Disaggregating input-output tables for the calculation of raw material footprints — Minimum requirements, possible methods, data sources and a proposed method for Eurostat

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Executive summary

Domestic material consumption (DMC) and material footprint (MF) economy-wide material flow indicators have been suggested to monitor the Sustainable Development Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all, and Goal 12: Ensure sustainable consumption and production patterns. While the DMC indicator is well-established and regularly quantified for many countries, the material footprint indicator is subject to scientific estimates and has not been institutionalised yet.

Environmentally extended multi-regional input-output analysis is currently the most promising way of estimating the material footprint of countries and regions on a global level, as it provides consistent results (the material footprint of all countries sums up to the material extraction of all countries). In input-output analysis, all existing products and economic activities are grouped into a limited number of product groups and economic sectors, which are assumed to be homogenous, i.e. they are assumed to be produced with an identical structure of inputs and to be sold with identical sales structures. The inhomogeneity of the product groups and economic sectors is responsible for the aggregation error which is therefore inherent to input-output calculations.

The intention is to estimate the material footprint using an official multi-regional input-output datasets, which are currently limited to FIGARO([1]) (developed by the EU) and OECD ICIO (developed by OECD). The OECD ICIO covers the entire world in a multi-regional framework, distinguishing 64 countries and regions. FIGARO covers just the EU countries and the USA. The most important drawback of those datasets is their coarse product/sector resolution, which results in high aggregation error for the estimated material flow indicators.

The goal of this document is to provide guidance on the use of the FIGARO multi-regional input-output dataset for estimation and in-depth analysis of the material footprint and other economy-wide material flow indicators in raw material equivalents (RME), such as RMI (raw material input) and RME of imports and exports for the European Union and its individual countries. The aim of this guidance is to minimize the aggregation error.

Aggregation error of the footprint indicators is a complex phenomenon as it propagates through the input-output calculation, which contains a matrix inversion. Therefore, the general way of its estimation is a test calculation within the aggregated system and a comparison with results derived within the more disaggregated system.

This report first reviews existing studies focused on aggregation error and disaggregation methods. Then it presents results from our test calculations of the aggregation error based on the current Eurostat RME model which is used for the calculation of the EU material footprint. The Eurostat RME model is highly disaggregated with a focus on the products and economic activities most relevant for the material footprint and applies physical units for selected product groups.

We show that monetary models are not able to provide sufficiently accurate results even at the full disaggregation level. Therefore, we propose to use a **hybrid unit model** (monetary sales structures for selected products are replaced by physical sales structures).

The precision level was defined as the deviation of the RME results from the reference approach HIOT182 (hybrid input-output table by 182 product groups). The relationship between precision and the level of disaggregation was checked by applying the model for Denmark, Germany and EU. It turned out that the minimum level of disaggregation is rather depending on the analytical purpose. If exclusively **economy-wide RME indicators** are needed and if a precision level of 2-3 % is considered to be sufficient, the HIOT117 could be applied as the minimum disaggregation option. In case a **breakdown by detailed raw material categories** is needed, the HIOT134 can be considered as minimum level, if an accuracy threshold of 5 % is accepted. But if **results by product groups** are required, the investigation results are suggesting that only option HIOT155 would be sufficient.

Based on our own investigations and the review of existing disaggregation methods we provide a suggestion on how FIGARO can be disaggregated and we review the adequate data sources. Considering the disaggregation costs as a function of the disaggregation level**, we recommend disaggregating the FIGARO dataset to 182 product groups**, which is the full level of detail of the Eurostat RME model. This recommendation is based on the fact that the costs of disaggregating FIGARO from a certain level on (which is way below the minimum disaggregation requirements) are almost constant and independent of the

([1]) https://ec.europa.eu/eurostat/web/experimental-statistics/figaro disaggregation level up to the recommended detail. This applies particularly for the EU, as consistent data are easily available in the required detail.

The question arises how the rest of the world outside the EU should be modelled. We discuss three possible alternatives and recommend supplementing the FIGARO model by a regionally aggregated IOT representing the rest of the world. Its product resolution may differ from the disaggregated FIGARO classification and it should be determined by data availability. We further review the potential data sources.

Lastly, we discuss the feasibility of implementing the disaggregation process within Eurostat. We conclude that, in general, it should be feasible, but we recommend rather outsourcing this process to an external partner. However, we foresee a problem of data gaps for confidentiality reasons. Organisational and methodical solutions have to be developed for assuring a high-quality standard for gap filling.

1 Introduction

Economy-wide material flow indicators have been suggested to monitor the Sustainable Development Goals, particularly Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all, and Goal 12: Ensure sustainable consumption and production patterns. While the DMC indicator is well-established and regularly quantified for many countries, the material footprint indicator is subject to scientific estimates and has not been institutionalised yet.

The goal of this document is to provide guidance on the use of the FIGARO([2]) multi-regional input-output table (MRIOT) in connection with the OECD ICIO MRIOT([3]) for estimating the material footprint (RMC, raw material consumption) indicator for the European Union and to provide recommendations for the further development of an institutionalised global MRIOT with linked material flows. This institutionalised MRIOT is among others foreseen to be used for the quantification of economy-wide indicators in raw material equivalents (RME), such as RMC, RMI (raw material input), and RME of imports and exports, which will enable a detailed analysis of the material footprint (RMC) indicator. The most important drawback of the existing FIGARO and OECD ICIO is a much lower product resolution in comparison to the product detail of the Eurostat RME model. Comparison of the product detail is provided in Table 1.

Table 1: Overview of the largest differences in sector / product detail between Eurostat RME model and FIGARO

	Number of sectors	
	Eurostat RME model	FIGARO MRIO
Total	182	64
Agriculture	19	1
Mining	35	1
Food and beverages	11	1
Chemical products	8	1
Basic metals and fabricated metal products	29	2
Furniture and other manufactured goods	7	1
Electricity, natural gas, etc.	3	1

Input-output analysis assumes that all products within one group are identical with respect to the production inputs and sales structure and equal to the average of the product group. As this is not generally the case, the results of input-output analysis are related to an aggregation error. This error is high for an estimate of the material footprint if highly inhomogeneous products with different direct or upstream material requirements and different sales structures are aggregated into one group. The aggregation errors can then either propagate through production chains and influence the material footprint of other products and final consumers or cancel out each other. In order to arrive at reliable results, the aggregation error should be limited and disaggregation should be preferred to aggregation.

([2]) https://ec.europa.eu/eurostat/web/experimental-statistics/figaro

([3]) http://www.oecd.org/sti/ind/inter-country-input-output-tables.htm

The content of this document is determined by the terms of reference for the Eurostat project, Task 4, which require:

1. Recommendations for minimum disaggregation of multi-country input-output tables with a specific focus on material footprints
   - Which economic activities need to be disaggregated; mining, basic products
   - How many and which subcategories would be needed
2. Proposal for a disaggregation method (or perhaps methods that differentiate by economic activities). If you come across other disaggregation methods in the literature, mention them and explain why you are not proposing that method.
3. Potential adequate data sources.
4. Assessment of the feasibility of implementing the disaggregation routine for Eurostat, possibly in coordination with the OECD.
5. Discussion of options (proposal of methods, investigate data sources, assess feasibility for Eurostat) to model non-EU material supply in case the multi-country input-output database excludes non-EU economies (or the disaggregation is too coarse).

This report is structured to correspond with these terms of reference. In the first section we focus on the minimum disaggregation requirement. First, we briefly review existing literature on aggregation error and disaggregation methods, which justify the need for specialized testing of the aggregation error based on the current Eurostat RME model (we call this “aggregation testing” throughout the whole report). Second, we present the results of our testing procedure of the aggregation error and suggest the minimum disaggregation requirements. Furthermore, we consider the costs related to disaggregation in our recommendation for the disaggregation level. Therefore, we end up with two clasifications, one as the minimum disaggregation and the second one as the recommended disaggregation.

In the second section, we provide a recommendation on the disaggregation approach for EU inter-country input-output model FIGARO. This is followed by a section on the potential adequate data sources. The fourth section is focused on the discussion of options for modelling of the non-EU rest of the world. The last section is provides the assessment of the feasibility of implementing the disaggregation routine by Eurostat. This section is placed after the discussion of option to model non-EU supply chains, in contrast to the terms of reference, as it comprises also modelling of non-EU countries. Lastly, we provide an outlook on the modelling the substitution of primary raw materials.

1.1 The complexity of aggregation error

Aggregation error is inherent to input-output. Products and economic sectors are grouped and these groups are assumed to be homogenous. However, since there are differences between the individual products aggregated within one product group (and the same for economic sectors), the results of input-output analysis suffer from the aggregation error. Aggregation error of the RMC, RMI, RME of exports and RME of imports is a complex phenomenon, which results from aggregating products with different input and sales structures into one product group. If just one – either input structure or sales structure – is similar, the aggregation error is low even if the other one differs much.

For example, assume electricity from different sources has exactly the same sales structure. In such a case, disaggregation of these sources does not change the results of any RME indicator mentioned above, even though, the electricity sector aggregates coal, hydro power and other power plants with largely different RME requirements. On the other hand, assume that electricity distribution services have different sales structures than electricity. Since the distribution services also have a different input structure, their disaggregation would in general change the RME indicators (ignoring some special mathematical cases in which not). The role of the sales structure makes it difficult to identify the product groups that need to be disaggregated.

Furthermore, the size of the aggregation error for RME indicators also depends on the volume of the aggregated product and its disaggregation leads to changes in RME of the rest of the product group. The effect of aggregation of one product group propagates through the supply chains and results in a change of RME of other product groups as well. For example, assume all primary crops are processed before exported to other countries and assume they have very different RME requirements and different sales structures. Their disaggregation will influence RME of exports, but that will be manifested as a change of RME of exported products different from the primary crops (it is assumed that these are not exported).

Another hypothetical example – assume that domestic final demand has the same share as exports for each product group. Then the resulting split of RMI between RMC and RME of exports will be always correct irrespective of the aggregation. If one product is different, it is important to disaggregate this product, but also the products in its supply chain, which contribute to its RME. Therefore, to summarise, it is easy to identify products with different input structure, but it is difficult to predict the effect of their disaggregation for RME indicators.

Due to its high level of product detail, the Eurostat RME model provides a basis for finding the suitable aggregation level of the multi-regional input-output model, which may replace the Eurostat model in the future. However, it is important to note, that even though the Eurostat RME model has a considerably high product detail it also suffers from the aggregation error and therefore does not provide fully accurate results. In some cases, physical units are applied to minimize the aggregation error, but as stated above, the aggregation error is inherent to any nation-wide input-output analysis.

1.2 Literature review on aggregation error

De Koning et al. (2015) provide a detailed analysis of the effect of spatial, product and material aggregation of Exiobase on the national material footprint (equivalent to the RMC indicator). Their product aggregation scenario is closely related to the purpose of this document, as the Exiobase product classification of 200 product groups is close to the product resolution of the Eurostat RME model. They aggregate this resolution to the level of 60 product groups of NACE rev1. Across EU countries the effect of this aggregation ranges from -4% for Romania up to 14% for Belgium. On a product level, the highest differences are reported for agriculture and other mining and quarrying products. They also show the effect of regional aggregation (2% for aggregating 48 Exiobase regions to 4 regions, in which EU is one single region). Since all the results presented in the paper are relative, it is not possible to calculate the overall effect of product aggregation on the RMC indicator of the EU. However, since the product aggregation reveals a positive difference for all EU countries except for Romania, it can be expected that it would increase EU RMC more than 2%, indicating that the product detail is more important for the RMC indicator of the EU than the regional resolution.

Piñero et al. (2015) focused on material flows for Finland. Based on the Finish Envimat 2010 model, distinguishing 230 product groups and 147 national industries for the year 2010 with LCA data for imported goods, they show how aggregation affects the results for material footprint of all final demand categories. Aggregating from 147 sectors to 64 sectors of the NACE rev2 classification increases the RME of exports of domestic materials by 28% but reduces them by 10% for imported materials with the resulting total effect of about 3%. This implies that RMC has not changed much due to this aggregation, even though the total change for private consumption is about 18% for the same aggregation step, but compensated by the change in investments and public consumption. The differences on a product level are higher. They compared the aggregation error for materials with emissions and concluded that aggregation of extractive sectors causes a stronger bias on the material flow indicators than the greenhouse gas emissions. They also show that the NACE rev2 classification is related to higher aggregation error than the older NACE rev1 classification due to the aggregation of three separate mining sectors into one.

Bouwmeester and Oosterhaven (2013) showed that aggregating Exiobase from 129 to 59 EU sectors implies significant errors for water use on a sector level. However, the effect is much smaller on the country level, with high variation across countries ranging from 1% for UK up to 79% for Turkey, but for the majority of countries the difference is below 20%.

In general, sector aggregation has been studied by other researchers as well. However, all other identified papers focused solely on greenhouse gases (Su, Huang et al. 2010; Majeau-Bettez, Strømman et al. 2011; Marin, Mazzanti et al. 2012; Steen-Olsen, Owen et al. 2014).

Overall, the articles point out that the product aggregation error is country and product specific and that higher aggregation errors can be expected on more detailed levels, such as in a breakdown of RMC by origin of materials (domestic extraction versus imports), final use categories (households, government, investments, etc.), material categories (biomass, metal ores, construction materials, etc.), and product groups, as the input-output framework does not change the total material input, it just allocates it to different users via different products and supply chains. None of the articles found focuses specifically on the Eurostat RME model 182 product classification. Moreover, de Koning et al. show the aggregation error based on the Exiobase product classification to 60 products in NACE rev1, but Piñero et al. (2015) show that aggregating to 64 products of the NACE rev2 classification gives even higher aggregation errors than the 60 products of the NACE rev1 classification used by de Koning et al. Therefore, in comparison to de Koning et al., there are two important steps where aggregation error can increase when aggregating the Eurostat RME model 182 product classification to the 64 NACE rev2 classification: (a) aggregating to the Exiobase classification and (b) the conversion from NACE rev1 to NACE rev2.

In 2018, the consortium partners IFEU and Karl Schoer developed a very similar analysis (Schoer, Dittrich et al. 2018) for UBA (Germany) within the project DeteRess(4). The aim of the document was to answer the following 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 of their report)
- What method could be applied for estimating a detailed sectoral disaggregation of country IOTs (Sections 2.4 and 3.2 of their report)
- Which principal approach and what level of regional resolution could be envisaged for a high-resolution MRIO model?

The results of the analysis are reflected in the discussion (Section 2.6) on the suggested aggregation level.

1.3 Literature review on disaggregation methods

Disaggregation means that at least one sector or product group is disaggregated into one or more sectors or product groups (Figure 1.). In the symmetric input-output system this means that both a row and a column of the input-output table have to be split into at least two rows/columns. Lenzen (2011) argues that disaggregation should be preferred over aggregation even if very limited data can be utilized and encourages disaggregation in order to increase the accuracy of input-output coefficients applied in environmental analysis.

