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Accounting for raw material equivalents of traded goods.

A comparison of input-output approaches in physical, monetary, and mixed units.

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Abstract

Globalisation results in rapidly growing trade volumes and an increasing international division of labour. This could lead to a globally uneven distribution of the costs (in terms of environmental pressure) and the benefits (in terms of material standard of living) of the use of material and energy. Regarding CO_2 emissions, such an uneven distribution has been termed "carbon leakage", more generally it is referred to as "ecologically unequal trade" or "ecological terms of trade". If such leakage phenomena will become more important quantitatively, this will have consequences for measuring dematerialization and ecologically unequal trade. In particular, the current definition of national indicators must be broadened to take into account also the upstream environmental pressures associated to the production of traded goods. Regarding indicators derived from national material flow accounting, Eurostat proposed the concept of raw materiel equivalents to specify the upstream requirements of imports and exports, in terms of used extraction. Until now no reliable method has been developed which would allow to compute the raw material equivalents for a national economy. In this paper we argue that a combination of input-output analysis and material flow analysis offers the appropriate tools to account for these raw materials equivalents and illustrate the feasibility with a case study. We present three open static input-output models, which differ in the units of measurement of sectoral output. Applied to the case of Denmark in 1990, we show that the three models deliver substantially different results. We discuss the results in terms of plausibly and accuracy of the concepts and draw conclusions for a further harmonization in accounting for upstream material requirements.

Keywords: material flow analysis, raw material equivalents, trade and environment, physical input-output analysis, monetary input output analysis, mixed unit input-output analysis, dematerialization, ecologically unequal trade.

Introduction

The large quantities of raw materials used in industrial economies and the rapidly increasing amounts demanded by industrializing economies such as China and India are essential causes of global environmental change. Decoupling or dematerialization have been proposed as solutions, and the use of materials has been identified as a key policy area for sustainable development strategies.[1] As a consequence, the need for periodically available and standardized economy-wide material flow accounts and indicators of material use has increased internationally.[2]

Economy-wide material flow accounts (MFAs) 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. MFAs cover all material inputs except for water and air, the unit of measurement is tons per year (Eurostat 2001a). A number of MFA derived indicators has been proposed by Eurostat (2001a), and the choice of appropriate indicators to support strategies of dematerialization and a sustainable use of recourses is intensively discussed in the OECD and EU.

Recent MFA studies show that the amounts of raw materials extracted annually from the domestic territories of industrialized countries increased only slightly over the past decades, whereas the physical quantities of annually imported and exported goods grew at a considerably higher pace (Eurostat 2002, Weisz et al. 2005). In essence, this reflects that the ongoing globalisation of economic activities is leading to a growing international division of labour and spatial separation of production and consumption activities. A national economy thus may, via imports, externalise to other countries particular stages of the production of its domestically consumed final goods, and by this also the associated environmental burden. At the same time a national economy may specialize into producing specific goods for the world market, and thus via exports internalise the associated environmental burden. This overall tendency of an increasing international division of labour has important consequences for the definition of national environmental sustainability targets and indicators if they are defined spatially.

With regards to CO_2 emissions this phenomenon has been termed "carbon leakage" (Gielen and Moriguchi 2002) and is increasingly a matter of concern (c.f. Hoekstra and Janssen 2002, Gielen and Moriguchi 2002, Machado et al. 2001). The argument goes that established national carbon accounting frameworks attribute CO_2 emissions generated in the course of producing goods for export to the exporting countries, although the final goods are consumed elsewhere. By the same token an equally unknown part of the CO_2 emissions, which factually serve the domestic final consumption of the focal economy, is attributed to those countries from which the focal economy receives its imports. Given further liberalization of the world market and the resulting increase in physical trade quantities, such "leakage" phenomena will likely become much more important in the future.

National material flow indicators face an analogous problem. A procedure would be needed by which the upstream material requirements of traded commodities could be traced back to a standardized system boundary. Such a procedure is still missing, despite the fact that analogous "leakage phenomena" or "ecological terms of trade" (Martinez-Alier forthcoming) have been recognized quite early in material flow analysis as "ecological rucksacks" (Schmidt-Bleek 1993).

This paper takes its start from the assumption that a procedure would be desirable which allowed deliveries to final domestic consumption of a national economy to be "charged" for in terms of the raw materials that were directly and indirectly used in the upstream production chain of these commodities, regardless of which economy the production took place in. We propose a combination of material flow analysis and input-output economics to account for such upstream - or in the terminology of Eurostat "raw material equivalents" - of exports and imports. We present and discuss three input-output approaches which differ in the units of measurement of sectoral output.

The organization of the remaining paper is as follows. Section 1 presents the concept of raw material equivalents, section 2 describes the three input-output approaches and the data sources used in the Danish case study. Section 3 presents the numerical results from an application of the three models to the case of Denmark in 1990, section 4 discusses and concludes.

The concept of raw material equivalents

In its methodological guide, Eurostat (2001a) introduced a new and improved terminology to distinguish between different types of upstream material requirements, formerly lumped together as 'hidden flows' or 'ecological rucksacks'. Eurostat suggests to distinguish between 'used' and 'unused' extraction on the one hand and 'direct' and 'indirect' flows on the other hand.

