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Cross-country comparison and determinants of material consumption

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Abstract

The economy-wide use of materials increasingly gains importance as sustainability issue. In this regard we investigate what determines observed differences in economy-wide material use among the European Union member states. The empirical basis for our analysis is an extended and revised material flow data-set for each of the EU-15 countries in time series (1970-2001), recently compiled by the authors for Eurostat. This data-set comprises consistent and sufficiently disaggregated data for domestic extraction, imports and exports as well as for derived material flow indicators. We compare variations in domestic material consumption and seek to identify determinants of the differences in material use. Our focus, thus, is on structures rather than on dynamics.

Across the European Union member states overall DMC per capita varies by a factor of three ranging between 12 tonnes per capita in Italy and the United Kingdom and 37 tonnes per capita in Finland. This variability of DMC in the EU-15 is in a similar order of magnitude as the variability of GDP per capita or total primary energy supply per capita. Linear correlation analysis reveals that national income and energy use relate to material use but cannot fully account for the observed differences in material consumption. By breaking down overall material flow indicators into some 12 categories of materials and analysing their use patterns in detail, we identified a number of factors, socio-economic and natural, that influence the level and composition of economy-wide material use. Many of these factors are specific for certain types of materials, others are more general, and quite some driving factors counteract each other regarding the direction of their influence. Concluding we discuss the significance of the indicator domestic material consumption and suggest a re-interpretation, stress the importance of population density as largely neglected but important explanatory variable for material use patterns, and sketch out how

a classification of materials flows could support their interpretation in terms of environmental impacts.

Keywords

physical economy, material flow analysis, European Union, industrial metabolism, domestic material consumption, MFA-indicators

1. Introduction

During the last decade, numerous material flow accounts for national economies in various geographical regions have been compiled. The literature on national MFAs predominantly discusses levels and trends of highly aggregated material flows for single countries (Schandl et al., 2000; Machado, 2001; Giljum, 2004; Xiaoqiu Chen and Lijia Qiao, 2001; Scasny et al., 2003; Pedersen, 2002; Mäenpää and Juutinen, 2001; Muukkonen, 2000; German Federal Statistical Office - Statistisches Bundesamt, 1995; German Federal Statistical Office - Statistisches Bundesamt, 2000; Hammer and Hubacek, 2003; De Marco et al., 2000; Femia, 2000; Schandl et al., 2004; Rapera, 2004; Mündl et al., 1999; Barbiero et al., 2003; Isacsson et al., 2000; Weisz et al., 2004c; DETR/ONS/WI, 2001; Schandl and Schulz, 2002; Castellano, 2001). Only few studies provide comparative analyses across countries (Adriaanse et al., 1997; Matthews et al., 2000; Fischer-Kowalski and Amann, 2001; ETC-WMF (European topic centre on waste and material flows), 2003) and no study, as far as we know, has attempted to analyse the reasons for the observed differences in per capita amounts of material use.

To some extent this was hampered by a lack of comparability among available datasets. Although major steps towards methodological harmonization have been achieved with the publication of a methodological guide by Eurostat (Eurostat, 2001a), still a number of important issues are not addressed in this guide and hence are not yet standardized. As a consequence economy-wide material flow accounts still may differ substantially with respect to system boundaries applied, and methods for estimating missing data (Eurostat, 2002b). Therefore, cross-country comparability of the calculated indicators has been limited (Weisz et al., 2004b).

But even if efforts towards a comparative perspective were undertaken, little attention was paid to identifying the factors that determine the structure and magnitude of the use of materials and that are responsible for the significant differences in material use even among highly industrialized nations.

In 2004, Eurostat published an MFA dataset[i] on the development of material flows of the EU-15 countries from 1970 to 2001 that provides consistent and sufficiently disaggregated data allowing for a detailed comparative analysis of material flows across EU-15 member states. We use this new opportunity for an attempt at gaining a deeper understanding of the structure of the physical economies of the European member countries. So far, no detailed results from this data set have been published, so our first task will be to give an overview and to provide a well-structured description.

To this end we disaggregate the MFA indicators according to different groups of materials and analyse them concerning their origin and the quantities in which they are used. Our main focus is on the variations in per capita materials use (measured as domestic material consumption) among EU member states. Based on such a description, we seek to identify factors that account for differences in the levels and compositions of the domestic materials use across the European Union countries. As potential explanatory variables, we consider various natural (e.g., geographic location, climate, resource availability, natural productivity) and socio-economic factors (e.g. consumption patterns, the structure of the industrial and manufacturing sector, economic development, population density) as well as the interrelations between them. Our focus is on describing, analysing and if possible explaining current differences between the physical economies of EU countries. Where

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[i] This MFA data set was compiled by the authors on behalf of the European Statistical Office and the European Commission (Eurostat, 2002b; Weisz et al., 2004a). It consists of a substantial revision and temporal extension of a data set previously provided for Eurostat by the Wuppertal Institute (Eurostat, 2001b; Bringezu et al., 2003). In addition this data set integrates the following national MFAs in a consistent way: Austria (Schandl et al., 2000), Denmark (Pedersen, 2000), Germany (German Federal Statistical Office - Statistisches Bundesamt, 2000; German Federal Statistical Office - Statistisches Bundesamt, 1995), Finland (Muukkonen, 2000), Sweden (Isacsson et al., 2000), United Kingdom (DETR/ONS/WI, 2001). Data for DE of biomass, construction minerals, fossil fuels and foreign trade data have been newly compiled based on data from FAO, UN,USGS, IEA/OECD, Eurostat and several national statistical sources (Eurostat, 2002b; Weisz et al., 2004a).

necessary for the understanding of present structures, we make use of the rich time-series data available. Our focus, however, is not on dynamics, but on structures.

When analysing a complex MFA data set, we learn about the structure of biophysical realities. At the same time we learn a lot about the quality of the data, the concepts, and the methods applied. We, thus, conclude our analysis by critically reflecting on the significance of the indicators we used, in particular "domestic material consumption" (DMC), as one of the most commonly used comprehensive indicators for material use.

2. Definitions and methods

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 (Fig. 1). MFA covers all solid material inputs (i.e. all material inputs apart from water and air) of a national economy in tonnes per year (Eurostat, 2001a). Economy-wide MFA thereby intends to complement the system of national accounts monitoring production and consumption activities in monetary terms, by a compatible system of biophysical national accounts.