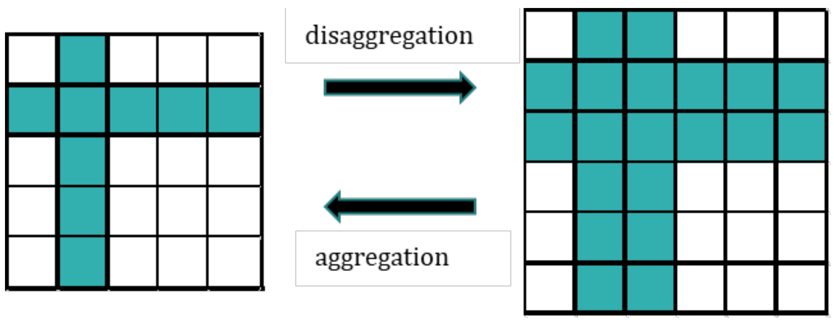

Figure 1: Disaggregation and aggregation in the symmetric input-output Framework

Source: Created by Authors.

Disaggregation is usually applied beyond the level of the directly underlying statistical data for the compilation of the intermediate consumption and final demand of the input-output table. Therefore, additional data have to be collected and utilised. Often, data from different sources are not consistent and their exact combination is impossible. Furthermore, the system on the more detailed level can be under or over determined by the additional data. Therefore, the problem of disaggregation changes into two problems: (a) first to collect the available data to provide a solid base to the disaggregation procedure and (b) to combine all the collected data in a meaningful way.

(4) https://www.ifeu.de/projekt/deteress/

The data that is usually collected and applied:

- Aggregated input-output table
- More disaggregated total outputs and inputs and imports and exports in monetary terms.
- Data from energy statistics, agricultural statistics, production statistics, international trade, etc. on physical data
- Estimate of the economic structure – a prior estimate of the disaggregated input-output table
- In order to end up with a balanced system, it is required to keep column totals equal to row totals and to keep the values of the initial aggregated IOT implicitly, in other words when aggregating the disaggregated table back to the initial table.

All those data points can have a different priority and uncertainty. For example, it is usually required to reach exactly the aggregated table by aggregating the disaggregated table. However, this can be the only hard constraint as all others can contradict each other and eventually also this one.

During the review we identified the following studies as major contributions to the disaggregation problem:

- Schoer et al. (2012): provide a good overview on the disaggregation technique and data applied within this Eurostat RME project during the development of the Eurostat RME model, which is specifically designed for the calculation of raw material equivalents. They base the disaggregation of the input-output table directly on the structure of the German disaggregated input-output table which is based on very detailed supply and use tables (nearly 3000 product groups). According to the documentation individual cells are disaggregated directly applying the German structure of the disaggregated cells. This provides an initial estimate of the disaggregated input-output table that is then balanced in RAS-type approach, to reach full consistency of total input, total output and the original aggregated values.
- Wood et al. (2014): provide a good description of the data utilised and some input on the disaggregation technique applied within the Exiopol project. They base the disaggregation on an initial estimate derived from estimates of total output and input technological coefficients. Total outputs are based on more detail data available directly within statistical information, export values and physical production combined with prices. The input technological coefficients are derived using input-output tables disaggregated to the required level of detail (e.g. for Canada, Japan, the US, and mainly Australia). The advantage of applying input technological coefficients for the initial estimate is that it is able to reflect differences in the structure of the economy in terms of the volume of individual economic sectors. Further, they apply linear programming and optimization for balancing and matching the original aggregated values at the same time.
- Vendries Algarin et al. (2015) describe the disaggregation of the electricity sector for the US into 6 sectors. They term disaggregation as “allocation”, due to the fact that the original aggregated values are allocated to the disaggregated cells. They use manual disaggregation, where data is available and the so called “default allocations” elsewhere. The manual allocations are applied on selected inputs only and they are particularly useful for the disaggregation of sectors with extremely different inputs, such as different electricity generation technologies (e.g. coal is consumed only in coal power plants within the electricity sector, while nuclear fuel is consumed by nuclear power plants, etc.). For such inputs it is possible to assume that they are consumed only by one of the disaggregated sectors. They further discuss the role of price homogeneity.
- Lenzen et al. (2013) do not deal directly with disaggregation within the development of Eora multi-regional input-output database, but they deal with a conceptually similar problem of updating and estimating input-output tables in the MRIO framework based on available data. They base the estimate of the rest of the world on input-output table of Australia, Japan and the US.
- Wenz et al. (2015) present a general algorithm which combines multiple data in a disaggregation of a multi-regional input-output table. They note that a disaggregation is a modelling of which the results deviate from the real values which are unknown. This highlights the uncertainty of the resulting disaggregated table and any indicators based on it. However, that applies for the Eurostat RME model as well. The algorithm they suggest is based on a hierarchy of proxies. While their approach is similar to Wood et al. (2014), it is described in more detail and including specific equations.

- The DeteRess report (Schoer, Dittrich et al. 2018) presents the method and the results of an investigation for testing the effect of using a simplified approach in comparison to the full disaggregation method of the EU model. The following methods were tested:
  - 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 their 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.

Figure 2 compares the calculation results, which are obtained from the three different methods for disaggregation.

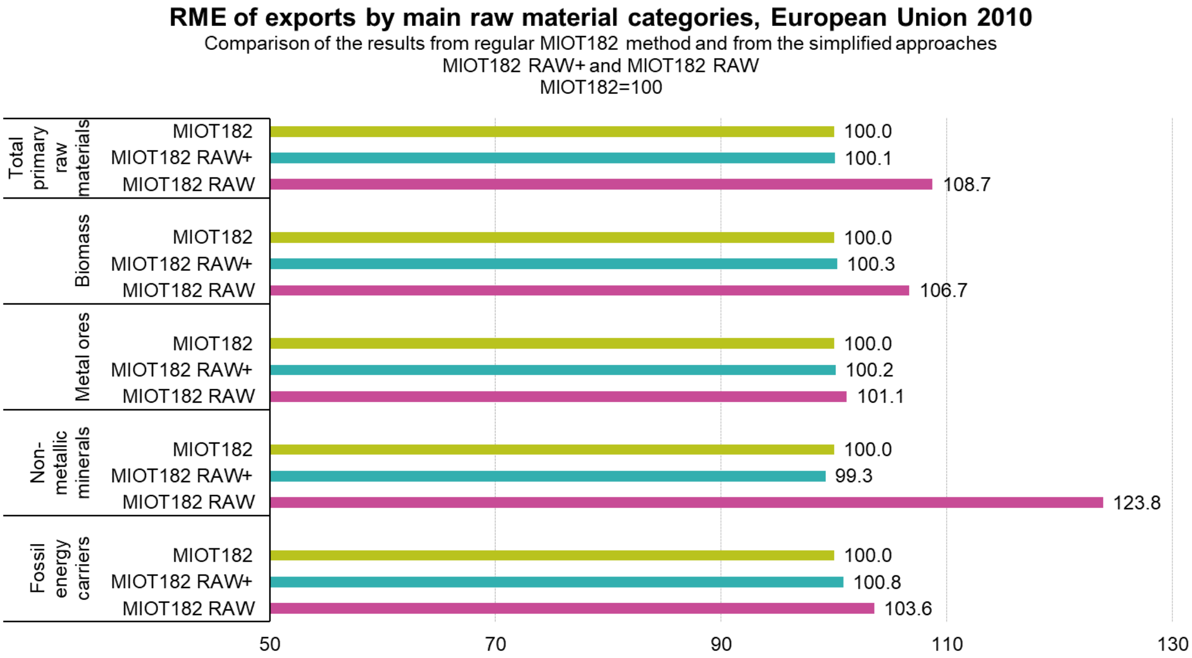

Figure 2: Results of testing the disaggregation procedure,

Source: Authors' calculations.

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.

The results illustrate that getting sufficiently disaggregated data on mining for applying the full approach is the crucial issue, whereas using the simplified approach for some manufacturing branches might have only a comparatively small impact on the accuracy of the RME calculation.

1.4 Specific features of the Eurostat RME model

In comparison to the existing input-output models, the Eurostat RME model has two specific improvements, which may limit direct comparison of the results to other studies. While the number of products does not exceed the number of products distinguished by Exiobase, the product categories are specifically designed for the purpose of calculating the RMC indicator. Therefore, it includes some important disaggregations not found elsewhere.

The second crucial feature of the Eurostat RME model is the application of physical sales structures for selected product groups. For allocation of material requirements to the users, physical sales structures may reduce the aggregation error of specific product groups. For example, if more and less processed materials are combined into one group, the value added to the processed material does not have to be related to an increase in material requirements, but can result in a higher price of the material. Should these materials have different sales structures, the allocation of upstream requirements to the users based on monetary flows will contain the aggregation error, which can be avoided through an application of the physical units. In general, hybridization is serving two purposes: a) physical sales structures can improve the allocation of materials within the economy, and b) the allocation between domestic use and exports can be improved. Point a) is especially relevant for energy carriers. Here, we originally have information in physical terms from the energy balance which most likely provides a much more accurate allocation within the economy than monetary relationships. And the differences are striking in the case of EU, as there are large differences between the results of monetary and hybrid input-output model. Point b) the further effect is that physical sales structures are able to cope with the effect that the composition within a product group can be different for domestic use and exports for specific product groups.

Since most current MRIO datasets are compiled in monetary units, this report has to reflect the role of hybridization as well. The testing of the aggregation error applied for the purpose of this report revealed that replacing the hybrid unit core of the current Eurostat RME model with the purly monetary units cannot reach the required compliance with the original results even in the full disaggregation level. Therefore, the aggregation testing reported in this report is provided for the hybrid unit core.

The third specific feature of the Eurostat model is the adjustment of the RME of extra-EU imports, in order to reflect regional differences in the production technology. Those adjustments are not replicated within the testing procedure reported in the results section. Therefore, the basis for estimating the aggregation error is set to the RME results calculated without those adjustments. This new set of results was derived specifically for testing the aggregation error.

Because of the specificity of the Eurostat RME model, the effect of a product aggregation was tested for EU, Denmark and Germany. The models for Denmark and Germany are conceptually fully identical with the Eurostat RME model. It is important to supplement the calculations with the EU model by some country examples, as the major aim is to find an approach which is suitable for disaggregating the IOTs of individual EU countries. By using three pilot countries, we tried to cope, at least partly, with the effect that the aggregation error can be different due to different production volumes of the disaggregated product groups and different sales structures on a country level. However, that is still no more than an approximation on what is happening in an MRIO model. However, there is no hybrid MRIO with an equivalent product resolution, which could be used for this testing. Eventhough Exiobase provides physical layers and distinguishes more product groups than the Eurostat RME model, it lacks some important disaggregations in material extraction and processing, particularly in the metal industry. Therefore, we use the Eurostat RME model and just list the limitations of this approach. The resulting aggregation errors are discussed in order to decide whether they are acceptable or not.

1.5 Problem setting

The intention of Eurostat is to gain insight into the aggregation error and the need for disaggregation in order to obtain reasonable results for the RME indicators via an MRIO approach. This intention has two levels: a) a global level and b) an EU level. The ultimate goal of the global level is one institutionalized EE-MRIO, managed by an OECD-UNEP-Eurostat network, which would provide consistent RME indicators for most developed countries and with a reasonable quality for the EU, while the ultimate goal for the EU level is to provide RME indicators for the EU and country level results consistent with the EU totals utilizing the FIGARO MRIO dataset.

The current Eurostat RME model provides RME indicators for the EU as one region and the country level results are estimated based on simplified models. The model runs in two loops. The first loop applies an “adapted domestic technology assumption” and is intended for estimating RME of extra EU imports, which are adjusted reflecting important technological differences in the countries of origin of specific imported products, such as energy mix of electricity generation and metal recycling ratios (iron, copper, aluminium). The second loop utilizes the RME of imports together with EU domestic material extraction in the calculation of RMC, RMI and RME of exports.

This double loop approach enables the utilisation of different type of models for RME of extra-EU imports and for the other indicators. The double loop also makes it possible to implement a, FIGARO based MRIO in the second loop for obtaining EU level results, without any effect on the first loop. Therefore, we can differentiate between two different questions:

a. What is the minimum disaggregation level for a global MRIO dataset?

b. What is the minimum disaggregation level for an EU MRIO dataset if RME of extra-EU imports is estimated outside the MRIO approach?

This dichotomy creates additional requirements on our testing approach, as we have to distinguish between those two options: a) the global level – one MRIO will provide all RME indicators in one run and b) the EU level – any model (for example, the current Eurostat RME model) can be used for the calculation of RME of imports and FIGARO based MRIO will be used for the calculation of the other RME indicators.

In the first option, the aggregation error of imports enters the calculation of other indicators, while in the second option the model can be run with RME of imports with the current accuracy and the sector aggregation error can arise only for the other RME indicators. Both options are considered in this report. The more detailed analysis focused on the EU is based on option a), while in order to derive results for Denmark and Germany, option b) was applied. Option a) is based on calculating RME with the domestic technology assumption (DTA). But for smaller countries like Denmark, DTA is not advisable, especially in case of RME accounting, due to the rather specific national economic structure. .

The disaggregation is targeted to the option “a” (global MRIO), with the expectation of better results when imports are calculated in a more appropriate way in option “b”, e.g. through the current Eurostat RME model. In option “a” the aggregation error of RME of imports propagates through the input-output calculations and increases the aggregation error of RMC, RMI and RME of exports. Eventhough this document is mainly targeted on the EU level, the rational for approach “a” is that it is related to higher aggregation errors and it is perceived that the suggested disaggregation in this report may navigate the disaggregation level of the future OECD-UNEP-Eurostat ICIO table

1.6 Cost-benefit considerations

In order to suggest an appropriate disaggregation level, it is important to consider the benefits (in terms of accuracy and analytical usefulness) as well as the costs of disaggregation. The principal relationship between costs and benefits of disaggregation of the model is illustrated schematically by the following Figure 3.

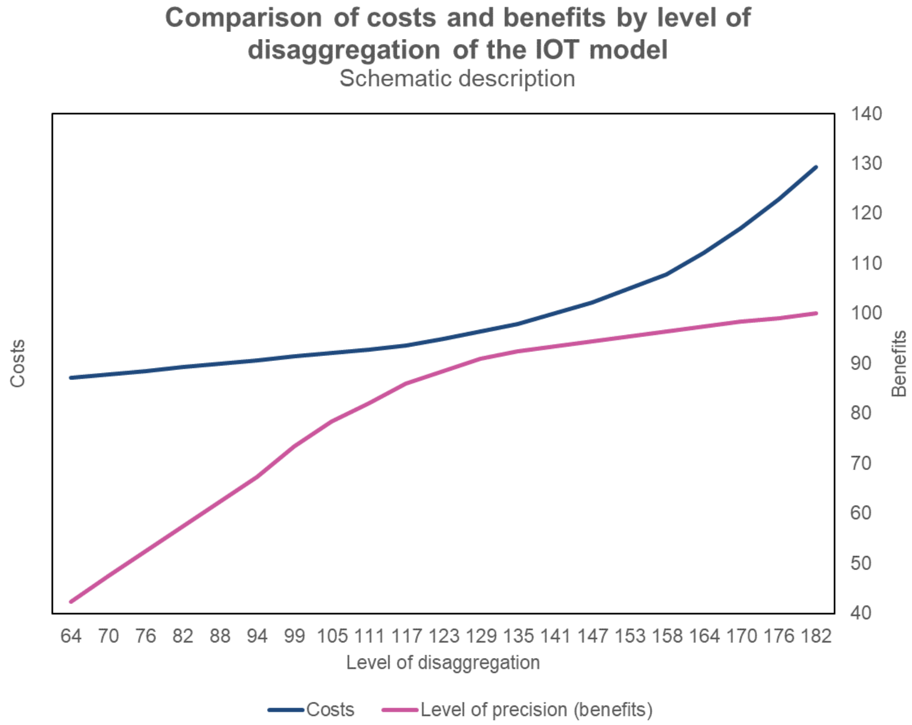

Figure 3: Comparison of costs and benefits by level of disagregation of the IOT model

Source: Authors' illustration.