The distinction 'used' and 'unused' extraction refers to the boundary between an economic system and its natural environment and specifies what should be regarded as an 'input' from the environment to the economic system, i.e. what should be regarded as a raw material. Eurostat states: "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). 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........'unused flows' are materials that are extracted from the environment without the intention of using them ..." (Eurostat 2001a, 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.

'Used' and 'unused' extraction differ greatly in many relevant aspects. Unused flows are huge flows of minor environmental relevance. In the EU-15, the estimated unused extraction is roughly twice as large as the used extraction (see Eurostat 2001b). Unused extraction mainly consists of inert materials, which are not subject to chemical or physical transformation, which are not accumulated within the socio-economic system, and which do not require considerable competitive land occupation. Unused materials are of minor if not no economic significance, and finally, the data quality to account for these materials is particularly poor resulting in poor comparability of the derived indicators.

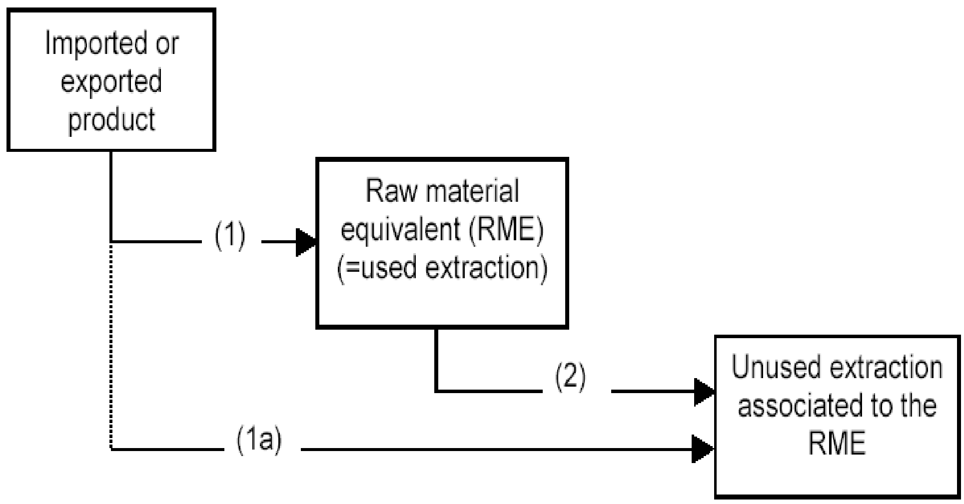
Most countries in the world do not report at all on these flows, so their magnitude has to be estimated, usually using coefficients from technical literature. These coefficients are available for a few countries and points in time only. If added together with used extraction, as for example in the MFA indicator "total material requirement" (TMR)[3], the substantially higher data quality of the direct flows (i.e. used extraction and direct imports), as well as their significantly higher environmental and economic relevance, is masked, and an in-depth analysis of the physical structure of an economy becomes difficult. For these reasons, an aggregation of 'used' and 'unused' extraction to one single indicator should be avoided (see also Ayres et al. 2004 for a similar argument).

In addition, the definition of what has to be considered as "unused" extraction still remains vague, and it is not clear what is included or not. Some studies for example include soil erosion into TMR (c.f. Bringezu et al. 2004), although Eurostat recommended not to include it into the aggregated indicators (Eurostat 2001a).

The distinction between 'direct' and 'indirect flows', on the other hand, refers to the boundary between a national economy vis a vis other national economies, i.e. to traded goods. All upstream material requirements which were needed to produce imported or exported commodities are denoted as 'indirect flows', see arrow (1a) in Figure 1. As goods in different stages of processing are traded, from basic commodities to final products, indirect flows consist of two fractions: The "raw material equivalents" represent the used extraction which was needed to produce the traded goods, see arrow (1) in Figure 1. The unused materials associated with these raw materials represent the ‘unused’ part of indirect flows see arrow (2) in Figure 1.

As the raw material equivalents represent the used extraction which was needed to produce traded commodities, a quantification of raw material equivalents would allow for a standardization of physical foreign trade flows to the same economy-environment system boundary as applied in used domestic extraction (DE)[4].

Figure 1: The concept of indirect flows of imports and exports



Source: Eurostat 2001a

With such information, both a net trade balance in terms of raw materials and the raw material requirements of domestic final consumption could be calculated for a national economy. A net trade balance in terms of raw materials is needed to investigate if, and to what extent, a country's domestic final consumption is indirectly dependent on raw materials from abroad. A time series of the raw material requirements of domestic final consumption would allow to monitor if an economy is dematerialising absolutely. So far, studies which analysed dematerialization for the whole economy in terms of raw materials did either ignore the indirect effects of foreign trade flows (see. e. g. Ayres et al 2004 for the US) or focused merely on the unused extraction associated with imported goods (Bringezu et al. 2004).