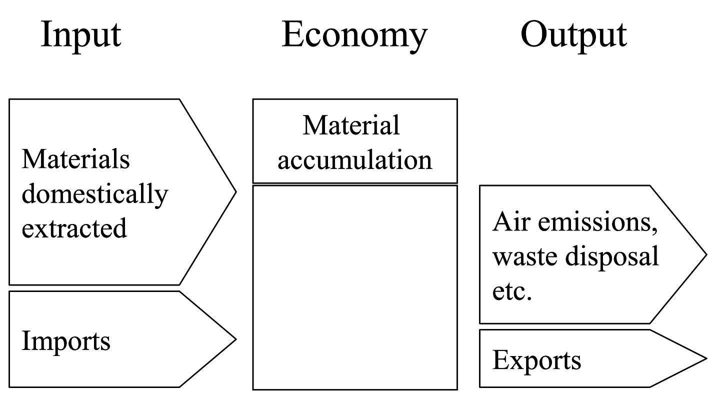

Fig. 1: Scope of economy wide material flow accounts.

Source: Eurostat (2001a)

This material flow data set for the European Union member states in time series has been compiled in accordance to the Eurostat guidelines (Eurostat, 2001a). In addition, a number of new methodological decisions in areas not covered by the Eurostat guide were necessary to achieve cross-country comparability. A detailed description of the accounting methods and the data sources is published in Eurostat (Eurostat, 2002b) and an updated version is in preparation (Weisz et al., 2004b). We therefore restrict ourselves here to a few clarifications and definitions decisive for the understanding of the analysis presented.

2.1. Material flow indicators

Similar to national (monetary) accounting, also in material flow accounting highly aggregated indicators can be derived from the detailed data sets normally comprising several hundred material categories. In our analysis, we refer to the following material flow parameters and indicators.

DOMESTIC EXTRACTION (DE): The aggregate flow DE covers the annual amount of solid raw materials (i.e. all materials 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.[ii] These materials consist of biomass[iii], construction and industrial minerals, gross ores, and fossil fuels. Concerning the water content of the raw materials the convention is to account for all raw materials in

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[ii] „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). “’Used’ refers to an input for use in any economy, i.e. whether a material acquires the status of a product ... ’Unused flows’ are materials that are extracted from the environment without the intention of using them, ...” (p. 20).

[iii] Domesticated animals are considered to be part of the economic processing system (Eurostat, 2001a). Therefore, not the body mass of the livestock is accounted for as DE, but rather the fodder that is needed to

fresh weight, with the exception of grass harvest, fodder directly up taken by ruminants, and timber harvest. These raw materials are accounted for at a standardised water content of 15% (Eurostat, 2001a).

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) equals domestic extraction plus imports minus exports. 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).

PHYSICAL TRADE BALANCE (PTB) equals physical imports minus physical exports. The physical trade balance, thus, is defined reverse to the monetary trade balance (which is exports minus imports), taking account of the fact that in economies money and goods move in opposite direction (Eurostat, 2001a). A physical trade surplus indicates a net import of materials, whereas a physical trade deficit indicates a net export.

Apart from these basic extensive material flow indicators which have been defined by Eurostat (2001a), 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 to DMC ratio as "domestic resource dependency".

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produce this body mass. The body mass of wild animals which are not fed (such as fish catch and game), if economically used, is accounted for as part of DE.

IMPORT TO DMC RATIO AND EXPORT TO DMC RATIO: The ratios between imports and exports, respectively, to DMC indicate the import or export intensities of the physical economies. Together they can be addressed as “trade intensity” indicators.

A basic problem in comparing material flows between economies lies in finding common denominators for standardization. Here we use mostly population as denominator, as is commonly applied in material flow analysis. In addition, we also introduce total land area as a denominator. With the use of different denominators, also different aspects of the physical economies become visible and comparable. Which aspects exactly are stressed by each of the denominators will be addressed by means of empirical analysis throughout the paper and discussed conceptually in the concluding section.

2.2. 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 further evaluate progress concerning dematerialisation and sustainable use of resources, however, detailed material flows rather than highly aggregated indictors should be examined. (Commission of the European Communities, 2003; Ayres, 2001; Hinterberger et al., 2003).

Such 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 (Weisz et al., 2004b). 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.

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
	Gas	All types of natural gas and derived products
	Other fossil fuels	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

Table 1: Classification of material flows.

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.

2.3. The research area

The European Union is a political and economic area which has, in the period covered by this study (1970-2001), experienced four phases of accession: 1973 (Denmark, Ireland and the United Kingdom), 1981 (Greece), 1986 (Portugal, Spain), and 1995 (Austria, Finland, Sweden) [iv]. Luxembourg, which is the smallest country in the EU-15 (2 584 km²; 384.000 inhabitants), forms a statistical union with Belgium, therefore those two countries are treated as an aggregate (Belgium/Luxembourg) also in our analysis. Hence, we only refer to 14 "national" entities. The term "EU-15" (or "EU-15 as a whole") always refers to the totality of all 15 countries, being member states of the EU in the year 2001, as one single economic area.

3. Results and discussion

3.1. Cross-country variability of domestic material consumption

The current magnitude of domestic material consumption in the EU-15 as a whole amounts to almost 6 billion tonnes or 15.7 tonnes per capita (in the year 2000). 5 billion tonnes are annually extracted from the domestic territory of the EU. Taken together, these amounts of

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[iv] In May 2004, after this study was completed, ten new countries joined the European Union, leading to a European Union of 25 (EU-25).

biomass, industrial minerals, construction minerals, ores, and fossil fuels result in an average extraction of 1 500 tonnes of raw materials per km^2 land area[v], or 0.5 kg per US$ GDP (in const. 1995 US$).

