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ESTIMATING RAW MATERIAL EQUIVALENTS WITH MULTI-REGIONAL INPUT-OUTPUT MODELS: THE IMPACT OF SECTORAL DISAGGREGATION

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Content

List of Figures

List of Tables

1 Abstract

An important issue at the UN, Eurostat and OECD expert workshop on demand-based measures of material flows and productivity in Paris, 18-19 September 2017, was the question of how the already existing OECD ICIO database for an MRIO model could be improved for the purpose of RME estimates by introducing a more suitable of level sectoral disaggregation. Taking that discussion as a starting point, this paper analyses the questions (1) what is the required level of sectoral disaggregation of an MRIO model for ensuring accurate results in raw material equivalents? (2) What method could by applied for estimating a detailed sectoral disaggregation of country IOTs? (3) Which principal approach and what level of regional resolution could be envisaged for a high-resolution MRIO model?

The reviewed disaggregation levels range between 64 and 182 product groups for pure monetary models. Hybrid models (mixed monetary and physical sales structures) are test-ed at the resolution level 155 and 182 sectors. Further, a so-called use extension was examined. Results show that if the analytical purpose calls for accurate results at the more detailed breakdown by 51 individual raw material categories, the required level of disaggregation of ICIO database has to be increased considerably. For metal ores, a purely monetary model by 155 sectors is sufficient. For other raw material categories, a hybrid model in a breakdown by 155 or 182 product groups is needed.

For future work, it was proposed to develop a high-resolution MRIO model by combining the OECD database with the EU RME model. A number of options for a regional resolution of that model were considered. A pragmatic approach for developing a regionally dis-aggregated model could be to follow a step-wise approach which may start with a low regional resolution.

2 Introduction

An important issue at the UN, Eurostat and OECD expert workshop on demand-based measures of material flows and productivity in Paris, 18-19 September 2017, was the question of how the already existing OECD ICIO database for an MRIO model could be improved for the purpose of RME estimates by introducing a more suitable of level sectoral disaggregation. Taking that discussion as a starting point, this paper deals with three questions:

- What is the required level of sectoral disaggregation of an MRIO model for ensuring accurate results in raw material equivalents (Sections 2 and 3.1)?
- What method could by applied for estimating a detailed sectoral disaggregation of country IOTs (Sections 2.4 and 3.2)?
- Which principal approach and what level of regional resolution could be envisaged for a high-resolution MRIO model?

The focus of this paper lies on the first question. To address it, concepts and empirical results of the DeteRess model of the German Environment Agency were used[1]. The treatment of the second question is confined to recalling the disaggregation method that was developed for expanding the official EU IOT with 64 product groups to the level of 182 product groups in the course of developing the EU RME model[2] and to trying out disaggregation methods with different levels of sophistication based on method and the data of the EU RME model. For answering the last question, an approach is proposed for establishing a high-resolution MRIO model by combining the OECD-ICIO model and the EU RME model at different levels of regional disaggregation.

[1] See: Dittrich, M. et al. (2018)

[2] See: Eurostat (2016)

3 Analysing the impact of the disaggregation level

3.1 The rationale of a single country model approach for assessing the sectoral disaggregation requirement

This paper offers a method for assessing the disaggregation requirements for MRIO models. The analysis is based on a set of 'single-country models' and not on a complete MRIO model.

There are various studies on assessing the impact of different levels of resolution on the accuracy of estimates of carbon footprint[3]. An investigation of that question with respect to material footprints was conducted by de Koning et al. (2015). The study was based on the MRIO model of Exiobase. The RMC of countries was calculated with two levels of sectoral resolution, a low-resolution model (60 sectors) and a high-resolution approach by 163 industries and 200 product groups. Further, the impact of regional disaggregation and of disaggregation with respect to material categories of domestic extraction were investigated. As conclusion with respect to sectoral disaggregation, it was strongly suggested that IOTs at the highest resolution practically feasible should be used.

However, the outcome of this study alone might not be sufficient for deciding on the appropriate level of disaggregation for MRIO models for two reasons:

- The conclusion remains rather vague in the sense that no specific advice is offered on which exact level or resolution is needed in view of different analytical purposes.
- Large discrepancies between the results of the EU RME model and EW-MFA data and Exiobase lead to doubts on whether the current state of the Exiobase model is already able to generate results with a sufficient degree of accuracy[4] .

[3] See Su et al. (2010), Lenzen (2011), Bouwmeester and Oosterhaven (2013), Steen-Olsen et al. (2014).

[4] The quality issue can be highlighted by comparing central calculation results of EXIOBASE for the EU with official EU data. For the year 2010, the EXIOBASE model has estimated an RMC of 11.635 Mio. t (EU-27 without Croatia). See: environmetalfoortprints.org. In comparison, the EU RME model gives a value of only 7.528 Mio. t. The DMC for the EU amounts to 7.092 Mio. t for the same year. There are different reasons that can give rise to those considerable discrepancies: The quality and the level of resolution of national IOTs are very different, and the level of disaggregation is usually far away from what is needed for a high resolution MRIO model. A further issue is that there are quality problems of data on international trade which are needed for establishing detailed trade links between countries. That is, large data gaps have to be bridged by models and estimates. Due to the huge mass of data, it seems to be very difficult to carry out all-embracing quality control procedures. For discussion of the quality issue regarding an earlier version of Exiobase see also: Schoer et al. (2013).

Therefore, it could be helpful to crosscheck the results of the study by an alternative approach. This paper offers a supplementary method for assessing the disaggregation requirements for MRIO models. The method analyses the impact of the disaggregation level using a set of 'single-country models'.

In comparison to a full MRIO model, it is much easier to develop a detailed country model with a high level of quality for a selected pilot country with good data availability. High data quality of the used model assures that the comparisons are conducted under fairly controlled conditions. Further, a single-country model is much more flexible for investigating a larger number of disaggregation options at low expense. The results for a wide range of options are useful for selecting an appropriate level of disaggregation for generating sufficiently accurate results by raw material categories in view of the envisaged analytical purposes.

In order to get more representative results, the core single-country model is supplemented by a set of additional single-country models.

For comparing disaggregation options, data from the original RME model of the DeteRess project[5] of the German Environment Agency in an updated version were used[6]. The model refers to Germany in the year 2010. It is a high-resolution model which is predominantly developed for establishing detailed long-term scenarios on raw material requirement of manufacturing final demand products. The DeteRess model is designed as a 3-region model in the sense that import coefficients for intra-EU imports are derived from the EU RME-model. The import coefficients for imports from non-EU countries are estimated by a so-called adapted DTA approach. The method integrates – similar to full MRIO approaches - regionalized information on the production technology of the countries of origin for the most relevant import flows in terms of RME[7]. Due to good data availability for Germany[8], an IO model could be established with a comparatively high level of sectoral resolution by 274 product groups with a mix of sales structures in monetary and physical terms.

In case of an assessment based on an MRIO model, the impact of the disaggregation level can be directly measured by looking at the effect on the central indicator RMC. Against that, in case of a single-country model an indirect approach has to be applied using RME of exports as the strategic variable. That variable is crucial for the following reason: It is the explicit aim of MRIO models to provide reliable results at the level of individual countries. Exports and imports are laterally reverse from the point of view of trade partners. That means that the accuracy of RME of imports of a country depends on the quality of the estimation of RME of exports for the countries of origin. Therefore, it can be concluded that a MRIO model can only generate accurate results at country level if the RME of exports of each of the countries or regions of the model are sufficiently accurate. This condition should at least hold for all countries that are contributing a non-negligible share to the world exports.

With a single-country model it can only be explored which disaggregation level is required to make sure that the RME of exports of the country under review are accurate. RME of exports are determined by the domestic production technology (transaction matrix), the

[5] DeteRess: Determinants of resource productivity. For a description of the model, see Dittrich, M. et al. (2018) and Schoer et al. (2017). With respect to the base year 2010, the model is conceptually closely related to the EU-RME model (s. Eurostat (2016)).

[6] For this paper, data for the year 2010 are not directly taken from the DeteRess model, but from the RTD-model which is an updated version of the DeteRess model.

[7] For a description of the A-DTA approach, see Eurostat (2016).

[8] Major data source is a use table of the Federal Statistical Office in a breakdown by about 2600 product groups.

environmental extension components, domestic extraction and the RME of imports. From the point of view of an individual country, RME of imports are determined by the production conditions of the countries of origin in an MRIO model. For different disaggregation levels of the single country model the same values for RME of imports that were estimated with the full level of resolution of the DeteRess model is utilized. Only the disaggregation level of imports is varied accordingly.

3.2 Supplementary single-country models for further countries

It is obvious that the results for Germany alone cannot be representative for all countries or regions in the world. Therefore, it is useful to supplement the calculations for the German model by comparable estimates for some other major export countries.

However, it has to be pointed out that comparable results for other countries play only a supplementary role. The reason is that the minimum required resolution of the model derived from German data alone is already an important and highly useful information. According to the logic of an MRIO model, it is only possible to generate accurate results in RME for each country, if the RME of exports for all - or at least for all countries that are substantially contributing to the world exports – are sufficiently correct. In so far, it would be a necessary but not sufficient condition for a world model that the general disaggregation level is able to provide accurate results for exports from Germany. Germany is the second largest exporter after China (2010).

For exploring the sufficient condition, the investigation of the single country model Germany is supplemented by examining the effect of disaggregation for some other major countries. By regarding further country examples, a 'least common denominator' can be established in the sense that the disaggregation level of the MRIO model should be sufficient for generating accurate results for each country which contributes a significant share to the world exports. Therefore, the question to be answered is whether there are other major economies that demand a level of disaggregation which is higher than the level for Germany. In that case, the general resolution level of the total MRIO model, which has to serve the purpose of providing accurate results for all countries, would have to be increased accordingly.

