDP or the Human Developmental Index (HDI), there is no fully satisfactory solution to these problems, and this also applies to indicators derived from material flow accounting.

What we also know, however, from the experience with other highly aggregated indicators, is that aggregate measures are indispensable to draw political attention to the processes they are trying to capture. Instead of covering many details, they are supposed to deliver a comprehensive message concerning the overall direction in which a country is moving and how it compares to other countries.

In the following chapter we will discuss the rational and significance of domestic material consumption as aggregated headline indicator for material use. We then turn to the question what kind of information is still missing from currently available MFA indicators and how this information could be provide. More precisely, we will pick up the conceptual suggestion from Eurostat (2001a) to use an physical input-output model to account for the raw material equivalents of imports and export and, based on this, develop new indicators, in particular raw material consumption and raw material trade balances.

Domestic material consumption

Domestic material consumption corresponds to the “apparent consumption” of materials in national economics. Conceptually, DMC is constructed in analogy to GDP, thus representing the closest physical equivalent to GDP (Eurostat 2001a). As we have seen many factors, often counteracting each other, determine the level and composition of domestic material consumption in the EU-15. Still the question remains of what exactly is the significance of the highly aggregated measure DMC and of its derived intensive indicators.

To understand this, we draw our attention from the apparent consumption perspective, which represents the method by which this indicator is compiled, to the final destination of all the materials flows aggregated to DMC. What happens with all these materials? They are, definitely not consumed by the inhabitants of a country, they do not even necessarily serve the material needs of the domestic population indirectly.

Still, these materials are consumed, although not by the inhabitants. They are “consumed” by the natural environment of a country, by its soil, its waters and its atmosphere. There are three possible environmental destinations for all the materials aggregated to DMC: (1) One part of DMC turns into CO_2 and is emitted to the atmosphere, thus contributing to global warming; (2) another part turns into emissions to air, water or soil, and into solid wastes to be stored in landfills, thereby exerting more local and regional effects on the environment; (3) the third part goes on stock, which means it serves to increase the physical stock, in particular the number of buildings and the size of the built infrastructure. The proportions between the three final destinations of DMC in terms of mass are roughly 5:1:5 in industrial economies (Matthews et al., 2000, ETC-WMF 2003). In a more long-term perspective, of course, also the materials that make up the physical stock are emitted to the environment through replacement or dissipative losses, although a total replacement of the physical stock most certainly will not occur within a period of time accessible to planning.

What is important to see is, that these final destinations have in common to be located within the national environment. We therefore talk about an annual flow of “potential domestic waste” to indicate the significance of DMC. This national waste potential will partly add to the environmental pressure within the national territory (immediately or some time in the future), or partly add to global environmental pressures (in the case of CO_2 emissions). Still, also this contribution to global environmental change will be attributed to the responsibility of the nation state. The unambiguous significance of the indicator DMC, therefore, consists in expressing the “domestic waste potential” rather then the “domestic material consumption” of a national economy, as the name of the indicator would suggest.

An indicator for the annual flow of potential domestic waste represents well what Herman Daly described as the “scale” of the physical economy (Daly 1992) and which, according to him, is the core of the sustainability problem. The different denominators (population, total land area, and total GDP) of DMC express the three relevant reference scales against which the physical scale of an economy is to be measured to relate to sustainability. Per capita amounts of DMC point to the social scale of the “domestic waste potential”, per land area amounts to the environmental scale and per GDP measures of DMC compare the scale of the physical to the scale of the monetary economy, as one way to indicate the overall material efficiency of a national economy.

Moreover, when interpreting DMC as “domestic waste potential”, the sometimes criticized conceptual characteristic of DMC, i.e. to attribute the upstream flows of the physical trade (which are, of course, considerable for some commodities) to those countries, where the waste actually occurs, immediately makes sense. These upstream flows in fact contribute to the waste potential of the exporting countries and not to the waste potential of the importing countries. Interpreted in terms of waste it is a strength of the DMC indicator that it allows to attribute the waste potential to that country within the international production chain where the waste actually occurs or will occur in the future.

Raw material consumption and raw material trade balances

Dematerialisation and ecologically unequal trade

The above introduced interpretation of DMC is quite straightforward and unambiguous. Still, there are other types of information about aggregated material flows in national economies which are needed but cannot be provided by DMC. We already mentioned the material standard of living of the population of a nation state, or more technically, the material intensity of final domestic consumption. Another area which cannot sufficiently be analysed by current MFA indicators is ecologically unequal trade.

The ongoing process of increasing global integration of economic activities is leading to a growing international division of labour and spatial separation of production and consumption activities. Via imports particular stages of the production of final commodities are externalised to other countries, and by this also the associated environmental burden. As has been pointed out frequently (Machado et al. 2001), (Hoekstra and Janssen 2002), (Gielen et al. 2003), (OECD and Ahmad 2003; OECD 2003) this has important consequences for environmental policy targets and indicators. In particular a definition of national targets (and thus a definition of national indicators) which refers to the national boundaries, may have distortionary effects (Hoekstra and Janssen 2002). For example, the Japanese government recently defined a target for reducing economy-wide material use in its official sustainable programme “Towards Establishing a Sound Material Cycle Society”. This programme used the indicator DMI to specify the target (OECD 2003c). Obviously, reducing DMI most easily can be reached by substituting imports from material intensive production sectors for domestic production of these goods. This would reduce the national material use, as measured by DMI, but globally the use of resources would not change, or could even increase, due to less efficient production technologies in the exporting countries. Thus, a procedure which allows to “charge” final goods with the raw materials that were used in order to produce those goods, regardless in which economy the production took place, would be desirable. In particular for an application of MFA indicators to dematerialization analysis and the analysis of ecologically unequal trade such a procedure is indispensable.

The concept of raw material equivalents

In its methodological guide Eurostat (2001a) introduced a very useful terminology to distinguish between different types of upstream material requirements (formerly lumped together as “hidden flows” or “ecological rucksacks”).

The distinction between “used” and “unused” extraction refers to the boundary between the economic system and its natural environment. „Inputs from the environment refer to the extraction or movement of natural materials on purpose and by humans or human controlled means of technology (i.e. involving labour).” (Eurostat 2001a). The term “used” therefore refers to acquiring value within the economic system, it signifies “an input for use in any economy, i.e. whether a material acquires the status of a product...” (Eurostat 2001a, p.20).

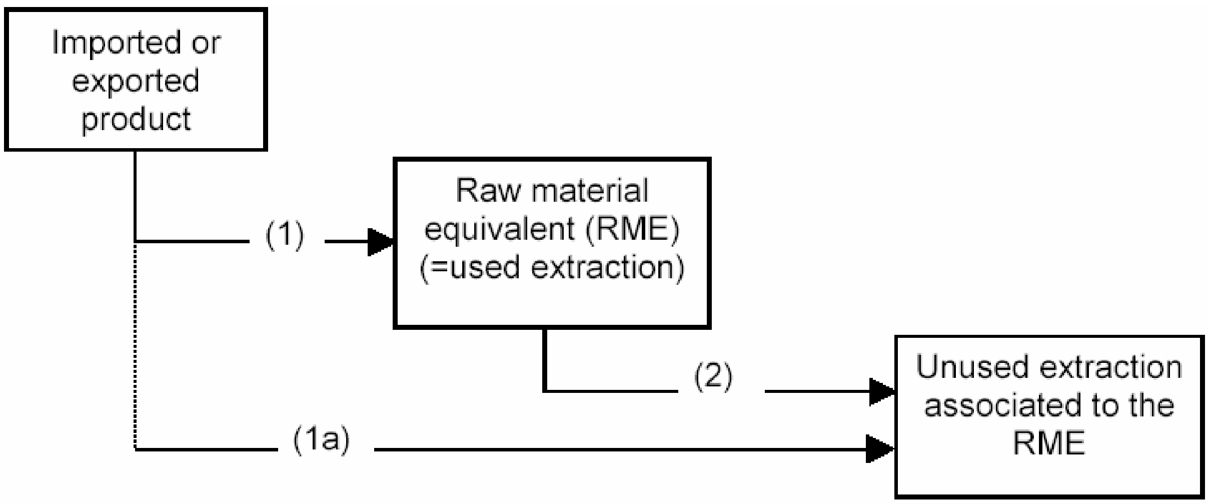
“’Unused flows’ are materials that are extracted from the environment without the intention of using them, ...” (p. 20). Dredging material, excavation material, overburden from mining (the sterile material which has to be removed in order to get access to the gross ores) and unused by-products from biomass harvest are the main components of “unused” extraction.

