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Global dimensions of European natural resource use

Results from the Global Resource Accounting Model (GRAM)

Giljum, Stefan[a], Lutz, Christian[b], Jungnitz, Ariane[b], Bruckner, Martin[a], Hinterberger, Friedrich[a]

[a] *Sustainable Europe Research Institute (SERI)*
Garnisongasse 7/27, A-1090 Vienna, Austria
T: +43 1 969 07 28 19, F: +43 1 969 07 28 17, E: stefan.giljum@seri.at

[b] *Institute for Economic Structures Research (GWS)*
Heinrichstraße 30, D-49080 Osnabrück, Germany
T: +49 541 40933 12, F: +49 541 40933 11, E: lutz@gws-os.de

Abstract

With increasing international trade in the world economy, the inclusion of indirect (or embodied) natural resources of traded products receives growing importance, when domestic production and consumption patterns are evaluated from the perspective of global sustainable development. In this paper, we present results of calculations with a newly constructed global, multi-regional, environmental input-output model, the Global Resource Accounting Model (GRAM). The model was developed to illustrate the physical dimension of Europe's economic interrelations with the rest of the world and to analyse European natural resource consumption and trade in a global perspective. GRAM disaggregates 52 countries and world regions, represented with input-output tables of 48 economic sectors and linked by bilateral trade flows in 25 product groups and 1 service sector. The model integrates the latest (2006) edition of IO tables published by the OECD with the OECD's Bilateral Trade Database and is extended by a global database on resource extraction in all countries of the world. We discuss the structure of the GRAM model, with a particular focus on the integration of the environmental data in physical units with the monetary core model and the technical implementation of the model system. We then present several types of results. First, we calculate aggregated indicators on material extraction versus consumption of countries and world regions. Even though the domestic extraction per capita in OECD countries is significantly above other world regions, consumption of raw materials is even higher.

Production of products for final consumption in industrialized countries thus uses more resources than extracted within the regions themselves. On the other hand, per capita material consumption in emerging and developing regions lies even below the already low level of domestic extraction. Second, we assess international trade flows to identify main net-importers and net-exporters of different categories of natural resources in the world economy. We illustrate that the EU has higher absolute net-imports than any other single country in the world economy (including the US and Japan) and faces the highest share of net-imports compared to domestic resource extraction of all analysed world regions. Finally, we disaggregate results in terms of economic sectors and types of materials for the case of Germany to illustrate the potential of GRAM for studies on sectors and product groups.

Keywords: embodied resource requirements, material flow accounting (MFA), input-output analysis, international trade, raw material consumption.

1. Introduction

This paper was produced in the international research project petrE (Resource productivity, environmental tax reform and sustainable growth in Europe; see www.petre.org.uk), funded by the Anglo-German Foundation. One of the forecast models applied in petrE is the GINFORS (Global Interindustry Forecasting System; see Lutz et al., 2005; Meyer et al., 2007, 2008) model, developed by GWS in Osnabrück. In the GINFORS model, a global data base on material inputs, comprising extraction of biotic and abiotic natural resources in all countries of the world, is fully integrated into the model system. This integration was first performed in the EU project MOSUS (see www.mosus.net) and is further developed and improved in the petrE project. As material extraction in different countries is determined by parameters ("drivers") of economic performance and energy use, this extension allows determining all indirect economic effects on resource extraction in the simulation and evaluation of different scenarios (see Giljum et al., 2008a). However, the GINFORS model cannot allocate material extraction to specific economic variables in the country models, such as domestic final consumption or exports. This impedes the assessment of all direct and indirect (up-stream) materials needed for producing specific imported and exported goods. Consequently, it is not possible to calculate comprehensive material consumption indicators on the macro and sector level and to determine the resource base of the European economy in a comprehensive manner, as the trade dimension cannot directly be taken into account.

Although comprehensive resource use indicators have been estimated applying life cycle assessment (LCA)-oriented approaches, these studies lack comprehensiveness, as in most cases, data on indirect material flows were only available for raw materials and basic commodities, but not for higher manufactured products. In this paper, we introduce a global, multi-regional, environmental input-output model, the Global Resource Accounting Model (GRAM), in order to fill some of the existing research gaps with regard to the analysis of global material flows and to illustrate the physical dimension of Europe's economic interrelations with the rest of the world.

The main purpose of this model is to assess direct and indirect resource extraction necessary in different countries and world regions to produce internationally traded products. Only if these data are available, a comprehensive physical trade balance for each country and world region can be calculated, which allows assessing to what extent an economy is dependent on natural resource inputs from abroad. This analysis also reveals over time, whether or not the production and consumption system of a country is actually improving its resource productivity or substituting resource-intensive domestic production by imports from other world regions.

Such results are also an important input to the current discussion on producer versus consumer responsibilities in the world economy (see, for example, Lenzen et al., 2006). Whereas most accounting frameworks (e.g. also in the Kyoto protocol) follow a production or territory accounting principle, a consumption-oriented accounting approach is required when discussing concepts such as an allocation of a "fair share" of world's resources to all inhabitants of the planet (see also Peters, 2008).

This paper is structured as follows. Section 2 explains the motivation for our research and presents the general policy background. Section 3 provides a methodological summary of input-output based approaches to calculate indirect material flows, which serves as the basis for the introduction of the Global Resource Accounting Model (GRAM) in section 4. Section 5 contains the description of the results, in section 6 we discuss the results from the perspective of European trade and environmental policy. The final section 7 discusses possible future improvements of the GRAM model.

2. International trade and material flows

Increasing international trade and deeper integration of different world regions in global markets are one central characteristic of current globalisation processes. Between 1990 and 2006, world export volumes augmented by 5.5% annually while production only grew by 2.5% per year. Growth in trade was highest for manufactured products (6.0%), followed by agricultural products (4.0%) and fuels and mineral products (3.0%) (WTO, 2007).

The inclusion of natural resource requirements of traded products therefore receives growing importance, when domestic production and consumption patterns are evaluated from the perspective of global sustainable development. In order to assess world-wide environmental consequences related to production and consumption of a specific country or world region (such as Europe), it is necessary to take trade aspects fully into account. In addition to direct imports and exports, all material requirements necessary to produce the traded goods (these are also termed indirect material flows associated with or embodied in imports and exports), have to be considered in the analysis. Only thereby possible shifts of environmental burden associated with extraction and processing of materials can be illustrated, resulting from changing global patterns of production, trade and consumption.

A number of studies examined the distribution of environmental pressures between different world regions due to the economic specialisation in the international division of labour, applying methods of physical accounting and environmental-economic modelling. Several studies found empirical evidence for increasing externalisation of environmental burden by industrialised countries through trade and increasing environmental intensity of exports of non-OECD countries (see, for example, Ahmad and Wyckoff, 2003; Atkinson and Hamilton, 2002; Giljum, 2004; Giljum and Eisenmenger, 2004; Machado et al., 2001; Muradian et al., 2002; Nijdam et al., 2005; Peters and Hertwich, 2006, 2008; Schütz et al., 2004). Some studies revealed that this shift is accompanied by an absolute increase in environmental pressures on the global level, as production technologies in developing regions are often more material, energy and emission intensive than the ones applied in industrialised countries (for example, Shui and Harriss, 2006). An important economic issue related to this shift of resource extraction and processing away from industrialised countries is the increasing dependency of domestic industries on imports of natural resources. In Europe, this dependency is particularly high for fossil fuels and metal ores, for example, 83% for iron ores, 80% for bauxite, and 74% for copper (European Commission, 2006a).