The following typical countries/regions were selected as supplementary economies for cross-checking the results for Germany: European Union, China, United States, Japan, Brazil, Russia and Australia. All selected economies substantially contribute to the world exports, and the selected economies show rather different export patterns. One important example are the differences regarding the shares of raw products and primary processed raw products. For Germany, EU, China, United States and Japan, the trade share of primary raw products and of the products of primary processing of raw products is ranging between 7% and 14%. In comparison, the share of those products for Australia, Brazil and Russia amounts to 55% to 72%.

Two principal approaches are used for investigating country conditions, depending on data availability:

- Direct approach with the example of the European Union (EU)
- Simulation approach for other selected economies

With respect to comparison with EU results, a direct approach could be applied because the DeteRess model for Germany is conceptually almost fully identical with the EU RME model. Therefore, it was possible to reproduce the calculations for Germany with corresponding data for the EU[9].

For the remaining selected countries, models and data which are comparable with the German approach are not, or at least not easily, available. Instead, a simulation method was applied. As far as possible, the disaggregation variants of the German model were run with the original export vectors (expressed in EUR) of China, United States, Japan, Australia, Brazil and Russia. For the purpose of those simulation approaches, German production technology was assumed implicitly. Therefore, the approach is limited to testing the isolated effect of differences in export structures. Further, the method is limited to comparing monetary models[10].

3.3 Options for disaggregation

3.3.1 Overview of disaggregation approaches

The options for disaggregation of the different models which were tested for the purpose of this paper are listed and described in Figure 1. Three principal types of disaggregation options are considered:

- A purely monetary model with the level of resolution ranging between 64 and 182 product groups
- A mixed monetary and physical model (hybrid) for the levels 155 and 182 product groups
- A use-extension approach (see figure 1)

The sectoral breakdown of the EU RME-model is designed for converting product flows into flows of raw material equivalents (RME) with the highest possible level of accuracy in view of statistical feasibility. As a result, not a pure monetary model, but a hybrid model in a breakdown by 182 product groups was established[11]. The disaggregation level of raw products of the model is following the classification of materials of the Economy-Wide Material Flow Accounts (EW-MFA) of Eurostat in an expanded version for the EU RME model with more details for metal ores. For almost each raw material category, a corresponding extraction branch (product group) was defined. In order to track the flow of raw materials through

[9] For the Czech Republic, a model is available in a breakdown by 182 product groups. The model is conceptually harmonized with the EU RME-model (Kovanda et al. 2018). Therefore, the above calculations could also be reproduced for that country. However, as Czech Republic only contributes a small share to world exports, the option was not taken into consideration.

[10] The export prices for Germany are different from other countries. Therefore, the results which are calculated under the assumption of German production technology for monetary and for hybrid models are not comparable.

[11] Compared to that, the DeteRess model, which is conceptually almost fully harmonized with the EU RME-model, is using a more detailed breakdown by 274 product groups, more physical sales structures and more information on material input to specific branches from sector specific studies (see Dittrich et al. (2018)). The primary purpose of that model is, beyond providing accurate results for RME flows for the base year 2010, to establish long-term scenarios on the development of raw material requirements for the economy under specific assumptions, especially regarding the development of final uses and the production technology of material intensive branches.

the economy as closely as possible.At least in the first step of the production chain, the disaggregation of the branches of primary processing of raw materials is widely corresponding to the breakdown of primary raw materials. Beyond that, some further material intensive production activities are disaggregated as well, like the production of chemicals.

Table 1: Description of different IOT disaggregation approaches

A. Monetary IOT approaches by disaggregation level	
MIOT64	Classification of the Eurostat RME model: 64 product groups*). Primary biomass products are broken down into three product groups, namely agriculture, forestry and fishery. Mining products are aggregated to one product group. For goods, this breakdown is fully identical with the classification of the OECD-ICO model. Only for some service items, the OECD-ICO classification is slightly more aggregated.
MIOT66	Difference to MIOT 64: Mining products are broken down into 3 product groups: energy carriers, metal ores and non-metallic minerals.
MIOT74	Difference to MIOT 66: Moderate disaggregation of raw products: Agriculture: breakdown into crop products and animal products Energy carriers: breakdown into coal, oil and gas Metal ores: differentiation of six product groups Non-metallic minerals: breakdown into construction minerals and other minerals
MIOT83	Difference to MIOT 75: Moderate disaggregation of primary processed raw products. Food products: breakdown into animal products and other food products Energy carriers: the product group "electricity, gas, steam and air-conditioning" is broken down into three product groups Basic metals: breakdown into six product groups on-metallic mineral products: breakdown by products predominantly for construction and others
MIOT124	Difference to MIOT 84: Detailed disaggregation of raw products: Agriculture: 19 product groups Energy carriers: 5 product groups Metal ores: 18 product groups Non-metallic minerals: 12 product groups
MIOT155	Difference to MIOT 124: Detailed disaggregation of primary processing of raw materials. Food products: 11 product groups Energy carriers: no further breakdown Basic metals: 22 product groups Non-metallic mineral products: 8 product groups
MIOT182	Classification of the Eurostat IOT model: 182 product groups; difference to MIOT 155: further disaggregation of the following product groups: Textiles, wearing apparel and leather products: 3 product groups Paper and paper products: 2 product groups Coke and refined petroleum products: 2 product groups Chemicals and chemical products: 8 product groups Rubber and plastics products: 2 product groups Fabricated metal products, except machinery and equipment: 7 product groups Other transport equipment: 4 product groups Furniture; other manufactured goods: 7 product groups
B. Hybrid IOT approaches by degree of hybridization and by disaggregation level	
HIOT155	Difference to MIOT 155: The monetary sales structures of the MIOT155 are replaced by physical ones for 38 product groups: agricultural crop products, forestry products, fishery products, primary non-metallic minerals, all energy carriers and main basic metals (iron, copper, aluminium). Basic metals in physical terms are not available for the EU-calculations.
HIOT182	Difference to HIOT 155: further disaggregation by following the breakdown of MIOT182.

C. Use extension approach	
USEEXT 51	The use extension approach calculation is based on the monetary IOT in a breakdown into 66 product groups (MIOT 66). A corresponding use extension matrix in a breakdown into 51 raw material categories (EU classification) is applied for depicting the direct domestic raw material inputs into the economy (domestic extraction). Whereas for the above standard approaches, the direct raw material inputs are assigned to the corresponding extraction branches, in the use extension approach, the individual direct domestic raw material inputs into the economy are assigned to the first users. For allocation of the physical inputs to the first users, the corresponding sales structures of the MIOT182 are utilized.

*) This classification differs from the classification of the OECD-CIO model by a more detailed breakdown for some product groups of services.

3.3.2 Monetary approaches

The level of resolution for approaches based on a purely monetary model range between 64 product groups and 182 product groups (for more details see Figure 1):

- **Basic level**: At the lowest level (MIOT64), all branches of raw material extraction and primary processing of raw products are highly aggregated.
- **Disaggregation of mining**: At the second level of resolution (MIOT66), mining and quarrying activities are subdivided into three sectors, primary fossil energy carries, metal ores and non-metallic minerals.
- **Moderate disaggregation** of **raw products**: The third level (MIOT74) is characterised by moderate disaggregation of raw products into 15 product groups.
- **Moderate disaggregation** of **primary processing** of raw products: At the fourth level (MIOT83) a moderate disaggregation of primary processing into 13 product groups is added.
- **Detailed disaggregation of raw products**: At the fifth level (MIOT124) a detailed disaggregation of raw products into 54 product groups is subjoined.
- **Detailed disaggregation of primary processing** of raw materials: At the sixth level (MIOT155) a detailed disaggregation of primary processing of raw products into 41 product groups is added.
- **Further disaggregation** of other manufacturing: At the seventh level (MIOT182) a further disaggregation of products of manufacturing into 38 product groups is added.

3.3.3 Hybrid approaches

The German DeteRess model and the Eurostat RME model are hybrid approaches in the sense that a mix of monetary and physical sales structures is applied. The approach is based on the finding that in some cases physical sales structures are able to improve the results. This applies to cases for which raw materials flows are better represented by physical than by monetary relationships.

Originally, sales structures are available in monetary units from the official Input-Output and Supply- and-Use tables. For the purpose of this comparison, the hybridisation approach of the EU RME-model was used with two principal approaches:

- For **energy carriers**, an alternative source for sales structures in energy units is available from the energy balances. It was assumed that the physical sales structures for energy carriers are more suitable for representing the raw material content than the monetary ones due to price differences and differences in distribution costs.

- For all **other cases** (see Figure 1), physical information was available for outputs, imports and exports only. Technically, complete physical sales structures were estimated by fitting the monetary structures for domestic use to the corresponding physical values for domestic use. Applying physical sales structures of this type can improve the estimate of the amount of RME of direct exports of a product group. By using the monetary approach, it is implicitly assumed that the amount of RME per unit of exports of a product group is equal to the relationship for total final use. However, in reality there may be differences between the structure of domestic final use and of exports within a product group. Quite frequently, the unit value of exported products within a product group is considerably higher for exports than for domestic use. If that is the case, the raw material content of exports may be overstated under a monetary approach. An admittedly extreme example is the case of raw diamonds. Diamonds are part of the product group “other non-metallic minerals”. That is, under the monetary approach, the RME of diamonds is heavily overstated as the mass is estimated by applying the average unit values of total “other non-metallic minerals”. Using physical sales structures for the product group would avoid or at least reduce the mistake of overstating the RME content of exported diamonds.

3.3.4 Use extension approaches

The so-called **use extension approach** was also tested as a simple alternative to sectoral disaggregation of the total IOT model. The approach used is described in Figure 1 (USEEXT51).