The term “indirect” flows refers to the boundaries between national economies. Indirect flows signify all upstream material requirements which were needed to produce imported or exported commodities. As commodities in all stages of processing from the raw materials to final products are traded, indirect flows consist of two fractions: The “raw material equivalents” comprise the used extraction which was needed to produce imported or exported commodities in the countries of origin. The unused materials associated with the raw material requirements represent the “unused” part of indirect flows (see Figure 11).

“Used” and “unused” extraction differ greatly in all relevant respects. Unused flows are huge flows (in the EU-15 the unused extraction is app. twice as large as the used extraction see (Eurostat 2001b), of minor environmental relevance (predominantly inert materials, which are not subject to chemical or physical transformation nor to colonisation), no economic significance, and last but not least particular poor data quality and comparability. Most countries in the world do not report at all about these flows, so their magnitude has to be estimated, usually using fixed coefficients, which are reported for a few countries and points in time only. If added together with used extraction (as for example in TMR) the substantially higher data quality of the direct flows as well as their environmental and economic relevance is masked and in depth analysis of the physical structure of an economy becomes difficult.

Finally the definition of what has to be considered as “unused” extraction is still very vague and changing, thus adding another obstacle to the interpretation and the comparability of these accounts. For these reasons an aggregation of “used” and “unused” extraction to one single indicator should be avoided.

Figure 11: The concept of indirect flows of imports and exports



Source: Eurostat 2001a

Things are different for raw material equivalents. As the raw material equivalents represent the used extraction which was needed to produce traded commodities, a quantification of raw material equivalents would allow to standardize foreign trade flows to the same economy-environment system boundary as applied in used domestic extraction. With this information both a net trade balance in terms of raw materials and the raw material inputs for final consumption can be calculated.

In the first case the raw material equivalents of imports and exports would be balanced, instead of the physical imports and exports themselves which are now used to compile physical trade balances. This new indicator could be termed “raw material trade balance” (RTB) and could be used to analyse environmental consequences of a growing international division of labour.

In the second case the raw material trade balance plus domestic extraction would results in an indicator which measures the raw material inputs to domestic final consumption, it could be termed raw material domestic consumption (RMC). Such an indicator is, in comparison to real GDP, an appropriate measure for dematerialisation (see (Ayres et al. 2002)).

The general approach

The method of choice to account for raw material equivalents is provided by input-output economics. A methodological alternative developed by the Wuppertal Institute is an LCA type approach which uses coefficients from the literature. This approach may in principle be appropriate to account for the unused extraction but cannot be applied to the much more complex estimation of raw material equivalents. For this reason TMR accounts normally do not comprise raw material equivalents (see e.g. EEA 2001, (Eurostat 2001b), (Pedersen 2002), (Barbiero et al. 2003) but only a few categories of unused extraction.

The strength of input output models is that a consistent aggregation of detailed process chain information to the national level is conceptually guaranteed. Input- output models consistently distinguish between factor inputs, which can be added up to the national level without double counting, and intermediate deliveries, which *cannot* be added up to the national level without double counting (Duchin 2003). IOA also provides a procedure to allocate the direct and *indirect* factor inputs to final demand categories.

Raw material requirements of imports and exports of the Danish economy in 1990: A comparison of two models

In this chapter we present the results of a case study on accounting for raw material equivalents. We estimated the new MFA indicators *raw material trade balance* – RTB and *raw material consumption*- RMC for the Denmark in 1990. We used two different input-output models, a conventional MIOT model extended by an additional vector of material primary inputs (in tonnes) and a newly developed physical input-output model to account for the raw material equivalents of imports and exports. The technical details of the two models are described in part II of this report.

Table 16 compares the results of our calculations in terms of the overall raw material intensities of the Danish imports and exports (1990, across all sectors), derived from the PIOT model, with those derived from the MIOT model.

According to the PIOT model, one kg of a typical exported commodity required 2.2 kg of raw materials in its production, whereas one kg of a typical imported commodity required 4.6 kg of raw materials (column 1 in Table 16). This means, that in Denmark in 1990 on average, raw material requirements of imports, measured in kg of direct and indirect material factor inputs per kg of imports, exceeded those for exports by 100%.

Measured in kg of raw material requirement per unit DKK, a unit of exports needed 0.2 kg of raw materials and a unit of imports 1.2 kg (see column 2 in Table 16). Thus, measured in kg per unit DKK raw material requirements of imports exceeded that of exports by more than 500%.

Now we turn to the results derived from the MIOT model (columns 3 and 4 in Table 16). As can be seen from Table 16 the computed material intensities derived from the MIOT model are completely different to the results derived from the PIOT model.

Table 16: Indirect raw material intensities of Danish exports and imports (1990): a comparison of MIOT and PIOT results

	PIOT approach		MIOT approach	
raw material requirements	kg per kg traded commodity	kg per DKK traded commodity	kg per kg traded commodity	kg per DKK traded commodity
exports	2.2	0.2	3.3	0.3
imports	4.6	1.2	1.0	0.3
column no.	1	2	3	4

Source: own calculations based on data from (Pedersen 1999), EUROSTAT/IFF 2004

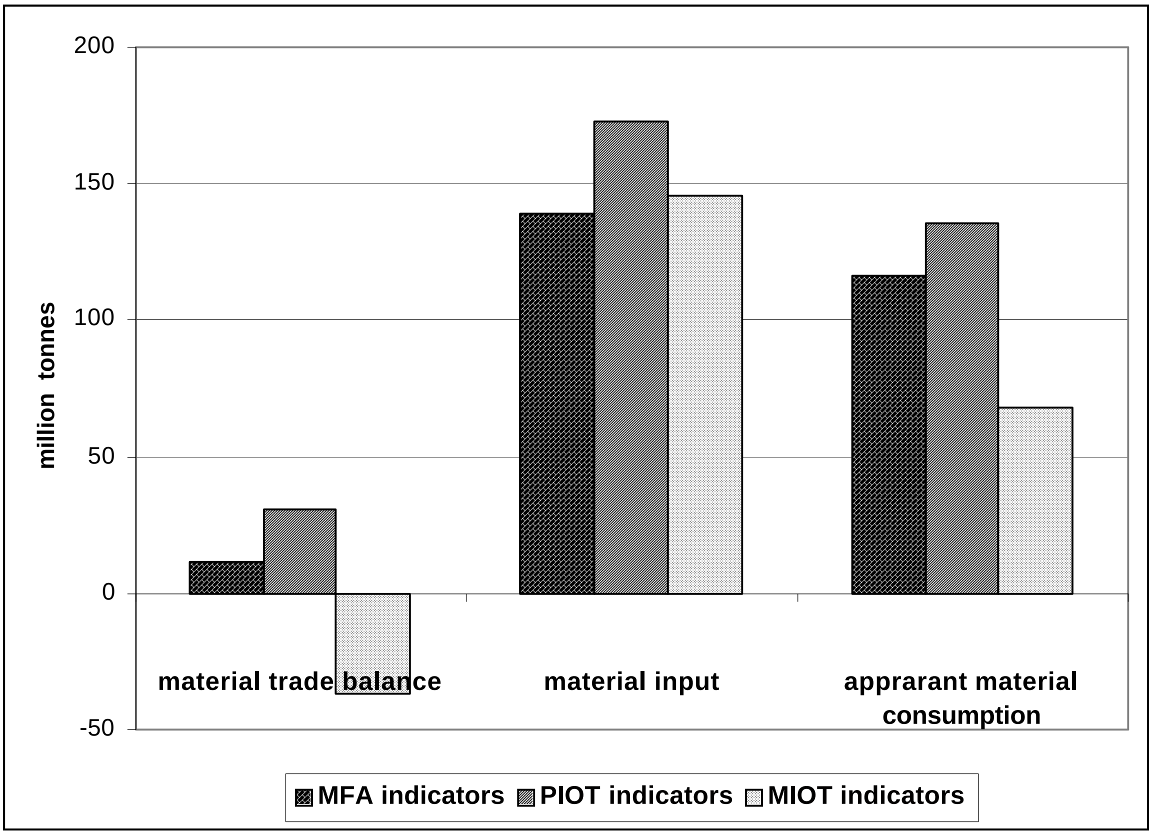
According to the MIOT model, the raw material intensity of exports, measured in kg of direct and indirect material factor inputs per kg of exports, amount to 3.3 (as compared to 2.2 from the PIOT model), whereas the raw material intensity for imports amounted to less than one third i.e. 1.0 kg per kg of imported commodity (as compared to 4.6 from the PIOT model). This means the MIOT model tells us that the raw material intensity (in terms of kg raw material requirements per kg traded commodity) of a typical Danish exportable was more than three times as high as the material intensity of a typical importable.