The global environmental responsibility related to high levels of natural resource use is increasingly addressed by environmental policy strategies of the European Union and the OECD. One of the overall objectives of the renewed EU Sustainable Development Strategy (EU SDS) is to "actively promote sustainable development worldwide and ensure that the European Union's internal and external policies are consistent with global sustainable development and its international commitments" (European Council, 2006, p. 20). High levels of resource use are regarded as one major obstacle for the realisation of an environmentally sustainable development in Europe and worldwide. The core strategy to achieve a transformation towards more sustainable production and consumption patterns is to realise de-coupling (or de-linking) between economic growth, the use of natural resources and related environmental degradation (European Commission, 2005). Also OECD environmental ministers adopted a recommendation on material flows and resource productivity that is aimed at better integrating resource flow-based indicators in environmental-economic decision making (OECD, 2004).

3. Input-output based approaches to calculate indirect material flows

In the methodological framework of material flow accounting and analysis (MFA), so-called indirect material flows associated with imports and exports describe the up-stream material requirements necessary to produce a traded product. This up-stream process includes resource extraction, processing and manufacturing and transportation to the border of the analysed country. As explained in the EUROSTAT guidebook for material flow accounting (EUROSTAT, 2001), indirect material flows should be measured in so-called "Raw Material Equivalents (RME)", which express the amounts of primary extracted materials required along the whole production chain of an imported or exported product. Quantifying trade flows in terms of RME thus allows for a standardisation of physical foreign trade to the same economy-environment system boundary as applied in used domestic extraction. For the material balance of a country it therefore makes no difference, whether, for example, a metal ore is extracted within the national boarders or imported from abroad. If imported in concentrated form, the metal would be transformed in its RME, i.e. the crude metal extracted in the mine. Analysing international trade in terms of RME is therefore better suited for international comparisons of countries and world regions than application of other indicators, which only consider international trade by direct imports and exports, i.e. the weight of the products crossing the border (Moll and Bringezu, 2005; OECD, 2007a; Weisz, 2006).

If RMEs of traded products are available, comprehensive MFA-based indicators on the macro level can be calculated. In this paper, we calculate the indicator "Raw Material Consumption (RMC)", which includes all economically used material extraction (of domestic and foreign origin) consumed by final demand in the analysed country. If we would also consider those parts of material extraction, which are not economically used (e.g. overburden from mining), we could calculate the indicator "Total Material Consumption (TMC)", which is envisaged as a headline indicator in the EU set of sustainable development indicators. We also illustrate physical trade balances (PTB) in terms of raw material equivalents of countries and world regions.

In order to consider the global dimension, indirect flows of traded products were so far mostly calculated applying a life-cycle assessment (LCA)-oriented approach. Following this approach, direct imports are multiplied by coefficients (or so-called "ecological rucksack factors"), reflecting – in theory – all RMEs related to extraction, processing and transport. However, due to high efforts in data collection along international production chains, indirect flows have so far been calculated for a very limited number of processed products. Comprehensive material flow-based indicators, which fully integrate the international dimension, could not be calculated so far. Therefore, in this paper, we present an alternative methodological approach to assess resource trade and consumption in a global framework, based on multi-regional, environmentally extended input-output analysis.

Within the large family of approaches for accounting and modelling material flows (for an overview see Femia and Moll, 2005), methods of environmental input-output analysis (eIOA) play a central role for performing policy-related MFA studies. In particular, eIOA enables opening up the "black box" of economy-wide MFAs and thus providing information on branch and product-specific developments of resource flows and resource productivity (Femia, 1996; Moll et al., 2002). Thereby, environmentally important sectors and products ("hot spots") can be identified and ranked (see, for example, Acosta-Fernandez, 2007). eIOA further allows analysing implications for natural resource use of structural changes of the economy, as well as of changes in technology, trade, investments and consumption and lifestyles.

One major advantage of the IO approach compared with LCA-oriented approaches is that it avoids imprecise definitions of system boundaries, as the entire economic system is the scope for the analysis. Furthermore, it allows estimating total resource inputs for all types of products with less effort than the LCA-based method, as only material inputs of those economic sectors have to be assessed, which are extracting raw materials (mainly agriculture, forestry and fisheries for biotic materials, and mining and construction for abiotic materials). However, applying the IO approach also entails disadvantages. These refer in particular to the high level of aggregation of economic sectors in the IO tables, which impede analysis of specific materials (such as single metals or single agricultural products) and lead to problems of inhomogeneities within (theoretically homogeneous) sectors.

In most studies at the national level carried out so far, imports were either included only as direct material flows (without considering up-stream indirect requirements) or indirect material requirements were estimated applying the assumption of an identical production technology of imported products and the domestic economy (for example, Moll et al., 2006; Weisz, 2006). However, distortions of results can be considerable, if countries show significant differences in technology and economic structure, which is often the case, when trade relations between industrialised and developing countries are investigated (see Haukland, 2004). In order to overcome the shortcomings of a single-country model, in particular with regard to environmental consequences of increasing international trade, a number of studies were published in the past few years, which applied multi-regional IO (MRIO) modelling to assess environmental pressures embodied in international trade.

Several major advantages of the MRIO approach can be identified (see

Wiedmann et al. 2006):

- MRIO models allow for integration of (monetary) trade flows with environmental databases and permit environmental impacts embedded in trade to be accurately and comprehensively evaluated, as variations in production structures and technologies between different countries and world regions are taken into account.
- Different IO-based analyses on the international level can be undertaken with a MRIO model (e.g. structural path analysis, production layer composition, quantification of shared environmental responsibilities between producers and consumers of goods).
- With a MRIO model, direct, indirect and induced effects of international trade can be captured.

A number of MRIO models have been presented in the literature, differing significantly with regard to the number of countries/regions and sectors disaggregated in the model (see Wiedmann et al. 2006, 2007 for extensive reviews of MRIO models to assess indirect environmental effects of trade).

4. The Global Resource Accounting Model (GRAM)

In the following, we provide a description of the Global Resource Accounting Model (GRAM), a multi-regional input-output MFA model constructed in the course of the petrE project (a more detailed description can be found in the corresponding methodology paper; Giljum et al., 2008b). The basic intention was to construct a model with a monetary core for the year 2000 through linking OECD IO tables and OECD bilateral trade data (BTD). This monetary core model was then extended by a global data set on material inputs in physical units, which is attached to the IO tables as an additional vector.

4.1. Data sources

Three main data sets are required for setting up the GRAM model: input-output tables, trade data and material extraction data. Many national statistical offices publish IO-tables on a more or less regular basis. However, as these tables differ in data quality, sectoral disaggregation, currencies, price concept and base years, they are not suitable for constructing a consistent multi-regional IO model system. To our evaluation, the OECD provides the most comprehensive, reliable and transparent international dataset. The latest, third revised (2006) edition of IO tables published by the OECD includes 27 OECD countries (except Iceland, Luxembourg and Mexico) and 9 non-OECD countries (Argentina, Brazil, China, India, Indonesia, Israel, Russia, Singapore and Taiwan). The tables of the 2006 edition are based around the year 2000 (Yamano and Ahmad 2006). The number of industries was extended to 48 (see Annex 1), which was very desirable against the background of analysing material flows related with international trade. Some material and resource intensive sectors were separated, such as splitting the “mining and quarrying” sector into two sub-sectors (fossil fuels and all other minerals).

At the moment our model comprises 52 countries and regions, with the OECD dataset providing IO tables for 35 of these countries and regions. For the remaining countries and regions IO tables were derived under the assumption that the country or region under consideration holds the same production technology as a neighbouring country or a country with a similar economic structure (see Annex 2 and Giljum et al., 2008b for details).