A use extension approach is serving the purpose of introducing more detailed sectoral information to the model without disaggregating the IOT matrix. Instead, the environmental extension is modified. In the standard model, the direct raw material inputs to the economy by domestic extraction are assigned to the corresponding extraction branches. The further allocation of extracted materials to the users is done by utilising the corresponding use structures of the IOT model. That type of allocation tends to be rather imprecise if it is based on a low-resolution model with respect to raw material extraction. The use extension approach tries to overcome that shortcoming by assigning domestic raw material inputs (in a detailed breakdown) into the economy not to the corresponding extraction branches but directly to the first users (production activities and final use categories).

The data requirement for disaggregating the environmental extension matrix is similar to disaggregating the corresponding sales structures of the IOT. The advantage is that a disaggregation of the IOT model can be avoided. The disadvantage is that the possibility of disaggregation is limited to primary raw materials. Primary processing of raw materials and other material intensive production activities cannot be covered.

3.3.5 Level of breakdown of raw material categories

Beside the level of sectoral disaggregation of the IOT matrix, the accuracy of the calculation results can also be impaired by an insufficient breakdown by raw material categories. A disaggregated model needs to be supported by a corresponding level of disaggregation of raw materials. Ideally, for each extraction branch, a corresponding raw material category should be available. For the purpose of this comparison, the breakdown of raw materials by 51 categories of the DeteRess and the EU RME model is used. The detailed breakdown is a precondition for applying high resolution IOT matrices. To give an example, if primary fossil energy carriers, metal ores and non-metallic minerals are only available as one aggregated category each, only calculations up to the level of MIOT66 are supported.

3.3.6 Measurement of the degree of accuracy

The impact of different disaggregation approaches on the RME of exports can be measured using an identical set of production technology, domestic extraction and RME of imports and varying only the level of disaggregation. The resolution level which is considered to be the most accurate one is used as a reference. However, the selection of the "highest level" is always a normative construct only providing a relative and not an absolute yardstick for accuracy. In practice, the achievable degree of resolution is limited by the availability of data and of resources for the refinement of estimation procedures. Thus, in reality one might have to optimize between accuracy and feasibility. In so far, any reference approach represents only a pragmatic decision in view of data availability. For the purpose of this comparison, HIOT182 is used as the reference approach as it is considered that a significantly higher level of resolution could only be achieved in exceptional cases and not for all countries.

Once a reference approach is defined, the degree of accuracy of all other options can be described as the deviation of the calculation results from the reference approach. The lower the positive or negative deviation from the corresponding reference value, the higher is the degree of accuracy. Which degree of deviation is regarded as sufficiently accurate depends, in principal, on the analytical purpose. However, for moving forward without getting lost in a discussion what the relevant analytical purposes are, we have looked for a pragmatic approach.

Therefore, the following quality classes are defined by a further normative decision for the purpose of this paper: An absolute deviation from the reference value up to 3 percent is considered as being "accurate". Results with an absolute deviation of more than 3 percent up to 5 percent are regarded as "sufficient", results with an absolute deviation beyond 5 and 10 percent are classified as "insufficient" and deviations of more than 10 percent are denoted as "highly insufficient". A look at the variation of results (see below) is suggesting that the margin for defining alternative quality classes is rather low. Anyway, as the full results are presented, readers could also apply an alternative set of thresholds for the quality classes. By establishing the quality classes, a standard is defined for deciding whether a specific disaggregation approach is able to offer sufficiently accurate results.

However, in addition, the analytical objectives have to be considered for selecting a suitable disaggregation level. In case of detailed MFA studies, accurate results in a detailed breakdown by raw material categories and product groups may be needed. In this paper, only the requirement for getting accurate results by using deeply structured raw material categories is measured. But the other issue of looking at a breakdown by detailed product groups was not regarded. It can be expected that the accuracy requirements tend to be even higher if the focus is put on product groups as well.

3.4 On the method for sectoral disaggregation of country IOTs

In the previous sections, the method for assessing the impact of different disaggregation levels on the accuracy of the calculation results for RME was described. For that exercise, the existing IOT with the maximum resolution level was aggregated to lower resolution levels. The results of the assessment can be utilized as a guideline for deciding on the appropriate level of sectoral resolution for the MRIO model. Once it has been decided which disaggregation level is needed, methods have to be developed for disaggregating the country IOTs from the OECD-ICIO database to the pre-defined disaggregation level.

It has to be pointed out that it is the primary objective of this paper to find out what disaggregation level is needed. It is out of scope of this paper to investigate the issue of disaggregation methods in a comprehensive manner. Therefore, this section is confined to contribute only two aspects:

- The disaggregation method which was developed for expanding the official EU IOT by 64 product groups to the level of 182 product groups in the course of establishing the EU RME model is recalled.
- Based on that method, data of the EU model are used for comparing the impact of three selected disaggregation methods on the accuracy of the calculation results.

Starting point for the disaggregation method for the EU RME model was the official monetary IOT by 64 product groups which had to be disaggregated to the level of 182 product groups. For the disaggregation of the EU IOT, data from the DeteRess model for Germany were used. Unlike for the EU, for Germany it was possible to establish a model in a breakdown by 182 and even 274 product groups due to the availability of very detailed official supply and use tables. At EU-level, that type of detail was not available. Therefore, an approach was developed which uses the detailed structural information from the German model as an input into the disaggregation procedure for the EU. The general method was a two-step approach which is based on the following information:

- Monetary IOT for the EU in a breakdown by 64 product groups (MIOT64)
- Monetary IOT for Germany in a breakdown by 182 product groups (MIOT182)
- The vectors for total outputs, imports and exports of the EU IOT which were disaggregated to the level of 182 sectors by referring to EU data sources.

In a first step, raw values for domestic uses of the IOT were estimated by disaggregating individual cells of the EU IOT by the corresponding relationships from the German model. In a second step, the raw values were adjusted to the detailed vector for total domestic use (outputs + imports - exports) by an iterative approach.

As one possible option, the disaggregation of the OECD-ICO database could follow a similar approach for disaggregation of the individual country IOTs. However, especially for establishing completely disaggregated vectors for outputs by 182 product groups, it is not realistic to assume that the necessary information is available for all countries. But, there is at least a good chance of getting suitable data on outputs of raw products. Therefore, three models were compared:

- MIOT182: The option represents the full disaggregation approach which was applied for the EU model. The approach is a two-step approach. In a first step, raw values for domestic uses of the IOT were estimated by disaggregating individual cells of the EU IOT by the corresponding relationships from the German model. In a second step, the raw values were adjusted to the detailed vector (182 product groups) for total domestic use (outputs + imports - exports) by an iterative approach.

- MIOT182 RAW: The simplified option uses the interim raw values (first step) of the method for the full approach. That simplification may be necessary mainly due to non-availability of a disaggregated vector for outputs.
- MIOT182 RAW+: This option is a mixed approach. The full MIOT182 approach is applied for raw products only. For the remaining product groups, the simplified method of MIOT182 RAW is used.

It is expected that the comparisons will be able to explore whether the simplified version MIOT182 RAW and MIOT182 RAW+ could be used as alternative to the full approach without losing too much quality.

3.5 Options for a high-resolution MRIO model

3.5.1 A combined high-resolution MRIO model

In this section, options are considered for establishing an MRIO model for estimating raw material equivalents of product flows with high resolution that is based on the official OECD-ICIO database[12]. As a way forward, we propose to develop a high-resolution MRIO model by combining the OECD database with the already existing EU RME model (combined approach).

The multi-regional OECD-ICIO data are available in a sectoral breakdown by 56 product groups and a regional breakdown by 43 countries. The model is available as a time series. The results are updated regularly. As the sectoral resolution level is by far too low in light of the results below, the model has to be disaggregated accordingly.

The EU-RME model is also available as time series, and the results are updated regularly. The model is designed as a hybrid approach with a resolution of 182 sectors. The sectoral resolution of the model fully complies with the envisaged disaggregation level for the MRIO model. The current EU RME-model is a single-country model. It is a specific type of DTA model which is labelled as ADTA-IO model (adapted DTA input-output model)[13]**.** In principal, the approach uses DTA for estimating RME of imports. However, the DTA-based results are adjusted by regional information in order to capture the most relevant differences between domestic production technology and the production technology in the countries of origin. By combining the Eurostat model with the (disaggregated) OECD-ICIO model the approach could be converted from an ADTA-IO to an MRIO approach.

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[12] Several MRIO models already exist. Their calculation results differ considerably (s. URL: www. environmetalfoortprints.org). Therefore, it appears to be advisable to look for a new model which is strongly based on official sources.

[13] See Eurostat (2016).

3.5.2 Options for regional disaggregation

A number of options differing by the level of regional resolution could be considered for establishing a combined approach:

- Two-region MRIO model with the regions total EU and total non-EU
- Total EU and moderate regional disaggregation of non-EU
- The EU block regionally differentiates 28 member-countries; total or moderate regional disaggregation of non-EU
- Full regional disaggregation according to the OECD-ICIO database by 43 countries

Which option is selected mainly depends on the criteria analytical purpose, availability of data and availability of financial resources. A pragmatic procedure for developing a regionally disaggregated model could be to follow a step-wise approach which may start with a low regional resolution of the first or second option.

4 Calculation results

4.1 Disaggregation level

4.1.1 Calculation results for Germany

The impact of sectoral disaggregation is studied at the example of Germany for two levels, namely at the level of four main raw material categories and with respect to a detailed breakdown by 51 raw material categories.

4.1.1.1 Main raw material categories

Figure 2 shows the calculation results by main raw material categories and by disaggregation approaches for RME of exports which are based on the original data for Germany. The disaggregation options are briefly described in Figure 1. It is assumed that the option HIOT182 provides the most accurate results. Therefore, HIOT182 is regarded as reference approach in the following.

Figure 2 presents calculation results of the different variants of disaggregation in relationship to the reference approach HIOT182. HIOT182 was chosen as the reference approach as a significantly higher level of resolution can only be achieved in exceptional cases and not for all countries[14]. Generally, it can be stated that the results react rather sensitively to the level of disaggregation. In most cases, the level of accuracy tends to improve with the level of disaggregation of the monetary IOT. Shifting from a monetary IOT to a hybrid IOT changes parts of the results considerably.The use extension approach can be classified as being a low to medium resolution option. The calculation results of that approach differ considerably from the reference approach.