This latter approach to account for indirect flows has been developed by the Wuppertal Institute and became known as "ecological rucksacks" or "hidden flows". It is a LCA type approach using coefficients from the literature which are then multiplied by the quantities of the used raw materials. This method may in principle be appropriate to account for the unused extraction of a few basic commodities, if regional specific coefficients are available. It cannot be applied, however, to the much more complex estimation of raw material equivalents of all imported and exported goods. Not only is the number of coefficients that would be needed by far too large to be compiled in practice. LCA approaches also lack appropriate standards to guarantee the consistency and comparability of the accounts, in particular when aggregated to larger scales. LCA factors cannot account for the so called second and third round effects of the intermediate use and supply chains of the industrial production system. [5] These intermediate flows have become extremely large in highly industrialized economies (see Ayres et al. 2004). It is therefore not surprising that TMR accounts so far hardly include the raw material equivalents of the imports but simply restrict to the unused extraction associated to some basic imported commodities (see e.g. Bringezu et al. 2001, Eurostat 2001b, Pedersen 2002, Barbiero et al. 2003). In addition, if fixed coefficients for unused extraction are used in time series analysis, the results may be deteriorated, because in reality these ratios change over time, in accordance with changing of ore grades, technologies and production sides.

Finally it should be noted that mere input indicators such as TMR or DMI (direct material input)[6] in general may yield misleading results regarding dematerialization or unequal trade, because these indicators neglect the indirect flows associated to exports. This is relevant as exports are increasing faster than imports in many countries. In the EU-15, for example, total increase of the physical import volume was 40% from 1970 to 2001, whereas exports increased by 100% over the same period. Compared to that the annual amount of raw materials extracted from the territory of the EU-15, was only 14% higher in 2001 as it was in 1970 (Weisz et al. 2005).

If dematerialization or a possible relocation of raw material intensive production is analysed for national economies the net effect of the upstream raw material requirements of imports and exports must be taken into account.

Methods and data sources

Input-output economics is a body of theory created by Nobel Prize laureate Wassily Leontief in the late 1930s (Leontief 1936, Leontief 1941) and was originally designed to analyse the interdependence of industries in an economy. Since the late 1960s, IO analysis was extended to allow for addressing economy-environment relationships, focusing predominantly on energy use and pollution (Cumberland 1966, Ayres and Kneese 1969, Bullard and Herendeen 1975, Griffin 1976, Leontief 1970, Proops 1977, Duchin et al. 1994, Duchin 1998). Within industrial ecology, IO analysis has been applied increasingly to LCA in past years (c.f. Lave et al. 1995, Suh 2004b, Peters and Hertwich in press). Limited work has been done concerning the application of IO analysis to economy-wide MFA (Konijn et al. 1997, Behrensmeier and Bringezu 1995, Hinterberger et al. 1998, Hoekstra 2005, Suh forthcoming).

To account for the raw material equivalents of any category of final deliveries we begin with a basic static open input-output quantity model of the type:

$$\mathbf{Z} + \mathbf{y} = \mathbf{x} \quad (1)$$

$$(\mathbf{I}-\mathbf{A})^{-1} * \mathbf{y} = \mathbf{x} \quad (2)$$

where $\mathbf{Z}$ is the n x n inter-industry table with elements {zij}, $\mathbf{y}$ is the n x 1 vector of final deliveries with elements {yi}, and $\mathbf{x}$ is the n x 1 vector of sectoral output with elements {xi}, $\mathbf{A}$

is the n x n matrix of direct input coefficients (also known as technical coefficient matrix), derived by dividing the n x n inter-industry table **Z** by the n x 1 vector of sectoral output **x**. Thus, **A** equals **Z** $<\mathbf{x}>^{-1}$ and the elements of **A** are $\{a_{ij} = z_{ij}/x_i\}$. Finally **I** is the n x n identity matrix (with ones down the diagonal and zeros elsewhere). The matrix $(\mathbf{I-A})^{-1}$ is called the Leontief inverse.

Further we need a 1 x n vector **f** (with elements $\{f_j\}$)of material factor inputs. In general, the concept of "factor inputs" represents the biophysical analogue to the monetised concept of "value added" and comprises the biophysical factors of production, such as raw materials, land, water, energy (Duchin forthcoming). For the purpose of computing the raw material equivalents needed to produce a given bill of exports we consider all raw materials and imported goods as material factors. This aggregate is known a direct material input (DMI) in economy-wide material flow accounting.

However, economy wide material flow accounts, so far, do not routinely provide a sectoral disaggregation of DMI. If a physical input-output table in one single unit of mass (PIOT) is available, a vector of sectoral material factor inputs (or sectoral DMI) is provided by the factor input quadrant of the PIOT (see e.g. Stahmer et al. 1998, Pedersen 1999). Still some caution is required as currently available PIOTs do often not apply the system boundary definitions of standard economy-wide MFA (Weisz and Duchin in press). An alternative would be an integrated NAMEA. NAMEA stands for “national accounting matrix including environmental accounts” (Eurostat 2001c). The environmental accounts typically include air emissions, emissions to water, energy supply, and waste generation. If also materials flows, in particular domestic extraction (DE) and DMI, are included, we talk about an integrated NAMEA. An integrated NAMEA assures full compatibility with the system boundary definitions of an economy wide MFA.[7]

Given the IO model (equations 1 and 2) and a vector of sectoral material factor inputs (**f**) the computation of raw materials equivalents of exports proceeds in two steps.