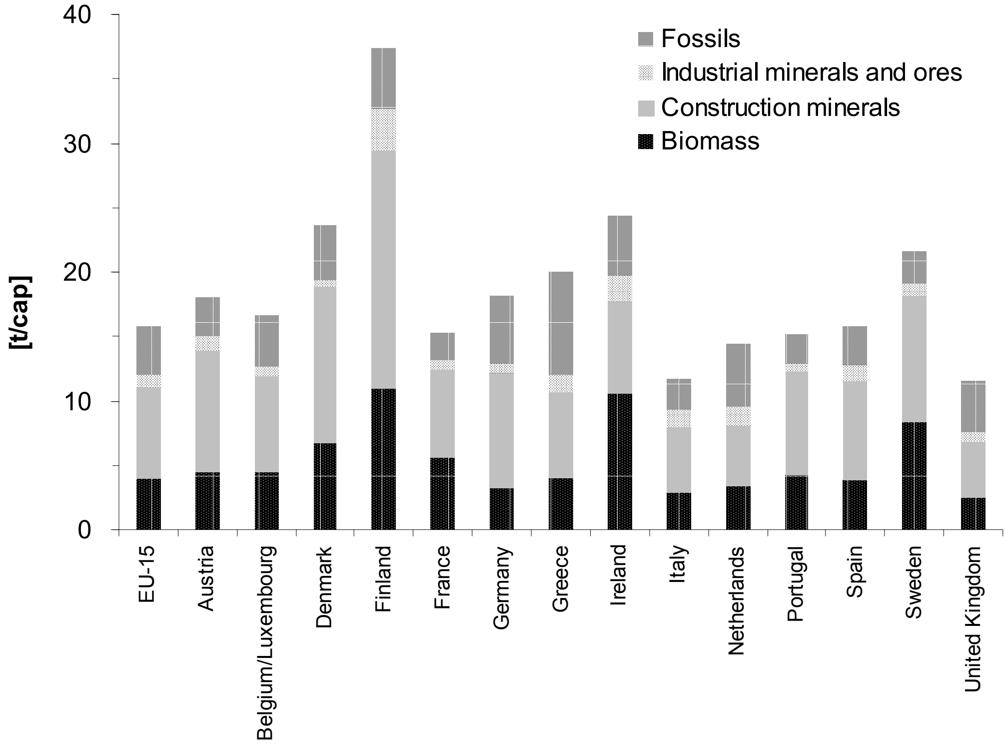

Fig. 2: Level and composition of per capita domestic material consumption (DMC) for European Union countries (2000).

Across the European Union member states the quantity of per capita material consumption varies by a factor of three (the extremes being 12 tonnes per capita in Italy and the United Kingdom and 37 tonnes per capita in Finland, Fig. 2 and Table 3). The share of the four main material categories in overall DMC per capita also varies significantly. The percent shares of biomass and construction minerals equally vary by factor two, industrial minerals and ores by factor five, and fossil fuels by factor three.

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[v] This value refers to total domestic extraction per unit of land area. However, it has to be noted that a small part of the DE of the European Union actually is extracted from the sea, above all North Sea oil and gas.

These variations of the level and composition of DMC per capita among a group of developed and highly industrialized countries pose the question which factors are determining the relative size and composition of the physical economies.

We will address this question in three steps. In a first step, we put the observed variability of DMC per capita into context by relating it to the variability of other biophysical and socio-economic macro-indicators. This will provide the necessary reference information to interpret the significance of the observed variability of material flows. In a second step, we test whether simple explanations for the differences in per capita DMC apply. In particular, we analyse the influence of per capita income and per capita energy use cross-country and in time series. Finally, we break down the aggregate flows into material categories, as defined above, and seek to identify factors that determine current patterns.

3.2. Cross-country variability of biophysical and socio-economic characteristics

The 15 European Union member states vary significantly in terms of extensive variables, such as area, population, energy supply and national income (Table 2). Total land area varies by a factor 18, population by factor 22, GDP[vi] by factor 25 and total primary energy supply by factor 24. The material flow indicator DMC varies somewhat less, by factor 16.

[vi] at constant 1995 prices

(2000)	Population	Area	GDP	TPES*	DMC
	[1 000 inhabitants]	[km²]	[10^9 US$]	[1 000toe]	[1 000t]
EU-15	376 462	3 240 015	9 786	1 444	5 921 301
Austria	8 103	83 858	267	28	146 419
Belgium/Luxembourg	10 675	30 528	343	62	177 969
Denmark	5 330	43 094	206	20	125 771
Finland	5 171	338 145	166	33	193 117
France	58 749	551 500	1 756	255	898 907
Germany	82 163	356 978	2 686	337	1 488 837
Greece	10 554	131 957	139	27	211 641
Ireland	3 777	70 273	107	14	91 873
Italy	57 680	301 318	1 205	169	675 091
Netherlands	15 864	41 526	497	74	229 284
Portugal	10 178	91 982	129	24	154 482
Spain	39 733	505 992	704	118	628 011
Sweden	8 861	449 964	278	51	191 441
United Kingdom	59 623	242 900	1 304	230	692 435

*TPES: Total Primary Energy Supply according to IEA Energy Balances refers to 1999
Sources: Eurostat New Cronos (Eurostat 2002) (Population EU, Area), OECD IEA (IEA 2002) (TPES), OECD (OECD 2002) (GDP in const.1995 US$)

Table 2. Extensive structural indicators for European Union countries (2000).

What about intensive variables? The variations of per capita national income (factor 3) and of primary energy supply per capita (factor 3) are the same as for per capita DMC (factor 3). Compared to the extensive variables they are lower by an order of magnitude. Contrary to that, the intensive variable “population density”, varies by a factor of 25 among EU member states, the same order of magnitude that we observe for the extensive variables.

We now take a closer look at the cross-country variability of the intensive structural indicators: per capita national income, percentage share of the tertiary sector in overall GDP, population density, and final energy consumption per capita and compare their variability to the cross-country variability of the overall and disaggregated material flow indicators DE and DMC (Table 4). For this comparison we use the statistical indicator “coefficient of variation” [vii]. instead of the simple ratio between the maximum and the minimum value used above. The difference in the percent share of the tertiary sector in overall GDP is lowest among the indicators shown in Table 4 (coefficient of variation 0.05), indicating a relatively high uniformity in terms of this crude indicator of macro-economic structure across EU-15 member states. The coefficients of variation for per capita national income and per capita final energy consumption (FEC) are equally 0.29.

[vii] The coefficient of variation is defined as the ratio of standard deviation to arithmetic mean. This indicator compensates for differences in the absolute numerical values between different variables.

(2000)	Population density	GDP per capita	TPES* per capita	DMC per capita
	[cap/km²]	[US$/cap]	[toe/cap]	[t/cap]
EU-15	116.2	25 993	3.8	15.7
Austria	96.6	32 955	3.5	18.1
Belgium/Luxembourg	349.7	32 093	5.8	16.7
Denmark	123.7	38 663	3.8	23.6
Finland	15.3	32 011	6.5	37.3
France	106.5	29 883	4.3	15.3
Germany	230.2	32 697	4.1	18.1
Greece	80.0	13 176	2.5	20.1
Ireland	53.7	28 235	3.7	24.3
Italy	191.4	20 889	2,9	11.7
Netherlands	382.0	31 325	4.7	14.5
Portugal	110.7	12 680	2.3	15.1
Spain	78.5	17 720	3.0	15.8
Sweden	19.7	31 365	5,8	21.6
United Kingdom	245.5	21 866	3.9	11.6

*TPES: Total Primary Energy Supply according to IEA Energy Balances refers to 1999

Sources: Eurostat New Cronos (Eurostat 2002) (Population EU, Area), OECD/IEA (IEA 2002) (TPES), OECD (OECD 2002) (GDP)

Table 3: Intensive structural indicators for European Union countries (2000).