At the level of **total primary raw materials,** all options provide “accurate” results for Germany in the sense of the pre-defined quality classes. However, the results for the individual main raw material categories are much more diverse. That is, the observed “accuracy” for total raw materials could be just a random result as opposing trends for the individual main raw material categories compensate each other to a certain extent. For other countries or

[14] It has to be pointed out that the chosen maximum level of disaggregation of HIOT182 can only be regarded as a yardstick for relative accuracy. HIOT182 does not denote a clear point of saturation beyond which the accuracy of the calculation cannot be expected to improve in a significant manner. On the contrary, the calculation results of the HIOT274 approach of the German DeteRess model differ considerably from HIOT182 (– 4.4% for total primary raw materials). Due to favourable data availability, a comparatively high disaggregation level could be realised for the German model. Three factors are responsible for the deviation, a) a more detailed sectoral disaggregation (274 sectors), b) replacement of more monetary sales structures by physical ones and c) improved quality of physical sales structures by utilizing information from specialised studies on the physical inputs into important production processes.

regional entities (see below), the results for total primary raw materials deviate in a stronger manner.

For the individual main raw material categories, the resolution requirements are different. For **biomass,** the approaches with a low resolution, including the use extension approach, show a considerable underreporting by around 10 percent. Only the results of options MIOT155 upward can be regarded as being accurate. That implies that detailed disaggregation of extraction as well as of primary processing of biomass is needed.

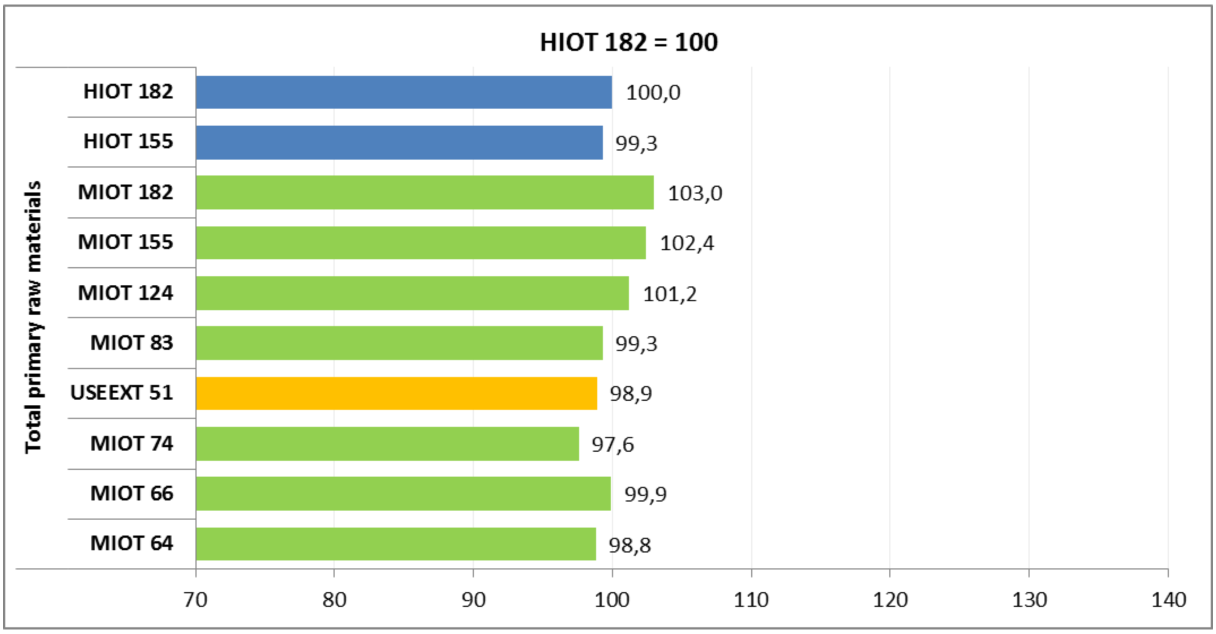
For the main raw material category **metal ores,** the minimum disaggregation level is MIOT83.Therefore, if the focus is only on that main raw material category, a moderate disaggregation of extraction and primary processing is satisfactory.

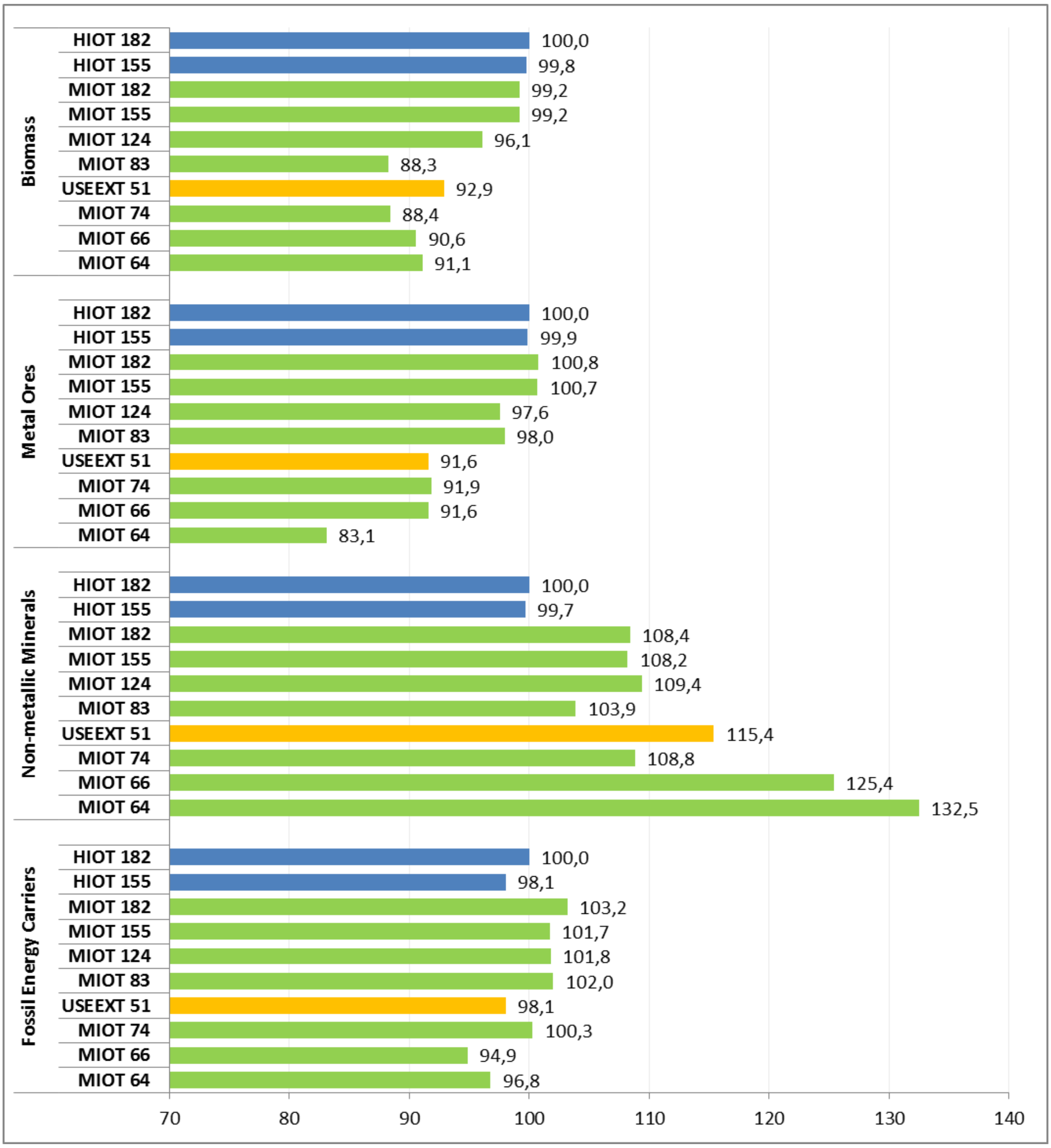
The results for **non-metallic minerals** show a clear pattern. Approaches with a low resolution heavily overstate the RME content. The results improve with increasing disaggregation level. However, only the hybrid approaches HIOT155 and HIOT182 provide accurate results.

With respect to **fossil energy carriers,** almost all options provide accurate results with the exception of the very low-resolution approaches MIOT64 and MIOT66.

A **preliminary conclusion** is that under the given pre-defined thresholds for assessing the degree of accuracy and under the specific German conditions, the necessary level of disaggregation differs for the main raw material categories. However, the degree of accuracy is clearly insufficient in the case of simple disaggregation approaches, like subdividing the mining sector into three sectors (MIOT66), a moderate disaggregation of raw materials (MIOT74) and a use extension approach.

Figure 1: RME of exports by type of disaggregation approach and by main raw material categories, Germany 2010





Eigene Darstellung

4.1.1.2 Detailed raw material categories

From an analytical point of view, a high level of disaggregation of the results by raw material categories is desirable. The tonnes alone are only a rough measure for assessing the environmental impact of the use of raw materials. For establishing meaningful ecological links, the results of the RME model should be available by detailed raw material categories. Figure 3 presents the results of the disaggregation options under review in a breakdown by 51 raw material categories.