Levels of disaggregation (horizontal axis): For the purpose of this report disaggregation levels are considered which are ranging between 64 (FIGARO) and 182 sectors.

Benefits (right vertical axis): The benefits can be measured indirectly by looking at the degree of precision. Accuracy is measured in relationship to the maximum disaggregation of 182 sectors and expressed as a percentage. The benefit curve is likely to be convex. That is, the relative degree of improvement tends to decrease with the level of disaggregation.

This type of benefit curve can preferably be established by showing dispersion measures for different levels of analysis: total RME over all raw materials, four main raw materials categories over all raw materials, detailed raw material categories and one or more aggregated measures for the RME by product groups.

A set of benefit curves is derived from our analysis of accuracy by level of disaggregation that is based on methodically identical models for total EU, Germany and Denmark. Those benefit curves are applied as an orientation for assessing the accuracy in relationship to the disaggregation level for intra-EU disaggregation. It might also be assumed that those results are also applicable with respect to disaggregation of non-EU countries.

Costs (left vertical axis): It is rather difficult to measure the costs. In principal the cost for establishing and maintaining the model could be expressed in monetary or other equivalent units like person years. The most important component is the cost for data procurement (collecting, validating and gap filling)in relationships to the level of disaggregation. But also other cost components might be relevant to some extent, like the effort for processing the data (complexity of the model, computing power). It was out of scope of this project to prepare concrete cost calculations for different levels of disaggregation. Therefore, the above cost curve is confined to simply reflecting some principal considerations on the most likely shape without applying a clearly defined unit of measurement.

That costs curve is likely to be of a concave shape. That is, the relative efforts for data procurement and processing are increasing with the level of disaggregation. As far as the data can be extracted easily from a well-established statistical system, cost may increase slowly (or even not at all) with the level of disaggregation of the model. However, costs are likely to increase progressively in case more detailed information can only be obtained by measures like a) applying sophisticated estimation models, b) expanding the degree of detail of existing surveys or c) even establishing new surveys.

Point of optimisation: Ideally the optimum level of resolution should be determined by comparing the curves for costs and benefits in the same unit of measurement (preferably in monetary units). However, in practice it appears to be difficult to establish to the same unit of measurement for both curves. A benefit curve or a set of benefit curves can be estimated by comparing the degree of accuracy of models with different levels of disaggregation. Degree of accuracy is a non-monetary unit of measurement. See Section 2.5. Compared to that, estimating a cost curve is comparatively difficult, if possible at all. That is, we have to look for a pragmatic solution for approximating the optimisation point.

Two options for approximation are considered by this report:

- Minimum level of benefits: In case, we do not have a cost curve, the minimum level of benefits can be used for approximating the optimum solution. The selection of the minimum level of benefits is predominantly depending on the analytical purposes. Determining a minimum level of benefits (precision) is a normative presumption which is based on number of criteria. See Sections 2.2 and 2.5.
- Maximum level of benefits: For that approach, at least the shape of the costs curve has to be known. That solution is regarded to be an option in the specific case of disaggregating the EU-country IOTs. In Section 3.2 it is argued that for EU countries the costs curve is almost remaining constant for a range of levels of resolution under consideration up to the level of 182 sectors (see Figure 10). With that specific shape of the curve the highest possible level of resolution (“maximum level”) along the constant branch of the curve could be selected as an approximation of the optimisation point.

2 Minimum disaggregation requirements

2.1 The target indicator in the tests

One of the aims of expressing material flows in raw material equivalents is to appropriately account for international trade (RME of imports and exports of which the balance is added to domestic extraction to derive the RMC indicator)(5). Testing the disaggregation levels for an MRIO model with a single-country model has some limitations. RMC from a single- country model cannot be a suitable yardstick. First of all, that variable is highly dominated by domestic extraction. For example, for non-metallic minerals there seems to be a systematic tendency that RME of non-metallic minerals are sensitive to changing the resolution level of the model, especially for imports and exports. Therefore, this investigation is primarily targeted on RME of imports and exports.

2.2 Required precision

It is crucial for the testing to decide on the required precision level.

Defining a minimum level of accuracy is basically a normative decision. However, for that decision a number of issues or criteria should be considered:

a. Limited accuracy of the baseline model (reference figures)

b. Analytical purpose

c. Knowledge of benefit curves

d. User expectations

Accuracy of the baseline model: It has to be regarded that the reference figures of the baseline model (182 sectors) are already inaccurate to some extent. That is, no accuracy level might be required which is coming extremely close to a 100% match with the reference figures. But it should also be regarded that errors of the baseline model and the errors from a too relaxed accuracy requirement might accumulate.

Analytical purpose: Results in RME can be used for different analytical purposes and the accuracy requirement may be different by purpose. The principal domains for application are economy wide indicators like RMC for total materials or main material categories. Results by detailed raw materials categories are needed for analysing the consumption of specific raw materials (e.g. scarcity) or for relating specific raw materials and environmental impacts. Results by product groups are able to establish a link between raw material consumption and the economic driving forces which are behind the consumption. That is, if the objective is to understand how changes of the economy-wide indicators can be explained, it is necessary to refer to that link in a detailed manner. That argument is even more relevant, if concrete measures have to be considered to influence resource consumption. An example is the approach of the DeteRess Project of the German Environment Agency where an IOT model by 274 product groups is used for that purpose (s. Dittrich,

(5) Another aim is to express final use and traded products in their raw material requirements.

M. et al. (2018)).

Knowledge of benefit curves: The benefit curves show the degree of accuracy by disaggregation level for the three pilot countries and the different analytical purposes. The empirical accuracy curves should be known before deciding on the minimum accuracy level. Those curves are presented below in Section 2.5.1

User expectations: Policy users need robust statistical data for backing their decisions. Even if they know that modelling results are not able to provide absolute precision, too relaxed accuracy thresholds, e.g. in the order of above 5% or even 10-20%, are not likely to be acceptable.

In order to enable insight into the precision levels for the more detail materials, we provide those results in the attached Excel file. Also, in order to enable a discussion of different required precision level, we provide results for alternative disaggregations in the same Excel file. We applied color-coding (different color emphasises) based on the relative aggregation error.

This can be particularly useful for discussing specific analytical purposes of the RME indicators, such as scarcity of individual materials. Applying different characterisation factors on detailed material categories may result in different materials being important than if just the weight is considered. Therefore, it might be smarter to focus on detailed material categories and aim to reach a reasonable compliance on this level of detail. On the other hand, criticality of materials might be better assessed by other more specialised techniques, such as substance flows analysis or others.

In order to assess the overall precision of individual aggregation levels, we propose to calculate standard deviations for the four main material categories and for the detailed materials and products by using the following formula:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{x_i}{r_i}-1\right)^2}$$

Where N is the number of material categories (4 and 51) and x_i is the result of the aggregated system and r_i is the results of the reference system, i.e. the full hybrid model for each material category i.

Different types of measures to report the accuracy of a product level, which is important for targeting product specific policy instruments, are applied for the detailed analysis for EU-results.

Note that different disaggregation levels can be selected based on the intended application of the RME indicators.

2.3 Utilization of physical use matrices (the physical use extension approach)

An alternative to disaggregation of both rows and columns is the application of physical use matrices as suggested by Ewing et al. (2012) for the calculation of ecological and water footprints within the MRIO framework. Its roots can be found in (Schoer 2006) and (Wiedmann, Minx et al. 2006) for a single country. It has also been further developed by different international institutions (e.g. UNEP 2016). This approach is suitable for commodities for which RME stems mainly from direct material extraction in comparison to upstream processes, such as direct products of agriculture, mining and extraction. Under this framework, extraction of those products is not allocated to the extracting sectors but to the sector of their first use.

Typically, the supply of the material to the country in question in physical units is first split into the use within the country and exports. For this, domestic extraction and physical imports are needed – for raw material indicators in mass units (weight, e.g. tons). The domestic use is then allocated directly to the first using sectors, such as processing or final demand. This option is related to similar data requirements as the full disaggregation and hybridization, but it may benefit from lower requirements on the computing power and even higher breakdown of raw materials, such as agricultural crops.

The detail of the sales structures therefore increases, even though the IO system is not disaggregated. The input structure has a lower effect in this case, as the majority of the RME of those products stems from their actual weight. While the full disaggregation of the IO system increases the overall complexity and it can be limited by the computational power, disaggregating the environmental extension, represented in this case by the material use tables, has almost no limits. Note that Weinzettel et al. (2013) utilized physical use matrices of more than 34 000 rows for the MRIO system of about 6000 x 6000 sectors. While disaggregating the whole MRIO system to the same level of detail would be too demanding on computing capacity, there was no technical problem with this approach.

Under this framework, it could be sufficient to target the disaggregation to the processing sectors, as the most of the primary sectors would be disaggregated through the physical use extensions, i.e. we suggest combining the physical use extension approach with selected disaggregations. E.g. it might be sufficient to represent all agricultural crops in just 1 product group as the use of all individual crops are disaggregated through the use tables. Similarly, metal ores and non-metallic minerals can be presented as two groups of products with additional disaggregation provided through the use matrices. In general, it may apply on all extracting sectors, in which the direct extraction is much higher than the raw material equivalents of the products consumed by the specific industry on intermediate consumption.

Therefore, this approach is included in the testing of suitable aggregation levels as well.

Ewing et al. (2012) argue that this approach improves the precision of the physical use product for international trade, as that is reported in physical units according to trade statistics and not relying on the monetary input-output data. Therefore, from the products supplied to one region by imports and domestic production, first exports are allocated according the external trade data and then the domestic use is allocated according to additional data. In this framework, we applied the most detailed HIOT structural information in order to allocate the extracted materials to their first users. It has to be noted that the data and effort needed for the creation of the physical use matrices is equivalent to the full disaggregation of the IO system.

2.4 Selection of (dis)aggregated classification for testing

The complexity of the aggregation error explained above makes it difficult to identify the “minimum disaggregation level”. Three different ways to identify the reasonable disaggregation level are discussed below together with their pros and cons.

2.4.1 Expert judgement

The first option is an expert judgement. The rationale of the expert judgement is to avoid the complexity of the aggregation error and to utilize expert experience, for example of the consortium that created the detailed EU RME model. Starting from the 182 product detail of the EU RME model, we tested about 8 different disaggregation levels of the FIGARO classification and compared to the original RME results and to the RME results of monetary core (MIOT). The results provided a basis for other disaggregation levels.

2.4.2 Total RME intensity of products

The second option is to utilize the knowledge on the RME intensity of individual detail product groups and compare them to the aggregated version. As the RME of product groups per monetary unit is quantified by the multiplication of the material intensity matrix denoted as F and the Leontief inverse matrix denoted as L, we call this option FL. The problem of this option is that the products with the highest differences in RME intensity do not necessarily contribute the most to the RME indicators (RMC, RMI, RME of imports and RME of exports). The identification of the most different product groups depends on the actual product composition of the respective country. It is tested for the EU, however, individual EU countries can have different product compositions of the aggregated product groups and therefore also different priority detail product groups for disaggregation. Note, that the aggregated product group represents a weighted average of the detailed product groups, of which the relative representation may differ across countries (both EU and non-EU). Furthermore, the effect of the disaggregation based on FL is unpredictable, as it depends also on the total volume, differences in sales structure and the effect on the rest of the aggregated product group, all of which are unknown or not evaluated specifically.

2.4.3 RME of exported and imported products

Some disadvantages of the previous approach are addressed by an approach that compares the RME of exported and imported products under the aggregated and then disaggregated model on the level of disaggregated product groups and detailed material breakdowns. This can help to identify the exported and imported products that lead to the highest differences between the two models. Exports were selected first based on argumentation that exports are the best testing variable for RMI, RMC and RME of imports (Schoer, Dittrich et al. 2018). However, imports were tested as well, as the structure of imported and exported products is different and it is expected that within the MRIO framework also the structure of exports of non-EU countries will be different. However, this approach suffers from the fact that a difference in one product group can be related to disaggregation upstream the supply chain of this product group. However, it is possible to start with disaggregation of products closer to material extraction sectors. This approach can be targeted to arrive at minimum disaggregation requirements based on the current data. However, if individual countries have different composition of the aggregated product groups, different disaggregation can be important. Therefore, this approach should be followed by expert judgment in order to identify aggregations that might be considered relevant to other countries. Also, as stated by Lenzen (2011), disaggregation should be preferred to aggregation, as the IO system can always be aggregated, but disaggregation is difficult.

2.4.4 Final procedure

The disaggregation exercise combined all of the approaches above. First, we selected a couple of disaggregation levels based on expert judgement. We continued by an approach in which the suitable aggregations were suggested based on the results – first just by looking into the differences in materials, and then by looking at the differences in RME of specific exported and imported products, sometimes checking for the RME product intensity. This approach had to be applied with care; it cannot identify the case in which the aggregation error in RME of a product results from aggregation upstream the supply chain. In fact, the important point of disaggregation can be anywhere between the traded product and the processes in its production chain which are responsible for material extraction. Therefore, based on this detailed description of the complexity of disaggregation, the purpose of this task and after a discussion with Eurostat, the expert judgement approach was employed in addition to provide insight into disaggregations that might be overlooked and important for other countries and times. The most important in navigating the disaggregation process were the results for detail materials. For example, gold ores reveal large errors in the case of FIGARO disaggregation level with a considerable impact on the level of broader material categories as well. Therefore, it was disaggregated from the other metal ores. Since this was not sufficient, gold was also disaggrgated from the processed metals, which yields reasonable results for gold ores with only a minor impact on the broader material categories. Similarly most of the other disaggregation requirement were identified and tested, sometimes with the help of a more detail analysis of the RME indicators.

The specific problem related to this approach is that it may provide reasonable results for the current Eurostat RME model, the model for Denmark and the model for Germany, but it may fail when applied to other countries or years with different product composition. However, generalizing the problem to all countries is out of scope of this report. The Deteress report (Schoer 2018) supports our approach, as it provides results for other major non-EU economies, which widely confirmed the results for Germany and the EU.

2.5 Results

The calculation results are presented in two steps. In the first part, summarised results are shown for the three pilot regions EU, Denmark and Germany. In the following section, a more detailed analysis is conducted by only referring to EU-level results.

2.5.1 Summarising results for RME of exports

The Figures below (Figure 4 to Figure 7) present the summarised results on RME of exports for the countries/regions EU, Denmark and Germany for the year 2010. Different levels of disaggregation and the main analytical purposes are covered. The results are presented as benefit curves for the different countries and domains of analysis. Selected disaggregation levels are presented, starting with the FIGARO disaggregation level MIOT64(6), which was included in order to demonstrate how much improvement of accuracy could be achieved by increasing the disaggregation level. Further, three options are regarded which are considered to be probably suitable as a minimum disaggregation degree (HIOT117, HIOT134, HIOT155(7)).