This is slightly below the variation calculated for overall per capita DMC (coefficient of variation 0.34) but well below the variation the disaggregated material flow indicators per capita DE of industrial minerals (1.14) and per capita DE of fossil fuels (1.08). In general, per capita amounts of domestic extraction show substantially higher variation across the EU member states than the per capita amounts of domestic material consumption, an indication of the different importance that the domestic territory has as a source of raw materials in the individual countries of the EU.

For point source resources (such as fossil fuels, industrial minerals and ores) the level of domestic extraction may be in particular determined by regional resource availability in combination with the competitiveness of local prices as compared to world market prices (including transportation costs) for these resources. Thus, the high variations in the domestic extraction of industrial minerals, ores, and fossil fuels across countries are not surprising.

(2000)		EU-15	Average	Minimum	Maximum	Standard deviation	Coefficient of variation
National income (GDP)	[US$/cap]	25 993	26 826	12 680	38 663	7 783	0.29
Population density	[cap/km2]	116	149	15	382	111	0.75
Share of tertiary sector in overall GDP	[%]	68	68	60	72	3	0.05
Final energy consumption (FEC)	[toe/cap]	2.7	3.0	1.7	4.9	0.9	0.29
Domestic Extraction (DE) per capita							
Total	[t/cap]	13.1	15.9	8.0	33.6	6.5	0.41
Biomass	[t/cap]	3.8	5.1	2.0	12.5	3.1	0.60
Construction minerals	[t/cap]	7.0	8.2	3.4	17.8	3.5	0.42
Industrial minerals and ores	[t/cap]	0.4	0.7	0.0	2.7	0.8	1.14
Fossil fuels	[t/cap]	1.9	1.9	-	6.0	2.0	1.08
Domestic Material Consumption (DMC) per capita							
Total	[t/cap]	15.7	18.8	11.6	37.3	6.4	0.34
Biomass	[t/cap]	4.0	5.4	2.5	11.0	2.7	0.49
Construction minerals	[t/cap]	7.0	8.3	4.3	18.4	3.5	0.42
Industrial minerals and ores	[t/cap]	1.0	1.2	0.5	3.3	0.7	0.56
Fossil fuels	[t/cap]	3.7	3.9	2.1	8.0	1.5	0.39

Sources: Eurostat New Cronos (Eurostat 2002a) (Population EU-15), OECD/IEA (IEA 2002) (TPES), OECD (OECD 2002a) (GDP in const. 1995 US$)

Table 4: Variability of intensive indicators across European Union countries (2000).

Variations in the per capita amounts of domestic material consumption are lower as compared to DE. For the individual material categories, especially for DMC of biomass (0.49) and DMC of industrial minerals and ores (0.56), variation among the European countries is substantially higher than the variation in per capita GDP, per capita final energy consumption, or overall per capita DMC (see Table 4). It is interesting to note that the cross-country variation of overall DMC per capita between the EU as a whole, Thailand, The Philippines, and Vietnam[viii] is less than the cross-country variation of per capita DMC among the single EU countries (coefficient of variation 0.30 as compared to 0.34).

3.3. National income and energy use as explanatory variables

A simple explanation for material consumption could be national income. The richer a country gets, the more materials it consumes. Table 5 shows a Pearson coefficient of only 0.37 for the correlation between per capita GDP and DMC across the EU member states for the year 2000. Thus, income disparities alone cannot account for the difference in material consumption. The use of energy seemingly is a better explanatory variable for cross-country differences: Total primary energy supply and final energy consumption per capita correlate by 0.56 and 0.6 respectively with per capita DMC (Table 5).

It is plausible that countries may achieve a certain income level with more or less materials, for example by drawing more or less of their income from (the materially intensive) primary and secondary sectors, or by functionally equivalent choices between rather producing or rather importing materially intensive commodities. With energy, the

[viii] calculated from unpublished results of the EU-FP5 INCO-DEV Project 'Southeast Asia in Transition' (www.seatrans.net)

causal link should be closer. The relation between weight manipulated and energy required is a direct physical one. Of course, the kind of manipulation and its efficiency is varying, but one should never expect a complete independence between materials and energy use.[ix]

Pearson coefficient	DMC per capita
GDP per capita	0.37
TPEC per capita	0.56
FEC per capita	0.60

Sources: Eurostat New Cronos (Eurostat 2002) (Population EU, Area), OECD IEA (IEA 2002) (TPES, FEC), OECD (OECD 2002) (GDP in const.1995 US$).

Table 5: Pearson correlation between national income, energy flows and DMC across European Union countries (GDP: 2000; energy data: 1999).

A more complex picture emerges when relations between material flows, energy and income are analysed for each country separately in time series. Table 6 compares the results of a time series correlation analysis of GDP primary energy supply, and final energy consumption with DMC between the EU member states and the EU as whole, for the time period 1970 to 2000.

[ix] For the close relation between DMC and volumes in freight transport see Fischer-Kowalski (forthcoming).

Pearsons coefficients	GDP/DMC	TPES/DMC	FEC/DMC
EU-15	0.78	0.84	0.85
Austria	0.86	0.85	0.88
Belgium/Luxembourg	0.09	0.48	0.56
Denmark	0.48	0.55	0.40
Finland	0.43	0.25	0.26
France	0.58	0.53	0.52
Germany	- 0.78	- 0.24	- 0.04
Greece	0.94	0.97	0.97
Ireland	0.92	0.91	0.92
Italy	0.80	0.78	0.73
Netherlands	0.14	0.39	0.42
Portugal	0.96	0.96	0.96
Spain	0.99	0.98	0.97
Sweden	- 0.25	- 0.36	- 0.15
United Kingdom	- 0.17	0.28	0.19

Sources: Eurostat New Cronos (Eurostat 2002) (Population EU, Area), OECD IEA (IEA 2002) (TPES, FEC), OECD (OECD 2002) (GDP in const. 1995 US$)

Table 6: Linear correlations of time series 1970-2000(1999).