Table 2 Degree of accuracy of RME of exports by disaggregation approaches and detailed raw material categories, measured as differences to reference value HIOT182 in %

(light blue)	0 Reference value
(green)	1 Accurate: absolute deviation from the reference value not more than 3%
(yellow)	2 Sufficient: absolute deviation from the reference value more 3% up to 5%
(red)	3 Insufficient: absolute deviation from the reference value more than 5% up to 10%
(magenta)	4 Highly insufficient: absolute deviation from the reference value more than 10 %

	MIOT64	MIOT66	MIOT74	USEXTM51	MIOT83	MIOT124	MIOT155	MIOT182	HIOT155	HIOT182
Germany 2010, original values										
Total primary raw materials	**-1.2**	**-0.1**	**-2.4**	**-1.2**	**-0.7**	**1.2**	**2.4**	**3.0**	**-0.7**	**0.0**
Biomass	**-8.9**	**-9.4**	**-11.6**	**-7.1**	**-11.7**	**-3.9**	**-0.8**	**-0.8**	**-0.2**	**0.0**
Cereals	-20.5	-20.5	-21.1	-8.3	-21.2	-4.1	-2.3	-2.3	0.0	0.0
Roots, tubers	64.8	64.8	61.8	-4.7	61.9	-13.2	-13.2	-13.2	0.1	0.0
Sugar crops	21.8	21.8	20.0	83.1	20.2	89.1	86.8	86.4	0.5	0.0
Pulses	2.5	2.5	1.6	11.4	1.6	15.4	22.2	22.1	0.1	0.0
Nuts	-18.4	-18.4	-19.6	-18.4	-19.6	-21.4	-22.8	-22.0	-0.8	0.0
Oil bearing crops	-35.0	-35.0	-35.5	-33.9	-35.3	-31.9	-3.3	-4.5	2.2	0.0
Vegetables	32.1	32.1	30.1	18.9	30.3	2.7	-0.4	-0.3	0.0	0.0
Fruits	57.2	57.2	54.7	35.9	54.9	9.4	5.0	5.0	0.0	0.0
Fibres	-10.6	-10.6	-10.7	-10.6	-10.7	-5.6	-5.6	1.5	-7.3	0.0
Other crops n.e.c.	-20.3	-20.3	-21.5	-20.4	-21.5	-22.1	-22.2	-21.5	-0.7	0.0
Straw	-9.1	-9.2	-10.0	-9.2	-10.2	-2.8	-1.5	-1.6	0.1	0.0
Other crop residues (sugar and fodder beet leaves, other)	-8.8	-8.8	-9.5	-8.8	-9.7	-2.6	-1.3	-1.5	0.2	0.0
Fodder crops (incl. biomass harvest from grassland)	-9.7	-9.7	-10.7	-9.7	-10.9	-3.0	-1.7	-1.8	0.1	0.0
Timber (Industrial round-wood)	-3.0	-4.7	-10.6	-10.7	-10.6	-10.5	-10.4	-9.8	-1.5	0.0
Wood fuel and other extrac-tion	-1.2	-4.2	-14.3	-14.4	-14.1	-14.0	-13.8	-13.5	-1.6	0.0
Fish catch	-21.5	-23.0	-27.4	-27.5	-27.9	-27.9	-24.8	-24.4	-0.4	0.0
All other aquatic animals and plants	-21.4	-23.0	-27.8	-27.8	-28.2	-28.2	-25.2	-24.8	-0.3	0.0
Hunting and gathering	-32.0	-32.0	-29.9	-8.9	-30.4	0.3	-0.5	-0.1	-0.4	0.0
Metal ores	**-16.9**	**-8.4**	**-8.1**	**-8.4**	**-2.0**	**-2.4**	**0.7**	**0.8**	**-0.1**	**0.0**
Iron ores	-21.1	-4.3	4.4	-4.3	3.5	3.5	3.5	3.4	0.1	0.0
Copper	-2.3	6.2	0.5	6.2	1.2	1.2	1.2	0.6	0.6	0.0
Nickel	3.2	5.9	4.2	5.9	-2.7	-2.2	1.3	1.7	-0.4	0.0
Lead	-27.6	-11.7	-10.2	-11.7	-11.4	-11.3	-0.1	0.3	-0.4	0.0

Zinc	2.6	9.7	10.3	9.7	8.7	8.6	1.7	0.6	1.1	0.0
Tin	1.3	1.3	1.3	1.3	0.0	0.0	-0.1	0.5	-0.6	0.0
Gold - gross ore	-32.3	-32.2	-32.4	-32.2	-7.6	-7.6	-0.2	-0.1	-0.2	0.0
Silver - gross ore	-13.8	-13.2	-14.4	-13.2	17.2	16.8	-0.7	0.0	-0.7	0.0
Platinum and other precious metal ores - gross ore	-27.5	-27.5	-27.5	-27.5	5.5	5.6	-0.6	0.0	-0.6	0.0
Bauxite and other aluminium	-5.2	0.8	3.9	0.8	-2.6	-2.6	-2.2	-2.6	0.3	0.0
Uranium and thorium	5.5	6.8	7.0	6.8	2.7	2.6	-4.4	-4.6	0.1	0.0
Tungsten - gross ore	8.3	9.0	9.2	9.0	4.2	2.8	3.8	3.4	0.5	0.0
Tantalum - gross ore	-10.9	-10.9	-10.9	-10.9	-24.1	-24.1	0.4	0.1	0.3	0.0
Mangnesium ores - gross ore	17.4	17.4	17.4	17.4	0.8	0.8	1.5	0.5	1.1	0.0
Titanium - gross ore	-37.6	-11.9	-6.4	-11.9	-14.6	-19.7	-2.2	0.1	-2.2	0.0
Manganese - gross ore	6.5	6.9	7.0	6.9	4.7	4.8	3.6	3.6	0.0	0.0
Chromium - gross ore	1.8	4.3	4.6	4.3	3.0	3.8	3.9	3.7	0.2	0.0
Other metal ores - gross ore	-10.5	-0.5	-2.8	-0.5	-8.7	-8.5	1.2	1.0	0.1	0.0
Non-metallic minerals	**32.5**	**25.4**	**8.8**	**15.4**	**3.9**	**9.4**	**8.2**	**8.4**	**-0.3**	**0.0**
Marble, granite, sandstone, porphyry, basalt, other ornamental or building stone (excluding slate)	4.3	3.5	2.0	6.6	1.7	6.4	6.1	7.4	-1.4	0.0
Chalk and dolomite	1.3	0.8	-2.8	5.9	-6.3	2.4	1.4	1.7	-0.3	0.0
Slate	10.3	6.8	-2.5	9.5	-8.1	6.5	2.1	2.9	-0.8	0.0
Chemical and fertilizer minerals	-46.3	-48.3	-38.5	-15.8	-39.1	-7.2	-6.8	-7.9	2.1	0.0
Salt	-21.1	-25.4	-4.3	6.4	-5.7	11.6	12.3	11.9	1.4	0.0
Limestone and gypsum	2.3	-1.6	-13.3	4.1	-16.4	-3.1	-8.7	-7.8	-0.9	0.0
Clays and kaolin	-1.1	-5.8	-19.5	-23.0	-22.9	-27.0	-24.7	-24.2	-0.4	0.0
Sand and gravel	69.8	59.1	27.5	30.3	20.1	20.7	20.2	20.4	-0.5	0.0
Other non-metallic minerals n.e.c	-18.7	-19.4	12.4	0.6	13.4	1.0	0.8	0.9	-0.1	0.0
Fossil energy carriers	**-3.2**	**-5.1**	**0.3**	**-1.9**	**2.0**	**1.8**	**1.7**	**3.2**	**-1.9**	**0.0**
Lignite (brown coal)	4.9	0.9	15.9	13.3	20.8	19.8	19.3	20.0	-1.2	0.0
Hard coal	-5.4	-7.3	0.3	-5.7	2.0	2.2	1.9	5.6	-5.3	0.0
Oil shale and tar sands	-3.6	-3.8	-3.6	-3.8	-3.0	-2.9	-2.6	-0.8	-1.8	0.0
Peat	-28.5	-30.3	-21.7	-30.3	-22.3	-17.6	-15.8	-16.5	0.3	0.0
Crude oil, condensate and natural gas liquids (NGL)	-10.5	-12.6	-19.1	-12.8	-19.3	-19.2	-19.0	-18.5	-0.4	0.0
Natural gas	-0.7	0.5	8.1	-2.4	7.8	7.8	8.1	9.7	-1.9	0.0

Eigene Darstellung

There are some few individual raw materials for which reasonable results are obtained at a lower disaggregation level than for the corresponding main raw materials categories. But in many other cases, the resolution requirement is higher for detailed raw material categories. Under the predetermination that all sub-categories of a main raw material category should fall into the quality classes “sufficient”, the disaggregation level of MIOT155 can be regarded as satisfactory for metal ores. For other raw material categories, a disaggregation level of HIOT155 and even HIOT182 is required.

4.1.2 Calculation results for other economies

As already mentioned, two principal approaches are used for investigating country conditions, depending on data availability:

- Direct approach at the example of the European Union (EU).
- Simulation approach for the other selected economies

The results which are presented in Figure 4 are based on the direct approach by comparing the results between Germany and the EU at the level of main raw material categories.