First we compute a vector of coefficients of *direct and indirect* raw material requirements **r**, (a 1 x n vector with elements {rj}), needed to produce one unit of a sector's total output, as follows (equation 3):

$$\mathbf{r} = \mathbf{f}\ \hat{\mathbf{x}}^{-1}\ (\mathbf{I}-\mathbf{A})^{-1} \qquad (3)$$

In equation (3) a vector of *direct* raw material coefficients $\mathbf{f}\ \hat{\mathbf{x}}^{-1}$ - derived by dividing each element of the given 1 x n vector of sectoral *direct* material factor inputs **f** by the corresponding elements of the given vector **x** of total outputs - is pre-multiplied with the Leontief inverse to yield the 1 x n vector **r**.

Second, we compute a 1 x n vector **e** (with elements $\{e_j\}$), expressing the total amount of raw materials needed directly and indirectly to produce a given bill of final deliveries, by post-multiplying **r** with $\langle \mathbf{y} \rangle^{-1}$ which is an n x n diagonal matrix with the inverse of the final deliveries down the diagonal and zeros elsewhere (equation 4).

$$\mathbf{e} = \mathbf{r}\ \langle \mathbf{y} \rangle^{-1} \qquad (4)$$

Thus the vector **e** shows the total raw material equivalents of all final sectoral deliveries in a national economy.

If the raw material equivalents of only one category of final demand is needed (as in our case the raw material equivalents of exports) equation (4) turns into:

$$\mathbf{e}_{ex} = \mathbf{r}\ \langle \mathbf{y}_{ex} \rangle^{-1} \qquad (4a)$$

with

$$\mathbf{y} = \mathbf{y}_{pc} + \mathbf{y}_{gv} + \mathbf{y}_{i} + \mathbf{y}_{ex} \qquad (5)$$

Total final demand (**y**) equals private consumption ($\mathbf{y}_{pc}$) plus governmental consumption ($\mathbf{y}_{gv}$) plus capital investment ($\mathbf{y}_{i}$) plus exports ($\mathbf{y}_{ex}$).

Note that the sum of all sectoral material factor inputs (row sum of **f**) must be equal to the sum of all raw material equivalents (row sum of **e**) needed to produce a given bill of final deliveries **y**.

$$\mathbf{f1} = \mathbf{e1} \qquad (6)$$

with **1** being the n x 1 aggregation vector, with all elements equal one. By this the consistency of the model can easily be checked.

So far, this is a standard method in environmental input-output analysis, applied to the special case of accounting for raw material equivalents within economy-wide material flow accounting. The innovative elements of our paper are the application of this method to material flow accounting, the comparison, empirically and conceptually, of three approaches, all of the general type described above, but differing in the units of measurement of sectoral output in the input-output tables, on which the models are based. Note that the analogous vectors and matrices (such as **x**, **y** or **A**) are numerically different in the three models, but that the material factor input vector **f** is the same in all three approaches and always measured in tonnes [t]. The three different data bases are illustrated in Tables 1 - 3, which show highly aggregated (2 x 2) versions the three tables for Denmark 1990.

Table 1: Input output table in approach 1

	1	**2**	**y**	**x**	**unit**
1	6	44	20	**69**	**[bill. DKK]**
2	19	369	824	**1212**	**[bill. DKK]**
v.a.	37	674	**710**		**[bill. DKK]**
imports	8	126	**134**		**[bill. DKK]**
$\mathbf{x}^T$	**69**	**1212**		**1282**	**[bill. DKK]**
DMI	88	57		**145**	**[mio.t]**

Source: Pedersen (1999) modified and aggregated by the authors, DMI modified according to Weisz et al. 2005

Approach 1 is the most common approach where the measurement to express the quantities of output of all sectors of the economy is money value (expressed in national currency and current prices). Such a table is called a monetary input-output table (MIOT) and its underlying data structure is shown in Table 1.

Note that the monetary value added and import vectors visible in Table 1 are not needed for the computation of raw material equivalents. Their integration into Table 1 merely has the purpose to illustrate that for a full input-output table in monetary units (i.e. one comprising of all three quadrants) sectoral inputs equal sectoral outputs.

Approach 2 is a purely physical model based on an input output table where the quantities of the output of all sectors is measured in one single unit of mass. Such a table is called a physical input-output table (PIOT) and its overall structure is shown in Table 2. Also for a PIOT sectoral input must equal sectoral outputs, according to the mass balance principle.