Some patterns are quite obvious. One of them is that wherever there is a strong positive (linear) relation between DMC and GDP, there is also a strong relation between DMC and two energy indicators.

Another pattern is not as obvious, but discloses itself upon scrutiny. In Austria, Greece, Ireland, Portugal, Spain and Italy the development of all three variables over the past three decades highly correlates with the development of DMC per capita. With the exception of Austria, these are the countries with the lowest per capita income in the European Union (their per capita national income was below European average throughout the time period or in the case of Ireland until the mid 1990s). On the other hand countries with high income tend to display a much less pronounced, and sometimes even negative, correlation between DMC, GDP and energy consumption (see Table 7).

	average GDP/cap	**average TPES/cap**	**average FEC/cap**
	[1 000 US$]	[toe]	[toe]
Countries with strong correlation DMC/GDP, TPES, FEC (r> 0.75); N = 6	20.8	3.0	2.3
Countries with low correlation DMC/GDP, TPES, FEC (r< 0.75); N = 8	31.3	4.9	3.4
EU-15 (N = 14)	26.0	3.8	2.7

Table 7: Strength of linear correlation between DMC, GDP, and energy consumption in relation to absolute levels of GDP per capita (2000 and 1999 resp.).

There are two exceptions from this pattern. We already mentioned Austria, that has much too high an income to fit neatly into the "strong correlation" group where it finds itself, and the UK that has too low an income to harmonize well with the "weak correlation" group of countries. Apart from that, however, as illustrated in Table 7, the pattern is quite consistent. On average, income and energy use (according to both indicators), in the group of "strongly correlated" countries is only two thirds or less of the "weak correlation" group of countries. This points in the direction of a non-linear (Kuznets-curve type) of relation between DMC and the other variables, which could be an indication of a decoupling of material flows on the one hand, income and energy consumption on the other, above a certain income (or energy) threshold. In the "weak correlation" group of countries, there is a high homogeneity of income, but a broad range of DMC levels, as well as a wide range of Pearson correlation coefficients of DMC with income and energy (from -0.78 to +0.58, see Table 6).

3.4. What determines levels of biomass use?

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, thereby jeopardizing the common wisdom of neo-classical economics, or weak sustainability which allow for perfect substitution. Even in the most advanced economies biomass DE and DMC significantly depend on natural conditions. Therefore, biophysical factors may be as important as socio-economic factors to explain economy wide biomass consumption.

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 UK (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 8).

Despite this seeming self-sufficiency in overall volume, the physical trade volume (imports or exports) of biomass is considerable in several 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 (-products) than they export, with the exceptions of Finland (net exports of 1.5 tonnes biomass per capita), France and Sweden (net exports of 0.6 and 0.5) and Belgium/Luxembourg (net imports of 1.3 tonnes of biomass per capita).

Biomass (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	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

Table 8: MFA parameters and indicators for biomass for European Union countries (2000).

We expect the level of per capita biomass use in an economy to depend 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. Some of these factors are biophysical, others are socio-economic, some are a combination of both. 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.

(1) Biomass is an area dependent resource and by this its per capita availability is closely related to population density. On a global scale the quantitative aspects of this relation largely depend on climate, technology, available substitutes for biomass as resource for extra somatic energy, and the diet of the people. On all scales below the global one trade is an important further possibility to overcome the area limitation of biomass production.

Despite these various possibilities to overcome the area limitation of biomass consumption, this limitation still exists. Even nowadays, under industrial conditions, the European countries use 70-90% of their territory for agriculture and forestry. Biomass flows may thus be considered one of the most important causes for competitive land occupation, competitive in particular for most non human species[x].

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 resp., see Table 8). 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 (see Table 3) whereas DE of biomass is between 2.0 and 3.2 t/cap (see Table 8). 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 3 and 8).

(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 Southern European 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.

[x] see e.g. (Haberl et al., 2004; Voet et al., 2003)

	Livstock	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 Statistik Austria (Statistik Austria 2002) (fertilizers)

Table 9: Selected biomass related indicators (2000).

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 9). 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.

(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 8). 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 timber 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 timber in the EU (the other major contributors of timber 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. We will return to the role of trade below.

(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 resp., compared to 0.3 LU/cap for the EU-15, see Table 9). 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 8). Clearly, fodder demand for the livestock influences per capita levels of domestic extraction of agricultural biomass in these countries.

(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 8), 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 and 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 Tables 8 and 9).[xi]

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 lesser amounts of domestic extraction of agricultural biomass (Belgium/Luxembourg: 2.9, the Netherlands: 2.6 t/cap, and France 5.5 t/cap). These countries import high amounts of agricultural plant biomass instead.

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,

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[xi] We here use the food and feed aggregate to indicate the magnitude of fodder demand because it is well known that a large proportion of the edible biomass extraction actually is used as animal fodder (see FAO food balances).

Belgium/Luxembourg, Denmark, Ireland and the Netherlands have net exports of animal products of more than 0.1 t/capita (see Fig. 3).