Figure 2 Degree of accuracy of RME of exports by disaggregation approach and main raw material categories for Germany and EU, measured as differences to reference approach HIOT 182 in %

light blue	0 Reference value
green	1 Accurate: absolute deviation from the reference value not more than 3%
yellow	2 Sufficient: absolute deviation from the reference value more 3% up to 5%
orange	3 Insufficient: absolute deviation from the reference value more than 5% up to 10%
magenta	4 Highly insufficient: absolute deviation from the reference value more than 10%

	MIOT 64	MIOT 66	MIOT 74	MIOT 83	MIOT 124	MIOT 155	MIOT 182	HIOT 155	HIOT 182
Germany									
Total primary raw materials	-1,2	-0,1	-2,4	-0,7	1,2	2,4	3,0	-0,7	0,0
Biomass	-8,9	-9,4	-11,6	-11,7	-3,9	-0,8	-0,8	-0,2	0,0
Metal ores	-16,9	-8,4	-8,1	-2,0	-2,4	0,7	0,8	-0,1	0,0
Non-metallic minerals	32,5	25,4	8,8	3,9	9,4	8,2	8,4	-0,3	0,0
Fossil energy carriers	-3,2	-5,1	0,3	-1,9	2,0	1,8	1,7	3,2	0,0
European Union									
Total primary raw materials	10,9	30,2	-6,4	-1,9	-3,2	-3,2	-2,1	-1,1	0,0
Biomass	11,3	8,6	2,1	2,4	2,2	1,8	2,3	-0,4	0,0
Metal ores	-31,6	-18,8	-18,8	-3,9	-3,7	-1,9	-0,3	-1,5	0,0
Non-metallic minerals	115,7	190,1	43,6	39,0	35,8	32,9	31,9	1,3	0,0
Fossil energy carriers	-10,3	-11,1	-26,9	-26,4	-28,1	-28,2	-26,1	-2,4	0,0

Eigene Darstellung

The results for the EU show a pattern which is partly similar to the outcome for Germany. But generally, the disaggregation requirements tend to be higher than for Germany, except for biomass.

Under EU-conditions, low-level options are not suitable for total primary raw materials. The results gradually improve with the level of disaggregation. Also, for **metal ores** the requirement for getting accurate results is higher than for Germany. With respect to **non-metallic minerals** and **fossil energy carriers,** a high difference between monetary and hybrid approaches can be observed. That is, only option HIOT155 is able to offer accurate results.

Figure 5 presents the results of the indirect approach for main raw material categories. For the purpose of this comparison, MIOT182 had to be used as reference approach, as the simulation approach is not able to provide results for hybrid options which are comparable to monetary options (see Section 2.4). The results of the table indicate that the disaggregation requirement is in many cases higher than under German conditions.

Figure 3 Degree of accuracy of RME of exports by disaggregation approach by main raw material categories and countries measures as differences to reference value MIOT 182 in %

(light blue)	0 Reference value
(green)	1 Accurate: absolute deviation from the reference value not more than 3%
(yellow)	2 Sufficient: absolute deviation from the reference value more 3% up to 5%
(orange)	3 Insufficient: absolute deviation from the reference value more than 5% up to 10%
(magenta)	4 Highly insufficient: absolute deviation from the reference value more than 10%

	MIOT 64	MIOT 66	MIOT 74	MIOT 83	MIOT 124	MIOT 155	MIOT 182
National exports produced under the assumption of German production technology							
Germany							
Total primary raw materials	-4,1	-3,0	-5,2	-3,5	-1,7	-0,5	0,0
Biomass	-8,1	-8,6	-10,9	-11,0	-3,1	0,0	0,0
Metal ores	-17,5	-9,1	-8,8	-2,7	-3,2	-0,1	0,0
Non-metallic minerals	22,2	15,7	0,4	-4,2	0,9	-0,2	0,0
Fossil energy carriers	-6,1	-8,0	-2,7	-1,2	-1,4	-1,4	0,0
China							
Total primary raw materials	-2,2	4,1	6,4	5,0	3,2	-0,5	0,0
Biomass	-16,2	-16,8	-7,3	-7,3	-1,6	0,6	0,0
Metal ores	-9,7	0,6	13,7	13,7	12,6	-0,3	0,0
Non-metallic minerals	11,3	19,9	8,4	2,9	1,1	-0,1	0,0
Fossil energy carriers	-1,6	2,4	4,7	5,3	-1,0	-1,5	0,0
United States							
Total primary raw materials	3,3	0,4	0,0	2,8	-1,2	-0,4	0,0
Biomass	-7,9	-8,0	-6,0	-6,0	-2,1	0,0	0,0
Metal ores	-22,9	-15,8	-12,8	-0,8	-1,9	-0,1	0,0
Non-metallic minerals	54,3	22,7	11,3	7,9	0,4	-0,3	0,0
Fossil energy carriers	3,6	7,4	9,1	8,9	-0,9	-0,9	0,0
Japan							
Total primary raw materials	-1,9	2,9	-3,7	-1,4	-1,8	-0,7	0,0
Biomass	1,7	-1,1	-5,9	-6,1	-3,3	0,4	0,0
Metal ores	-24,8	-11,9	-10,4	-2,6	-2,8	0,0	0,0
Non-metallic minerals	39,1	22,0	5,5	-2,2	1,7	-0,5	0,0
Fossil energy carriers	9,0	17,4	2,4	2,5	-2,3	-0,2	0,0
Australia							
Total primary raw materials	3,5	-9,1	-2,9	2,7	-0,4	-0,1	0,0
Biomass	2,9	-1,8	-10,5	-10,6	-2,4	0,0	0,0
Metal ores	-31,0	-9,9	-9,5	0,3	-0,2	0,0	0,0
Non-metallic minerals	324,6	16,6	-7,2	-10,4	-2,4	-0,5	0,0
Fossil energy carriers	-0,5	-12,5	12,4	11,9	-0,2	-0,2	0,0

Brazil							
Total primary raw materials	10,6	14,5	1,2	2,7	-1,7	-0,4	0,0
Biomass	-6,5	-9,9	-10,6	-10,6	-2,8	-0,2	0,0
Metal ores	-46,0	-2,1	-3,2	0,1	-1,2	0,0	0,0
Non-metallic minerals	397,1	119,0	74,4	66,8	-1,1	-1,7	0,0
Fossil energy carriers	96,9	77,7	0,9	1,2	-2,4	-2,1	0,0
Russia							
Total primary raw materials	42,4	8,5	3,7	3,5	-2,2	-0,3	0,0
Biomass	59,2	61,1	-4,5	-4,6	-2,7	-0,9	0,0
Metal ores	2,7	-6,9	-7,6	-7,0	-9,4	-0,4	0,0
Non-metallic minerals	484,4	72,8	-6,5	-10,1	-7,5	-0,2	0,0
Fossil energy carriers	6,4	3,4	7,2	7,2	-0,3	-0,3	0,0

Eigene Darstellung

As explained above, we have to look for the 'east common denominator'. In case the disaggregation requirement is higher for a country under review than for Germany, we have to opt for the higher disaggregation variant (see Section 2.4). Having that in mind, the results suggest that only the disaggregation levels HIOT155 or HIOT182 comply with the criterion 'least common denominator'[15].

4.2 Disaggregation methods

For the purpose of establishing the EU RME model by 182 sector, a disaggregation approach had to be developed for subdividing the existing IOT for the EU by 64 product groups to the level of 182 sectors.

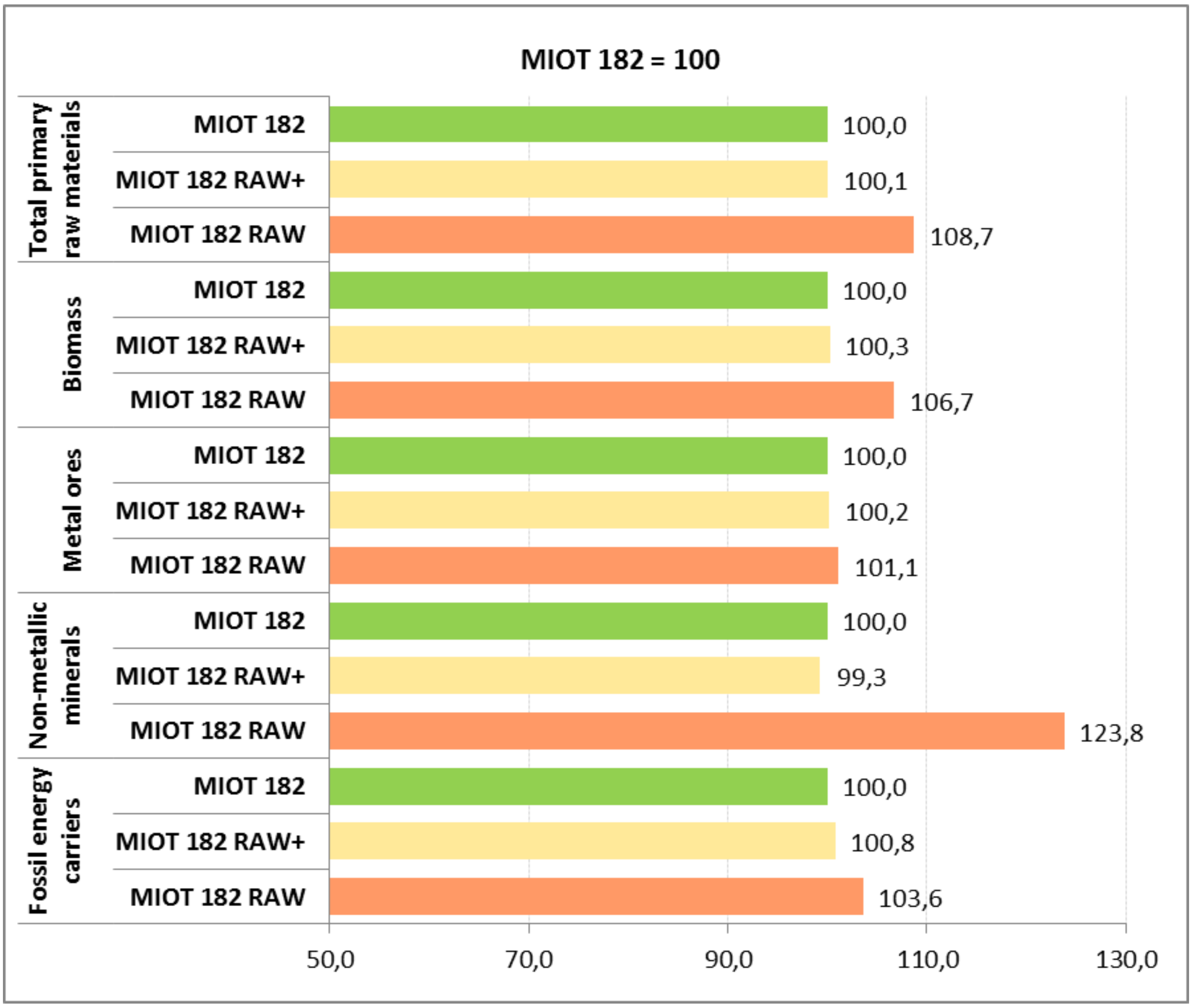
The disaggregation approaches which are discussed below are based on the experiences which were gained in the course of that project. The following methods are tested (for a more detailed description see Section 2.4):

- MIOT182: The option represents the full disaggregation approach which was applied for the EU model.
- MIOT182 RAW: The simplified option uses the interim raw values (step one) of the method for the full approach.
- MIOT182 RAW+: The option is a mixed approach. The full approach of MIOT182 is applied for raw products only. For all other product groups, the simplified method of MIOT182 RAW is used.