Table 2: Input output table in approach 2

	1	**2**	**y**	**x**	**unit**
1	6	53	11	**70**	**[mio t]**
2	5	29	78	**112**	**[mio t]**
DMI	88	57	**145**		**[mio t]**
waste	-30	-27	**-57**		**[mio t]**
xT	**70**	**112**		**182**	**[mio t]**

Source: Pedersen (1999) modified and aggregated by the authors, DMI modified according to Weisz et al. 2005

The PIOT structure shown in Table 2 implements wastes and emissions (together denoted as "wastes" in Table 2) with negative signs as additional vectors into the factor input matrix. This interpretation of emissions and wastes as factor inputs is already apparent in early attempts to apply input-output economics to environmental analysis (see c.f. Leontief 1970), and has been proposed for single unit mass PIOTs already in 1993 by Fleissner an co-authors (Fleissner et al. 1993) and again recently by Hoekstra (2003), Suh (2004a) and Dietzenbacher (2005).

Approach 3 is a mixed unit model based on an input-output table where the output from the production sectors is measured in mass units and the output from the service sectors is measured in money value (see Table 3).

Table 3: Input output table in approach 3

	1	**2**	**y**	**x**	**unit**
1	6	53	11	**70**	**[mio t]**
2	19	369	824	**1212**	**[bill.DKK]**
DMI	88	57	**145**		**[mio t]**

Source: Pedersen (1999) modified and aggregated by the authors, DMI modified according to Weisz et al. 2005

It is apparent from Table 3 that in a mixed unit input-output table only total output (which equals the row sums), but not total input (which would equal the column sums), can be computed, because total input would imply adding different units. It follows that no input output equation can be applied to a mixed unit input-output table.

Finally, it is important to note, that if factor requirements of imports are calculated using the same tables as for exports (as we did in our study, and as is commonly done) the interpretation of the computed raw material equivalents for imports is somewhat different from the interpretation of the computed raw material equivalents for exports. 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 characterized by different technologies. The computed raw material equivalents for imports thus no longer show the *actual* raw material equivalents 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.

For the computation of the raw material equivalents of Danish exports and imports in 1990 we used the Danish MIOT, a 27 x 27 industry-industry table in million Danish Crones (DKK), current prices and the Danish PIOT, a 27 x 27 industry-industry table in 1000 metric tones for the year 1990 both derived from Pedersen (1999). For the physical model we aggregated and rearranged the tables to a 16 x 16 physical table, as all service sectors except for one had zero output in the original physical table. The computations with the monetary and the mixed unit models were done at a 27 n resolution. For reasons of comparability the results were then aggregated to the same 16 n classification as in the physical model. We distinguished three final demand vectors (1) private consumption (including government consumption), (2) exports and (3) capital formation which corresponds to the increase in physical stocks measured in tons. We corrected the factor input vector "Danish resource extraction" from the PIOT in accordance with the numerical results for DMI of Denmark in 1990 (Weisz et al. 2005) to ensure that DMI equals the latest official material flow accounts for Denmark.

Results

A comparison of the raw material equivalents for total final deliveries (**e**) computed with the three models is shown in Table 4.

Unexpectedly, the results obtained from the purely physical model and the results obtained from the mixed unit model are almost identical, whereas the monetary model gave substantially different results.

Table 4: Sectoral raw material equivalents of total final deliveries

	monetary model	physical model	mixed unit model
Agriculture, horticulture etc.	19,2	11,9	19,3
Forestery and logging	0,5	0,8	0,5
Fishing	0,2	1,1	0,2
Mining and quarrying	5,6	18,9	5,6
Manuf. of food, beverages, tobacco	29,2	36,0	29,4
Textile, clothing, leather industry	0,7	0,7	0,7
Manuf. of wood products, incl. Furnit	1,9	1,9	1,9
Manuf. of paper, printing, publishing	1,0	0,6	1,1
Chemical and petroleum industries	6,9	16,5	6,9
Non-metalic mineral products	1,7	1,3	1,7
Basic metal industries	0,6	0,3	0,6
Manuf. of fabricated metal products	2,8	3,9	3,0
Other manufacturing industries	0,1	0,2	0,1
Electricity, gas and water	5,4	8,2	5,4
Construction	57,7	21,1	58,0
Services	9,1	19,4	8,4
SUM	142,5	142,8	142,8

Source: Pedersen 2002, own calculations based on data from Pedersen 1999 and Weisz et al. 2005.

The largest amount of raw material equivalents are attributed to the construction sector in the physical and the mixed unit model, whereas the monetary model suggests that food manufacturing would be the most material intensive sector. The row sum of **e** exactly equals the row sum of **f** in the results of the monetary and the mixed unit model. The physical model gives a slightly different value.

Table 5 gives the same information for exports only ($\mathbf{e}_{ex}$). Again the physical and the mixed unit model gave almost identical results. The calculated total of raw material equivalents of all exported goods (row sum of of $\mathbf{e}_{ex}$) amount to 48 and 49 million tons respectively with the two models. The corresponding figure from the monetary model is much higher; it amounts to 74 million tons. The monetary model allocates the largest amount of raw material equivalents to the food manufacturing sector (22 million tons), and the mining and quarrying sector (19 million tons). The physical and the mixed unit model also allocate the largest fraction of raw materials to the food manufacturing sector, but the absolute amount is substantially lower (16 million tons). Second largest according to these two models is the agricultural sector with 14 million tons of raw material equivalents.