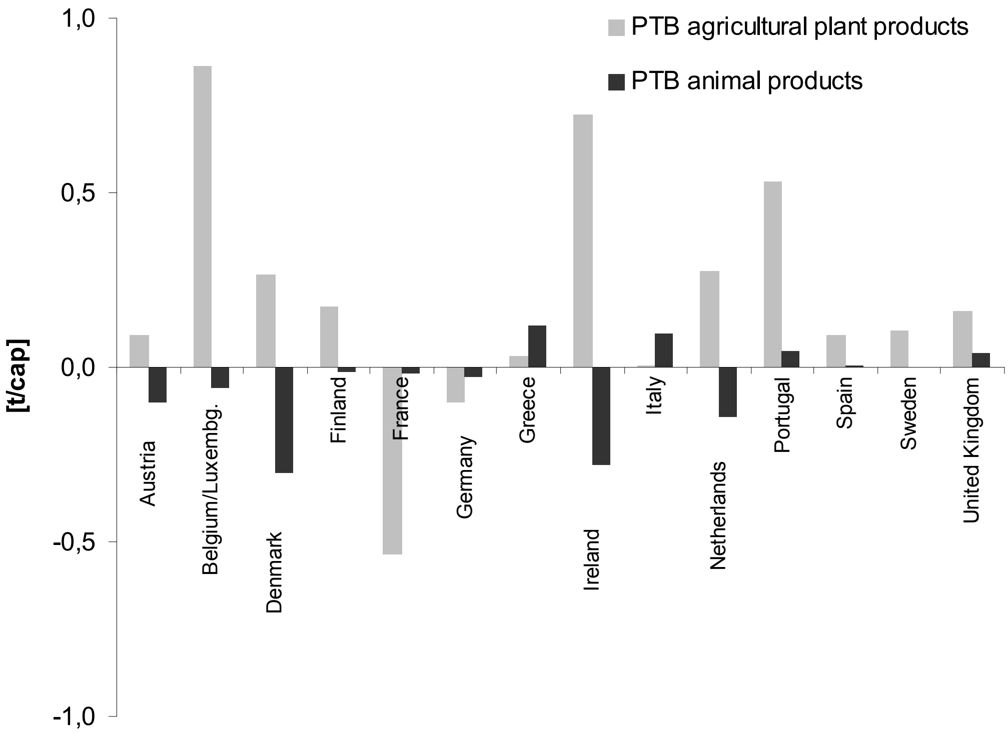

Fig. 3: Physical trade balances for plant and animal products in European Countries countries (2000).

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.

Our analysis demonstrates how a complex set of socio-economic and natural factors has to be brought into play to explain the differences in the per capita values of biomass use across EU-15 countries. The peak values of DMC which are found in Scandinavian countries and Ireland are related to extremely low population densities and, thus, huge per capita resource availability. The lowest values of biomass DE are seen in the densely populated countries in the North (2.0-3.2 t/cap) and Mediterranean (2.5-3.6 t/cap) countries with medium population densities (Portugal 111 cap/km², Greece 80 cap/km², Spain 79 cap/km²), low biological productivity and thus lower biomass yields per area (due to climatic conditions and lagging less industrialization of the agricultural system).

Overall the most important factors determining differences in per capita biomass DMC across the European Union member appear to be population density, climatic conditions, macro-economic structure, and agro-technology.

Final consumption, such as dietary patterns, 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 most materially 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 9) and vice versa. This seemingly paradox pattern diminishes if we relate DE or DMC of biomass to the territory (see Table 8). The countries with the highest values for per capita DMC and DE of biomass show the lowest values per km². For example, Finland's and Sweden's domestic material consumption of biomass amounts to 160-170 t/km². 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/km². 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 km², which is appr. 1000 tonnes dry weight per km2 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 9). We may thus consider the land related biomass flow to be a better indicator for environmental pressure than the per capita amounts.

3.5. Piled everywhere but statistically neglected: 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 Fig. 2). 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 (see Table 10). Despite their quantitative importance, there remains considerable uncertainty. The quality of the data for construction minerals is low compared to all other categories and uncertainties are considerable (Eurostat, 2002b; Weisz et al., 2004b). The same applies to physical data on final uses of construction minerals (such as data on transport infrastructure, dwellings, industrial and commercial plants, or net additions to physical stock) and to data related to the size of physical stocks (i.e. length of road networks, number of buildings, built up area etc.).

There are good reasons for such a profound negligence towards data on supply and demand for mass minerals. Low prices, lack of political attention, and a production structure which often counteracts regulations for data gathering, contributed to a long term development which generated little incentive to accurately represent this category of material flows in national statistics.

This hampers an in-depth analysis, let alone a cross-country comparison, of the DMC of construction minerals. It also implies that 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 10). 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. This means that (bulk) construction minerals are hardly traded.

There is a general explanation for the low trade volume of construction minerals. Ubiquitous high volume and low-price commodities are sold locally, as transport costs are high compared to production costs. Thus, DMC of construction minerals predominantly reflects the size of DE (r^2=0.98)[xii] and Import to DE ratios or Export to DE ratios are lowest among all types of material distinguished in our analysis.

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. On the national level, this is reflected in the need of the Netherlands and Belgium to rely on imports of construction materials.

[xii] Pearson correlation of per capita values of DE of and DMC of construction minerals

Construction minerals (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	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

Table 10: Material flows of construction minerals in the European Union countries (2000).

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 m^2 in Finland and Sweden compared to 60 and 75 in densely populated countries like the UK and the Netherlands (EEA, 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).

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.[xiii] 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.

[xiii] In Austria, Belgium, Germany, Portugal, and Spain the value added of the construction sector and DMC of construction minerals correlate between 0.73 (r^2) and 0.91 (r^2) (estimated for the period 1970-2000).

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

	total change DMC construction minerals
	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%

Table 11: Total change in domestic consumption (DMC) of construction minerals 1970-2000.

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.

3.6. Industrial minerals and ores: key mobile ingredients of industrial production

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 16).

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

Table 12: Material flows of industrial minerals and ores in the European countries (2000)

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 %).

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 (2.3 t/cap).

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 the lowest among all raw material types we distinguished in our study (DE to DMC ratio of ores is 0.2 in the EU).

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.

3.7. Fossil fuels: weight and energy disparities

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 13). The variability of fossil fuel consumption across countries (variation coefficient of 0.39) is almost as low as with food (variation coefficient of 0.31). Contrary, the domestic extraction of fossils is extremely variable (variation coefficient 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 1989 and now has a DE of fossils of 2.7 t/cap in 2000.[xiv] Despite the considerable amounts of domestically extracted fossil fuels, no European Union country is a significant net exporter. In all countries (even in those with high DE of fossil fuels), fossil fuel imports account for 10-55% of total imports and have the largest share of total imports.

[xiv] 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, 2002b).

Fossils (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

Table 13: Aggregated material flows of fossils in European Union countries (2000)

In the highly industrialized EU-15 countries, 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 renewables 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 13) due to their low share of coal and comparatively high share of nuclear power and renewables. 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.

3.8. Aggregate material flows, population density and the environmental load on national territories

Domestic material consumption over all four material categories ranges between 11.6 t/cap in the United Kingdom and 37.3 t/cap 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. The variability of DMC was greater in 1970 (variance coefficient of 0.5) than in 2000 (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.