Finally, measured in kg per unit money value the MIOT model computes that one DKK's worth of a typical exportable required exactly the same amount of raw materials than one DKK's worth of a typical importable, namely 0.3 kg per DKK.

As a consequence, the levels of the new indicators, which can be derived from IO models, *raw material trade balance*-RTB, *raw material input*-RMI, and *raw material consumption* -RMC are substantially different if a MIOT model is used instead of a PIOT model (figure 12).

The black bars in Figure 12 show the indicators PTB, DMI and DMC (from left to right) for Denmark in 1990, as computed by conventional MFA methods (see pp 7 for a definition). The physical trade balance (PTB), as derived from MFA, was slightly positive in 1990, amounting to 11 million tonnes of net imports. Direct material inputs (DMI) were at app. 140 million tonnes and domestic material consumption (DMC) at 120 million tonnes.

Figure 12: Material flow indicators for Denmark 1990: comparison between MFA, PIOT and MIOT indicators



Source: Source: own calculations based on data from Pedersen 1999, EUROSTAT/IFF 2004

The new indicators, *raw material trade balance*-RTB, *raw material input*-RMI, and *raw material consumption* –RMC, derived from an integration of MFA and IO methods are of course not directly comparable to the indicators derived from MFA alone, because the former also account for the raw material equivalents of imports and exports. What can be seen, though, from a comparison between MFA and IO derived indicators, is the order of magnitude and thus the importance of the used fraction of indirect flows. Measured in raw material equivalents the weight of traded commodities in Denmark 1990 was about two to three times higher than the weight of the traded commodities themselves (see the first three bars in Figure 12 summarized as material trade balance bars).

Probably the most striking differences apparent in Figure 12 generates from a comparison between the results of the MIOT and the PIOT model. Conceptually the two IO models are equivalent (see part II of this report), they only differ in their units of measurement (mass flows versus monetary flows in the IO tables). The monetary model allocates far more material factor inputs to the production of exports. Therefore the raw material inputs as computed by the MIOT model is only slightly above the direct material input, the raw material consumption is half of the (direct) domestic material consumption (DMC) and the material trade balance is negative, indicating an indirect net export of raw materials (see the white bars in Figure 12).

Using the PIOT model to compute the raw material requirements, we arrive at a raw material trade balance (RTB) of 111 million tonnes - an order of magnitude above the physical trade balance, a raw material input of 170 million tonnes and a raw material consumption of 135 million tones (see grey bars in Figure 12): Overall the PIOT model tells us that Denmark was indirectly a net importer of 111 million tonnes of raw materials. Contradicting this, the MIOT calculation results in an estimated raw material trade balance of minus 43 million tonnes, indicating that Denmark was indirectly a net exporter of 43 million tonnes of raw materials in 1990.

Table 17: Direct and indirect material factor inputs of sectoral total final demand: in mio. tonnes Denmark 1990

	sector			sum of direct and indirect material factor inputs to final demand = DMI
	1	2	3	
PIOT model % change to PIOT	16 (0 %)	122 (0 %)	8 (0 %)	145
MIOT model % change to PIOT	29 (44 %)	97 (-25 %)	20 (62 %)	145

Source: own calculations based on data from Pedersen 1999, EUROSTAT/IFF 2004

Since the 1970s, monetary input-output tables have been used for environmental analysis (Miller and Blair 1985). As early as three decades ago, (Proops 1977) showed that for analysing the energy intensities of final demand, the use of an energy coefficient matrix is *the* method of choice. More specifically, he showed that although it is true that a MIOT model extended by a vector of energy coefficients correctly estimates the economy-wide energy intensity of total final demand, it incorrectly computes the individual elements of the energy intensity vector (i.e. the sectoral energy intensities). In the case example Proops estimated, the sectoral energy intensities were inaccurate by up to –83% in the MIOT model, as compared to the energy input-output model (Proops 1977).

From our comparison of a MIOT and a PIOT model for calculating the raw material equivalents of exports and imports, we draw exactly the same conclusion. Both models correctly attributed all material factor inputs to total final demand (see Table 17). Regarding the sectoral distribution of the direct and indirect material factor inputs to final demand, however, the MIOT calculation deviates from the PIOT calculation by up to 62% (see Table 17).

Conceptually, the two models would be equivalent if all relative prices in the economy were zero. As can easily be tested by dividing the monetary table by the physical table, relative prices are not zero, not even within one sector. Thus, a PIOT table indeed provides new information about the structure of an economy. Moreover, it is plausible that the use of material factor inputs relates to the mass of the commodities delivered between the production sectors and the final demand, rather than to the money value attributed to these commodities.

Conclusions and recommendations

As a next step to improve MFA indicators, a national indicator “raw material consumption”, which measures the apparent raw material consumption of domestic final demand, should be used to monitor overall economy-wide progress in dematerialisation and decoupling. Likewise, we recommend an indicator “raw material trade balance” (defined as the difference between the raw material equivalents of imports and exports), which measures the physical net trade volume in terms of raw materials, as one way of monitoring the dislocation of environmental burden caused by international trade. Both indicators can be calculated by the proposed physical input-output model, using data from MFA, which are disaggregated by sectors (i.e. integrated into the NAMEA system) and physical input-output tables.

Up to now, the empirical basis for such analyses has been very limited. We therefore recommend that the compilation of PIOTs and efforts to harmonize methods for the compilation of PIOTs should be encouraged. In this regard compatibility to the system boundary definitions of MFA as well as compatibility to the monetary IO tables are essential. Likewise, the disaggregation of material flow data by economic sectors (i.e. an integration of MFA into the NAMEA system) is necessary and should be promoted and methodologically harmonized. If the method proposed here should become applicable for regular indicator compilation, not only the model and method for compiling PIOTs must be specified, but also some details of the empirical computation itself. For example, the accuracy of the proposed method increases with the level of disaggregation of the inter-industry matrix. Therefore, the level of disaggregation should be specified in a common procedure to allow comparability of the accounts.

Finally, we appreciate that a number of more basic conceptual and theoretical details have yet to be solved in order to consistently apply input-output economics to material flow analysis. In particular we urge a careful analysis of the implicit assumptions and restrictions of the chosen input-output model (a point that has recently been stressed by (Hubacek and Giljum 2003) et al (2003), (Suh 2004), and (Giljum et al. 2004)), a critical eye on data quality and compilation methods, and the development of means to improve the conceptual framework

Part II: Methods and data sources

Methods and data sources were already described in the EUROSTAT (2002). On the basis of this, Part II of this Working Paper only describes methods and data sources used that were not mentioned before or that were changed in comparison to EUROSTAT (2002). We organised this part II along the main material categories, i.e., biomass, industrial minerals and ores, construction minerals, and fossil fuels, as well as trade. In addition, this part contains methodological details on the physical input-output analysis that was conducted.