Data on international trade, which's modelling is the core element of a model calculating all direct and indirect material requirements of countries, should cover a maximum number of industries in a classification consistent with that of the applied IO tables. The bilateral trade data (BTD) of OECD are based on the ISIC Rev. 3 likewise IO tables provided by OECD. In total, BTD comprises imports and exports of goods for each OECD country broken down by 61 trading partners and 25 industries. One disadvantage of the BTD data set is that it captures only OECD trade with the rest of the world, while trade between two non-OECD countries is not recorded. Thus, trade between major material consuming countries such as China and India and major material extracting countries such as Brazil, South Africa and Russia was completed by UN COMTRADE data and country by country trade data from the Direction of Trade Statistics from the IMF (2006 edition). By consolidating these three datasets, trade matrices for 52 countries/regions were established, showing for every good k all trade flows between exporting countries and importing countries. A trade matrix for an aggregated service sector in the same dimension is also included.

With regard to material input data, a large and increasing number of material flow studies are available from national and international statistical offices, environmental agencies and research institutions (see OECD, 2007b). The first global dataset in a time series of 1980 to 2002 was compiled in the framework of the EU project MOSUS project, funded by the European Commission (see www.mosus.net and Behrens et al., 2008). Resource extraction data, disaggregated by more than 200 raw material categories, was compiled for 188 countries in a time series from 1980 to 2002, following the nomenclature and categorisation of materials listed in the handbook for economy-wide material flow accounting published by the Statistical Office of the European Union (EUROSTAT, 2001). This global database has been updated to 2005 and improved in the course of the petrE project. The international database on natural resource extraction is mainly based on international statistics from the International Energy Agency (IEA), the Food and Agricultural Organisation of the United Nations (FAO), British Geological Survey (BGS), United States Geological Survey (USGS) and the German Federal Institute for Geosciences and Natural Resources (BGR).

4.2. Allocation of raw material extraction to industries in the IO table

One key decision concerns the allocation of the material extraction data to economic sectors in the IO tables, in order to calculate the material intensity coefficients. In contrast to e.g. emissions of greenhouse gases, which origin in many economic sectors (see Ahmad and Wyckoff, 2003; Peters and Hertwich, 2008), raw materials are only extracted by a very limited number of industries. Therefore, the very detailed material input data, covering more than 200 raw materials, need to be aggregated, in order to link material input data to the sectors available in the IO tables.

The OECD IO tables only disaggregate three primary extraction sectors: agriculture, forestry, fishery (sector 1), mining and quarrying/energy (sector 2) and mining and quarrying/non-energy (sector 3). If we would apply an approach, where material extraction is allocated at the point of extraction, we could only separate the three broad material categories biomass, fossil fuels and minerals. This level of disaggregation is not satisfying, as it would imply that, for example, the same mix of mineral raw materials would be delivered to industries of processing of metal ores, production of non-metallic mineral products as well as construction. It is obvious that such an allocation would produce significant errors with regard to the composition of material use in different sectors. Schoer (2006) therefore suggests an approach, which allocates specific raw material inputs to those industries, which serve as the main recipient of raw material inputs at the first stage of further processing. We tested this approach with the GRAM model and found that also this approach produces errors, as some countries export significant shares of their raw material extraction without previous processing. Material extraction would therefore not be treated as embodied materials of raw material exports, but as input to the domestic processing industry, which, particularly for primary sector dominated economies, is not significant.

Based on these experiences, a mixed approach was developed, where we first separate material extraction, which is directly exported as raw materials. This part of extraction is thus directly linked to the exports of the three extracting sectors (1, 2 and 3). As these three sub-groups aggregate a number of materials, no distinction could be made e.g. between agriculture and forestry, or between metal ores and industrial minerals. In a second step, the remaining material extraction was then allocated to the domestic processing industries. For example, if sector 3 (mining, non-energy) delivers exports totalling 30% of its overall production, we allocate 30% of all ore and mineral extractions to exports and 70% to the respective domestic sector of processing as indicated in Table 6 (in the example of minerals, these sectors are 12, 13, 14 and 30). Table 1 summarises the allocation scheme.

Table 1: Allocation of MFA categories to economic sectors in the IO tables

Category of material extraction	Allocated to sector of IO table (number of sector in brackets)
Agriculture, grazing, fish and fibre crops	**Unprocessed exports: Agriculture, hunting, forestry, fish (1)** **Further processing: Food products (4)**
Forestry	**Unprocessed exports: Agriculture, hunting, forestry, fish (1)** **Further processing: Wood and wood products (6) and Pulp and paper products (7)**
Coal and oil	**Unprocessed exports: Mining and quarrying (energy) (2)** **Further processing: Coke and refined petroleum products (8)**
Natural gas	**Unprocessed exports: Mining and quarrying (energy) (2)** **Further processing: Manufacture of gas (27)**
Iron ores	**Unprocessed exports: Mining and quarrying (non-energy) (3)** **Further processing: Iron and steel (13)**
Other metal ores	**Unprocessed exports: Mining and quarrying (non-energy) (3)** **Further processing: Non-ferrous metals (14)**
Industrial minerals	**Unprocessed exports: Mining and quarrying (non-energy) (3)** **Further processing: Non-metallic mineral products (12)**
Construction minerals	**Construction (30)**

Through this initial disaggregated allocation, both exports of raw materials and specific compositions of material inputs to certain industries at further stages of processing can (at least to some extent) be captured by the model. If more than one sector serves as recipient at the first stage of processing (as is the case with wood), we divide material extraction according to the shares of (monetary) deliveries from the extraction sector to the processing sector (in the example of wood: deliveries from sector 1, Agriculture, to sector 6 and 7), assuming that the weight/value ratio is equal for deliveries to different sectors. For the case of construction minerals, we assumed that exports are zero and all materials are allocated to sector 30 (construction) for domestic use, as the monetary relations are mainly driven by industrial minerals and would overestimate the export share of construction minerals.

4.3. Technical implementation of the model calculations

A true multi-regional IO model requires the construction of an IO table that comprises all upstream requirements between and within the considered industries and countries. The technical computation of such a model can be done in two ways. The first approach would be to construct one “super-matrix”, which contains all IO tables, trade data and material intensity coefficients in one matrix. Considering the large number of countries modelled in GRAM and the high detail of sector and trade information, such a matrix would be very large and complex. Additionally, technical problems during data processing have to be solved, for example storage and inversion of such a large matrix.

Against this background, a second approach is applied here, which calculates direct and indirect materials embodied in traded goods in an iterative procedure (see Ahmad and Wyckoff, 2003 for a similar approach). For identifying material inputs embodied in international trade flows we calculate total direct and indirect material embodied within domestically consumed products whether imported or produced domestically. This requires a distinction between four categories of (product) use:

(1) Manufactured goods and services produced and consumed domestically: “Domestic Final Demand (DFD)“

(2) Domestically produced manufactured goods and services exported to other countries: “Domestic Production of Exports (DEX)“

(3) Imported manufactured goods and services consumed domestically: “Imported Final Demand (IFD)“

(4) Imported manufactured goods and services exported to other countries again: “Imported Production of Exports (IEX)“