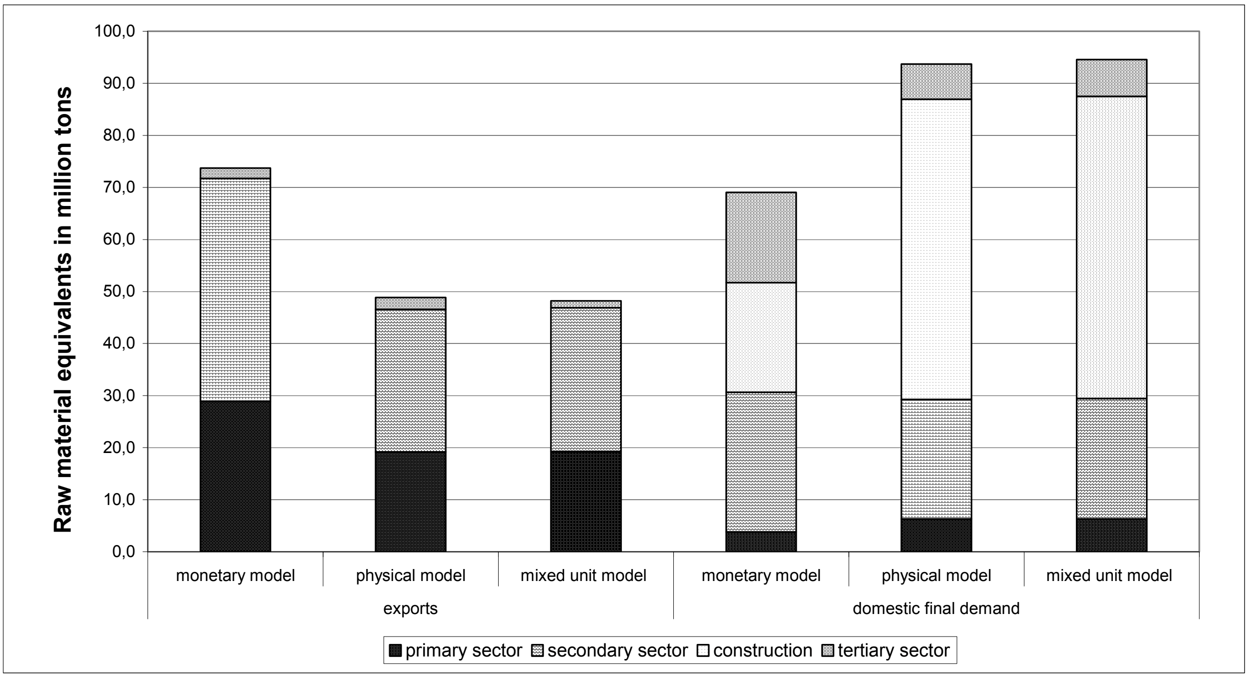
Table 5: Sectoral raw material equivalents of exports

	monetary model	physical model	mixed unit model
Agriculture, horticulture etc.	8,7	13,8	13,8
Forestery and logging	0,6	0,3	0,3
Fishing	1,0	0,2	0,2
Mining and quarrying	18,6	4,9	4,9
Manuf. of food, beverages, tobacco	22,4	16,1	16,2
Textile, clothing, leather industry	0,4	0,3	0,3
Manuf. of wood products, incl. Furnit	1,4	1,1	1,1
Manuf. of paper, printing, publishing	0,3	0,7	0,7
Chemical and petroleum industries	13,6	4,8	4,9
Non-metalic mineral products	1,2	1,6	1,6
Basic metal industries	0,3	0,6	0,6
Manuf. of fabricated metal products	2,7	2,0	2,2
Other manufacturing industries	0,2	0,1	0,1
Electricity, gas and water	0,5	0,0	0,0
Construction	0,0	0,0	0,0
Services	2,0	2,3	1,3
SUM	73,7	48,8	48,2

Source: Pedersen 2002, own calculations based on data from Pedersen 1999 and Weisz et al. 2005.

The high amount of raw materials allocated to exports in the monetary model has its logical counterpart in the relatively low amount that is allocated to domestic final demand. The results for exports and domestic final demand from the three models are summarized in an aggregated form in Figure 2. It reveals that the difference in the three models is largely determined by the attribution of extremely large quantities of raw materials to the construction sector in the physical and in the mixed unit models. The monetary model allocates roughly the same amount of raw materials, 70 million tons, to exports and to final goods for domestic consumption. On the other hand, the physical and the mixed unit model allocate 50 million tonnes to exports, but 95 million tonnes to domestic use.

Figure 2: Raw material equivalents of exports and domestic final demand (in million tonnes)



Source: own calculation based Pedersen (1999) modified and aggregated by the authors, DMI modified according to Weisz et al. 2005

How do these different results translate into the new MFA indicator "raw material trade balance"? Table 6 and Figure 3 compare aggregates for direct imports, exports, and physical trade balance derived from standard MFA to the calculated figures for the directly and indirectly required raw material equivalents of imports, exports and the physical trade balance derived from the three models applied. All figures refer to Denmark in 1990.