Material Flow Accounting

With the use of additional data sources (in particular physical foreign trade data from the UN at a 3 digit level and data from national statistics of the former GDR) a reliable time series 1970 –2001 could be compiled. With a few exceptions (see below) the 1970 to 2001 data set shows no substantial statistical breaks throughout the time period at the level of aggregation presented here. As a general trend, however, data availability and data quality tend to worsen the farer one goes back in time.

Differences between the 2002 and the 2003 data set:

In the course of the extension some revisions had to be made of the 1980 to 2000 data set. The resulting differences in the new estimate are almost exclusively due to revisions of the domestic extraction category.

We revised data of the 2002 data set if at least one of the following criteria was met: (1) substantial revisions in the primary data sources (e.g. USGS, FAO), (2) cross-checks with national data sources or nMFAs revealed major differences (e.g. construction minerals in The Netherlands and Denmark), (3) identification of previously unrecognised flaws in particular double counts (e.g. in Finland and Ireland for biomass, construction minerals in Portugal), (4) the application of new methods. The latter was necessary in some cases in order to consistently extend the time series back to 1970 (in particular in the category of construction minerals, e.g. Portugal, Spain, Sweden, Italy).

As a consequence of the applied revisions per capita values of DE in the 2003 data set differ from the corresponding values in the 2002 data (see). The difference is in an order of magnitude of 1 ton or less for DMC and DE per capita for all member states except Greece (see Table 18).

In the case of Greece DMC and DE per capita are four tonnes higher in the 2003 estimate as compared to the 2002 estimate. The reason for this exceptional high difference is that there are almost no primary data for the extraction of construction minerals in Greece. The overall indicators are therefore highly depended on the model used to estimate the missing data. The difference generates from a new method to estimate DE of construction minerals in Greece (see below).

Table 18: *DMC and DE per capita in the EUROSTAT/IFF 2002 and in the EUROSTAT/IFF 2003 data set*

	DMC		DE		Difference between 2002 and 2003 est.	
	2002 estimat	2003 estimat	2002 estimat	2003 estimat	DMC	DE
	t/cap	t/cap	t/cap	t/cap	%	%
EU-15	16	16	13	13	1	1
Austria	18	18	15	15	0	0
Belgium/Luxembourg	17	16	11	11	-2	-3
Denmark	23	24	22	23	4	4
Finland	36	37	32	34	5	5
France	15	16	13	13	2	2
Germany	18	18	15	15	1	1
Greece	16	20	13	17	26	31
Ireland	24	24	19	19	3	4
Italy	13	12	9	8	-7	-10
Netherlands	13	14	9	10	11	20
Portugal	14	15	11	12	6	9
Spain	17	16	14	13	-6	-7
Sweden	21	22	22	22	2	1
United Kingdom	12	12	11	11	0	0

Below we briefly summarize the most substantial revisions (i.e. where the difference between the 2002 and the 2003 estimate was more than 3 %).

Denmark: Difference plus 4 %: Figures for construction minerals are now adjusted to the level of national data and in accordance with the nMFA of Denmark.

Finland: Difference plus 5%: In general we here used the data for the most recent years in all cases where no primary data were available for the 2000 and/or 2001 updates. In our previous estimate we extrapolated the time series. The resulting difference was most pronounced in the case of Finland.

Greece: Difference plus 31 %. A new estimation of construction minerals for the whole period of time was necessary to consistently extend the time series back to 1970.

Ireland: Difference plus 4 %: Changed level originates from a revision of livestock (sheep and cattle) data by FAO.

Italy: Difference minus 10 %: A new estimation of construction minerals for the whole period of time was necessary to consistently extend the time series back to 1970.

Netherlands: Difference plus 20 %: As USGS data for extraction of sand and gravel appeared to be extremely low we cross-checked with data from national data sources and adjusted the level according to the latter.

Portugal: Difference plus 9 %: A new estimation of construction minerals for the whole period of time was necessary to consistently extend the time series back to 1970.

Spain: Difference minus 7%: Again we applied a new estimation of construction mineral for the whole time period. In addition, a conversion from fresh weight to hey weight for the fodder categories: rye grass grasses nes. and alfa alfa, was applied (seemingly a mistake in the 2002 data set).

Used data sources and applied methods

Domestic extraction:

Biomass

Biomass data were taken from a new download from FAOSTAT.

For agriculture, 2001 data are available for all categories except for permanent pastures areas. In some cases data for primary crops had been revised by FAO back to 1984 (category vegetables fresh, nes). Other categories revised by FAOSTAT are apples, vetches, wheat, and agricultural products used for forage and fodder. As a result mainly minor changes appear in the 1980 –2000 time series (an exception is Ireland, see above). For a consistent extension back to 1970 we applied the same procedures as described in EUROSTAT (2002). In particular this refers to corrections of fodder categories. Due to missing data, mainly in the period of 1970 to 1984, it was necessary to fill data gaps. In most cases we used data from the first year for all previous years.

Forestry data were updated to the year 2001 using the same method as in EUROSTAT (2002).

Fishery data were revised by FAO, leading to slightly different production data. 2000 and 2001 data are not published yet. Therefore we used 1999 data for the missing years.

Construction Minerals

The extension of DE of construction minerals back to 1970 appeared to be the most difficult step in the compilation of the whole data set. One main result of the last revision was that data quality in this field is extremely low compared to all other categories of the MFA data set. We identified more inconsistencies when we tried to extend the time series back to 1970. To arrive at least at a medium level of consistency we developed and applied new methods for estimating missing data, for correcting flaws in the primary data, and for cross checking trends and levels. An additional challenge was that data quality differs across countries, across data sources and across points in time.

Regarding the time period it turned out that data quality tend to be lowest for the earlier years and also for the most recent years. The data sources we used in our estimate all have specific advantages and disadvantages. USGS is easily available via the web and is the only international database providing readily accessible data for the most recent years. Data quality, however, is particular low. We already described this in detail in EUROSTAT (2002). Moreover, data prior to 1990 were not available via internet. The UN database is exceptional in providing digital data starting from 1950 on. To our judgment data quality is higher than in USGS. However, the UN database publishes updates app. one to two years later than USGS, a period too long for the purposes of an MFA updating routine. Taken together USGS and UN cover the whole period of time and offer a perspective for future updates. The most important prevailing difficulty with both USGS and UN is that both databases tend to underestimate the amount of extracted mass minerals such as sand, gravel and crushed stone. Therefore a third data source is needed which provides more reliable data for mass minerals and can be used as a cross check database or as a backbone to adjust the levels. In the EUROSTAT/WI 2001 data set the EMY was used to provide such a backbone and we applied this same method in our 2002 estimate. EMY covers only a short period of time (1986-1995) and is no longer updated so it cannot be used as the primary data source. Thus, for the international estimate of DE of construction minerals three different databases have been used. This leads to the necessity to consistently assign the different material categories from each of the databases.

Already in our 2002 revision we realized that a consistent allocation between UN, USGS, and EMY has not been achieved in the EUROSTAT/WI 2001 data set. During the first revision we identified some inconsistent allocations and double counts (see EUROSTAT 2002) and revised the figures accordingly. With the extension back to 1970 more inconsistencies turned up. We identified that the compilation of the data from the three data sources still contained double counts. Moreover, double counts as well as lack of data appear also within the EMY. This may lead to substantially underestimated as well as overestimated adjustment factors derived from EMY. Considering the flaws in the primary data sets of UN and especially of USGS this may result in implausible values for the domestic extraction of construction minerals. Finally, the above-mentioned problems differ from country to country. To the end of illustrating these issues, we discuss two examples Greece and Finland.