[15] The corresponding results for detailed raw material categories have been calculated as well, but those results are not shown for reasons of space and for lack of relevance. As expected, the disaggregation requirements tend to be higher than for main categories if the focus is put on more detailed raw material categories.

Figure 6 compares the calculation results which are obtained from the three different methods for disaggregation.

Figure 4 RME of exports by main raw material categories, European Union 2010 - Comparison of the results from regular MIOT 182 method and from the simplified approaches MIOT 182 RAW+ and MIOT 182 RAW



Eigene Darstellung

Significant deviations between the simplified approach MIOT182 RAW and the full approach MIOT182 can be observed for non-metallic minerals, biomass and total primary raw materials. But, those discrepancies mostly disappear if option MIOT182 RAW+ is used with an elaborate approach for raw products. It should be mentioned that world wide data availability for estimating output values for raw products - at least in physical units – is rather good due to different world-wide databases on Domestic Extraction (especially non-metallic minerals), FAO (products of agriculture, forestry and fishery), Energy Balances (energy carriers), USGS and BGS (metals).

As a preliminary conclusion, it can be stated that the above results for the EU indicate that a considerable portion of the gain expected from a higher level of disaggregation might get lost if the chosen disaggregation procedure is too simple, but the mixed approach seems to provide fairly accurate results. However, for arriving at a final conclusion, the issue of the quality of disaggregation approaches needs further investigation by trying out further options and by looking at other countries as well.

5 Summary and conclusions

Starting point of this investigation was the issue of improving the already existing the multi-regional OECD-ICIO database for the purpose of estimating raw material equivalents of product flows by increasing the level of sectoral disaggregation of the model.

For determining an appropriate disaggregation level for the MRIO model, the effect of different disaggregation options on the quality of the calculation results of the model was tested at the example of a single country model for Germany (2010).

The reviewed disaggregation levels range between 64 and 182 product groups for pure monetary models. Hybrid models (mixed monetary and physical sales structures) are tested at the resolution level 155 and 182 sectors for a 'single country model'. Further, a so-called use extension was examined.

In case of a single country model, the effect on the accuracy of the calculation result can only be measured indirectly by looking at the variable RME of exports. The rationale for an indirect approach is as follows: An MRIO model can in principle only generate accurate results for an individual country on the condition that the RME of exports of at least the major countries of origin of the imports are correct. The required degree of disaggregation for the selected single country therefore only denotes a necessary condition for providing accurate results on the RME of exports. The sufficient condition is only satisfied if the RME of exports is correct for all or at least for all major countries of origin. That is, the degree of disaggregation has to be high enough for ensuring correct results for the exports of all countries which contribute a significant share of world exports.

For exploring the sufficient condition, the investigation of the single country model Germany was supplemented by examining the effect of disaggregation for the European Union, China, the United States, Japan, Brazil, Russia and Australia.

Major features of the model for Germany are conceptually almost fully identical with the EU RME model. Therefore, in case of the EU it was possible to reproduce almost exactly the calculations for the single country model for Germany with corresponding data from the single country model EU. For the other selected countries, models and data which are comparable with the German approach are not, or at least not easily, available. Instead, a simulation method was applied. As far as possible, the disaggregation variants of the German model were run through with the original exports vectors of China, the United States, Japan, Australia, Brazil and Russia. For those simulation approaches, German production technology is assumed implicitly. Therefore, the approach is limited to testing the isolated effect of differences in export structure.

As far as the focus is only put on four main raw material categories, the calculation results for Germany show the following results:

- For biomass, the approaches with a low resolution indicate a considerable underreporting by around 10 percent. Only the results which are based on a resolution level by 155 product groups (detailed disaggregation of extraction as well as of primary processing) are sufficiently accurate.
- For metal ores, a disaggregation by 83 product groups (moderate disaggregation of extraction and primary processing) turned out to be satisfactory in the case of Germany.
- The results for non-metallic minerals show a rather clear pattern. Approaches with low resolution heavily overstate the RME content. The results improve with increasing disaggregation level. Only the hybrid approaches with a breakdown by 155 or 182 product groups, however, render accurate results for Germany.
- With respect to fossil energy carriers, almost all options provide accurate results with the exception of the very low resolution by 64 or 66 sectors.

The so-called use extension approach belongs to the category of low or medium resolution approaches. The investigation shows that the option is not able to provide sufficiently accurate results.

If the analytical purpose calls for accurate results at the more detailed breakdown by 51 individual raw material categories, the required level of disaggregation has to be increased considerably. For metal ores, a purely monetary model by 155 sectors is sufficient. For other raw material categories, a hybrid model in a breakdown by 155 or 182 product groups is needed.

For the EU, results were checked only for main raw material categories. For metal ores, the requirement for getting accurate results is higher than for Germany. With respect to non-metallic minerals and fossil energy carriers, a high difference between monetary and hybrid approaches for the EU can be observed. That is, only hybrid options with a disaggregation level by 155 sectors are able to offer accurate results.

The results of the simulation approaches for other countries indicate that the disaggregation requirement is higher than under German conditions.

To conclude, in case the disaggregation requirement is higher for a country under review than for Germany, we have to opt for the higher disaggregation variant (necessary condition). Having that in mind, the results suggest that only hybrid disaggregation levels in a breakdown by 155 or 182 product groups are able to offer accurate results.

Beyond the question of the required disaggregation level, which is the main focus of this paper, the question was explored how to estimate the required high-resolution IOTs. After deciding which disaggregation level is needed, methods have to be developed for disaggregating the country IOTs from the OECD-ICIO database to the pre-defined disaggregation level. The issue is only shortly explored in this paper by referring to the experiences which were gained when establishing the disaggregated EU RME model.

On the basis of the disaggregation method which was applied for establishing the EU model and by using data from that model, three approaches were tested: a full approach which follows the disaggregation method for the EU model, a strongly simplified and a mixed approach which applies the full approach for raw products and the simplified method for all other products groups.

The results of the examples indicate that a considerable portion of the gain which is expected by using a higher level of disaggregation might get lost if the chosen disaggregation procedure is too simple. But the mixed approach which uses a sophisticated method for raw products seems to provide fairly accurate results, at least for the example under investigation.

For **future work**, it was proposed to develop a high-resolution MRIO model by combining the OECD database with the EU RME model. A number of options for a regional resolution of that model were considered. A pragmatic approach for developing a regionally disaggregated model could be to follow a step-wise approach which may start with a low regional resolution.

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Annexes

Table 3 MIOT64: Product classification for the Eurostat IOT

01	Products of agriculture, hunting and related services
02	Products of forestry, logging and related services
03	Fish and other fishing products; aquaculture products; support services to fishing
CPA_B	Mining and quarrying
10, 11, 12	Food products, beverages and tobacco products
13, 14, 15	Textiles, wearing apparel and leather products
16	Wood and of products of wood and cork, except furniture; articles of straw and plaiting
17	Paper and paper products
18	Printing and recording services
19	Coke and refined petroleum products
20	Chemicals and chemical products
21	Basic pharmaceutical products and pharmaceutical preparations
22	Rubber and plastics products
23	Other non-metallic mineral products
24	Basic metals
25	Fabricated metal products, except machinery and equipment
26	Computer, electronic and optical products
27	Electrical equipment
28	Machinery and equipment nec
29	Motor vehicles, trailers and semi-trailers
30	Other transport equipment
31, 32	Furniture; other manufactured goods
33	Repair and installation services of machinery and equipment
35	Electricity, gas, steam and air-conditioning
36	Natural water; water treatment and supply services
37, 38, 39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services
41, 42, 43	Construction and construction works
45	Wholesale and retail trade and repair services of motor vehicles and motorcycles
46	Wholesale trade services, except of motor vehicles and motorcycles
47	Retail trade services, except of motor vehicles and motorcycles
49	Land transport services and transport services via pipelines
50	Water transport services

51	Air transport services
52	Warehousing and support services for transportation
53	Postal and courier services
55, 56	Accomodation and food services
58	Publishing services
59, 60	Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services
61	Telecommunications services
62, 63	Computer programming, consultancy and related services; information services
64	Financial services, except insurance and pension funding
65	Insurance, reinsurance and pension funding services, except compulsory social security
66	Services auxiliary to financial services and insurance services
68	Real estate services
69, 70	Legal and accounting services; services of head offices; management consulting services
71	Architectural and engineering services; technical testing and analysis services
72	Scientific research and development services
73	Advertising and market research services
74, 75	Other professional, scientific and technical services; veterinary services
77	Rental and leasing services
78	Employment services
79	Travel agency, tour operator and other reservation services and related services
80, 81, 82	Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services
84	Public administration and defence services; compulsory social security services
85	Education services
86	Human health services
87, 88	Social work services
90, 91, 92	Creative, arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services
93	Sporting services and amusement and recreation services
94	Services furnished by membership organisations
95	Repair services of computers and personal and household goods
96	Other personal services
97, 98	Services of households as employers; undifferentiated goods and services produced by households for own use