The HIOT182 is regarded as the reference approach, the results of the individual options are, thus, expressed as deviation from the reference results. Standard deviation is applied as a dispersion measure.

We are aware that by presenting the data in that condensed form, a lot of interesting and relevant information may get lost. Therefore, a much more detailed presentation is provided in the following section at the example of the EU model. Notwithstanding, these general results are already useful for drawing major conclusions.

Figure 4 presents the results for total raw materials.

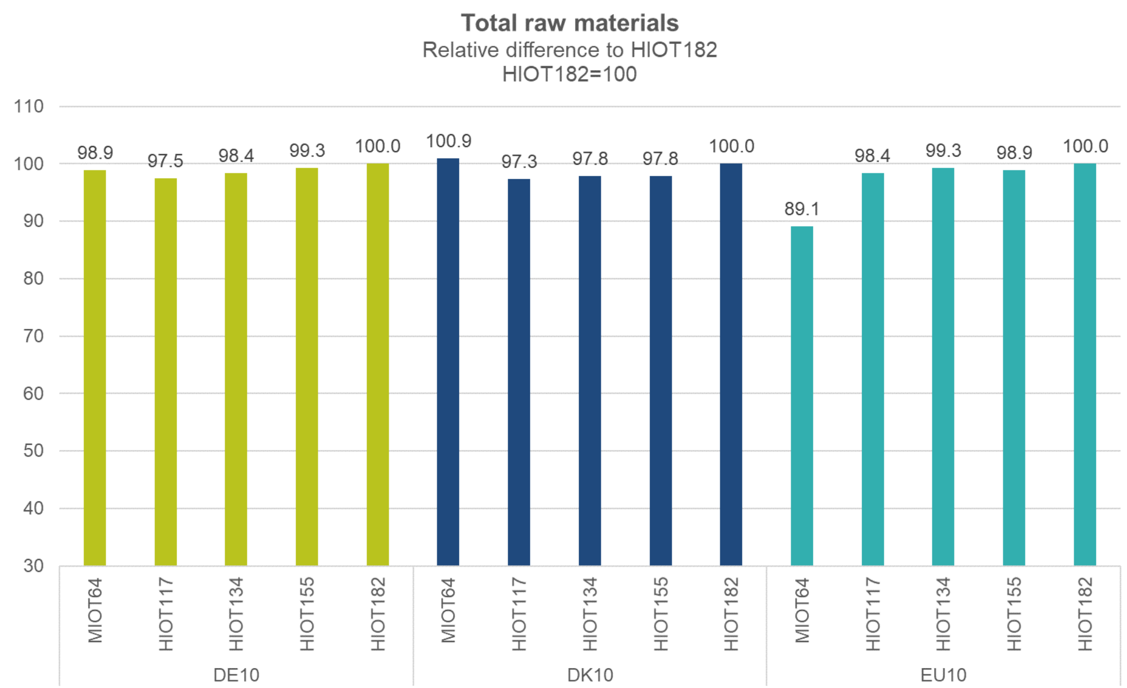

Figure 4: Results of total raw materials

Source: Authors' calculations.

The obtained levels of accuracy are rather high for all options under consideration. The results are looking also rather similar for all three pilot countries. The level tends to increase slightly with the level of disaggregation. If a deviation of up to 3 % from the reference value is considered sufficient, option MIOT117 is already complying. If the required accuracy level is tightened to 2 %, HIOT134 can be regarded as sufficient. However it has to be noted that the rather good match of MIOT64 results with HIOT182 for Germany and Denmark has rather to be regarded as random event, as strong negative and positive deviations at the level of main raw materials categories are counterbalancing each other (see also Figure 5).

Figure 5 is showing the results for the four main raw material categories.

(6) MIOT = monetary input-output table

(7) HIOT = hybrid input-output table

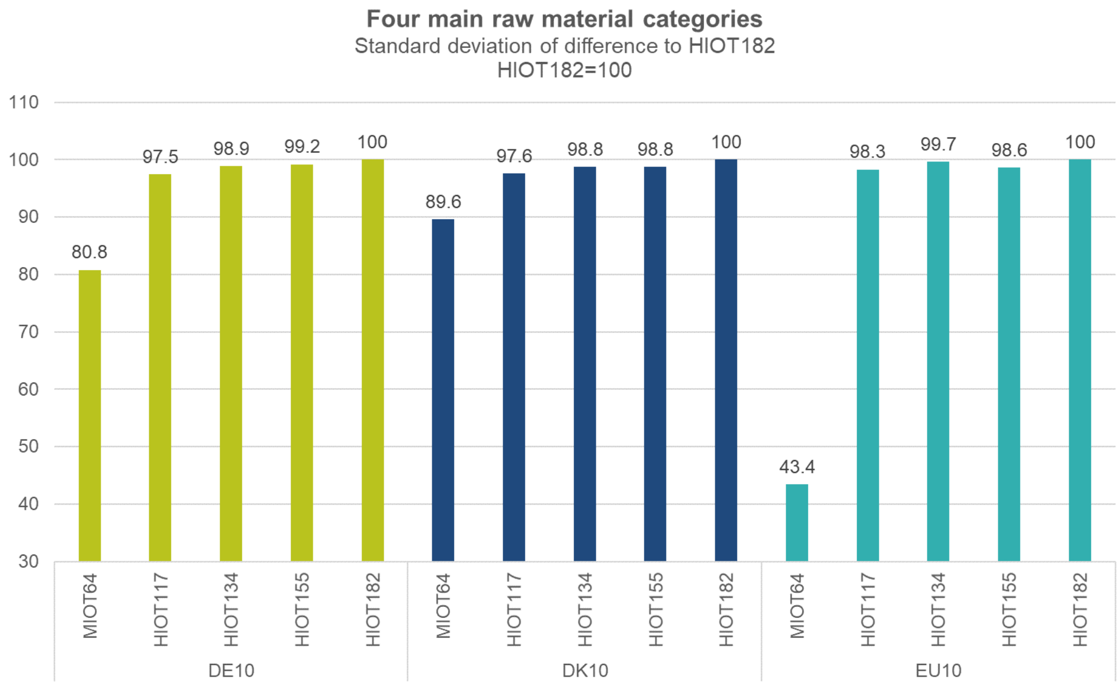

Figure 5: Results for the four main raw material categories

Source: Authors‘ calculations.

The results for four main raw material categories look quite similar to the results for total raw materials, except for the MIOIT64 option. With a threshold of 3 %, as well as 2 % for a minimum level of accuracy, option HIOT117 turns out to be sufficient.

Figure 6 presents the benefit curves for the case that a detailed breakdown by raw material categories is needed.

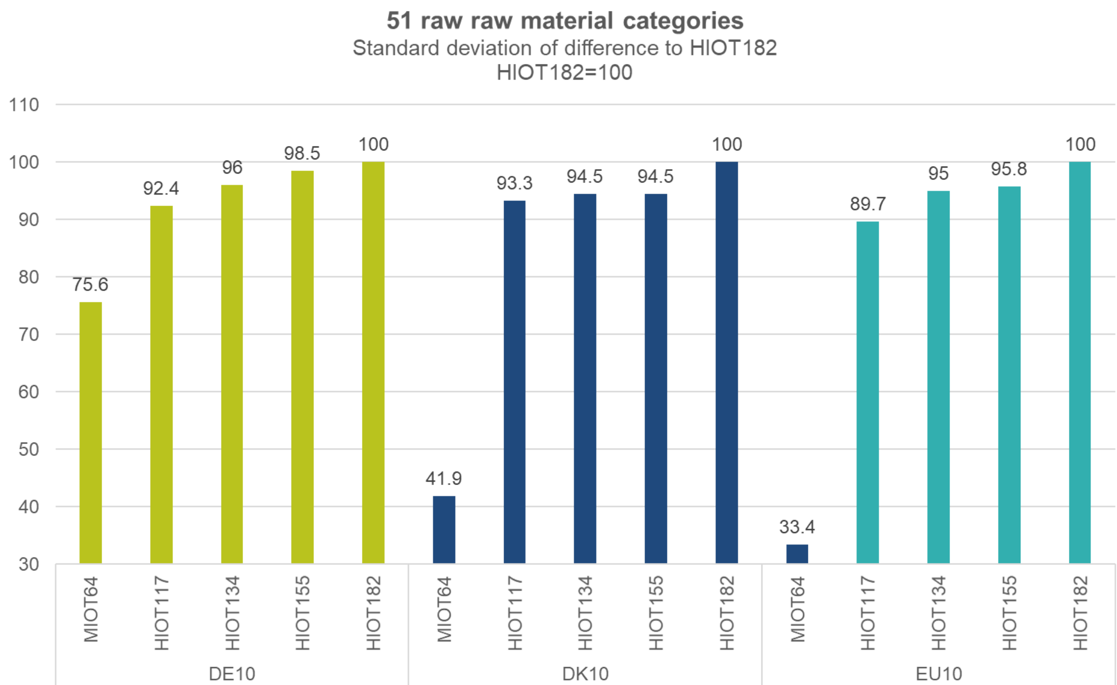

Figure 6: Results of detailed raw material category breakdown

Source: Authors' calculations.

Under a threshold of 3 %, only the accuracy for Germany is satisfactory for option HIOT155. If the threshold is loosened to the level of 5 %, HIOT134 can be regarded as sufficient for all three regions.

Figure 7 shows the benefit curves with respect to a detailed breakdown by 64 product groups.

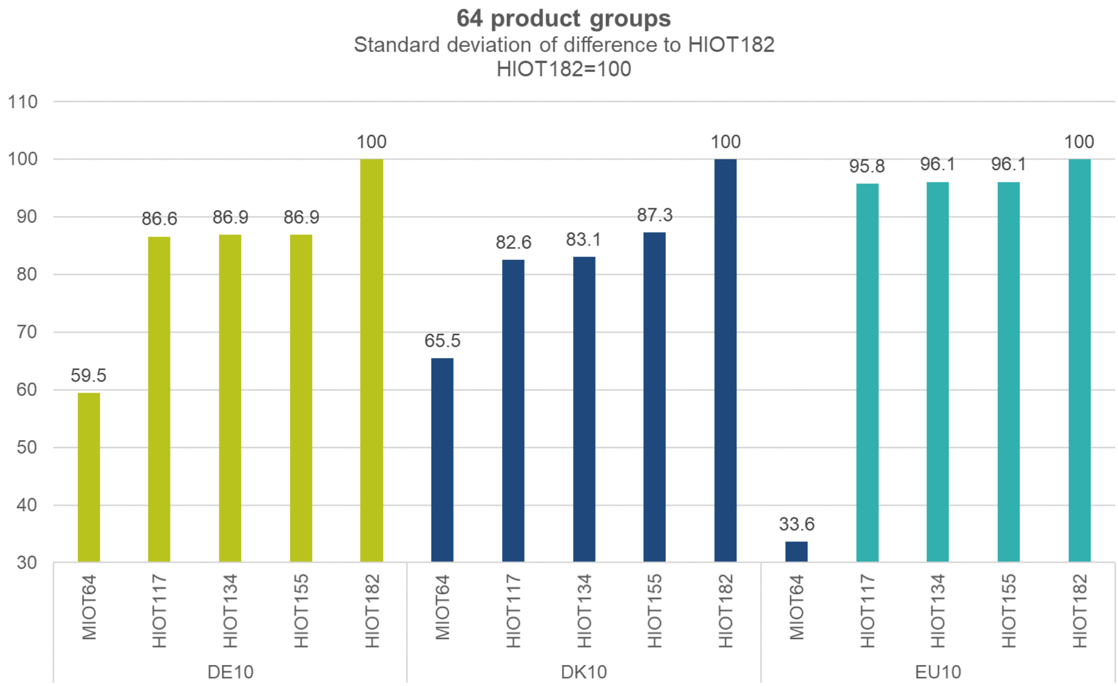

Figure 7: Results of detailed breakdown by 64 product groups

Source: Authors' calculations.

The curves from Figure 7 only regard the results at the level of total raw materials. It has to be noted that for analysis at least the results for product groups in a further breakdown by four main raw material categories might be needed. In special cases, if the focus is on specific raw materials, even a full breakdown by product groups and detailed raw material categories might be required.

For the EU, it appears that all options are complying with a threshold of 4 or 5%. However, for Denmark and Germany the deviations are up to more than 10 %. In addition, it can be expected that the obtained level of accuracy will be even lower, if an additional breakdown by raw materials is required (see below 2.5.3, Table 5).

The results of this section can be summarised as follows: For total raw materials and for main raw material categories the option HIOT117 could be chosen as the minimum level. If a breakdown by detailed raw material categories is needed, HIOT134 can be considered as minimum level, if an accuracy threshold of 5 % is accepted. However, if results by product groups are required, the results suggest that only option HIOT182 would be sufficient.

The results suggest that the choice of the required minimum disaggregation level mainly depends on the required analytical scope. If it is intended to limit the application of the model in order to provide economy-wide indicators, MIOT117 is sufficient. If sufficiently accurate results are required for detailed raw materials, option MIOT134 is suitable, assuming that an accuracy threshold of 5 % is accepted. Yet, if it is intended to use the results for analysing the link between raw material consumption and the economic production and consumption activities (product dimension) a resolution by 182 sectors (HIOT182) would be needed.

2.5.2 Aggregation error for EU total RME indicators

In this section, more detailed results for the EU are presented based on option a) – the aggregation error of RME of imports enters the calculation of the other RME indicators, as already mentioned before (see

Section 1.5).

We tested three different approaches:

1. monetary input-output model (MIOT)
2. hybrid unit input-output model (HIOT)
3. physical use extensions (PU, in monetary and hybrid unit for energy carriers input-output model) (see Section 2.3)

In Table 2 and Table 3, we present selected results of the testing procedure in relative and absolute units. The first column displays the original values of the RME model. However, those results are obtained with the modification of RME of imported products, which cannot be replicated in the testing procedure. Therefore, the second column displays the results of the hybrid model with the full product detail. This is considered as a basis for comparison of the tested aggregations and it is therefore set as 100% for the relative comparison.

It can be seen from the third column (MIOT182) that even the fully disaggregated monetary core cannot reach the required level of accuracy for the main material groups. The most striking error is reported for non-metallic minerals within RME of imports and exports and for fossil energy carriers within RME of exports. Therefore, it does not make sense to test aggregations on the monetary IO core. We only report results for FIGARO (NACE rev.2 (64)) and NACE88 classifications, which yield unacceptably different results, in order to show the size of the expected error.

Therefore, we tested aggregations on the hybrid IO core. We present FIGARO hybrid and NACE88 hybrid disaggregations which is based on the FIGARO NACE rev.2 (64) and NACE88 classifications, but further disaggregate products, which are reported in different units (therefore, they contain already a number of important disaggregations). It can be seen (the cells highlighted in red) that those disaggregation levels do not meet the required precision for several materials and indicators. The most striking are non-metallic minerals within RME of imports and exports.