In the case of Greece EMY does not report any figure for the amount of extraction of sand, gravel and crushed stone. In EMY all domestically produced construction minerals add up to the implausible low figure of app. 2.8 mio tonnes, which corresponds to 0.3 tonnes per capita (predominantly dimension stone). The corresponding figure in USGS is 2.2 mio tonnes (predominantly marble, gypsum and perlite) and app. 1.2 mio tonnes in UN (mostly gypsum and marble). Except for a few years in the UN database (see below) no data for the extraction of mass minerals are reported in any of the three data sources. An adjustment of data from UN and USGS to the level of EMY would severely underestimate the domestic extraction of construction minerals in Greece (see the EUROSTAT/WI 2001 data set). In the 2002 data set we took data for sand and gravel for Portugal to arrive at a more plausible result for DE of construction minerals. Here we chose a different approach (see below).

In the case of Finland EMY reports almost exclusively data for sand and gravel, which amount to 70 - 90 mio tonnes, a level close to the total amount of domestic extraction of construction minerals reported in the Finish nMFA. Contrary to EMY, USGS reports no data for sand and gravel and all construction minerals add up to 3.5 mio tonnes (3 of which is limestone and the rest is talc). Thus the EMY factor that is calculated as the relation of USGS data (excl. limestone) and EMY data, is 131. In other words, in the case of Finland the method using EMY as a backbone and USGS as data source for updates would require that the amount of talc extraction reported by USGS would be multiplied by 131 to arrive at a number for total extraction of construction minerals. The whole trend of construction minerals would be determined by this small figure for talc given in USGS.

Given the above-mentioned difficulties to arrive at a consistent time series for the DE of construction minerals we decided for a case-by-case approach.

Extending the time series back to 1970:

As far as possible we used data from UN for the historical time series (in the previous estimates USGS data were used for all years from 1990 on). We used linear interpolation or other modeling techniques to fill up missing data and statistical breaks in the UN and the USGS database. In many cases we evaluated the estimates using national data sources. Wherever available we used data from national MFAs as backbones. This applies to Austria, Denmark, Finland, Germany, Sweden and UK. For Austria, Finland and the UK national data from 1970 on are already available. Primary data from UN were almost complete for Denmark and Sweden (a few corrections had to be made) and an adjustment to the level of the nMFAs revealed plausible results. Data compilation was much more complicated for Germany. For the years 1970 to 1989 UN provides separate data sets for the former FRG and for the former GDR. Whereas data for the FRG are more or less complete no data are reported for limestone, clays and sand for the former GDR from 1970 to 1978. The only data reported prior to the year 1979 are for gravel and crushed stone. We compared the trend of gravel and crushed stone reported in the UN database to the aggregated trend of cement, “Betonerzeugnisse” and “Brandkalke” from the “Statistisches Jahrbuch der DDR 1990”. As the two trends appeared to be almost the same we used them to estimate the missing 1970-1979 data. After adding the adjusted GDR data to the FRG data we again adjusted the 1970-1979 time series of DE of construction minerals to the level of the EUROSTAT/WI 2001 data set and again the 1970 to 1989 time series to the level of the German nMFA (adjustment coefficients EUROSTAT/WI to UN: 1,5 and nMFA to EUROSTAT/WI: 0,85).

For The Netherlands we used national data for DE of construction minerals as a backbone because the previous estimates (both the 2001 and the 2002 data set) revealed implausible low levels for DE of construction minerals. The UN database contains no data for gravel and crushed stone for the years 1970 to 1978 and for sand and silica for the years 1970 to 1976. To estimate the trend we used data for the length of motorways/auto routes (from OECD Statistical trends in transport 1965 – 1987).

For Italy, Portugal, and Spain we used data from UN for all years available (1970 to 1999). The UN database reports data for mass minerals for theses countries, which are quite complete and at a plausible level. Some corrections of statistical breaks had to be made, but there was no need to use a third dataset as backbone. A recently published long term MFA for Spain (Carpintero 2002) allowed us to evaluate the data reported in UN for Spain.

In the case of Greece the UN database provides complete and plausible figures for a few years only (1993-1996). Contrary to the 2002 estimate we here used the UN data for Greece 1993-1996 as a backbone to adjust the level of DE of construction minerals. To estimate the trend 1970 to 1993 we used data for Portugal (DE of construction minerals, coefficient Greece to Portugal is app. 0,93). For the years 1996 to 2000 we used gross value added, indexed to the year 1995 (cp) for the construction sector in Greece (these data are only available from 1995-2000 from New Cronos, so we could not used this method for the whole period of time). The level of construction minerals extraction in Greece as reported in UN for the years 1993 to 1996 is higher than our 2002 estimate using data for sand and gravel from Portugal: According to UN it amounts to app. 55 mio tonnes between 1993 and 1996, which is app. 5,5 tonnes per capita, whereas in the 2002 dataset we estimated app. 30 mio. tonnes or 3 t per capita for the year 1993 to 1996.

For Belgium/Luxembourg, France, and Ireland we applied the original method i.e. using EMY as a backbone to adjust the level and UN as the primary data source for the extension back to 1970. In principle the time series for DE of construction minerals could be based on UN also for theses countries. It has not been done because of time restrictions.

Update 2001

For the 2001 update data from USGS were used. In the 2001 edition USGS published some revised data for the years 2000 and 1999 (and in some cases for 1997 and 1998). It seems to be customary for the USGS updating routine that estimates are published two years after the reporting year and theses estimates are then replaced by reported figures one year later. So we expect final data for the year 2001 to be published by USGS in the year 2004. These revisions by USGS resulted in some minor differences between the 2002 and the 2003 data set.

In three cases an allocation of the categories distinguished by USGS for the years 2000 and 2001 to the categories of the previous years - as distinguished in the MFA data set - was not possible. We already discussed the case of Finland (see above). A similar situation applies to

Spain regarding the categories marble, travertine, and granite, and The Netherlands regarding the category “grind”. In all these cases we used 1999 values for the years 2000 and 2001.

Industrial Minerals, Ores

The method for the compilation of industrial minerals and ores was left unchanged except for some specific corrections of minor importance. Peat for agricultural use was subtracted from category industrial minerals and ores and added to fossils fuels. 1970-1980 data were taken from UNICSY, 2001 data were taken from USGS. Additionally, 2000 (in some cases 1997-2000) data from USGS were revised in several cases due to changes in the USGS minerals information.

Fossil fuels

Data for fossil fuels were taken from OECD/IEA, we used the same procedure as described in EUROSTAT 2002. According to the methodological guide (EUROSTAT 2001) but in contrast to the EUROSTAT/IFF 2002 data set, peat for agricultural use was added to the category fossil fuels (instead of industrial minerals).

Foreign trade

Foreign trade data stem from three main sources:

1. EUROSTAT database ‘Comext’ for all member states of the EU since 1976 or since the year of accession respectively
2. UN database ‘Comtrade’ for all member states from 1970 to 1976 or to the year of accession
3. national data were available, i.e., Austria, Finland, Sweden, and GDR
4. Statistical Yearbook of the GDR

Table 19gives an overview of the used data sources per country and year.

Table 19: Overview of the used data sources for the compilation of physical foreign trade flows

	UN	*Comext*	nMFA	Stat. Jahrbuch der DDR 1990
Austria			1970 – 1998	
Belgium/Luxembourg	1970 – 1975	1976 – 2001		
Denmark	1970 – 1975	1976 – 2001	1981, 1990, 1997	
Finland		2001	1970 – 1999	
France	1970 – 1975	1976 – 2001		
Germany		1991 – 2001		
Former GDR				1970 – 1989
Former FRG	1970 – 1975	1976 – 1990		
Greece	1970 – 1980	1981 – 2001		
Ireland	1970 – 1975	1976 – 2001		
Italy	1970 – 1975	1976 – 2001		
The Netherlands	1970 – 1975	1976 – 2001		
Portugal	1970 – 1985	1986 – 2001		
Spain	1970 – 1985	1986 – 2001		
Sweden	1970 – 1986	1999 – 2001	1987 – 1998	
United Kingdom		2001	1970 – 2000	

Data for 1976 or the year of accession to 2001 (EUROSTAT database 'Comext')

As already described in Eurostat (2002) the main source for foreign trade data was the Comext database from Eurostat. For the years 1976 to 1987 trade data are classified according to the Nimexe classification, from 1988 onwards the HS ("Harmonized Commodity Description and Coding System" or simply the „Harmonized System") nomenclature was applied. Both nomenclatures are numerical coding systems, which classify the goods by criteria based on the stage of processing. The two nomenclatures are very similar. Both classifications provide about 99 categories on the 2digit level, which correspond to each other nearly for all categories. Besides the traded products the database contains the following items: imports and exports for all 15 EU member states in ECU/Euro (or different currencies) or physical units (metric tons). These data given for all years from 1976 or year of accession respectively to 2001 and downloadable for all partner countries or as aggregates for intra-EU and extra-EU trade flows.