DFD, DEX, IFD and IEX represent economic variables. We define M^{DFD}, M^{DEX}, M^{IFD} and M^{IEX} as the corresponding material flows embodied in these economic variables. This distinction allows calculating some of the standard material flow indicators described earlier in this paper. If the vector of material inputs in each of the countries / world regions comprises only used extraction, “Raw Material Consumption (RMC)” is calculated as follows:

$$RMC = M^{DFD} + M^{IFD} \quad (1)$$

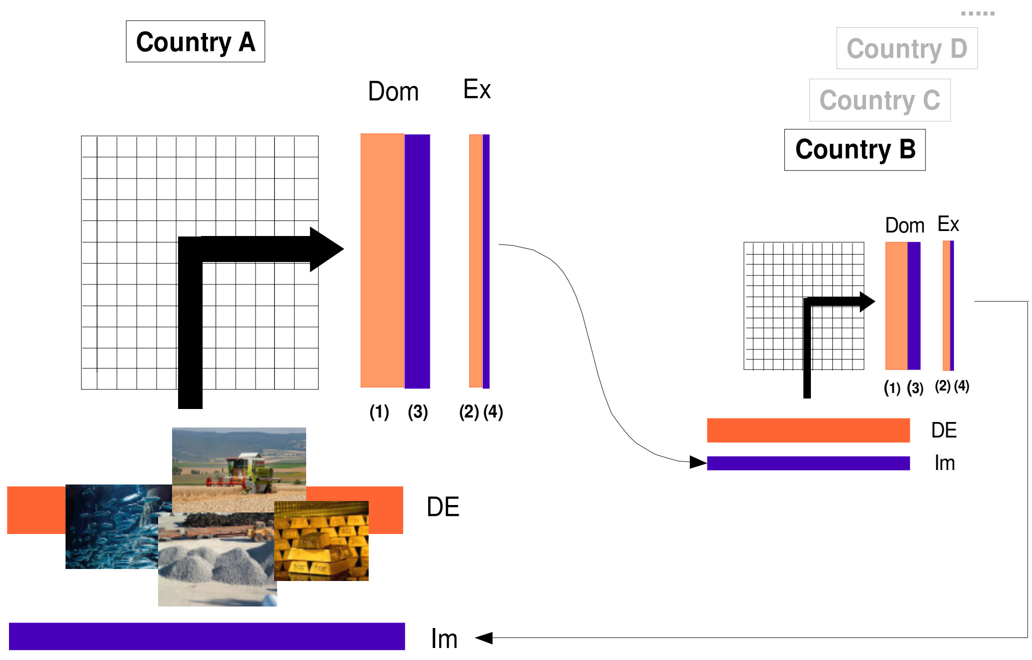
If the vector of material inputs would additionally include unused domestic extraction, we would arrive at “Total Material Consumption (TMC)”.

We can also calculate a comprehensive physical trade balance (PTB) by subtracting the exported categories from the imported:

$$PTB = (M^{IFD} + M^{IEX}) – (M^{DEX} + M^{IEX}) = M^{IFD} - M^{DEX} \quad (2)$$

In order to solve the model system, we follow an approach introduced by Ahmad and Wyckoff (2003), which apply an iterative calculation procedure, which is graphically illustrated in Figure 1. For details of this calculation procedure and the corresponding expression in formulas, see the separate methodology paper (Giljum et al., 2008b).

Figure 1: Graphical illustration of the calculation procedure



Notes: DE ... Domestic Extraction; Dom ... Domestic Consumption; Im ... Imports; Ex ... Exports
Categories (1) to (4): four categories of product use (see main text above)

In the first step, domestic material extraction (DE) of country A is allocated to its domestic consumption (Dom) and exports (Ex) to countries B, C, D, etc., assuming that exports are solely produced with domestic material resources. This is done for every country parallel. The result of this process is a model of international material flows that describes all exports from any country in the world to any recipient, on the supposition that all goods are produced only with the country's domestic extraction. Thus, all steps of international division of labour are completely modelled after that step of procedure, but, as the material intensities of one country's exports depend on that of its imports, the results have to be revised, considering the imports of materials additional to domestic extraction. This has to be carried out several times for every country, as changes in the import structure of one country always entail changes in its export structure and therefore in the composition of imports of other countries. For example, changes in the material intensity of the German imports affect the material intensity of the German exports and therefore that of the British imports and vice versa. We thus face a problem of interdependencies, which we solve through an iteration process. The divergences decrease with each of the iterations and finally, material intensities of imports and exports no longer change between two iteration steps.

5. Results

The GRAM model allows analysing domestic resource consumption in a global perspective, including international trade and related raw material extraction along international production chains. In the following we present the first results, which were generated by the GRAM model.

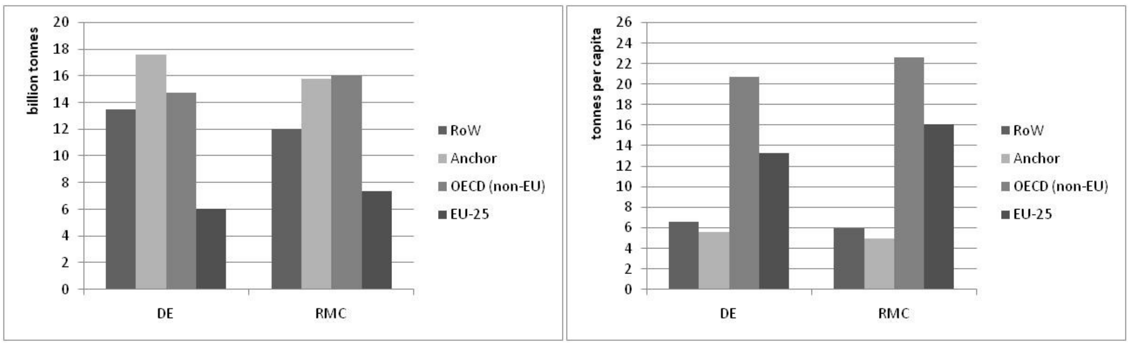
Data generated by the GRAM model can be analysed in several ways: first, aggregated indicators on raw material consumption of countries and regions (such as the EU) can be calculated. Thereby, we can compare where raw material extraction takes place in the world economy versus where the final products manufactured with these raw materials, are consumed. Second, international trade flows can be assessed to identify main net-importers and net-exporters of natural resources in the world economy. Finally, the generated data can be disaggregated by sectors and product groups as well as material categories to identify, which traded products have the highest material intensities along their production chains. A detailed data sheet with key variables per country is attached in Annex 3.

The first calculations were carried out for the year 2000; however, providing time series is in principle possible and desired in order to illustrate trends and changes in production, trade and consumption patterns over time (see also section 7 below).

5.1. Material extraction versus material consumption in different world regions

The GRAM model allows determining, in which countries and world regions resource extraction is mainly taking place versus which countries and world regions have the highest levels of (direct and indirect) raw material consumption. In Figure 2 the indicators of Domestic Extraction (DE) and Raw Material Consumption (RMC) in four different world regions are presented. The diagram on the left side shows the absolute numbers in billion tonnes; on the right side the results are illustrated in tonnes per capita.

Figure 2: Domestic extraction (DE) and raw material consumption (RMC) in different world regions (total, per capita)



The model calculations show that although domestic extraction (DE) of resources in absolute numbers is highest in the group of the so-called Anchor countries , in terms of Raw Material Consumption (RMC) the non-EU OECD countries are slightly ahead. A considerable share of resources extracted in Anchor countries thus flows directly or indirectly to other world regions through international trade. Also the region of “Rest of the World” (RoW) shows a decline from resource extraction to resource consumption in parallel to the Anchor countries. The EU-25 in contrast consumes more resources than it extracts, but their DE and RMC in absolute numbers is significantly lower compared to other world regions.