We present two aggregation levels for the hybrid framework with reasonable aggregation errors: HIOT117 and HIOT134. While HIOT117 can be seen as the minimum disaggregation requirement in order to reach reasonable results for the main material categories, HIOT134 performs satisfactorily on the level of detail material categories (Table 4). As it can be seen in Table 2, disaggregations beyond 95 product groups perform poorly even for the four main material categories.

The last seven columns of the tables are devoted to the concept of physical use extensions. As the data on international trade in physical units was applied for all materials directly extracted from the environment, the results of this approach differ for the full HIOT framework for materials expressed in units, which do not represent weight (column PU HIOT 182). However, as stated earlier, this is in general seen as an improvement, as the international trade is treated directly in mass units and not approximated using other characteristics, such as economic value or energy content. Therefore, the basis for the relative comparison of the physical use approach is set to the results calculated under the physical use extension framework under the HIOT with full product detail (PU HIOT 182) and this represents 100% for the rest of the table.

It can be seen from column PU MIOT 182 that the physical use extension approach improves the performance of the monetary core significantly in comparison to the basic approach. However, since it still yields unacceptable results for fish catch and fossil energy carriers within RME of exports, we decided to represent Fish and other fishing products, Coke oven products, Refined petroleum products, Electricity, transmission and distribution services, and Steam and air conditioning supply services in physical units as in the HIOT framework. This approach is applied in the rest of the table. Representing Fish products in physical units is only important for the detail material category of Fish catch, but has only negligible effect on the biomass material category. We present two classifications which are equivalent to the HIOT classifications. It can be seen that their results are slightly worse. This is due to the fact that the input structures (columns) are not disaggregated.

The complete set of results is provided in Appendix I, including the results for the option in which the aggregation error of RME of imports does not enter the calculation of the other RME indicators (it is assumed to be calculated using a separate model outside the MRIO framework) and the tested classification is applied only in the calculation of RMC, RMI and RME of exports.

Results from the DeteRess project can be seen in the Appendix VI (Figure 11 - 13).

Table 2: Overview of aggregation error for option a) in which the aggregation error of RME of imports enters the calculation of the aggregation error of the other RME indicators (relative results, red color indicates relative deviation higher than 15%, the green columns emphasize classifications with a reasonably good match) (%) *Source*: Authors' calculations.

	RME model	HIOT 182([8])	MIOT 182	FIGARO	NACE 88	HIOT 117	HIOT 134	FIGARO H	NACE 88H	PU HIOT 182	PU MIOT 182*	PU MIOT 182HE*	PU MIOT 73HE*	PU MIOT 90HE*	PU MIOT FIGARO HE*	PU HIOT NACE88 HE*
Imports																
Total	**109.0**	**100.0**	**98.0**	**172.0**	**120.0**	**97.7**	**99.2**	**101.0**	**98.0**	**96.7**	**96.0**	**99.2**	**97.7**	**99.1**	**97.0**	**97.6**
Biomass	101.0	100.0	103.0	143.0	146.0	98.5	99.9	105.0	109.0	100.0	97.0	97.4	98.3	98.8	133.8	136.3
Metal ores	117.0	100.0	99.0	76.0	80.0	96.5	99.1	76.0	80.0	92.2	99.0	99.5	94.6	97.2	78.3	79.3
Non-metallic min.	110.0	100.0	124.0	678.0	263.0	99.0	98.1	109.0	108.0	100.0	99.0	100.3	102.3	101.5	112.1	110.8
Fossil energy carr.	103.0	100.0	90.0	109.0	105.0	98.1	99.4	114.0	106.0	98.3	94.0	98.9	98.4	99.7	99.1	99.7
RMC																
Total	**102.0**	**100.0**	**99.0**	**124.0**	**93.0**	**99.6**	**99.7**	**101.0**	**101.0**	**99.5**	**102.0**	**99.7**	**99.6**	**99.7**	**100.7**	**100.8**
Biomass	100.0	100.0	100.0	106.0	107.0	100.2	100.1	100.0	101.0	100.0	100.0	99.5	100.0	99.8	103.6	104.6
Metal ores	116.0	100.0	100.0	115.0	100.0	98.8	99.0	102.0	99.0	94.9	100.0	99.3	99.4	99.5	102.2	100.2
Non-metallic min.	101.0	100.0	94.0	142.0	69.0	99.3	99.6	99.0	99.0	100.0	100.0	100.0	99.5	99.8	99.3	99.2
Fossil energy carr.	102.0	100.0	107.0	113.0	120.0	99.9	99.9	107.0	105.0	100.0	107.0	99.4	99.5	99.5	99.6	100.1
RMI																
Total	**103.0**	**100.0**	**99.0**	**128.0**	**108.0**	**99.1**	**99.7**	**100.0**	**99.0**	**98.7**	**99.0**	**99.7**	**99.1**	**99.7**	**98.9**	**99.1**
Biomass	100.0	100.0	100.0	106.0	106.0	99.8	100.0	101.0	101.0	100.0	100.0	99.6	99.8	99.8	104.6	105.0
Metal ores	115.0	100.0	99.0	80.0	83.0	97.0	99.2	79.0	83.0	93.4	99.0	99.6	95.5	97.6	81.7	82.4
Non-metallic min.	101.0	100.0	103.0	173.0	121.0	99.9	99.8	101.0	101.0	100.0	100.0	100.0	100.3	100.2	101.5	101.4
Fossil energy carr.	102.0	100.0	93.0	106.0	104.0	98.7	99.6	110.0	105.0	98.8	95.0	99.2	98.9	99.8	99.4	99.8
Exports																
Total	**106.0**	**100.0**	**101.0**	**138.0**	**149.0**	**97.7**	**99.5**	**97.0**	**95.0**	**96.4**	**90.0**	**99.7**	**97.7**	**99.5**	**93.7**	**94.1**
Biomass	100.0	100.0	103.0	103.0	99.0	97.5	99.5	104.0	100.0	100.0	100.0	100.5	98.3	100.2	110.1	106.7
Metal ores	114.0	100.0	99.0	49.0	68.0	95.4	99.5	59.0	69.0	92.0	99.0	99.9	92.0	95.9	63.4	66.6
Non-metallic min.	103.0	100.0	153.0	344.0	402.0	103.0	100.5	113.0	113.0	100.0	98.0	100.3	104.6	102.2	113.9	113.3
Fossil energy carr.	103.0	100.0	68.0	94.0	74.0	96.4	99.0	116.0	103.0	96.5	73.0	98.9	97.6	100.4	98.8	99.2

([8]) This uses physical units and the full product detail, but does not include the adjustments of RME of imports between the two loops.

* those columns have PU HIOT 182 as a 100% reference, therefore, the absolute values differ from HIOT 182 results.

Table 3: Results of the testing procedure in absolute values (the blue color highlights reference results, the green color highlights the classifications with a reasonably good match) *Source*: Authors' calculations.

	RME model	HIOT 182([9])	MIOT 182	FIGARO	NACE 88	HIOT 117	HIOT 134	FIGARO H	NACE 88H	PU HIOT 182	PU MIOT 182*	PU MIOT 182HE	PU MIOT 73HE*	PU MIOT 90HE*	PU MIOT FIGARO HE*	PU HIOT NACE88 HE*
Imports																
Total	**3 879**	**3 574**	**3 517**	**6 133**	**4 272**	**3 493**	**3 546**	**3 595**	**3 511**	**3 456**	**3 328**	**3 427**	**3 377**	**3 424**	**3 353**	**3 374**
Biomass	267	265	272	378	385	261	264	279	288	265	257	258	260	261	354	361
Metal ores	1 358	1 156	1 149	882	920	1 115	1 145	874	922	1 066	1 059	1 061	1 009	1 036	835	845
Non-metallic min.	488	444	551	3 014	1 169	440	436	485	481	444	440	446	455	451	498	492
Fossil energy carr.	1 766	1 710	1 546	1 860	1 797	1 678	1 700	1 956	1 820	1 680	1 572	1 662	1 653	1 676	1 665	1 676
RMC																
Total	**6 965**	**6 800**	**6 724**	**8 440**	**6 313**	**6 774**	**6 783**	**6 896**	**6 863**	**6 769**	**6 875**	**6 747**	**6 744**	**6 750**	**6 814**	**6 824**
Biomass	1 638	1 636	1 634	1 740	1 758	1 640	1 637	1 639	1 659	1 636	1 628	1 627	1 636	1 632	1 695	1 712
Metal ores	725	624	622	717	622	616	618	638	615	592	591	588	589	590	605	593
Non-metallic min.	3 000	2 972	2 790	4 215	2 055	2 951	2 961	2 942	2 939	2 972	2 978	2 972	2 958	2 967	2 950	2 948
Fossil energy carr.	1 602	1 568	1 678	1 768	1 878	1 567	1 567	1 677	1 650	1 569	1 678	1 560	1 562	1 561	1 563	1 571
RMI																
Total	**9 521**	**9 217**	**9 159**	**11 775**	**9 914**	**9 136**	**9 188**	**9 237**	**9 153**	**9 098**	**8 970**	**9 070**	**9 020**	**9 066**	**8 995**	**9 016**
Biomass	1 940	1 937	1 944	2 050	2 058	1 933	1 937	1 952	1 961	1 937	1 929	1 930	1 933	1 934	2 027	2 033
Metal ores	1 550	1 348	1 341	1 074	1 113	1 307	1 338	1 067	1 114	1 258	1 251	1 254	1 201	1 228	1 028	1 037
Non-metallic min.	3 560	3 516	3 623	6 086	4 241	3 512	3 508	3 557	3 552	3 516	3 512	3 518	3 527	3 523	3 570	3 564
Fossil energy carr.	2 472	2 415	2 251	2 565	2 503	2 383	2 406	2 662	2 526	2 386	2 278	2 368	2 359	2 381	2 371	2 381
Exports																
Total	**2 556**	**2 416**	**2 435**	**3 335**	**3 601**	**2 362**	**2 405**	**2 341**	**2 290**	**2 329**	**2 095**	**2 323**	**2 275**	**2 317**	**2 181**	**2192**
Biomass	302	301	311	310	299	294	300	313	301	301	301	304	296	302	332	322
Metal ores	825	724	718	357	491	691	720	429	499	666	660	665	612	638	422	444
Non-metallic min.	560	544	833	1 871	2 186	561	546	615	614	544	534	546	569	556	620	617
Fossil energy carr.	869	847	573	797	624	817	839	985	876	817	599	808	797	820	807	810

* those columns have PU HIOT 182 as a 100% reference, therefore, the absolute values differ from HIOT 182 results.

Table 4: Relative aggregation error for detail material categories (deviations higher than 20% are highlighted by red shading) (%)

([9]) This uses physical units and the full product detail, but does not include the adjustments of RME of imports between the two loops.

Source: Authors' calculations.

Material*		HIOT117				HIOT134				PU MIOT 73HE				PU MIOT 90HE			
		Imports	RMC	RMI	Exports	Imports	RMC	RMI	Exports	Imports	RMC	RMI	Exports	Imports	RMC	RMI	Exports
Biomass	Cereals	128	103	103	104	101	100	100	101	130	104	104	104	103	100	100	101
	Roots, tubers	99	100	100	101	99	100	100	101	120	100	100	107	121	100	101	107
	Sugar crops	121	100	102	111	104	99	100	108	127	101	102	112	110	100	101	109
	Pulses	102	100	100	101	100	100	100	101	103	100	101	101	100	100	100	101
	Nuts	101	100	101	103	100	99	100	103	100	100	100	103	99	99	99	103
	Oil bearing crops	60	84	78	58	100	101	100	97	59	83	78	58	98	100	99	96
	Vegetables	117	100	101	114	95	99	100	108	120	100	101	115	98	99	100	110
	Fruits	102	100	100	104	96	99	99	101	102	100	100	105	97	99	100	102
	Fibres	106	106	102	94	106	106	102	94	106	106	102	94	106	106	102	94
	Other crops n.e.c.	101	100	101	104	100	99	100	104	100	100	100	103	99	99	99	103
	Straw	105	101	100	95	98	100	100	97	113	102	101	96	102	100	100	98
	Other crop resid.	105	101	100	95	98	100	100	97	113	102	101	96	102	100	100	98
	Fodder crops	105	101	100	95	98	100	100	97	113	102	101	96	102	100	100	98
	Timber	101	101	100	98	101	101	100	98	91	98	98	101	91	98	98	101
	Wood fuel	101	101	100	98	101	101	100	98	91	98	98	101	91	98	98	101
	Fish catch	55	84	84	87	100	100	100	100	55	84	84	87	100	100	100	100
	Other aquatic extr.	55	84	84	87	100	100	100	100	55	84	84	87	100	100	100	100
	Hunting and gath.	55	108	91	43	100	100	100	99	57	108	92	43	101	100	100	99
Metal ores	Iron ores	100	100	100	99	100	100	100	100	98	99	98	97	98	99	99	98
	Copper	99	97	99	102	99	97	99	102	101	101	100	100	101	100	101	101
	Nickel	99	102	99	97	99	102	99	97	99	103	99	96	100	103	100	96
	Lead	102	104	101	99	103	103	102	101	114	114	108	100	116	113	109	103
	Zinc	111	112	108	103	112	111	108	105	120	120	113	103	121	119	113	106
	Tin	55	53	55	59	99	100	99	99	57	58	57	56	104	106	104	99
	Gold - gross ore	94	102	95	93	100	101	100	99	94	106	94	91	99	106	99	97
	Silver - gross ore	140	80	114	179	95	102	98	91	149	81	116	181	97	102	99	93
	Pt and other PGM	124	-521	123	91	100	110	100	101	124	-522	123	91	100	111	100	101
	Bauxite	91	93	91	89	94	93	94	95	91	94	92	88	94	94	94	94
	Uranium and thor.	99	100	99	95	99	100	99	97	85	67	85	153	86	67	86	158
	Tungsten	98	99	99	98	100	99	100	101	101	101	101	101	103	101	102	104
	Tantalum	87	95	87	76	88	88	88	88	87	95	87	76	88	88	88	88
	Magnesium	52	50	52	57	102	100	102	106	53	50	53	57	102	100	102	106
	Titanium	88	98	88	77	99	100	99	98	68	80	68	56	72	82	72	62
	Manganese	97	95	97	99	98	97	98	99	94	97	94	91	95	98	95	92
	Chromium	104	119	103	84	100	99	100	100	108	123	105	86	104	103	103	103
	Other metal ores	94	97	94	91	94	96	95	93	92	97	92	85	93	97	93	88

Non-metallic minerals	**Marble, granite, ...**	94	99	99	101	95	99	99	101	98	99	100	103	98	99	100	103
	Chalk and dolom.	95	99	99	99	98	100	100	100	98	99	100	100	101	100	100	102
	Slate	98	100	100	102	98	100	100	102	102	100	100	104	103	100	100	105
	Chemical and fert.	98	90	99	112	96	91	98	109	98	91	99	112	96	91	98	109
	Salt	94	91	98	111	94	93	98	109	94	91	98	111	95	93	98	109
	Limestone and g.	91	99	99	96	96	99	99	99	97	100	100	97	102	100	100	101
	Clays and kaolin	105	100	101	106	101	100	100	100	106	100	101	107	102	100	100	101
	Sand and gravel	104	100	100	106	100	100	100	99	108	100	101	107	104	100	100	101
	Other non-met.	99	100	100	100	99	100	100	99	101	100	100	101	100	100	100	101
Fossil energy materials	**Lignite**	95	100	99	96	97	100	100	98	98	100	100	98	101	100	100	100
	Hard coal	99	99	100	102	99	100	99	99	100	99	100	102	99	100	99	99
	Oil shale and tar s.	95	100	99	95	98	100	100	98	97	100	99	97	100	100	100	100
	Peat	99	98	100	104	98	98	100	103	109	101	102	104	109	102	102	103
	Crude oil, and NGL	98	100	98	96	100	100	100	100	97	100	97	94	99	99	99	98
	Natural gas	99	100	99	95	100	100	100	99	101	99	101	106	102	99	102	110

* Here we provide just a short name for each material. The complete name is provided in Table 12 in the Appendix II.