As already described in Eurostat (2002) we downloaded the following primary data: imports and exports for all 15 EU member states according to intra-EU and extra-EU trade in ECU/Euro and metric tons for all years available, i.e. 1976 or the year of accession to 2001.

In order to aggregate trade data to the twelve material categories, we downloaded all products on the 2-digit level (99 categories of traded commodities) and in addition the categories 25 (construction minerals and industrial minerals) and 27 (fossil fuels) on the next more detailed level, i.e., the 4digit level.

The downloaded product items were then aggregated to twelve groups of materials. All semi-manufactured and finished products were allocated to one of the twelve categories according to the main component.

Total trade downloaded and calculated

In the database at hand the twelve material categories were then summed up to obtain the total foreign trade for each member state. These calculated sums were different to the values for total trade, which can also be downloaded from the Comext database. The deviations range from negligible up to significant amounts as described in EUROSTAT 2002.

For evaluating which values give a better approximation we compared the figures (calculated and downloaded trade) to national MFA data. National MFAs are available for Austria, Finland, Sweden, Germany and the UK. As the first three accessed the EU in 1995 Comext offers data only for 1995 to 2000. In these years the deviation between calculated and downloaded trade figures are negligible. National data for Germany exist since the year 1991, Comext data from 1991 on show no significant deviation. Thus, for comparison and analysis only the remaining UK data was used.

In the UK a significant difference between calculated and downloaded trade figures only appears in the years 1976 to 1987. The downloaded sum shows a better correspondence with the national data in the years 1976 (imports and exports) and 1984-1986 (exports). For all other years and flows the calculated trade sum shows the better approximation to national MFA, we therefore decide to use calculated sums in our MFA data set.

Statistical breaks

Rough crosschecks of the compiled data set for statistical breaks resulted in a detailed analysis of several figures and where possible or where necessary specific corrections were made.

The applied methods for cross checking were:

- We first identified the material category on the 2digit or 4digit level that causes the break.
- In a second step we calculated the prices (1000 ecu/tonnes) for the specific category. In case that the break also appears in the price series we calculated an arithmetical mean price for the regarding year using the prices in the previous and following year and utilized this estimated price for calculating a revised physical value.

  à This method was applied to the following countries: Denmark (exports: ores 1996), Greece (exports: wood 1990), Ireland (imports: other fossil fuels 1991 and 1996, coal 1993 and 1994, ores 1996), Netherlands (exports: construction minerals 1977, gas 1977)

  If the prices showed no significant break this method could not be applied for revision. In this case further analysis is needed.

  à This method was applied to the following countries: Denmark (exports: oil and gas 1989 and 1996), France (imports: coal 1995), Netherlands (imports: ores 1993; exports: ores 1988)

- In case of breaks in the fossil fuel data, we crosschecked the Comext data at the 4digit level with the referring figures of the IEA/OECD energy statistics. If the IEA/OECD data seems (a) more reasonable and (b) the break seen in the Comext data does not occur, we substituted Comext data by the corresponding IEA/OECD data.

  à This applies to the following countries: Denmark (imports: coal 1977-1990), Greece (imports: oil 1983-2001)

  If the IEA/OECD data shows the same data series we assumed the data to evidence real trends. Hence, we didn't revise the data.

  à This applies to the following countries: Italy (exports: oil 1980), Portugal (exports: oil 1994-1996)

Foreign trade for the years prior to accession and for the years prior to 1976 (UN database 'Comtrade')

For some countries and years data on imports and exports were not available from EUROSTAT'S COMEXT database: For Belgium+Luxembourg, Germany (BRD), France, Denmark, Netherlands, Italy, Ireland for the years 1970 to 1975; Greece (1970-1980), Portugal and Spain (1970-1985), Sweden (1970-1987). For these countries and years trade data were purchased from United Nations Commodity Trade Statistics Database (COMTRADE) http://unstats.un.org/unsd/comtrade/.

Primary data were processed at the three digit level, SITC revision 1. However, at the three digit level only 90-95% of all items were reported in physical units. In terms of monetary values the missing items accounted for roughly 10% of total trade. Most of the items not reported in physical units are characterized by an above average monetary value per unit of weight (above average price), hence, we estimate that COMTRADE data at the 3-digit level underestimate total imports and exports in physical units by 5-10%.

Data given in physical units other than metric tons (e.g. cubic metres, square meters etc.) were converted to tons by applying item-specific conversion factors. However, this applied only for a very small number of items.

In a small number of cases of obviously incorrect physical values and mistakes (missing data, outliers of one or more orders of magnitudes) in the database, data were corrected by applying a calculated average price per physical unit of the neighbouring years to the monetary value for the year under consideration.

Data on imports and exports of the German Democratic Republic were taken from various issues of the Statistical Yearbook of the GDR (Statistisches Jahrbuch der DDR). Chapter VIII of this yearbook reports selected items of imports and exports in physical units.

Although not all traded goods were reported in physical units, we assume from a rough comparison with the structure of foreign trade in other countries that underestimation does not exceed 20% of total trade. Particularly data concerning imports and exports of final products are not reported in physical units, while raw materials and semi-manufactured goods are covered more or less complete.

Calculation of intra- and extra-EU trade for UN data and data from national MFAs

For UN data and nMFAs no distinction between intra- and extra-EU trade is available, instead only the total foreign trade for the country is available. To estimate the intra- and extra-EU share we used the following approach:

- For nMFA data and those years where Comext data was available: we calculated the proportion intra-EU/total trade for each year and multiplied the total trade of the national MFA with the calculated share to obtain the figures for intra-EU trade. The values for extra-EU trade were calculated through subtracting the intra-EU share from the total trade.
- For those years where no Comext data was available: For nMFA data for the years prior to the accession and for the UN data we used the share of intra- and extra-EU trade of the year of accession and used this share for calculating the intra- and extra-EU trade for the years prior to the accession.

Integration of national MFAs

Material flow accounts compiled and published from national statistical offices are available for the following countries.

Austria: 1970-1998

Denmark: 1980, 1990, 2000

Finland: 1970-1999

Germany: 1991-1999

Sweden: 1987-1998

United Kingdom 1970-2000

Austria

Data for 1999-2001 were compiled using the same methodology and the same data sources as „Statistik Austria“.

Denmark: We discussed the nMFA and the EUROSTAT/IFF 2002 data set with Ole Gravgaard Pederson (Statistics Denmark) and came up with a joint agreement for harmonization. We revised data for the domestic extraction of construction minerals and Statistic Denmark agreed to revise data for DE of fodder crops.

Finland

Biomass data had to be revised for 1998 and 1999 due to a previous calculation error (double count). For 2001 FAO data were used as far as possible. Data for agricultural products harvested in household gardens were updated using 1999 data for 2000 and 2001. The same method was applied for forage and some other biomass items, not covered by FAOSTAT.

For updating industrial minerals and ores USGS data were used and adjusted to the level of the national MFA. Data for Fossil fuels were taken from IEA and USGS and adjusted to the level of the national MFA. For construction minerals, no comparable data that can be used for the 2001 update are available at all. Therefore, 1999 data were taken for 2000 and 2001 (see above for a detailed description).

Germany

Biomass data were taken from FAO compiled according to Eurostat (2002) for the whole time series.

Fossils data for the missing years were taken from IEA and USGS (excl. peat!), adjusted to the level of the national MFA.