All materials (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	13.1	3.7	1.1	15.7	16.8	2.6	1 828	0.83
Austria	14.7	8.1	4.7	18.1	22.8	3.4	1 746	0.81
Belgium/Luxembourg	10.8	23.7	17.8	16.7	34.4	5.9	5 830	0.65
Denmark	23.3	8.4	8.1	23.6	31.7	0.3	2 919	0.99
Finland	33.6	11.0	7.2	37.3	44.6	3.8	571	0.90
France	13.3	5.4	3.4	15.3	18.7	2.0	1 630	0.87
Germany	15.1	6.2	3.2	18.1	21.3	3.0	4 171	0.84
Greece	17.1	5.1	2.2	20.1	22.3	2.9	1 604	0.85
Ireland	19.2	8.2	3.0	24.3	27.4	5.1	1 307	0.79
Italy	8.0	5.7	2.0	11.7	13.7	3.7	2 240	0.68
Netherlands	10.3	18.5	14.3	14.5	28.7	4.2	5 521	0.71
Portugal	11.7	5.0	1.5	15.1	16.7	3.5	1 679	0.77
Spain	12.6	5.6	2.3	15.8	18.1	3.2	1 241	0.80
Sweden	21.8	8.0	8.2	21.6	29.8	- 0.2	425	1.01
United Kingdom	11.4	3.5	3.3	11.6	14.9	0.2	2 851	0.98
Minimum	8.0	3.5	1.5	11.6	13.7	- 0.2	425	0.6
Maximum	33.6	23.7	17.8	37.3	44.6	5.9	5 830	1.0
Average	15.9	8.7	5.8	18.8	24.6	2.9	2 371	0.8
Standard deviation	6.5	5.4	4.7	6.4	8.3	1.7	1 579	0.1
Coefficient of variation	0.41	0.62	0.82	0.34	0.34	0.59	0.67	0.13

Table 14: Aggregate material flows in the European Union countries (2000)

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 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 related to the high domestic consumption of coal, mainly low quality lignite. Last but not least the large Central European Countries France and Germany are in the European midfield. Due to their absolute size (see Table 2) these two countries also largely determine overall EU-15 material flow indicators.

Among the numerous factors affecting overall domestic material consumption, we would like to stress the role of population density, a factor hardly recognized so far.[xv] Although population density shows little (linear) correlation with per capita DMC ($r^2 = 0.29$)[xvi] across all countries, its influence on the size of DMC is apparent when we look at the extremes. Our results indicate that high population density are prohibitive for extremely high values of DMC per capita (Table 3 and Table 14). This might be due to the influence of the following factors: (1) High population density results in below average requirement of certain materials (e.g. construction materials) as there are material-saving high density settlement and transport patterns. (2) High population density is equivalent to low per capita domestic resource availability. (3) Low resource availability may enhance high material efficiency of economic processes. (4) Finally, high population density often is related to high net imports and hence to the externalisation of materially intensive processes (e.g. meat imports).

In turn, very low population density allows for extraordinary high per capita material consumption for exactly the same reasons, spelled the other way round. Low population density may cause a high demand of certain materials (e.g. construction minerals in

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[xv] Although in classical political economy, and also among the founding fathers of sociology, population density was considered important, it receives only minor attention from contemporary economics (with the notable exception of Ester Boserup (Boserup, 1981), and was not much discussed in the MFA literature so far, either.

[xvi] Land availability (i.e. the reverse of population density: area per capita) is better correlated with DMC (Pearson $r^2=0.65$).

Scandinavian countries) and low population density often relates to high per capita resource availability, favouring the establishment of materially intensive industries (e.g. animal products, timber products, ore mining) but also high per capita household consumption of abundant resources (e.g. wood).

Population density, thus, seems to be an explanatory factor especially for extremely low or extremely high values of DMC.

Environmental significance, however, cannot directly be deduced from per the capita volumes of socio-economic material use. On a global scale, it is obvious that the volumes of socio-economic material use relate to environmental pressures caused by extraction as well as by disposal. The same is not true for scales below the global. To indicate and compare the environmental significance of material flows on lower scales, for example national states, requires to take into account that the regional environmental pressure caused by the use of materials depends on the size of the regional "environmental space" acting as source and sink for the materials flows in relation to the volume of these flows. At the high level of aggregation of national material flow accounts, the best proxy for environmental space probably is the size of the territory, i.e. the total land area. If we use area as denominator for domestic extraction and domestic material consumption and compare the EU member states according to this ratio, a picture arises that completely reverts the impressions gained so far from comparing per capita values (Fig. 4). The area intensity of material use as expressed by DMC per unit land area is over 5 000 tonnes per km^2 in Belgium/Luxembourg and in the Netherlands, around 4 000 tonnes in Germany and 3000 tonnes in Denmark and the United Kingdom. In Finland and Sweden, the countries dominating in their per capita use of materials, there is only a material use of approximately 500 tonnes per km^2. There is a very clear and immediate message to be drawn from Fig. 4. From a (regional) environmental point of view, the high per capita amounts of material use in Finland and Sweden bother much less than the huge pressures on land in Belgium/Luxembourg, the Netherlands, Germany, Denmark and the United Kingdom.

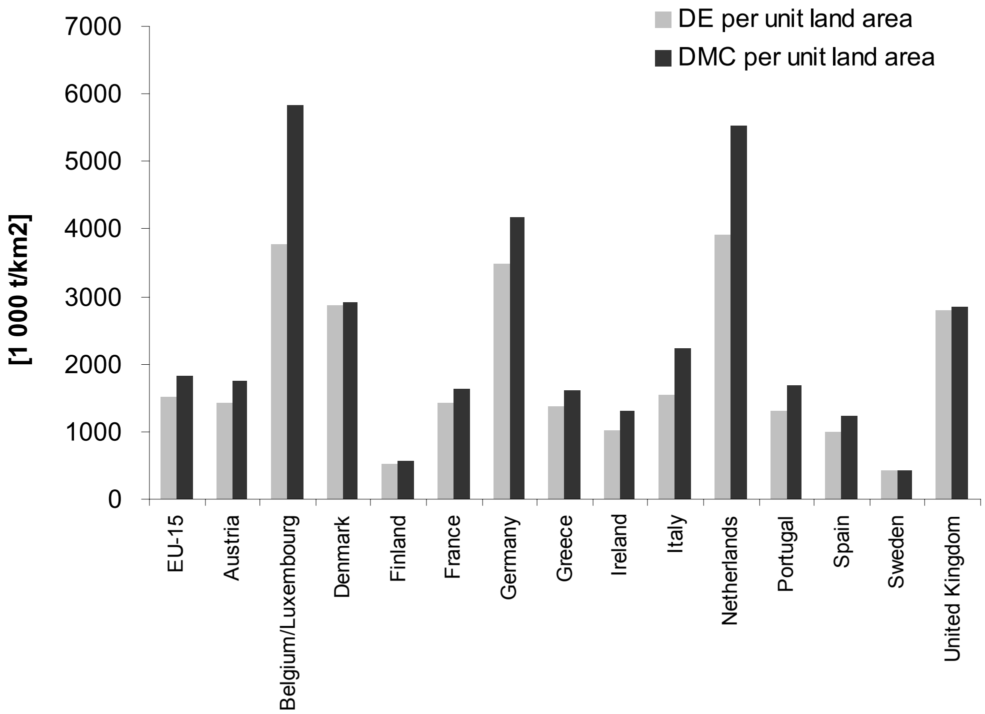

Fig. 4: DE and DMC per unit land area (2000).