2.5.3 Product level results

Since policies that aim to reduce RME indicators can be targeted to specific products and economic sectors, we provide an overview of the aggregation errors on the product level in this section In general, the precision of the input-output calculation is much lower on the product level and furthermore considering more detail material breakdown.

In order to assess the accuracy on the product level, it is important to focus on the purpose of the product level results. We foresee several purposes: (a) product specific total material footprint; (b) the material composition of product specific footprints (either the four main material categories or the full detail material breakdown and (c) the material distribution over products on final demand (including exports), as well, this can be targeted on different level of the material detail, i.e. total material footprint, the four main material categories or the detail material breakdown. The purpose determines how the required precision should be assessed. Focusing explicitly on those purposes avoids focusing on accuracy of values, which are of minor importance. We consider that it makes the most sense to focus the product level results on the RMI indicator, as that comprises all products delivered by the respective economy for final demand, irrespective of the destination of consumption.

The accuracy of product specific total material footprints (a) can be assessed through standard deviation of the relative deviation for the total material footprint of products, calculated as:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}\left(\frac{m_i}{r_i}-1\right)^2}{N}}$$

Where i is an index over N products, m_i is the total material footprint of the aggregated system, and r_i is the corresponding result of the disaggregated system aggregated to the same level as the aggregated system. In this approach, the relative accuracy of each product has the same weight. Should the bigger focus be given on products with higher material footprints it is possible to utilize relative standard deviation:

$$\sigma = \frac{1}{\mu}\sqrt{\frac{\sum_{i=1}^{N}\left(m_i - r_i\right)^2}{N}}$$

Where μ is the mean value over all products.

The accuracy of the material composition of product specific footprints can be assessed through standard deviation of

The material composition of product specific footprints (b) can be assessed through standard deviation of the relative material composition over all products:

$$\sigma = \sqrt{\frac{\sum_{i,j=1}^{N,S}\left(\frac{m_{ij}}{M_i}-\frac{r_{ij}}{R_i}\right)^2}{N \cdot S}}$$

Where M is the total product specific material footprint, j is an index over materials, S is the number of detail material categories.

The rational for this approach is that it gives equal weight to each product, but higher weight to materials dominating each product, while lower weight to materials of minor importance for the specific product.

The accuracy of the material distribution over products can be assessed through standard deviation of the material share over products:

$$\sigma = \sqrt{\frac{\sum_{i,j=1}^{N,S}\left(\frac{m_{ij}}{M_i} - \frac{r_{ij}}{R_i}\right)^2}{N \cdot S}}$$

The rational for this approach is that it gives the same weight to each material and higher weights to products with higher relative importance for each material.

We do not design any specific disaggregations for the product level, but we report the results for the disaggregation levels reported earlier in order to show their performance. The results are reported in Table 5.

Table 5: Standard deviations of differences for the product level

	HIOT155	HIOT133	HIOT117
Total RME	**6%**	**10%**	**13%**
Main materials	9%	17%	24%
Detail materials	36%	50%	63%
Material distribution main materials	8%	20%	28%
Material distribution detail materials	32%	54%	127%
Material composition main materials	4%	5%	5%
Material composition detail materials	18%	20%	29%

Source: Authors‘ calculations.

It should be noted that the precision of the Eurostat RME model is most probably also lower on the product level than on the level of total imports, exports and domestic consumption. It is out of scope of this report to analyse that. However, it can be seen that reasonable results are only reached for HIOT155 for the detail material breakdown. Therefore, lower product resolutions should not be used for the analysis of the product level and cannot therefore serve as a basis for product and sector targeted policies, especially in case these are targeted to specific materials.

2.5.4 Regional dimension

In order to test the regional dimension, we disaggregated input-output tables of Germany and Denmark to the level of HIOT182 and performed the calculations according to option b) in which RME of imports are not changed, and therefore the aggregation error of RME of imports does not enter the calculation of the other RME indicators. Therefore, the results are not directly comparable to the detailed results of the EU which are presented in this section (in which the aggregation error of RME of imports influences the aggregation error of the other RME indicators). The reason for this approach is that option a) requires an application of domestic etchnology assumption, which would be highly inappropriate in the case of Denmark. The resulting relative results for RMC and RME of exports in the breakdown by the four main as well as detail material categories are displayed in Table 6.

Table 6: Disaggregation error for Germany and Denmark for selected disaggregations levels (RMC and RME of exports, detail material breakdown, highlighted cells have relative deviation from the reference model higher than 10% for the main material categories and 20% for the detail material categories) (%)

Material*	Germany						Denmark					
	HIOT155		HIOT134		HIOT117		HIOT155		HIOT134		HIOT117	
	RMC	Exports	RMC	Exports	RMC	Exports	RMC	Exports	RMC	Exports	RMC	Exports
Total	101	99	102	98	103	97	101	99	102	97	103	98
Biomass	100	100	102	97	102	96	100	100	102	96	102	97
Metal ores	101	100	103	99	114	97	101	100	103	97	114	99
Non-metallic min.	100	100	101	99	99	102	100	100	101	102	99	99
Fossil energy carr.	102	98	103	97	105	96	102	98	103	96	105	97

Biomass	Cereals	100	100	102	97	102	98	100	100	102	98	102	97
	Roots, tubers	100	100	100	100	100	100	100	100	100	100	100	100
	Sugar crops	100	100	99	102	98	107	100	100	99	107	98	102
	Pulses	100	100	103	92	102	95	100	100	103	95	102	92
	Nuts	100	99	100	100	100	101	100	99	100	101	100	100
	Oil bearing crops	98	102	101	99	120	80	98	102	101	80	120	99
	Vegetables	100	100	100	102	99	106	100	100	100	106	99	102
	Fruits	100	100	99	103	99	106	100	100	99	106	99	103
	Fibres	108	93	108	93	108	93	108	93	108	93	108	93
	Other crops n.e.c.	100	99	101	99	100	100	100	99	101	100	100	99
	Straw	100	100	103	95	102	95	100	100	103	95	102	95
	Other crop resid.	100	100	102	95	102	95	100	100	102	95	102	95
	Fodder crops	100	100	103	94	102	95	100	100	103	95	102	94
	Timber	102	98	102	98	102	98	102	98	102	98	102	98
	Wood fuel	102	98	102	98	102	98	102	98	102	98	102	98
	Fish catch	100	100	100	100	102	97	100	100	100	97	102	100
	Other aquatic extr.	100	100	100	100	102	98	100	100	100	98	102	100
	Hunting and gath.	100	100	99	101	128	70	100	100	99	70	128	101
Metal ores	Iron ores	100	100	100	100	103	99	100	100	100	99	103	100
	Copper	99	101	99	101	99	100	99	101	99	100	99	101
	Nickel	101	100	102	99	103	99	101	100	102	99	103	99
	Lead	102	100	184	83	184	82	102	100	184	82	184	83
	Zinc	98	101	100	100	100	100	98	101	100	100	100	100
	Tin	102	99	104	98	119	93	102	99	104	93	119	98
	Gold - gross ore	97	100	99	100	-30	93	97	100	99	93	-30	100
	Silver - gross ore	104	99	103	99	6	117	104	99	103	117	6	99
	Pt and other PGM	89	99	90	99	208	106	89	99	90	106	208	99
	Bauxite	99	100	98	101	99	100	99	100	98	100	99	101
	Uranium and thor.	100	100	101	99	102	99	100	100	101	99	102	99
	Tungsten	99	100	98	101	100	100	99	100	98	100	100	101
	Tantalum	99	100	160	88	192	81	99	100	160	81	192	88
	Magnesium	98	101	97	102	89	107	98	101	97	107	89	102
	Titanium	112	98	102	100	184	84	112	98	102	84	184	100

	Manganese	100	100	97	101	99	101	100	100	97	101	99	101
	Chromium	100	100	100	100	102	99	100	100	100	99	102	100
	Other metal ores	100	100	119	93	120	93	100	100	119	93	120	93
Non-metallic minerals	**Marble, granite, …**	102	99	101	99	102	98	102	99	101	98	102	99
	Chalk and dolom.	101	100	99	101	100	100	101	100	99	100	100	101
	Slate	101	99	97	104	99	102	101	99	97	102	99	104
	Chemical and fert.	541	102	336	101	459	102	541	102	336	102	459	101
	Salt	98	101	97	102	96	103	98	101	97	103	96	102
	Limestone and g.	101	99	98	102	105	95	101	99	98	95	105	102
	Clays and kaolin	100	100	94	106	96	105	100	100	94	105	96	106
	Sand and gravel	100	100	102	96	98	104	100	100	102	104	98	96
	Other non-met.	100	100	100	100	99	101	100	100	100	101	99	100
Fossil energy materials	**Lignite**	101	99	106	94	106	93	101	99	106	93	106	94
	Hard coal	108	94	103	98	112	92	108	94	103	92	112	98
	Oil shale and tar s.	102	98	102	99	103	97	102	98	102	97	103	99
	Peat	100	100	100	100	102	99	100	100	100	99	102	100
	Crude oil, and NGL	100	100	100	100	101	100	100	100	100	100	101	100
	Natural gas	102	98	101	99	102	98	102	98	101	98	102	99

Source: Authors' calculations.

The RMI indicator is not reported as it is identical over all aggregations, due to the identity RMI = DE + RMEimp, as domestic extraction (DE) and the RME of imports (RMEimp) are identical in this case. The RME of imports that would correspond to this level of aggregation is not reported.

The results show that the disaggregation error is higher for Denmark and Germany than for the EU for the same disaggregation levels. This results from designing the disaggregation to the EU model. While satisfactory results are displayed for HIOT134, we present also results for HIOT155 disaggregation level, as it provides a very good match for both regions.

2.5.5 The recommended minimum disaggregation level – classification of HIOT134

The disaggregation option HIOT134 is considered to be the minimum disaggregation level for estimating results for detailed raw material categories for the EU. If only economy wide indicators are needed, HIOT117 is sufficient. The HIOT182 disaggregation option is required for getting reliable product level results.

A general comparison of the four disaggregated classifications is listed in Table 7, the complete description of the disaggregations is included in Annex II.

Table 7: General comparison of the different disaggregations.

	Eurostat RME model	FIGARO MRIO	HIOT117	HIOT134	HIOT155
Total	**182**	**64**	**117**	**134**	**156**
Agriculture (NACE 01)	19	1	12	14	19
Mining and quarrying (NACE B, 5-9)	35	1	35	35	35
Food, beverages and tobacco (NACE 10-12)	11	1	2	4	11
Coke and refined petroleum products (NACE 19)	2	1	1	2	1
Chemicals and chemical products (NACE 20)	8	1	1	2	1
Rubber and plastic products (NACE 21) check	2	1	1	2	1
Other non-metallic mineral products (NACE 23)	8	1	2	3	8
Basic metals (NACE 24)	22	1	6	15	22
Fabricated metal products (NACE 25)	7	1	1	1	1
Other transport equipment (NACE 30)	4	1	1	1	1
Furniture and other manufactured goods (NACE 31-33)	8	1	1	1	1
Electricity, gas, steam and air-conditioning (NACE 35)	3	1	2	2	3

Source: Authors' calculations.

Table 8 is presenting the classification for the HIOT134.

Table 8: Disaggregation for HIOT134

FIGARO	Proposed disaggregation for HIOT134
Agriculture (NACE 01)	- Cereals - Green leguminous vegetables, vegetables and melons (excl. edible roots and tubers and sugar beet) - Dried leguminous vegetables - Soya beans, groundnuts and cotton seed, other oil seeds - Edible roots and tubers with high starch or inulin content - Sugar beet and sugar beet seed, sugar cane - Unmanufactured tobacco - Fibre crops - Forage crops, incl. grazed biomass - Fruits - Other crop products - Dairy cattle (live) other cattle and buffaloes (live) and their semen aggregated with raw milk from dairy cattle - Swine (live), poultry (live), eggs (in shell, fresh), farm manure and other agricultural waste products, and agricultural and animal husbandry services (except veterinary services) - Other animals and animal products, incl. hunting and trapping and related services

Mining and quarrying (NACE B)	- Hard coal - Lignite - Petroleum oils and oils obtained from bituminous minerals, crude - Bituminous or oil shale and tar sands - Natural gas, liquefied or in gaseous state - Iron ores - Uranium and thorium ores - Copper ores and concentrates - Nickel ores and concentrates - Aluminium ores and concentrates - Gold - Silver - Platinum MG - Lead - Zinc - Tin - Tungsten ores and concentrates - Tantalum ores and concentrates - Magnesium ores and concentrates - Titanium ores (Ilmenite) and concentrates - Manganese ores and concentrates - Chromium ores and concentrates - Other ores and concentrates - Ornamental or building stone - Limestone and gypsum - Chalk and uncalcined dolomite - Slate - Gravel and sand, excl. mixtures of slag and similar industrial waste products, whether or not incorporating pebbles, gravel, shingle and flint for construction use - Mixtures of slag and similar industrial waste products, whether or not incorporating pebbles, gravel, shingle and flint for construction use - recycling - Clays and kaolin - Chemical and fertiliser minerals - Peat - Salt and pure sodium chloride; sea water - Other mining and quarrying products nec - Mining support services
Food, beverages and tobacco (NACE 10-12)	- Livestock food products (preserved meat and meat products and dairy products) - Processed and preserved fish, crustaceans and molluscs - Vegetable and animal oils and fats - Other food beverages and tobacco products, processed and preserved fruit and vegetables, grain mill products, starches and starch products, other food products, Prepared feeds for farm animals, prepared pet foods, beverages, tobacco products
Coke and refined petroleum products (NACE 19)	- Coke oven products - Refined petroleum products
Chemicals and chemical products (NACE 20)	- Basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in excl. fertilisers and nitrogen compounds, excl. plastics in primary forms - Other chemical products
Rubber and plastic products (NACE 22)	- Rubber products - Plastic products
Other non-metallic mineral products (NACE 23)	- Glass and porcelain (glass and glass products, other porcelain and ceramic products) - Articles of concrete, cement and plaster - Other non-metallic mineral products (refractory products, clay building materials, cement, lime and plaster, cut, shaped and finished stone, other non-metallic mineral products)
Basic metals (NACE 24)	- Iron and steel (basic iron and steel and ferro-alloys, casting services of steel) - Casting services of iron - Gold - Silver - Platinum - Copper - Nickel - Processed nuclear fuel - Tin - Magnesium products - Tantalum products - Titanium products - Chromium products - Casting services of other non-ferrous metals - Other metals and services (aluminium, lead, zinc, tungsten products, manganese products, other non-ferous metal products, casting services of light metals)
Electricity, gas, steam and air-conditioning (NACE 35)	- Electricity and steam (electricity, transmission and distribution services, steam and air conditioning supply services) - Manufactured gas; distribution services of gaseous fuels through mains

Source: Authors' calculations.