Table 4 MIOT182: Product classification for the Eurostat RME model

CPA2008

01.11.1-4, 01.12	Cereals
01.11.6, 01.13 (excl. 01.13.5, 01.13.7)	Green leguminous vegetables, vegetables and melons (excl. edible roots and tubers and sugar beet)
01.11.7	Dried leguminous vegetables
01.11.8, 01.11.9, 01.26.1	Soya beans, groundnuts and cotton seed, other oil seeds
01.13.5	Edible roots and tubers with high starch or inulin conten
01.13.7, 01.14	Sugar beet and sugar beet seed, sugar cane
01.15	Unmanufactured tobacco
01.16	Fibre crops
01.19.1, 01.11.5	Forage crops, incl. grazed biomass
01.2 (excl 01.25.3, 01.26.1, 01.27, 01.28. 10.29)	Fruits
01.19.2, 01.19.3, 01.25.3, 01.27, 01.28, 01.29, 01.3	Other crop products
01.41.1, 01.42	Dairy cattle, liv,e other cattle and buffaloes, live and their semen
01.41.2	Raw milk from dairy cattle
01.46	Swine, live
1.43, 01.44, 01.45, 01.49	Other animals and animal products, incl. hunting and trapping and related services
01.47.1	Poultry, live
01.47.2	Eggs, in shell, fresh
01.9	Farm manure and other agricultural waste products
01.6	Agricultural and animal husbandry services (except veterinary services)
02	Products of forestry, logging and related services
03	Fish and other fishing products; aquaculture products; support services to fishing
05.1	Hard coal
05.2	Lignite
06.10.1	Petroleum oils and oils obtained from bituminous minerals, crude
06.10.2	Bituminous or oil shale and tar sands
06.2	Natural gas, liquefied or in gaseous state
07.1	Iron ores
07.21	Uranium and thorium ores
07.29.11	Copper ores and concentrates
07.29.12	Nickel ores and concentrates
07.29.13	Aluminium ores and concentrates
07.29.14.a	Gold
07.29.14.b	Silver
07.29.14.c	Platinum MG
07.29.15.a	Lead
07.29.15.b	Zinc
07.29.15.c	Tin

07.29.19.a	Tungsten ores and concentrates
07.29.19.b	Tantalum ores and concentrates
07.29.19.c	Magnesium ores and concentrates
07.29.19.d	Titanium ores (Ilmenite) and concentrates
07.29.19.e	Manganese ores and concentrates
07.29.19.f	Chromium ores and concentrates
07.29.19.g	Other ores and concentrates
08.11.1	Ornamental or building stone
08.11.2	Limestone and gypsum
08.11.3	Chalk and uncalcined dolomite
08.11.4	Slate
08.12.1, excl 08.12.13	Gravel and sand, excl. mixtures of slag and similar industrial waste products, whether or not incorporating pebbles, gravel, shingle and flint for construction use
08.12.13	Mixtures of slag and similar industrial waste products, whether or not incorporating pebbles, gravel, shingle and flint for construction use - recycling
08.12.2	Clays and kaolin
08.91	Chemical and fertiliser minerals
08.92	Peat
08.93	Salt and pure sodium chloride; sea water
08.99	Other mining and quarrying products nec
09	Mining support services
10.1	Preserved meat and meat products
10.2	Processed and preserved fish, crustaceans and molluscs
10.3	Processed and preserved fruit and vegetables
10.4	Vegetable and animal oils and fats
10.5	Dairy products
10.6	Grain mill products, starches and starch products
10.7, 10.8	Other food products
10.91	Prepared feeds for farm animals
10.92	Prepared pet foods
11	Beverages
12	Tobacco products
13	Textiles
14	Wearing apparel
15	Leather and related products
16	Wood and of products of wood and cork, except furniture; articles of straw and plaiting
17.1	Pulp, paper and paperboard
17.2	Articles of paper and paperboard
18	Printing and recording services
19.1	Coke oven products
19.2	Refined petroleum products
20.1, (exc.l 20.15, 20.16)	Basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in excl. fertilisers and nitrogen compounds, excl. plastics in primary forms
20.15	Fertilisers and nitrogen compounds
20.16	Plastics in primary forms

20.2	Pesticides and other agrochemical products
20.3	Paints, varnishes and similar coatings, printing ink and mastics
20.4	Soap and detergents, cleaning and polishing preparations, perfumes and toilet
20.5	Other chemical products
20.6	Man-made fibres
21	Basic pharmaceutical products and pharmaceutical preparations
22.1	Rubber products
22.2	Plastic products
23.1	Glass and glass products
23.2	Refractory products
23.3	Clay building materials
23.4	Other porcelain and ceramic products
23.5	Cement, lime and plaster
23.6	Articles of concrete, cement and plaster
23.7	Cut, shaped and finished stone
23.9	Other non-metallic mineral products
24.1-3	Basic iron and steel and ferro-alloys
24.41.1, 24.41.4, 24.41.5, 24.41.9	Silver, unwrought or in semi-manufactured forms, or in powder form
24.41.2	Gold, unwrought or in semi-manufactured forms, or in powder form
24.41.3	Platinum, unwrought or in semi-manufactured forms, or in powder form
24.42	Aluminium
24.43.11, 24.43.21, 24.43.9	Lead
24.43.12, 24.43.22, 24.43.23	Zinc
24.43.13, 24.43.24	Tin
24.44	Copper
24.45.1, 24.45.2, 24.45.9	Nickel, unwrought; intermediate products of nickel metallurgy
24.45.3.a	Tungsten products
24.45.3.b	Tantalum products
24.45.3.c	Magnesium products
24.45.3.d	Titanium products
24.45.3.e	Manganese products
24.45.3.f	Chromium products
24.45.3.g	Other non-ferrous metal products
24.46	Processed nuclear fuel
24.51	Casting services of iron
24.52	Casting services of steel
24.53	Casting services of light metals
24.54	Casting services of other non-ferrous metals
25.1	Structural metal products
25.2	Tanks, reservoirs and containers of metal
25.3	Steam generators, except central heating hot water boilers
25.5	Forging, pressing, stamping and roll-forming services of metal; powder metallurgy
25.6	Treatment and coating services of metals; machining

25.7	Cutlery, tools and general hardware
25.4, 25.9	Other fabricated metal products, incl weapons and ammunition
26	Computer, electronic and optical products
27	Electrical equipment
28	Machinery and equipment nec
29	Motor vehicles, trailers and semi-trailers
30.1	Ships and boats
30.2	Railway locomotives and rolling stock
30.3	Air and spacecraft and related machinery
30.4, 30.9	Transport equipment nec, incl military fighting vehicles
31	Furniture
32.1	Jewellery, bijouterie and related articles
32.2	Musical instruments
32.3	Sports goods
32.4	Games and toys
32.5	Medical and dental instruments and supplies
32.9	Manufactured goods nec
33	Repair and installation services of machinery and equipment
35.1	Electricity, transmission and distribution services
35.2	Manufactured gas; distribution services of gaseous fuels through mains
35.3	Steam and air conditioning supply services
36	Natural water; water treatment and supply services
37, 38, 39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services
41, 42, 43	Construction and construction works
45	Wholesale and retail trade and repair services of motor vehicles and motorcycles
46	Wholesale trade services, except of motor vehicles and motorcycles
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64	Financial services, except insurance and pension funding
65	Insurance, reinsurance and pension funding services, except compulsory social security
66	Services auxiliary to financial services and insurance services
68	Real estate services
69, 70	Legal and accounting services; services of head offices; management consulting services

71	Architectural and engineering services; technical testing and analysis services
72	Scientific research and development services
73	Advertising and market research services
74, 75	Other professional, scientific and technical services; veterinary services
77	Rental and leasing services
78	Employment services
79	Travel agency, tour operator and other reservation services and related services
80, 81, 82	Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services
84	Public administration and defence services; compulsory social security services
85	Education services
86	Human health services
87, 88	Social work services
90, 91, 92	Creative, arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services
93	Sporting services and amusement and recreation services
94	Services furnished by membership organisations
95	Repair services of computers and personal and household goods
96	Other personal services
97, 98	Services of households as employers; undifferentiated goods and services produced by households for own use

Table 5 Classification of primary raw materials for the Eurostat RME model

MF111	Cereals
MF112	Roots, tubers
MF113	Sugar crops
MF114	Pulses
MF115	Nuts
MF116	Oil bearing crops
MF117	Vegetables
MF118	Fruits
MF119	Fibres
MF1110	Other crops n.e.c.
MF1211	Straw
MF1212	Other crop residues (sugar and fodder beet leaves, other)
MF122	Fodder crops (incl. biomass harvest from grassland)
MF131	Timber (Industrial roundwood)
MF132	Wood fuel and other extraction
MF141	Fish catch
MF142	All other aquatic animals and plants
MF143	Hunting and gathering
MF21	Iron
MF221	Copper

MF222	Nickel
MF223	Lead
MF224	Zinc
MF225	Tin
MF2261	Gold
MF2262	Silver
MF2262	Platinum and other precious metal ores
MF227	Bauxite and other aluminium
MF228	Uranium and thorium
MF2291	Tungsten
MF2292	Tantalum
MF2293	Mangnesium
MF2294	Titanium
MF2295	Manganese
MF2296	Chromium
MF2297	Other non-metal ores n.e.c.
MF31	Marble, granite, sandstone, porphyry, basalt, other ornamental or building stone (excluding slate)
MF32	Chalk and dolomite
MF33	Slate
MF34	Chemical and fertilizer minerals
MF35	Salt
MF36	Limestone and gypsum
MF37	Clays and kaolin
MF38	Sand and gravel
MF39	Other non-metallic minerals n.e.c
MF411	Lignite (brown coal)
MF412	Hard coal
MF413	Oil shale and tar sands
MF414	Peat
MF421	Crude oil, condensate and natural gas liquids (NGL)
MF422	Natural gas