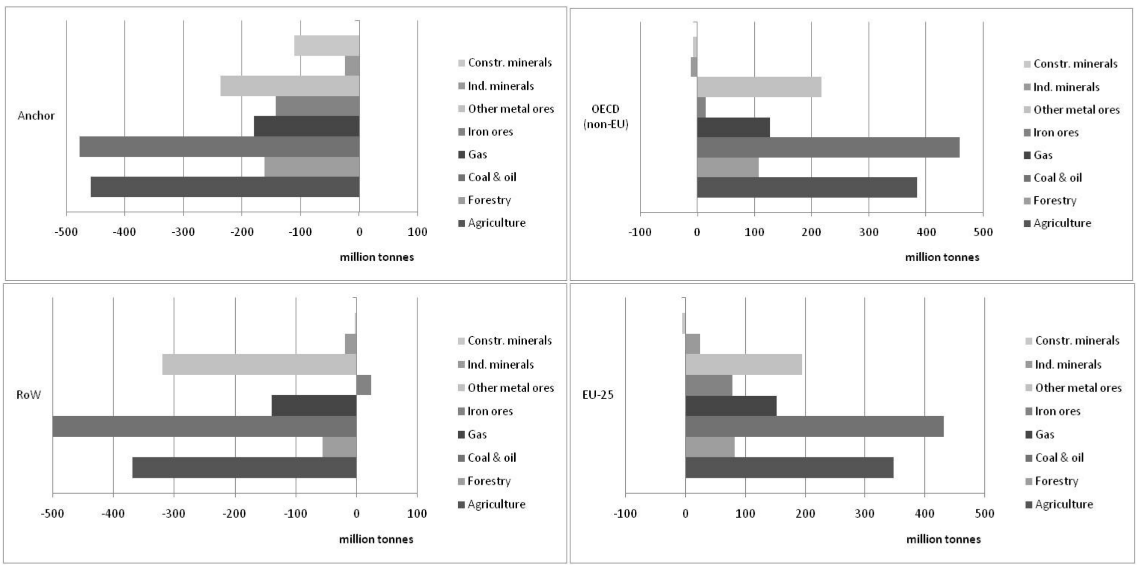
The picture changes considerably when turning to a per capita perspective. Even though the domestic extraction per capita in EU-25 countries, and even more in the non-EU OECD countries, is significantly higher compared to the other world regions, this measure is even exceeded by the consumption of raw materials. This means that the production of products for final consumption in industrialized countries (OECD) uses more resources than are extracted within the regions themselves. The Anchor countries, which count almost 3.2 billion inhabitants, lead the list of resource extracting world regions, but fall far behind all other regions when investigating per capita values. As the RoW countries, their per capita consumption lies even below the already low level of extraction.

On a country basis the first model calculations reveal that the USA and China are the biggest consumers of raw materials in absolute terms. Germany ranks 6th and the UK 12th. In a per capita perspective, other countries with highly resource-intensive sectors, such as Australia, and some industrialized Asian countries, such as Hong Kong, show the highest numbers for raw material consumption.

5.2. Physical trade balance of world regions

The GRAM model also allows calculating comprehensive trade balances of world regions and countries in terms of raw material equivalents and can therefore identify net-importers and net-exporters of different categories of raw materials. As 8 material categories are separately modelled in GRAM, we can disaggregate trade patterns of different countries and world regions by types of natural resources, in order to identify typical external trade patterns for different groups of countries (see Figure 3).

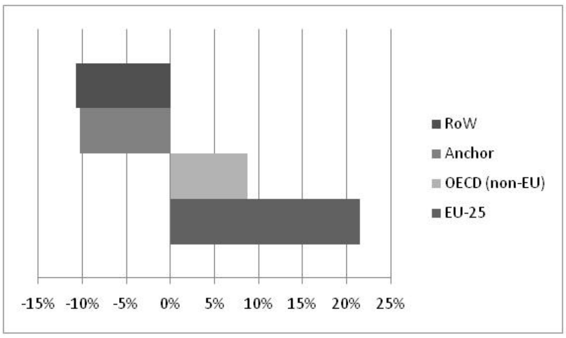
Figure 3: Physical trade balance (PTB) in four different world regions for eight material categories

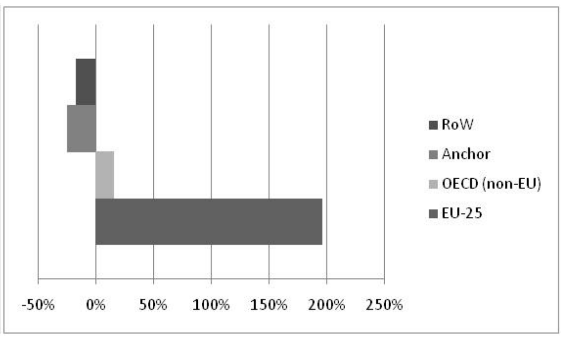


In terms of net-importers versus net-exporters, the results reveal that the group of OECD countries is a significant net-importer of direct and indirect material resources from other world regions. Production of goods consumed in the OECD countries requires significantly more natural resources than those exported from the OECD to the rest of the world, in particular regarding agricultural products, coal/oil and other metal ores. Also the EU-25 countries (most of them members of the OECD) have high net-imports, basically in the same resource categories. In addition, the EU-25 has high net-imports of iron ores. An interesting aspect is that the EU-15 even exceeds the net-imports of the EU-25, meaning that the 10 new EU member countries are net-exporters of embodied natural resources, particularly due to high net exports of Poland and the Czech Republic. The Anchor countries and the RoW region each have high net-exports and therefore provide the resources for the net-importing countries. In the Anchor region, the main net-exported materials in terms of weight are coal and oil as well as agricultural products. In the RoW region, net-exports are also highest for the categories of coal and oil, agricultural products and, additionally, non-ferrous metals.

Net-trade flows can also be related to levels of domestic extraction, in order to illustrate to what extent different world regions are outsourcing material and energy-intensive production processes abroad. Figure 4, thus, shows to what extent the consumption in the four world regions is observing or overshooting the potential self-sufficiency.

Figure 4: Net-trade flows as a percentage of domestic resource extraction (total, metal ores)



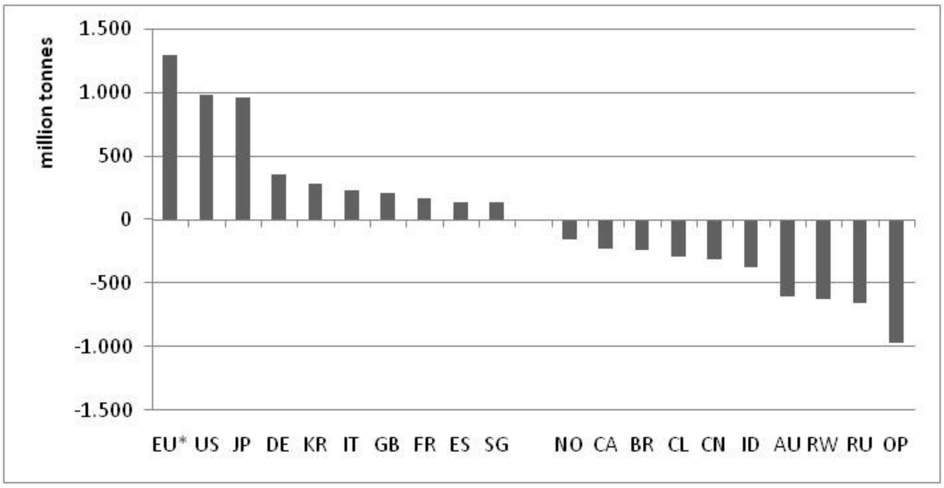


Setting the values of the physical trade balance (PTB) in relation to the domestically extracted materials (DE) suggests that the EU-25 is the world region that outsources the biggest part of resource extraction required to produce goods for final demand (private and public consumption and investment). The highest difference between domestic extraction and consumption are within the material categories iron ores and other metal ores, where net imports exceed domestic extraction by 294% and 174%, respectively (or 197% for the aggregated group of metal ores).

5.3. Physical trade balance of countries

As the GRAM model disaggregates a large number of countries, the model can also calculate net-imports of single countries. Figure 5 illustrates a first ranking of the biggest importers and exporters of embodied material resources in the world economy.

Figure 5: Physical trade balance (PTB) of different countries (total)



* For illustrative purposes we included the region EU-25 (EU*) in this country ranking.