Note, looking at the detailed results is showing that it is irrelevant whether the minimum disaggregation requirement is set to 95 or 155 product groups, as far as it is higher than approximately 80 product groups (estimate). No reasonable results could be expected below this level of detail.

2.6 Discussion

2.6.1 The role of hybridization

As mentioned in Section 1.4, the Eurostat RME model contains physical units for several product groups. The results for the EU show very high differences between the MIOT182 and the HIOT182 approach. It clearly demonstrates that increasing the degree of resolution at the level of the monetary model alone cannot be a solution. A general pattern seems to be that for exports the share of high priced products is higher than for domestic use. In those cases, applying physical sales structures is a substitute for increasing the level of resolution at the monetary level. That effect is most striking for non-metallic minerals for EU.

The product groups to be handled in physical units within the HIOT simple approach include: agriculture crop products, forestry products, fishery products, primary non-metallic minerals, and all energy carriers (including electricity).

The product groups to be handled in physical units in the physical use extension approach include: Fish products, Coke oven products, Refined petroleum products, Electricity, transmission and distribution services, and Steam and air conditioning supply services. However, hybridization of Fish products is only important for the detail material category Fish catch.

Electricity is one of the product groups for which the physical units influence the results. If the hybrid framework is not applied, the results of the monetary input-output model can be improved by disaggregating the electricity sector into electricity and electricity distribution and transmission services. However, it seems insufficient, as also the price for energy differs across different users. This could not be tested under the scope of this study. Therefore, we suggest the application of physical units for electricity and not its disaggregation to electricity, and distribution and transmission services.

2.6.2 Broader regional representation of results

The benefit curves (Section 2.5.1) are diverging between the selected countries. That is not surprising, as it can be expected that the economic structures of the EU countries are very different. Especially smaller countries tend to show rather specific structures. Specific structures are not only occurring with respect to the general economic structure, but also at lower aggregation levels. That is, any aggregation can give rise to biased reporting, especially in case of smaller countries. Therefore, it can be expected that country results are reacting much more sensitively to a change of the level of disaggregation than EU-results. For that reason, it is advisable to go always for the highest possible level of disaggregation.

In Table 8 the structural differences between EU countries are investigated with data from the Prodcom survey n for the production value at the example of other basic metals (non-ferrous basic metals excluding copper and aluminium). Those basic metals are only reported separately at the disaggregation level HIOT155. That is, if lower disaggregation levels are applied much of the specific structural information gets lost.

The structural differences between EU countries are shown in the following embedded table with data from Prodcom for selected countries and metals (the complete table is presented in the electronic supporting information).

Table 9: Composition of metal production in selected EU countries (a short extract) (%)

	EU-28	Belgium	Denmark	Germany	Spain	France	Italy	Netherlands	Portugal	Sweden	UK
24412030 Gold, unwrought or in powder form for non-monetary use (including plated with platinum)	29	0	0	24	20	0	75	0	63	0	0
24411030 Silver, unwrought or in powder form (including plated with gold or platinum)	10	0	0	11	2	0	8	0	2	0	0
24431230 Unwrought non-alloy zinc (excluding zinc dust, powders and flakes)	9	18	0	4	45	0	6	0	0	0	0
24412050 Gold, in semi-manufactured forms for non-monetary use (including plated with platinum) (excluding unwrought or in powder form)	6	0	0	14	18	2	1	0	4	0	7
24431130 Refined unwrought lead (excluding lead powders or flakes)	5	29	2	5	2	10	1	0	8	0	20
24431250 Unwrought zinc alloys (excluding zinc dust, powders and flakes)	4	23	0	4	10	0	0	0	0	0	5
24453043 Titanium and articles thereof (excluding waste and scrap), n.e.c.	3	0	29	2	0	31	1	100	0	100	24
24432300 Zinc bars, rods, profiles, wire, plates, sheets, strip and foil	3	9	50	4	0	0	2	0	0	0	0
24413030 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form	3	0	0	2	0	1	0	0	0	0	0
24411050 Silver, in semi-manufactured forms (including plated with gold or platinum) (excluding unwrought or in powder form)	3	0	1	7	2	0	2	0	0	0	1

Source: Authors' calculations.

For full results, see the embedded table below.

Prodcom %5 share countries.xlsx

It appears that the structural relations for Germany are looking fairly similar as the EU-level structure. But for almost all other member countries the relationships are very different. Moreover, especially for basic metals, it has to be regarded that neglecting the structural differences is likely to have a strong impact on reporting in RME, as the RME intensities of the individual metals are very different.

That is, even if the results for EU suggest that the impact of applying higher disaggregation levels for basic metals is changing the results in RME not significantly, that observation may not hold at the level of individual EU countries. But, it has to be stressed that it is the aim of the disaggregated model to generate reliable results in RME for individual countries. While it is impossible to predict the aggregation error for those countries, as the resulting RME intensity of the aggregated products will reflect the detail product composition, it is recommended to apply rather higher product resolution. Insofar, the above proposal to use the highest possible level of disaggregation is also confirmed by this specific perspective.

3 Disaggregation procedure and data sources for EU countries

Eurostat's priority is to develop a disaggregated EU inter-country input-output (ICIO) dataset suitable for the calculation of RME indicators. Developing a fully disaggregated world ICIO is much more complex due to diverging data availability for individual countries and it is therefore assumed to be rather a long term task for OECD. Therefore, we focus on EU level, while we only briefly review options for non-EU countries.

3.1 The FIGARO EU inter-country model

The basis for developing a disaggregated model is the FIGARO EU inter-country model (Eurostat 2018). Experimental data for 2010 are already available and data on time series are under preparation.

The FIGARO IOT-model shows a sectoral breakdown by 64 product groups and a regional breakdown by all 28 EU countries and the US. The link to RoW is shown only as a vector of imports and a vector of exports. Figure 8 shows a schematic description of the model by using a breakdown by 3 countries.

Schematic overview EU inter-country IOT model (FIGARO project) with added environmental extension for raw materials

			Intermediate consumption			Final use			RoW	Total use
			Country A	Country B	Country C	Country A	Country B	Country C		
			Product groups	Product groups	Product groups	Categories of final use	Categories of final use	Categories of final use	Product groups/ categories of final use	Product groups/ categories of final use
			A01 ... A64	A01 ... A64	A01 ... A64	S01 ... S05	S01 ... S05	S01 ... S05	All	All
Country A	Product groups	A01 ... A64	Intermediate consumption of domestic products by country A	Intermediate consumption of import from country A by country B	Intermediate consumption of import from country A by country C	Final use of domestic products by country A	Final use of imports from country A by country B	Final use of imports from country A by country C	Imports of RoW from country A	Total use of domestic products from country A
Country B	Product groups	A01 ... A64	Intermediate consumption of import from country B by country A	Intermediate consumption of domestic products by country B	Intermediate consumption of import from country B by country C	Final use of imports from country B by country A	Final use of domestic products by country B	Final use of imports from country B by country C	Imports of RoW from country B	Total use of domestic products from country B
Country C	Product groups	A01 ... A64	Intermediate consumption of import from country C by country A	Intermediate consumption of import from country C by country B	Intermediate consumption of domestic products by country C	Final use of imports from country C by country A	Final use of imports from country C by country A	Final use of domestic products by country C	Imports of RoW from country C	Total use of domestic products from country C
RoW	Product groups	All	Intermediate consumption of imports from RoW by country A	Intermediate consumption of imports from RoW by country B	Intermediate consumption of imports from RoW by country C	Final use of imports from RoW by country A	Final use of imports from RoW by country B	Final use of imports from RoW by country C		
Total all countries	Product groups	All	Total intermediate consumption by country A	Total intermediate consumption by country B	Total intermediate consumption by country C	Total final use by country A	Total final use by country B	Total final use by country C		
Environmental extension	Raw material categories	M01 ... M51	Domestic extraction country A	Domestic extraction country B	Domestic extraction country C					

Figure 8: Schematic description of the model by using a breakdown by 3 countries

Source: Created by Authors.

The system is comprised of a set of country-wise matrices for intermediate consumption and final use of the items domestic production and imports. An important feature is that the bilateral international trade flows of the FIGARO model are fully balanced in the sense that the imports by product groups of country A which originate from country B are equal to the exports from country B to country A. That is for example, the matrix for intermediate consumption of imports from country A to country B is identical with the matrix for intermediate consumption of exports from country A to country B.

For disaggregating the FIGARO model from 64 to 182 sectors we have designed a comparatively simple "country by country approach" as the preferred method.

By that approach each country block is balanced separately. The country blocks are consisting of the matrices for the use of domestic products (intermediate consumption and final use excluding exports (final domestic use) and for the imports from different countries/regions of origin (see below).

That approach is especially designed for disaggregating already trade balanced systems, as it is the case for the FIGARO model.

The task is to disaggregate the FIGARO model (64x64 sectors) by keeping the already balanced system with coherent imports, exports, outputs and inputs.

Therefore, we start with the already balanced FIGARO model. The country-by-country approach is designed for generating disagregated country blocks which are fully complying with the initial FIGARO country blocks. We keep each country block balanced.

With our method, the complete system, which is comprised of the individual country blocks, will also stay balanced.

This objective of disaggregating an already balanced systemis quite different and much less complex than establishing a new MRIO model on the basis of non-harmonized national IOTs´, as it was the case for the Exiopol model.For that purpose applying a final all at once balancing approach was required.

But with respect to the envisiged country-by-country approach, it has to be noted that no practical experiences with the country-by-country method are available so far. Open questions are for example wether the available information (indicators) for disagregationg imports, exports and outputs is sufficiently compatibel with the FIGARO IOTs. Inconsistencies could arise for different reasons, as for example demarcation differences (deviating price concepts, different treatment of „goods sent for processing" and of re-exports) and data quality problems (e.g. gap filling). A further question would be wether the available generic structural information (see below) is suitable for all country cases. Therefore, that procedure should be tested with real data at the example of some pilot countries beforehand.

Based on the evaluation of those test results, it could be decided wether the contry-by-country approach is a feasible option or wether alternatives have to be developed.

The value-added section of the IOT is not required for the RME model. Therefore, the disaggregation of that section would not be obligatory. But optionally, a disaggregated value-added block could be included, if it is intended to use the model also for other purposes for which that information is needed.

As the system is already fully balanced at the level of 64 product groups the disaggregation to the required level (e.g. 182 product groups) can be done country by country. The result will be a disaggregated model which stays to be fully balanced.

The country by country disaggregation framework is schematically shown in Figure 9.

Country block A for sectoral disagregation of the FIGARO model

			Intermediate consumption Country A Product groups	Final domestic use Country A Categories of final use	Total domestic use
			A01 … A182	S01 … S05	
Country A	Product groups	A01 … A182	Intermediate consumption of domestic products by country A	Final use of domestic products by country A	Total domestic use of domestic products from country A
Country B	Product groups	A01 … A182	Intermediate consumption of import from country B by country A	Final use of imports from country B by country A	Total use of imports of country A from country B
Country C	Product groups	A01 … A182	Intermediate consumption of import from country C by country A	Final use of imports from country C by country A	Total use of imports of country A from country C
RoW	Product groups	All	Intermediate consumption of imports from RoW by country A	Final use of imports from RoW by country A	Total use of imports of country A from RoW
Total inputs			Total intermediate consumption by country A		
Environ-mental extension	Material cantegories	M01 ,,, M51	Domestic extraction country A		

Figure 9: Schematic framework of country by country disaggregation of the FIGARO model

Source: Created by Authors.

The country blocks for disaggregation have the following format: (product groups + final use categories) x (domestic products by product groups + imports by product groups by country of origin of the imports). The product group dimension of the disaggregated matrices is following the format 182x182 sectors. In addition, the two RoW vectors for imports from EU countries and imports of EU countries from RoW by country and product groups have also to be disaggregated accordingly in order to get vectors of the format 182 product groups.

For disaggregation of the IOT country blocks the following elements are required:

1. Detailed structural information: Country specific structural information is not available in a systematic manner (e.g. from Eurostat's database). Examining huge numbers of special studies is out of scope and budget of this project. But as far as easily accessible country specific structural information is available, that information will be entered to the model, as it is the case for for energy carriers and partly for agricultural crops. It might also be possible to utilize special studies in a later stage of the process. For the time being, it is proposed to use generic structural information in the required breakdown from a country or region for which a corresponding disaggregated model is available. Preferably, the annual structural information of the EU model should be used. The large and very diversified EU economy is likely to offer a good representation with respect to more specific country conditions. Alternatively, it could also be considered to utilize the structure from the disaggregated Alternatively, the structural information from the disaggregated IOT model for Germany could be used. The German structure is based on very detailed internal supply and use tables. However, currently that model is only available for the year 2010. Further, it has to be considered that the German economy is more specific and a number of product groups are less well or even not represented by the German model.
2. Disaggregated column-vector for total domestic use: The vector at the level of 64 sectors is obtained by summing-up the vectors for intermediate consumption and final domestic use. The vector is comprised of the following segments: domestic production and import by country of origin, including RoW (see Figure 9). The vector is disaggregated by balanced information from international trade statistics (Comext) and information on outputs from structural business statistics (SBS) and some other sources.
3. Disaggregated row-vector for total inputs: That vector is describing the total intermediate consumption by production branches at the level of 64 sectors. The disaggregation is predominantly done by using information from SBS.

4. The disaggregation of the country matrix is conducted by fitting the structural information into the framework of the disaggregated vectors for domestic use and inputs by applying a suitable balancing procedure, like a RAS type or an optimization approach. For that purpose, in the first step cells of the original 64x64 matrices are disaggregated symmetrically by using the structural information, e.g. by applying input coefficients. In the further procedure, those raw values are adjusted to both, the disaggregated domestic use vector and the disaggregated input vector by keeping the original values from the 64x64 aggregation level.
5. The environmental extension matrix is not part of the FIGARO-model. But it has to be added to the model for calculating RME. That matrix is assigning the domestic extraction of raw materials from economy wide material flow accounts (EW-MFA) to the corresponding domestic production activities for extraction of raw materials. Therefore, in case the IOT model is disaggregated, the environmental extension has to be disaggregated accordingly.

3.2 Disaggregation method

Above, the disaggregation of the FIGARO model has already been shortly described in technical terms. Generally, we suggest a disaggregation method based on our previous experience with the disaggregation of the EU IOT (Eurostat 2016), the disaggregation approach applied for Exiobase and the comprehensive literature review on disaggregation provided in this report. First, we list the main disaggregation steps for EU countries followed by a section on data sources.