3.9. A re-interpretation of "domestic material consumption" (DMC)

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 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.

We based our analysis mainly on the indicator "domestic material consumption" (DMC). This indicator corresponds to the "apparent consumption" of materials in national economics. As we have seen many factors, often counteracting each other, determine the level and composition of domestic material consumption. Still the question remains of what exactly is the significance of the highly aggregated measures DMC and of its derived 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 6:1:6 in the EU (Matthews et al., 2000). 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. This line of analysis which uses economy-wide material flow accounts for estimating waste potential is conceptually similar to Robert Ayres' early material balance approach to account for dissipative losses (Ayres and Ayres, 1999).

An indicator for the annual flow of potential domestic waste represents well what Herman Daly described denoted 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 - as has been shown - 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.

4. Conclusions

In the empirical analysis of aggregate measures from new data sets the conclusions ultimately have to combine two aspects. One is to take the data at face value and to resume the insights about the real world to which the data refer. The other is to draw a resume on the quality of the data or the appropriateness of the concepts and methods used. These two aspects are, in the process of data analysis, inseparably intertwined. When data seem to convey confusing messages about reality, you may either believe your interpretation of reality to be confusing or data to be not reliable. When data convey clear and plausible messages, you tend to believe in data quality, and in the comprehensibility of reality just the same. An appreciation of these two aspects is in particular important when long standing experience with the accounting framework is lacking, as is the case in materials flow accounting.

We focused our analysis on the variability of material use among European Union member states. We determined how large these variations are, also in relation to other macro features, and we attempted to find plausible interpretations for the results. We found that the range of variation between the European member states is large for the aggregate indicator domestic material consumption (DMC) per capita but similar to the range of variation of other aggregate measures, such as, national income or total final energy consumption. For the domestic extraction of materials (DE), the range of variation is considerable larger, but this is reliable since DE reflects the different natural conditions more than DMC. We conclude that the comparison of variations of MFA and other macro-economic indicators confirms the validity of the accounting framework.

The next issue we tried to tackle was finding factors to account for the cross-country variations. Our analysis of per capita material consumption across the European Union member states revealed that the amount and the composition of the materials which are used in industrialized market economies depend on a number of factors. The magnitude of trade, the stage of economic development, the standard of living, resource endowment of a country, population density, climatic conditions, macro-economic structure, natural productivity, the structure of the energy and the agricultural system are among the factors which influence the level of DMC per capita.

In this regard, our results stresses population density as an important but neglected factor closely related to the variation in materials use. Countries with an abundance of space probably have some sort of comparative advantage for material intensive production and consumption and thus specialise in those activities, whereas countries with high population densities would economize on material and land extensive activities. Overall our hypothesis is, that the structures of the physical economies represent different historical socio-metabolic paths, contingencies and constrains. Even under highly industrial and increasingly global market conditions these physical structures are surprisingly persistent.

Historically, the structure of the physical economy was determined by the domestic extraction of materials. An analysis of the extraction history of national economies, thus, would be an appropriate way to increase our understanding of the socio-metabolic paths, contingencies, and constraints of national economies. In this regard, a comparative analysis of the transition from an agrarian to an industrial socio-metabolic regime, its time structure and dynamic, is of particular interest.

Breaking down the overall material flows to a number of components, and discussing their specifics, is a challenging task that the MFA research community had often been urged to accomplish. With the now established quality of data a first round of this task could be undertaken. From both an analytical and a policy point of view the development of a hierarchy of material categories is a decisive step and should be further developed.

Concerning driving forces, patterns of use, environmental impacts, economic and social significance, options for a sustainable management our analysis suggests a basic distinction between two broad categories. The first category comprises industrial minerals and ores. Their overall magnitude of use is low as compared to the second group but their specific environmental impacts (impact per mass unit) may be particular high and divers, so their impact type may be denoted as toxic. In the European Union the supply of these materials is to a large and increasing degree satisfied by imports.

The second group comprises non-toxic bulk materials: biomass, construction minerals and fossil fuels. Their environmental impacts are largely a function of their magnitude of use (as compared to the scale of the eco-sphere), so they may be denoted eco-sphere related materials. All three types of bulk materials are indispensable for the functioning of industrial market economies, however their level of use is highly variable and determined by different factors, as our analysis clearly showed. The categorisation of bulk materials into biomass, construction minerals, and fossil fuels flows should, thus, be a useful starting point for further analysis in terms of driving forces, environmental impacts, best practise examples, and potential for reduction. They seem to be the logical focal area of a sustainable resource use strategy. Toxic materials have been subject of sustainability and health concerns for a long time, but it is the specific contribution and value of material flow analysis to draw the attention to the use of bulk materials in addition to providing a overall picture of economy-wide materials use.

Finally, our results reveal that trade plays an increasing role in the physical economies of the European Union. Although the domestic resource dependency is still high for some materials (above all construction minerals) physical trade volumes and overall trade intensities are increasing rapidly in all EU member states. This supports, on the one hand, the increasing attention issues of global inequality, e.g. ecological unequal exchange, currently gain in ecological economics. On the other hand this causes difficulties in interpreting levels and interrelations of economy-wide indicators. Specifically for material flow analysis this means that the nation state as a unit of analysis for the material (final) consumption of its inhabitants (a material consumption for which we do not have any appropriate indicators yet), and the nation state as a territory where certain materials are extracted and transformed into commodities are drifting more and more apart, functionally and spatially. Under highly developed industrial conditions, populations live on their national territories, but they less and less sustain themselves upon them. Measuring this in terms of raw materials would require to account for the raw material requirements of the domestic final consumption of a national economy. This in turn requires an integration of material flow and input-output analysis, a pursuit already under way. The conceptual conclusion we draw at point is to suggest a re-interpretation of the indicator “domestic material consumption” as “domestic waste potential”, since the materials aggregated in this indicator are in no meaningful way domestically consumed by humans, but they clearly have to be absorbed by the domestic natural environment. Seen this way, DMC reflects what Daly termed the “scale” of socio-economic materials use vis-a-vis the environment very well.

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