According to the model calculations, the region EU-25 leads the ranking of net-importers, followed by the US and Japan. Single Western European and some Asian countries follow (Germany, Korea, Italy, Great Britain, France, Spain and Singapore). On the other end of the spectrum, the biggest net-exporters are located. The biggest net-exporter is the group of OPEC countries, followed by Russia, the region Rest of the World (RW), Australia, India, China, Chile, Brazil, Canada, and Norway.

The level of net-imports or net-exports depends particularly on three factors: first, the national endowment with natural resources, second, the population size and density, and third the level of regional economic activities (affluence). Small, densely populated and economically prosper countries tend to have high net-imports, while countries with high population density, but big resource deposits and often small economic activity are to be found within the group of net-exporting countries.

As already shown in Figure 4 in relative terms, Figure 5 demonstrates the high level of dependency of European consumption activities on foreign resources also in absolute terms. The EU combines relatively low endowment with resources, in particular, regarding fossil fuels and metal ores, with high population density and high GDP per capita. Despite high national resource availability and extraction, the US rank second in the list of net-importers, due to highly resource intensive life-styles. Raw material consumption in Japan, as a very densely populated country with high economic wealth, exceeds its domestic resource availability by a level comparable to the US.

Since the data refer to the year 2000 it can be expected that shifts have been taking place since then, especially for China and India, which – according to the World Bank's World Development Indicators database – have doubled their GDP (in PPP) between 2000 and 2006. It can be expected that China transformed from a net-resource exporter in 2000 to a net-importer in 2008, given its huge increase in natural resource demand.

5.4. Material consumption by sectors

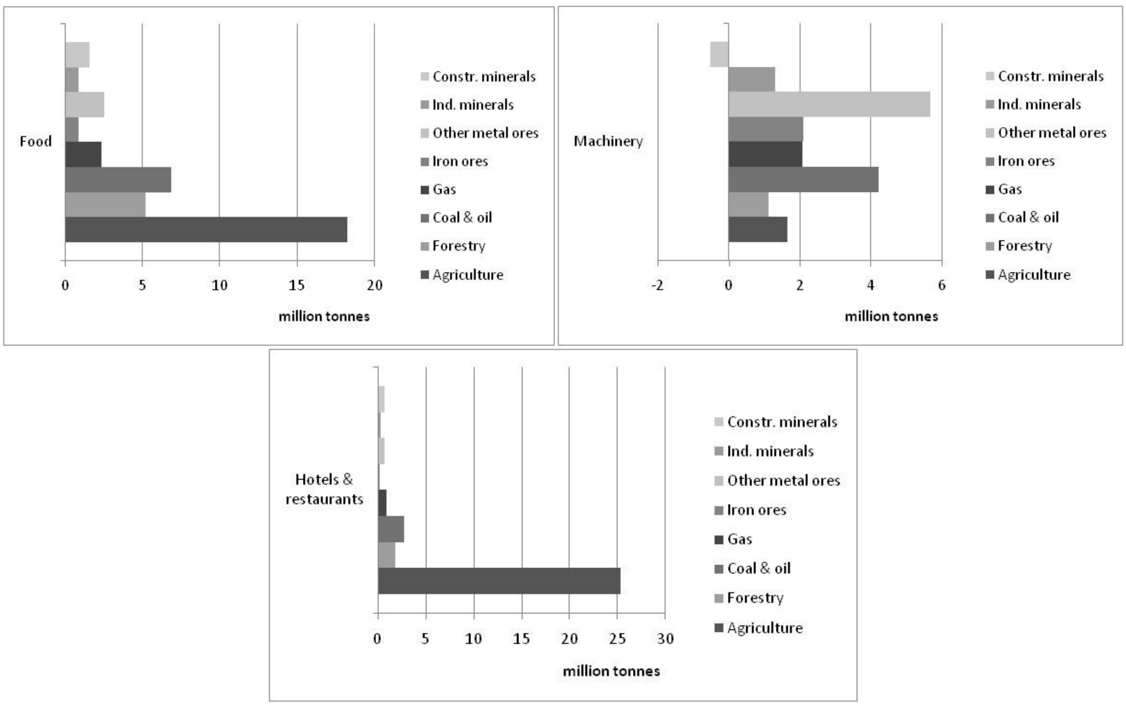
The GRAM model integrates input-output tables, which disaggregate a large number of primary, manufacturing and service sectors (see Annex 1). Therefore, the GRAM model can identify those economic sectors, which depend to the largest extent on resource inputs from other world regions.

In the next step of the analysis we distinguish 48 sectors, in order to identify the biggest net importers and exporters of certain product groups and to analyse the most important economic sectors of selected countries and regions in terms of material requirements. This analysis allows identifying those sectors with the largest direct and indirect resource requirements and those, which (directly and indirectly) are net-exporters of materials. For this type of analysis, we present data for Germany as an example country. This kind of data can be generated for all countries in the GRAM model.

The calculations suggest that almost all sectors in the German economy are characterized by a higher amount of direct and indirect imports of raw materials than they export, and are therefore net-importers of resources. The German sectoral PTB shows that the construction and the food industry have the largest net-imports. Also a number of other sectors are significant net-importers, such as hotels and restaurants, motor vehicles, wholesale, health and social work, iron and steel, machinery, etc.

In Figure 7 we examine in more detail three selected sectors, two industrial and one service sector. Such sectoral PTB can be shown in disaggregation by eight material categories.

Figure 6: Physical trade balance (PTB) for selected sectors of the German economy



The food sector ("Manufacture of food products and beverages" according to UN ISIC) shows big amounts of net biomass-imports (agriculture, forestry). These consist in a large part of resource flows coming from the foreign food industry and carrying large ecological rucksacks of e.g. fodder and grazing.

The high export share of the sector machinery ("Manufacture of machinery and equipment n.e.c.") does not prevent net imports in almost all material categories. Germany is mainly producing machines with high value and low direct material content. Only (indirect) exports of construction minerals, as they are assumed to stem always from domestic extraction, exceed the imports. Due to the specific model assumptions for construction minerals (no direct trade flows), it can thus be concluded that these net exports arise from indirect flows.

The sector hotels and restaurants is even a bigger net importer of biotic raw material from agriculture than the food industry. Of course, the biotic raw material consumption in the food sector is much higher in absolute numbers. But the German food industry is at the same time a large exporter and delivering intermediate inputs to other industries, whereas hotels and restaurants are mainly serving final domestic consumption.

6. Discussion of results

The GRAM model is one of the most comprehensive models introduced so far, which aims at calculating production-chain wide material extraction required for producing and trading goods and services. The model can be applied for a number of analytical purposes and research questions. In particular, it is suitable to illustrate the distribution of resource extraction vs. resource consumption in different world regions and to identify their typical trade patterns. The GRAM model also allows calculating indicators of resource consumption for countries and world regions, which reflect resource consumption of final demand. This is an innovative aspect compared with other, traditional material flow-based indicators, which regarded the economy as a black-box and aggregate intermediate and final demand under the heading of "consumption". Finally, data can also be generated on the level of economic sectors, in order to identify the resource intensity of different sectors / product groups and their dependency on foreign resource supply. If further developed, this type of analysis could be important to identify "hot spots" of material consumption in the domestic and the international economy and could support determining policy priorities, for example in the EU policy frameworks of "Integrated Product Policy" and the "Thematic Strategy for the Sustainable Use of Natural Resources".

In the section above, we presented the first data and indicators generated with the GRAM model for the year 2000. The results illustrate that the unequal levels of resource extraction are reinforced through international trade. Although the OECD countries already have the highest levels of per capita resource extraction, international trade increases the gap and, from a perspective of world regions, allocates additional natural resources from Southern countries to material consumption in the North. However, as the physical trade balances of single countries revealed, also OECD countries are among the most significant net-exporters of embodied materials, most notably Australia and Canada.