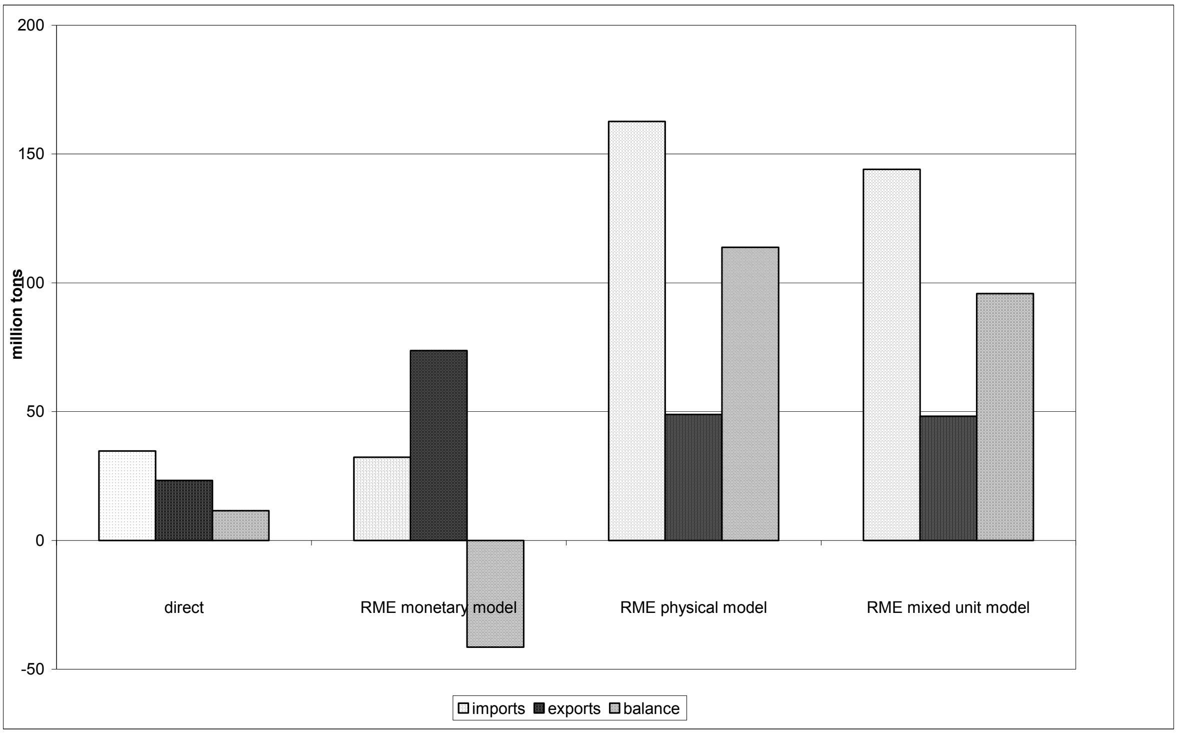
As is visible in Table 6, Denmark imported 35 million tons and exported 23 million tons of commodities in 1990, thus was a direct net importer of 11 million tons. This amount of net imports reflects the fact that Denmark in 1990 had not yet started to exploit North Sea oil and gas fields, and did not produce any substantial amount of industrial minerals and ores (see Pedersen 2002, Weisz et al. 2005). Virtually all fossil fuels, industrial minerals, and ores required for the production had to be imported.

Table 6: A comparison of direct MFA indicators and indicators including raw materials equivalents

indicators	imports	exports	balance
Direct MFA accounts	35	23	11
RME monetary model	32	74	-41
RME physical model	163	49	114
RME mixed unit model	144	48	96

Source: Pedersen 2002, own calculations based on data from Pedersen 1999 and Weisz et al. 2005.

Figure 3: MFA indicators com,puted by different methods



Source: own calculation based Pedersen (1999) modified and aggregated by the authors, DMI modified according to Weisz et al. 2005

The next row in Table 6 shows how the monetary input-output model allocates the raw materials equivalents to this amount of imports and exports. According to this model raw material equivalents of imports amounted to 32 million tons, and for exports to 74 million tons, more than twice as much. Consequently, the raw material trade balance obtained from this model is negative. In fact the monetary model suggests that Denmark indirectly was a net exporter of 40 million tons of raw materials in 1990 (Figure 3).

In sharp contrast, the physical model allocates 162 million tons of RMEs to imports and 50 to exports. This results in a raw material trade balance of 114 million tons for 1990. Finally, the mixed unit model computes 144 million tons of RMEs for imports, less than computed by the purely physical model. Consequently, the raw material trade balance suggested by the mixed unit model amounts to 96 million tons of indirect net imports.

Discussion

Given the standard assumption of input-output economics that an open static input-output model is insensitive to a change of units in the inter-inter-industry and final demand tables (Fisher 1965, Weisz and Duchin in press), the huge differences found in the results from the physical and mixed unit model as compared to the monetary model are surprising.