The 2001 update of minerals was done using USGS data, adjusted to the level of the national MFA. For 1980-1990 data from the EUROSTAT/WI estimate (construction minerals; industrial minerals, ores) were adjusted to the nMFA level. For the extension back to 1970 see above.

Sweden

Biomass data were taken from FAO compiled using the same procedure as in EUROSTAT 2002 for the whole period of time.

Fossils data were taken from IEA and USGS without any change.

Construction minerals were taken from UNICSY and USGS and adjusted to the level of the Swedish MFA.

United Kingdom

For the 2001 update Biomass data originate from FAO. We applied the same methods and coefficients as ONS. Fossils fuel data were taken from IEA and adjusted to the level of the UK MFA, and data for minerals were taken from USGS without adjustment.

The Input-Output analysis

Introduction

Input-output is an analytical framework created by Nobel Prize laureate Wassily Leontief in the late 1930s (({Leontief 1936 10783 /id}), ({Leontief 1941 11006 /id}1941)) and was originally designed to analyse the interdependence of industries in an economy. Today the compilation of input-output tables is standard in national accounting statistics in almost all countries of the world and input-output methods are routinely applied in economic analyses. Since the late 1960s, IO analysis was extended to also address economy-environment relationships, focusing predominantly on energy use and pollution ((Cumberland 1966), ({Ayres & Kneese 1969 46 /id}1969), ({Bullard & Herendeen 1975 11008 /id}1975), ({Griffin 1976 11007 /id})). ({Leontief 1970 739 /id} 1970), (Proops 1977) ({Duchin, Lange, et al. 1994 9615 /id} et al. 1994), ({Duchin 1992 321 /id} 1992; {Duchin 1998 9621 /id} 1998)). In the field of Industrial Ecology, IO analysis has been applied increasingly to LCA in past years in order to overcome the persistent allocation and double counting problems of LCA (see e.g. {Suh 2004 15216 /id}.). Limited work has been done concerning the application of IO analysis to MFA, and only a few analytical applications of PIOTs have been published so far. Konjin, (Hubacek and Giljum 2003; Giljum et al. 2004) and 2002 {Hoekstra 2003 15215 /id}, {Nathani 2003 15239 /id}(Suh 2004)).

Conceptual background

In principle, a standard, static input-output model is used to calculate gross output and factor inputs required to satisfy a given final demand. Alternatively, final demand can be deduced for a given gross output. A static open IO model is constructed as shown in Figure 13.

Figure 13: Scheme of an input-output table

j i	sectors 1...n	final demand 1.................m	total output
1 2 . . n	z_{ij} inter-industry flows	y_{ik}	x_i
1 . . . . q	fa_{lj} factor inputs		
total input	x_i		

It consists of the following matrices and vectors:

$z_{ij} = \mathbf{Z}$ n x n matrix of flows of inter-industry deliveries

$y_{ik} = \mathbf{Y}$ n x m matrix of flows from production sectors to final demand sectors

$fa_{lj} = \mathbf{Fa}$ q x n matrix of factor input flows to production sectors

$x_i = \mathbf{x}$ n x 1 vector of total sectoral output (gross production or gross output)

$x_j = \mathbf{x}^\mathbf{T}$ 1 x n vector of total sectoral total input (gross production or gross output)

The consistency conditions of the model are:

$$x_i = \sum_{j=1}^{n} z_{ij} + \sum_{k=1}^{m} y_{ik} \qquad (1)$$

$$x_j = \sum_{i=1}^{n} z_{ij} + \sum_{l=1}^{q} fa_{li} \qquad (2)$$

The sum of sectoral inputs equals the sum of sectoral output, and input equal output economy-wide.

Given the balance equations and some other preconditions (see (Miller and Blair 1985) and (Fleissner et al. 1993)), the derivation of a coefficient matrix (**A**) and the subsequent calculation of the basic static Leontief model is possible

$$\mathbf{(I-A) * x = y} \qquad (6)$$

$$\mathbf{(I-A)^{-1} * y = x} \qquad (7)$$

A	is the direct input coefficient matrix (also known as technical coefficient matrix) derived by dividing each element of **Z** (z_{ij}) by total input x_j. The elements of **A** are thus $a_{ij} = z_{ij}/x_j$ [n x n] and A equals Z ˆx $^{-1}$
I	is the identity matrix
x	is the vector of gross input/output
y	is the vector of final demand
(I-A) $^{-1}$	is the Leontief inverse

The basic static IO model can be used to address the following general types of questions ({Fleissner, Böhme, et al. 1993 4086 /id}et al. 1993):

Calculation of final demand for a defined total output (see equation 6)

Calculation of total output needed to satisfy a defined final demand (see equation 7)

For our purpose, the second type of question is relevant. As total output equals factor inputs plus intermediate supply, see equation (2), we can calculate factor inputs needed to satisfy a defined final demand by applying the following procedure (Duchin 2003).

First, we define a vector (or several vectors if we want to distinguish between different types of factor inputs) of factor input coefficients (q_j), which is computed by dividing the elements of vector of factor inputs (faj) by the elements of the vector of total outputs (xj):

$$q_j = \{fa_j/x_j\} \qquad [1 \text{ x } n] \tag{8a}$$

or

$$\mathbf{q} = \mathbf{fa}\,\hat{\mathbf{x}}^{-1} \tag{8b}$$

The vector **q** thus expresses the *direct* sectoral factor inputs needed to produce one unit of a sector's total output.

By pre-multiplying this vector of material factor coefficients with the Leontief inverse (also known as multiplier) we get an extended multiplier vector **mext**.

$$\mathbf{mext} = \mathbf{q} * \mathbf{(I\text{-}A)}^{-1} \tag{9}$$

The extended multiplier **mext** is a vector that expresses all *direct and indirect* factor inputs needed to satisfy one unit of a sector's deliveries to final demand. By pre-multiplying the extended multiplier **mext** with the diagonalised vector of final demand (•) from the IO table, we get a vector of *direct and indirect* factor inputs (**fay**) needed to produce the total final demand.

fay = **mext** * • (10)

This means that the vector fay_j represents a reallocation of the *direct* sectoral factor inputs (fa_j), which are expressed in the input-output table, to those sectoral deliveries to final demand (y_i) which have *directly* or *indirectly* (via intermediate supplies from other production sectors) been used to produce this sector's deliveries to final demand. In short, the extended multiplier vector explicitly tells us how much factor inputs are needed to produce one unit of a final commodity i. Evidently, the following equation must be true:

$$\sum_j fay_j = \sum_j fa_j \qquad (11)$$

The sum of all factor inputs (row sum of fa_j) is equal to the sum of factor input needed to produce total final demand (row sum of fay_i).

This calculation can be performed for each of the final demand categories (i.e. domestic private consumption, government consumption, investments to capital, and exports) and for all kinds of factor inputs. If we want to calculate the direct and indirect factor inputs required to produce a specific final demand category, e.g. exports, we simply pre-multiply the extended multiplier vector with the vector of exports (**ye**) from the IO table and compute a new vector **faye**.

faye = mext * • **e** (12)

Following Duchin (2003), DMI represents the material factor inputs into the economy and by this, material flows can be integrated in an IO model. Thus, the minimum requirement for computing direct and indirect material factor inputs of exports are a static open IO model that distinguishes between domestic final demand and exports and DMI accounts that are disaggregated by economic sectors.

The MIOT and the PIOT model:

We now turn to the empirical basis of the IO model. The customary way to express the flows of commodities and factor inputs in an IO table is the use of money value (usually expressed in national currency and current prices). Such a table is called a monetary input-output table (MIOT).The sum of factor inputs (i.e. value added plus imports in a monetary table) plus inter-industry supplies must equal the sum of inter-industry deliveries plus deliveries to total final demand (i.e. including exports), economy-wide.

A physical input-output table expresses all flows of commodities and factor inputs in terms of physical units, in our case mass units. The input-output consistency is guarantied by the mass balance principle: inputs equal outputs plus stock increases.