This trade pattern of net-imports to the North is particularly visible for the EU-25, which faces the strongest dependence on resource imports of all investigated world regions, in particular regarding fossil fuels and metal ores. In the new EU trade strategy ("Global Europe"), the issues of access to resources and resource security are highlighted as a key for future success of the European export economies: "*More than ever, Europe needs to import to export. Tackling restrictions on access to resources such as energy, metals and scrap, primary raw materials including certain agricultural materials, hides and skins must be a high priority. Measures taken by some of our biggest trading partners to restrict access to their supplies of these inputs are causing some EU industries major problems*" (European Commission, 2006b, p. 7).

Furthermore, the EU region shows higher (direct and indirect) net-imports of natural resources than any other single economy, including USA and Japan. Material consumption in the EU is by far not met only by domestic resources; a result that confirms calculations with other indicators, in particular the Ecological Footprint (WWF et al., 2005).

Given that current levels of resource consumption in countries of the EU are regarded as unsustainable (European Commission, 2005), while at the same time many countries in the South face severe material poverty, current global trade patterns must be regarded critically from a sustainable development perspective. Results suggest that countries in the emerging and developing world have the lowest per-capita consumption levels, while at the same time serve as the most significant net-exporters of natural resources. From the perspective of development economics, the question arises, whether a development strategy based mainly on primary commodities is successful and sustainable. From the 1970ies up to the turn of the 21st century, real prices for raw materials were in general declining (World Bank, 2004). A large number of studies reached the conclusion that rich endowment with natural resources and orientation towards commodity-based exports generally led developing countries into a "specialisation trap", characterised by decreasing export revenues and increasing environmental destruction (for example, Muradian and Martinez-Alier, 2001; Sachs and Warner, 1999). However, since 2002, prices for natural resources have been soaring upward, particularly due to the high demand from China (and other emerging economies), which allowed many developing countries to significantly improve their terms of trade. High commodity prices will thus play an important role in future growth prospects for developing countries (World Bank, 2008).

7. Conclusions and further research

This paper presented the first preliminary results calculated with the newly constructed GRAM model, which is one of the most comprehensive models for the calculation of indirect material flows introduced so far. The construction of the GRAM model is an important methodological step towards the calculation of truly global resource consumption indicators of single countries and world regions such as Europe. However, these first results must be refined and extended in future research and the GRAM model requires a number of extensions and improvements, in order to deploy its full potential.

7.1. Improving the input-output tables

With regard to the use of IO tables in the model, several improvements shall be undertaken in the future. First, improvement is required with regard to the procedure of approximating the production structure of countries, where so far no IO table is available, by the structure of a neighbouring country. With this regard, we intend to replace the assumed IO tables by real tables from national sources, either already published or expected to be published in the coming years. The second concern is the number of sectors, which are disaggregated in the IO tables. Currently, only a small number of sectors of high relevance for material extraction and processing are separated in the OECD tables. A more detailed resolution of IO tables is a prerequisite to provide a detailed analysis of the environmental impacts related to sectors or products (see, for example, Huppes et al., 2006; Tukker et al., 2005). Here, current work undertaken in the EU project "EXIOPOL" (see http://www.feem-project.net/exiopol) will be useful, where both SERI and GWS are project partners and currently available IO tables are further disaggregated, in order to improve their application in environmental studies. Finally, in particular for the calculation of material flow-based indicators, a number of countries in Africa, Asia and Latin America, which have high levels of material extraction and export, are currently aggregated in the category of "Rest of the World". In order to avoid distortions of results due to this geographical aggregation and in order to be able to calculate material flow-based indicators for a larger number of emerging and developing economies, the integration of additional country models is a necessary future step.

7.2. Integrating additional trade data

Trade relations between two countries in the model are currently represented only by a total of 25 groups of manufactured products plus an aggregated service sector according to the industry classification of OECD BTD and IO tables databases. Additionally we calculate trade relations for an aggregate of service products. In order to enable more detailed analysis of specific trade flows with particular relevance for material flow-based indicators, the number of categories in the trade models must be increased. This is particularly important for raw materials (of both renewable and non-renewable sources) and semi-processed products (such as basic metal products). Possible data sources for such extensions are the UN COMTRADE database, which contains very detailed trade on goods level. Advantages of a more detailed representation of international trade, however, can only be fully exploited, if also in the IO tables, further disaggregation is undertaken (see above).

7.3. Providing time series

One important objective for future expansion is the calculation of time series, in order to illustrate possible shifts of environmental pressures between the different world regions, resulting from changing patterns of specialisation in the international division of labour. One restriction is that the set of IO tables published by the OECD, covering 27 OECD countries and 9 non-OECD countries, only exists for the year 2000 so far. Therefore, in the calculation of time series, the economic structure has to be assumed as constant.

However, trade data as well as material input data is available on a yearly basis. Therefore, it is planned to calculate a time series from 1995 to 2005, in order to illustrate changing patterns of trade and material extraction and their consequences for material flow-based indicators.

7.4. Analysing international production chains and structural paths

Further analysis with the GRAM model will allow analysing specific international production chains with particular importance for the country of interest. This type of analysis can illustrate the number of processing steps, their geographical distribution and estimations of the transport intensity. The application of the method of „structural path analysis“ (see, for example, Peters and Hertwich, 2006) allows determining those chains of interindustry deliveries, which contribute most to the material consumption of a country.

7.5. Extending GRAM by other environmental categories

As explained above, the GRAM model is flexible towards the inclusion of other environmental categories. SERI and GWS aim to include energy-related CO_2 emissions in the 2008 update of the model and to calculate embodied CO_2 emissions of traded products. Such basic data on the total climate-related emissions of traded products are a key requirement for a proper evaluation of climate measures on the national and international level, as the Indian proposal of equal emission rights for every human being should be based on consumption. Currently CO_2 emission data is based on production (see Peters and Hertwich, 2008). It will also be possible to link other environmental data, which is available on the sectoral level, such as the use of energy, land and water. Also with this respect, it is intended to link closely to the EU project "EXIOPOL", where a detailed input-output database including environmental extensions is developed.

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Annex 1: Industry classification in the OECD IO tables and concordance with ISIC Rev. 3

ISIC Rev. 3 code	IO industry	BTD industry	Description
1+2+5	1	1	Agriculture, hunting, forestry and fishing
10+11+12	2	2	Mining and quarrying (energy)
13+14	3	2	Mining and quarrying (non-energy)
15+16	4	3	Food products, beverages and tobacco
17+18+19	5	4	Textiles, textile products, leather and footwear
20	6	5	Wood and products of wood and cork
21+22	7	6	Pulp, paper, paper products, printing and publishing
23	8	7	Coke, refined petroleum products and nuclear fuel
24ex2423	9	8	Chemicals excluding pharmaceuticals
2423	10	9	Pharmaceuticals
25	11	10	Rubber and plastics products
26	12	11	Other non-metallic mineral products
271+2731	13	12	Iron & steel
272+2732	14	13	Non-ferrous metals
28	15	14	Fabricated metal products, except machinery and equipment
29	16	15	Machinery and equipment, nec
30	17	16	Office, accounting and computing machinery
31	18	17	Electrical machinery and apparatus, nec
32	19	18	Radio, television and communication equipment
33	20	19	Medical, precision and optical instruments
34	21	20	Motor vehicles, trailers and semi-trailers
351	22	21	Building & repairing of ships and boats
353	23	22	Aircraft and spacecraft
352+359	24	23	Railroad equipment and transport equipment n.e.c.
36+37	25	24	Manufacturing nec; recycling (include Furniture)
401	26	25	Production, collection and distribution of electricity
402	27	25	Manufacture of gas; distribution of gaseous fuels through mains
403	28	25	Steam and hot water supply
41	29	Services	Collection, purification and distribution of water
45	30		Construction
50+51+52	31		Wholesale and retail trade; repairs
55	32		Hotels and restaurants
60	33		Land transport; transport via pipelines
61	34		Water transport
62	35		Air transport
63	36		Supporting & auxiliary transport activities; activities of travel agencies
64	37		Post and telecommunications
65+66+67	38		Finance and insurance
70	39		Real estate activities
71	40		Renting of machinery and equipment
72	41		Computer and related activities
73	42		Research and development
74	43		Other Business Activities
75	44		Public administration and defence; compulsory social security
80	45		Education
85	46		Health and social work
90-93	47		Other community, social and personal services
95+99	48		Private households with employed persons & extra-territorial organisations & bodies