As long as only input-output tables in monetary units were available, this assumption hardly had been put on empirical test. Now, that physical input-output tables have become available - at least for a few countries - the relation between unit prices, physical output and monetized IO tables can also be tested empirically. Recently, it has been shown for the German PIOT and MIOT published by Stahmer and co-authors (1998) that they are related to each other by a price matrix and not by a vector of prices, and therefore a model based on the physical table will deliver results different from those obtained with a model based on a monetary table (Weisz and Duchin in press). We got the same result when dividing each entry of the Danish monetary inter-industry table by the corresponding entry of the physical input output table. In the sectors construction and wholesale and retail trade unit prices vary by several thousand Denmark Kroners (DKK) per kg, in several other manufacturing sector by more than a hundred DKK per kg. Clearly, the assumption of homogenous prices is not satisfied. It follows that measuring the quantity of the sectoral output of the primary and the secondary sectors (i.e. all sectors which produce physical outputs) in tonnes must be regarded as superior to the monetised measurement, because the assumption of homogenous prices is a necessary condition for measuring the quantity of sectoral output in monetary units but not for measuring the quantity of sectoral output in physical units.[8] The reverse applies to the service sectors. As services hardly produce any physical output, mass is certainly an inappropriate unit of measurement. Here money value is a better choice to measure the quantity of the output than tonnes. Taken together, we therefore assume that the mixed unit model should provide the most reliable results. Considering the physical structure of the Danish economy in 1990 (hardly any domestic extraction of fossil fuels and industrial minerals, imports exceed exports by 30%) the positive raw material trade balance (indicating a net export of raw materials) obtained by the monetary model is highly implausible.

Some further limitations of the above introduced method must be mentioned. Firstly, the material factor inputs of a national economy are composed of both raw materials extracted from the domestic territory and imported commodities in various stages of processing. It is therefore not quite correct to interpret the calculated direct and indirect material factor input requirements of exported commodities as "raw material equivalents" of exports. It would be more correct to denote them as "domestic material input equivalents".

Second, the use of the same coefficient matrix to compute the raw material equivalents for exports and imports is not satisfactory and may lead to serious flaws in the results. Essential methodological improvements can be expected from a world trade models in mixed units (e.g. Duchin 2005).

Third, in input-output statistics, different methods exist how to allocated imports to the sectors of the economy (Miller and Blair 1985, Fleissner et al. 1993). The chosen methods, in turn, determines whether the above proposed method to calculate material factor requirements of imports is justified or not.

For input-output computations to deliver reliable results, an appropriate level of dis-aggregation by sectors or commodities is necessary. To our knowledge the resolution of the physical model we used is the highest ever applied in purely physical input-output models and is also the highest possible with currently available physical input output tables. Still, the conceptual questions remains unanswered, which level of resolution would be necessary for this type of analysis.

It is probably too early to draw definite conclusion from these results. However, now that input-output tables in physical units are gradually used also to construct coefficient matrices and IO models we can at least expect more explicit empirical information about the relation between physical quantities of materials used, their unit prices and the money value attributed to the material flows within and between economies (see Duchin forthcoming). Despite the limited data base and some open methodological questions we think that mixed unit input-output analysis is the method of choice to account for raw materials equivalents of imports and exports or more generally, to account for the implications of trade in economy wide biophysical analysis.

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[1] The 6th environmental action programme of the European Commission specified the sustainable use of resources as one priority field for the period 2002 to 2012 (CEC 2002). 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. The G-8 industrial nations recommendation in 2004 to create an OECD wide material flows and resource productivity work plan created a decisive momentum towards international commitment. Regarding the use of economy-wide material flow accounting for target setting targets the Japanese government is a forerunner. In its recent official sustainability

program “Towards Establishing a Sound Material Cycle Society”, MFA derived indicator are used to specify political targets.

[2] The potential of economy wide material flow accounts was first recognized by Eurostat and the WRI. Both organizations took the lead towards establishing internationally harmonized accounts in the later 1990s (Matthews et al. 2000, Eurostat 2001a). Recently the OECD and Eurostat joined forces to further promote internationally harmonized material flow accounts.

[3] TMR includes domestic extraction (see footnote 4), imports , and the indirect flows that are associated to imports but take place in other countries (Eurostat 2001a)

[4] Domestic extraction (DE) is the sum of all solid, liquid and gaseous materials (excluding water and air but including the water and air content of materials) that are extracted from the national territory and enter the economy for further use (Eurostat 2001a).

[5] For these reasons LCA is now increasingly combined with input-output analysis when applied to the whole economy (Lave et al. 1995; Suh 2004b; Peters and Hertwich in press).

[6] DMI is defined as domestic extraction plus imports (Eurostat 2001a).

[7] Eurostat currently discusses the feasibility of providing integrated NAMEAs on a routine basis.

[8] It is obvious that only if there is one unique sectoral price the money value of the output will proportional to the quantity of the output. Contrary to this tons are a direct measurement of quantity, assumptions regarding prices are not necessary.