Physical factor inputs into an economy are raw materials and imports (together DMI), whereas in a monetary economy the factor inputs are payments to labour, taxes, profits, and capital (together value added) plus payments for imports.

The physical output consists of the weight of commodities delivered to other production sectors and final demand plus un-priced emissions and wastes, whereas the physical output of a monetary economy consists of the money value of intermediate deliveries and the value of the deliveries to final demand only.

Thus, the treatment of wastes and emissions is a crucial issue of the structure of PIOTs. There are many different ways to deal with that (see Konijn, Giljum and Hubacek, Suh). For our purpose, we propose the following structure of a PIOT as proposed by (Fleissner 1993, Duchin 2003, Hoekstra 2003, Suh 2003).

This PIOT treats final demand in analogy to a MIOT. For our type of question this is necessary, because we want to distinguish between two fractions of DMI: One which is directly and indirectly needed for the production of domestic final demand, and another which is directly and indirectly needed for the production of foreign final demand. Treating waste as another final demand category would hamper this objective, as we would allocate a huge proportion of factor inputs to wastes and emissions as final demand category.

We still have to fulfil the mass balance, therefore the waste vector (w_j), comprising of all wastes and emissions (to water, air and land) is implemented with negative numbers as additional row vector into the factor input matrix. In total the material factor inputs are thus, domestic extraction of raw materials (p_j), physical imports (m_j) as positive flows and wastes and emissions (w_j) as negative flows.

Then the sectoral and overall input-output equation of a PIOT is:

$$x_i \text{ (total output)} = \sum_j z_{ij} + y_i \qquad i = 1\text{...........}n \qquad (13)$$

$$x_j \text{ (total input)} = \sum_i z_{ij} + p_j + m_j - w_j \qquad j = 1\text{...........}n \qquad (14)$$

The sectoral and overall input-output equation of a MIOT is:

$$x_i \text{ (total output)} = \sum_j z_{ij} + y_i \qquad (15)$$

$$x_j \text{ (total input)} = \sum_i z_{ij} + va_j + m_j \qquad (16)$$

with

va_j ....is value added

m_j is imports

Please note that all analogous vectors and matrices (such as **x**, **y** or **A**) are numerically different in the monetary model as compared to the physical model. If we denote for example the physical x as x^{ph} and the monetary x as x^{m} we can express: x^{ph} • x^{m}. For reasons of readability we will not apply this additional complication in denotation.

Given these specifications of the PIOT, the calculation of primary material requirements for the production of exports is quite straightforward for the MIOT as well as the PIOT model using the above analytical model. However, the picture is only complete if we apply the same analysis for imports. At this point it is important to note, that if factor requirements of imports are calculated using the same tables as for exports, and this is commonly done, the interpretation is somewhat different. The coefficient matrix defines input-output ratios, which are commonly interpreted as representing the technology of the economy for which the input-output table was constructed. This focal economy actually produces its exports using the technology expressed in the input-output table. Imports, however, are produced by other economies, which are most probably characterised by different technologies. The computed factor requirements for imports, thus, no longer show the *actual* factor requirements that were needed to produce the imported goods, but rather show a biophysical analogy to opportunity costs, i.e. the factor requirements that would have been needed had the focal economy been forced to produce all the imported commodities domestically.

Data sources:

To account for the raw material requirements of Denmark we used MFA data ((Pedersen 2002), Eurostat/IFF 2004, the Danish MIOT (in million DKK current prices) and the Danish PIOT(in 1000 metric tons) for the year 1990 both derived from (Pedersen 1999). We aggregated and re-arranged both tables to arrive at an analogous structure. We distinguished three final demand vectors (1) private consumption (including government consumption), (2) exports and (3) capital formation (increase in physical stocks). We aggregated the inter-industry table to a 15 x15 matrix, by aggregating the sectors wholesale and retail trade, restaurants and hotels, transport and storage, communication, financing and insurance, dwellings, business services, market services of education, health, recreational and cultural services, household services, including vehicle repair, other producers, excluding government, producers of government services to one “service sector”. We corrected the factor input vector “Danish resource extraction” in accordance with the results from EUROSTAT 2004, to ensure that DMI equals the row sum of the vector of primary material inputs.

Conclusions and recommendations

List of abbreviations

Acronyms

BMELF	Bundesministerium für Ernährung, Landwirtschaft und Forsten (Germany)
cap	capita
CEC	Commission of the European Communities
CN	Combined Nomenclature
cov	coefficient of variation (the ratio of standard deviation to arithmetic mean. This indicator compensates for differences in the absolute numerical values between different variables
CUM	cubic meter
d.m.	dry matter
DE	domestic extraction
DETR	Department of the Environment, Transport, and the Regions (United Kingdom)
DG	Directorate-General (of the European Commission)
DKK	Danish Krones
DMC	domestic material consumption
DMCbio	DMC of biomass
DMCcons	DMC of construction minerals
DMCind	DMC of industrial minerals, ores
DMI	direct material input
EEA	European Environmental Agency
ECU	European Currency Unit (up to and including 1998; from 1999: euro)
EI	energy intensity
EIFEC	EI based on FEC
EKC	Environmental Kuznets Curves
EMY	European Minerals Yearbook
ETC-WMF	European topic centre on waste and material flows
EU	European Union
Eurostat	Statistical Office of the European Communities
ext.	extended
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO statistical database
FEC	final energy consumption
FRA	Global Forest Resources Assessment 2000 (Main Report FAO Forestry Paper 140)
GDR	German Democratic Republic (former)
GDP	gross domestic product
GNP	gross national product
HDI	Human Developmental Index
HS	Harmonized Commodity Description and Coding System
ID	import dependency
IDDMC	import dependency of DMC
IDDMI	import dependency of DMI
IEA	International Energy Agency
IFF	Institute for Interdisciplinary Studies at Austrian Universities (Vienna, Austria)
IIASA	International Institute for System Analysis (Laxenburg, Austria)

IO	Input-Output
IPAT	[Impact = Pollution*Affluence*Technology]
ISSCAAP	FAO International Standard Statistical Classification of Aquatic Animals and Plants
kgoe	kilograms oil equivalent
LU	livestock units
ME	material efficiency
MEDMC	material efficiency of DMC
MEDMI	material efficiency of DMI
MFA	material flow account
MI	material intensity
MIDMC	material intensity of DMC
MIDMI	material intensity of DMI
mio	million
MIOT	monetary input-output table
MS	Member State(s)
NAMEA	
NGL	natural gas liquids
nMFA	national MFA (MFA compiled by national statistical offices)
OECD	Organisation for Economic Co-operation and Development
ONS	Office for National Statistics of the United Kingdom
p.a.	per annum
PIOT	physical input-output table
PPP	Purchasing Power Parities
PTB	physical trade balance
r	Pearson index, correlation coefficients
r^2	coefficient of determination
rev.	revised, revision
RMC	raw material consumption
RME	raw material equivalent
ROM	run of mine
s	standard deviation
t, mt	tonne(s) (metric ton(s))
TBFRA	Forest Resources of Europe, CIS, North America, Japan and New Zealand (Main Report UN Publication 99-II-E-36)
TMR	Total material requirement (DMI plus unused extraction and indirect flows)
toe	tonnes oil equivalent
TPES	total primary energy supply
UN CSD	United Nations Commission on Sustainable Development
UN	United Nations
UN-ECE	United Nations Economic Commission for Europe
UN-ICSY	United Nations Industrial Commodity Statistical Yearbook
USGS	United States Geological Survey
wc	water content
WI	Wuppertal Institute for Climate, Environment, Energy (Wuppertal, Germany)

Country codes used for the figures (ISO 3166-1)

AT	Austria
BE	Belgium
DE	Germany
DK	Denmark
ES	Spain
FI	Finland
FR	France
GB	United Kingdom
GR	Greece
IE	Ireland
IT	Italy
JP	Japan
LU	Luxembourg
NL	Netherlands
PT	Portugal
SE	Sweden
US	United States of America

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