Annex 2: Countries and world regions in the GRAM model

Country	Country group	OECD IO table	Country	Country group	OECD IO table
Austria	EU-25	Y	Japan	OECD (non-EU)	Y
Belgium	EU-25	Y	Korea	OECD (non-EU)	Y
Luxembourg	EU-25	(Belgium)	Australia	OECD (non-EU)	Y
Denmark	EU-25	Y	New Zealand	OECD (non-EU)	Y
Finland	EU-25	Y	Cyprus	EU-25	(Greece)
France	EU-25	Y	Estonia	EU-25	(Poland)
Germany	EU-25	Y	Latvia	EU-25	(Poland)
Greece	EU-25	Y	Lithuania	EU-25	(Poland)
Ireland	EU-25	Y	Malta	EU-25	(Greece)
Italy	EU-25	Y	Slovenia	EU-25	(Slovakia)
Netherlands	EU-25	Y	China	Anchor	Y
Portugal	EU-25	Y	Hong Kong	Rest of World	(Korea)
Spain	EU-25	Y	Indionesia	Anchor	Y
Sweden	EU-25	Y	India	Anchor	Y
United Kingdom	EU-25	Y	Malaysia	Rest of World	Y
Czech Republic	EU-25	Y	Philippines	Anchor	(Korea)
Hungary	EU-25	Y	Singapore	Rest of World	(Korea)
Poland	EU-25	Y	Thailand	Anchor	(Korea)
Slovak Republic	EU-25	Y	Taiwan	Rest of World	Y
Turkey	OECD (non-EU)	Y	Argentina	Anchor	Y
Iceland	OECD (non-EU)	Y	Brasil	Anchor	Y
Norway	OECD (non-EU)	Y	Chile	Rest of World	(Brazil)
Switzerland	OECD (non-EU)	(Germany)	South Africa	Anchor	(Brazil)
Canada	OECD (non-EU)	Y	Russia	Anchor	Y
Mexico	OECD (non-EU)	(Brazil)	OPEC*	Rest of World	(Indonesia)
United States	OECD (non-EU)	Y	Rest of World	Rest of World	(Argentina)

Note: Brackets in the column "OECD IO table" indicate that no country IO table is available from the OECD and the structure was approximated by the country in brackets.

Annex 3: Summary table of results from GRAM calculations (in 1000 tonnes)

Code	Country	DE	M^{DFD}	M^{DEX}	M^{IFD}	M^{IEX}	PTB (+) Net-importer (-) Net-exporter
AT	Austria	117.131	95.817	21.315	56.763	11.611	35.448
BE	Belgium	119.563	78.716	40.848	138.650	91.133	97.802
LU	Luxembourg	9.416	6.199	3.217	9.113	3.579	5.896
DK	Denmark	124.453	82.165	42.287	49.323	18.177	7.036
FI	Finland	154.267	119.898	34.369	44.840	18.405	10.471
FR	France	794.746	701.190	93.556	267.255	66.611	173.698
DE	Germany	1.245.210	1.050.867	194.343	552.029	124.006	357.686
GR	Greece	185.166	154.904	30.262	38.252	4.015	7.990
IE	Ireland	71.326	41.403	29.923	22.730	10.045	-7.193
IT	Italy	475.641	424.731	50.910	282.011	40.662	231.101
NL	Netherlands	155.952	92.261	63.692	156.126	85.978	92.435
PT	Portugal	120.957	109.915	11.042	40.853	6.109	29.811
ES	Spain	527.908	469.868	58.040	204.333	32.122	146.293
SE	Sweden	206.293	131.019	75.274	66.738	22.525	-8.536
GB	United Kingdom	719.099	567.089	152.010	366.934	35.266	214.924
CZ	Czech Republic	178.497	123.887	54.609	33.963	9.171	-20.646
HU	Hungary	100.866	77.253	23.613	22.084	6.504	-1.529
PL	Poland	550.175	418.990	131.185	49.970	7.486	-81.215
SK	Slovak Republic	50.311	35.075	15.236	18.315	5.349	3.079
TR	Turkey	486.828	404.608	82.220	85.228	11.322	3.009
IC	Iceland	6.213	4.712	1.501	2.170	590	669
NO	Norway	272.028	86.414	185.614	32.837	7.223	-152.777
CH	Switzerland	89.438	77.822	11.615	44.969	8.373	33.354
CA	Canada	1.099.081	674.382	424.699	203.167	50.267	-221.532
MX	Mexico	1.043.510	920.721	122.790	116.232	8.084	-6.558
US	United States	8.292.910	7.764.685	528.226	1.516.727	74.015	988.502
JP	Japan	1.399.372	1.365.825	33.547	996.347	109.043	962.799
KR	Korea	420.731	402.523	18.208	302.606	84.111	284.398
AU	Australia	1.572.154	890.961	681.193	80.337	9.943	-600.856
NZ	New Zealand	79.031	58.958	20.073	20.309	3.970	236
CY	Cyprus	19.216	18.314	902	5.995	705	5.093
EE	Estonia	30.340	22.703	7.637	5.721	906	-1.916
LV	Latvia	28.578	22.210	6.368	4.343	620	-2.024
LT	Lithuania	28.317	22.976	5.340	11.050	1.780	5.710
MT	Malta	3.346	3.175	170	3.351	482	3.180
SI	Slovenia	38.726	26.990	11.737	9.547	2.088	-2.189
CN	China	6.238.996	5.632.028	606.968	303.010	34.682	-303.958
HK	Hong Kong	551.057	459.040	92.017	207.432	42.064	115.416
ID	Indionesia	1.471.819	1.040.023	431.796	63.145	10.973	-368.651
IN	India	2.796.708	2.616.654	180.055	111.409	5.632	-68.646
MY	Malaysia	290.427	245.900	44.527	87.291	19.383	42.764
PH	Philippines	298.596	266.091	32.505	34.022	8.035	1.518
SG	Singapore	40.469	39.411	1.058	143.236	36.520	142.178
TH	Thailand	415.088	361.606	53.483	78.153	18.125	24.671
TW	Taiwan	216.260	177.733	38.527	178.547	41.182	140.021
AR	Argentina	777.946	658.020	119.926	62.496	5.996	-57.430
BR	Brasil	2.792.937	2.456.213	336.724	106.580	7.750	-230.144
CL	Chile	659.233	326.503	332.729	40.810	2.709	-291.919
ZA	South Africa	746.375	559.006	187.369	48.617	4.063	-138.752
RU	Russia	2.086.225	1.358.054	728.170	74.983	6.594	-653.188
OP	OPEC	3.076.084	1.900.572	1.175.512	213.531	30.886	-961.981
RW	Rest of World	8.687.652	6.795.213	1.892.439	1.266.115	165.353	-626.324