We suggest the following general approach for disaggregating the existing FIGARO model:

1. Collect data on international trade (imports and exports) and domestic production on the level of disaggregated product groups (see the section specifically on data sources)
2. Check consistency and fill data gaps
3. The sum of the more detail data should be equal to the original data
4. Check for missing data and utilize additional resources to fill the data gaps (those resources are beyond the capacities of this report, as we do not know what might be missing)
5. Get the structural information of the disaggregated IOT, such as the input technology coefficients of the corresponding classification for another country or region (this can be obtained from the monetary core of the Eurostat RME model)
6. Derive the first estimate of the disaggregated MRIO table by combining the information on the total output and the structural information and scale each block of disaggregated cells of the MRIO to the original MRIO data, so the aggregated version of the first estimate of the disaggregated MRIO is equal to the original MRIO data.
7. Apply RAS or RAS-based iterative techniques or other programming and optimization tools to balance the table (row totals to match column totals), while keeping it equal to the original aggregated MRIO table and the disaggregated vectors of international trade and domestic production (obtained in step 1 and 2).
8. Make a plausibility check of the resulting monetary MRIO table
9. Hybridize the MRIO table – adjust the sales structures according to additional data on physical use (see Section on data sources)
10. Make a plausibility check of the resulting hybrid unit MRIO table by expert judgement

Note that this type of disaggregation will provide a model, which might differ from reality. Reality would be best approximated if primary data would be collected on the required level of detail directly by the statistical institutes.

3.3 Data sources for disaggregation and hybridization of the EU MRIO table

The issue of data sources is presented in two steps. Firstly, the requested data sources are described in a summarising manner. In a second step, data requirement is investigated in more detail under the perspective of data procurement costs. That is, we tried to assess the procurement costs against the level of sectoral disaggregation of the model. Looking for costs is important in order to ensure a balance between costs and benefits of disaggregation.

In a final section of this chapter, the calculation of a disaggregated RME model for Denmark (single-country model) is shortly described. That calculation is a first preliminary example for applying the disaggregation approach of this report to an individual country.

3.3.1 General overview of data sources

As already mentioned, beyond the initial FIGARO model the following types of information are required for disaggregation:

- Structural information
- Detailed vectors for imports and exports by product groups
- Detailed vectors for outputs and inputs by product groups

Structural information: As discussed above, we propose to use the annual MIOT182 of the EU RME as generic structural information, at least for intra-EU disaggregation.

The classification of the model by 182 product groups is presented in Appendix II Table 12.

The implicit proposal of limiting the degree of resolution to the 182 level of the EU RME-model (maximum disaggregation level) could be challenged. For example, a model with a breakdown by 274 sectors was established for Germany by the DeteRess project of the German Federal Environmental Agency. The purpose was to enhance the analytical scope of the model by a more detailed disaggregation of RME intensive or RME saving activities, like production of road transport vehicles (e.g. distinguishing vehicles with conventional and electrical kind of drive), or production of electricity, construction and transport activities and activities of waste management (e.g. recycling). Yet, it has to be regarded that in case of intra-EU disaggregation, data availability for this undertaking is much less comprehensive than for Germany. That is, going for a breakdown beyond the level of 182 sectors of the EU RME-model is likely to be rather costly, if being feasible at all.

Therefore, it is suggested to limit the maximum level of sectoral disaggregation to the MIOT182 format for the purpose of this report.

For the initial disaggregation, detailed vectors for imports, exports, outputs and inputs in monetary terms are required. Only in a later step the monetary values are overwritten by information in physical terms.

Detailed vectors for imports and exports by country: For intra-EU, that information can in principle be extracted from Comext in monetary terms. Corresponding information in tonnes for hybridization is also provided by Comext. The international trade Comext data has to be checked for completeness and plausibility. With respect to Non-EU countries the Comtrade database could be used.

It has to be stressed that using a fully balanced trade link (imports by a country from a specific country have to be equal to the corresponding exports) is a crucial pre-condition in an MRIO environment. Therefore, a specific approach is useful with respect to data on international trade. In principle, intra-EU information on exports and imports can be extracted from Comext. However, using original Comext data for sectoral disaggregation of imports and exports may have some limitations in view of the logic of an MRIO model. The bilateral international trade flows of the FIGARO model are fully balanced. However, in the trade statistics considerable discrepancies between bilateral imports and exports are partly occurring, especially due to differences in price concepts, the issue of re-exports and inconsistent system boundaries. Thus, applying the relationships of unadjusted Comext data for disaggregation will give rise to misallocation. Yet, for the purpose of the FIGARO project, balanced data on international trade data on imports and exports are being estimated at the level of the very detailed HS-6 classification in order to cope with the discrepancies and some conceptual differences. Those adjusted data from the FIGARO project should preferably be utilized for disaggregation instead of the original data.

It is recommended to apply physical sales structures for some selected product groups. For imports and exports, Comext data in tonnes are used for that purpose. Those physical data have to be adjusted for discrepancies in bilateral imports and exports. A suitable estimation approach that is based on the FIGARO approach for monetary figures has to be developed.

As it is not envisaged to disaggregate the FIGARO data for services, no data from balance of payment are needed. For energy carriers the results of the Energy balance and the energy statistics on imports and exports in tonnes oil equivalent (TOE) are applied for hybridization.

Detailed vectors for outputs by country: The data availability for EU countries is uniform for this purpose and much more comprehensive than for many non-EU countries. An overview on the data sources which are available at country level for intra-EU disaggregation and hybridization are summarised in Table 9.

Table 10: Annual data requirement for the disaggregation of the intra-EU FIGARO model by member country

Calculation step	Data	General source
Basic IOT model for EU by country and 64 sectors	Trade-linked intra-EU MRIO model by 64 or (if available) by 88 product groups	FIGARO model
Structural information for total EU	Monetary IOT for total EU by 182 product groups	Eurostat RME model
Monetary import and export vectors by country and 182 product groups	Comext: Intra- and extra exports and imports in euros by 182 product groups of the RME classification. Data have to be adjusted by removing bilateral discrepancies for mirroring imports and exports	Data extraction Eurobase
Monetary output vector by country and 182 product groups	Agricultural Accounts: Production value by product groups	Data extraction Eurobase
	Structural Business Statistics: Production value by NACE rev. 2 activity	Data extraction Eurobase
	Prodcom: Production value for basic metals	Data extraction Eurobase
	BGS metal mining for selected metals by country	Data extraction BGS
	USGS: metal prices	Data extraction USGS
Monetary input vector by country and 182 product groups	Structural Business Statistics: Total purchases of goods and services by NACE rev.2 activity	Data extraction Eurobase
Physical sales structures by country	EW-MFA: Domestic extraction (DE) by country and by detailed material categories (output of raw products)	Data extraction Eurobase
	Crop balance sheets on the use of agricultural crops by production and consumption activities	Data extraction Eurobase, FAO and national sources
	Comext: Intra- and extra exports and imports in tonnes by 182 product groups of the RME classification	Data extraction Eurobase
	Fishery Statistics: Production of aquaculture in tonnes	Data extraction Eurobase
	EU Energy balance: complete energy balance	Data extraction Eurobase
	Hybrid IOT for total EU by 182 product groups	Eurostat RME model
Environmental extension	EW-MFA: Domestic extraction (DE) by detailed material categories	Data extraction Eurobase
	BGS metal mining for selected metals	Data extraction BGS

Source: Created by Authors.

With respect to intra-EU disaggregation of **outputs and inputs** a combination of different sources has to be utilized which are predominantly available from Eurobase. As additional sources, only BGS and USGS prices are needed, for which no significant problems with quality and completeness appear (as shown below). As already mentioned, the initial disaggregation has to be conducted in monetary terms.

For the monetary disaggregation the following sources are applied:

- Agricultural accounts (outputs of agricultural activities and summarised inputs).
- Structural business statistics (SBS): That source is providing detailed information on outputs (production value) and inputs (purchases of goods and services) for the mining and quarrying and of manufacturing activities in euros. However, the level of breakdown of SBS regarding extraction of non-metallic minerals, metal ores (3 sectors) and basic metals (4 sectors) is not sufficient for establishing a breakdown by 182 product groups. For getting a full breakdown the SBS results have to be supplemented by a combination of Prodcom results and some other sources.
- Prodcom: That source is utilized for estimating more detailed outputs of extraction of non-metallic minerals, of metal ores and production of basic metals in euros. Due to limited quality and degree of disaggregation of Prodcom data for metal ores, the data have to be cross-checked and supplemented by BGS data and some other sources on metal mining (extraction of ores). Data on non-metallic minerals are also cross-checked by corresponding data from EW-MFA in tonnes which are converted into monetary units by using unit price information from Comext.

- BGS: That source is providing data on metal mining in tonnes of metal content. The BGS data are converted into euros by combing different sources: USGS metal prices, unit prices from Comext for ore concentrates and factors from the ifeu world metal model for converting metal content into tonnes of ore concentrates.

For estimating non-monetary sales structure (hybridization) for selected product groups physical output values are obtained from the following sources:

- Domestic extraction (EW-MFA): That source is applied for estimating the outputs in tonnes for the following sectors: agricultural crops, fish (wild), wood and non-metallic minerals.
- Statistics on aquaculture: That source is needed to estimate the output of aquaculture which is not regarded by domestic extraction (Eurobase)
- Energy balance: That source is applied for estimating the output of all energy carriers in TOE (Eurobase). Beyond output, the energy balance also provides rather detailed physical sales structure in a breakdown by about 30 sectors. All main energy using activities are shown separately.
- Crop balance sheets: As far as agricultural crops are concerned, further information on crop use by economic activities from crop balance sheets can be used. Those sheets are providing information on the use of important agricultural crops in tonnes in a coarse break down into the use categories seed, feed, industrial use, energy use and human consumption. Crop balance sheets can be obtained from FAO (full coverage of countries and years and rather comprehensive coverage of crops). Sheets are also available from Eurobase (selected countries and selected crops) or from national sources.

3.3.2 Costs of data procurement in relationship to the resolution level

3.3.2.1 PRINCIPAL LEVELS OF SECTORAL DISAGGREGATION

Different levels of sectoral disaggregation are considered for the intra-EU RME-model. The following principal levels of disaggregation are considered in this report:

- A full breakdown according to the level of the 182-sector classification.
- Moderate disaggregation levels for extraction of the different categories of raw products (agricultural crops, fossil energy carriers, metal ores and non-metallic minerals) and the categories of primary processing of raw products (animal production, food production, production of non-metallic mineral products, production of basic metals and production of secondary energy carriers). Moderate disaggregation means that a lower level of disaggregation is applied for the individual categories than for the 182-sector classification.
- No disaggregation of some other material intensive product groups, as for example production of fabricated metals products or of chemicals.

The possible disaggregation levels are ranging between 64 sectors of the initial FIGARO model, some settings with moderate disaggregation levels for activities of extraction and primary processing of raw materials (e.g. 117 sectors) to the maximum level of 182 sectors.

The efforts of data procurement are considered to be the crucial cost item. In the following the impact of the level of resolution on the data procurement costs is investigated.

The initial FIGARO IOTs and the structural information from the EU RME-model are taken as given. Therefore, only the data requirement for establishing detailed monetary vectors for imports, exports, outputs and inputs is discussed here.

The additional data requirements for hybridization of monetary sales structures are described below.

3.3.2.2 DATA PROCUREMENT COSTS

The costs of data procurement with respect to different levels of aggregation have to be investigated under three perspectives:

- Extraction of auxiliary data (sources and accessibility)
- Closing of data gaps

- Removal of reporting errors

3.3.2.2.1 Extraction of data

As already described above, almost all data for establishing detailed vectors for imports, exports, outputs and inputs for EU member countries are easily accessible from the public source Eurobase. Some few supplementary data on extraction of metal ores are taken from British Geological Survey (BGS). But likewise, those data are also easily accessible at low costs. That is, it can be assumed that the level of detail of the extracted data does not have a significant impact on the cost of pure extraction of the required data. That is, the costs for extracting the required data is not likely to be significantly different between the envisaged levels from 117 sectors to 182 sectors of the model.

3.3.2.2.2 Data gaps

Beyond pure extraction, it has to be kept in mind that the data which are extracted from the public sources mentioned above are containing a considerable number of missing values. Missing values are almost completely due to the suppression of confidential data. Closing those data gaps may require additional efforts beyond the act of extraction.

In the following the efforts (costs) for closing data gaps with respect to different aggregation levels of the IOT model are investigated for the different relevant sources.

Comext: Confidential values at the most detailed level of Comext (CN8-digit level) are not suppressed, but are reported at a higher aggregation level. Therefore, gap filling is neither possible nor necessary for Comext. With respect to the 182 classification there are some few items which are not assignable at the level of the 182-classification. The share of non-assignable items lies in the order of magnitude of roughly 1 % of total. For that reasons, the non-assignable values are neglected for the purpose of the EU RME-model and also for the RME country tool. It is proposed to neglect non-assignable values also for the intra-EU disaggregation. That is, with respect to Comext, no additional efforts are necessary for gap filling, irrespective of the considered levels of disaggregation. This would also apply for balanced data from the FIGARO project.

Agricultural accounts: The European agricultural accounts are delivering detailed data on production values (outputs) for agricultural crop production and animal production and summarised information on inputs. No missing values are reported in the agricultural accounts for the individual countries. That is, no additional efforts are necessary for gap filling, irrespective of the considered levels of disaggregation.

Structural business Statistics (SBS) and Prodcom: For SBS and Prodcom two issues are relevant regarding the costs for gap filling:

1. What is the absolute number of gap filling cases at the level of 182 sectors?
2. Are the number of gap filling cases different if the level of disaggregation is changed within the relevant range of 117 to 182 sectors?

<u>Absolute number of gap filling cases</u>: The SBS is providing information for disaggregating the outputs and inputs for individual product groups for mining and manufacturing. The public SBS data which are needed for the disaggregation of the model by 182 sectors are showing a high share of missing values at country level (roughly 20% for production value), see Table 10.

Table 11: Structural business statistics – overview

Structural Business Statistics
Data for disaggregating production values from the 64 FIGARO format to the format of 182 product groups fo the EU RME-model
All EU memeber countries 2008-2016

	Extraction of raw materials (mining and quarying)	Primary processing of raw materials				Other disaggregated sectors	Total
		Food	Non-metallic mineral products	Basic metals	Electricity		
Cells with missing values	1 153	467	271	957	187	1 877	4 912
Total cells	3 276	3 276	2 016	3 276	756	9 324	21 924
% share missing values	35%	14%	13%	29%	25%	20%	22%

Source: Authors‘ calculations.

That is, a considerable number of data gaps have to be closed.

For the purpose of the EU RME-model a simple automated approach is applied for gap filling. By that approach gaps are either filled by using values of previous or subsequent years as an approximation and/or it is referred to the value at the next higher aggregation level. Under that simplified approach, the number of gaps to be filled do not matter significantly in terms of costs, but it has to be regarded that the simplification may have an impact on the quality (benefits).

But at country level, especially for smaller countries, the share of missing values is much higher than for total EU. Using a simple gap filling approach under that condition may impact the quality of the model. Therefore, the preferred method for gap filling at country level should be to use confidential information. Using confidential values will make the work process more complicated. For example, for some working steps, the compliance with the confidentially rules has to be observed. But again, as for the simple gap filling approach, the absolute number of confidential cases does not matter significantly. It can therefore be stated that under the perspective of absolute number of gap filling cases, the chosen level of disaggregation is not likely to have an impact on the costs of data extraction and gap filling, as far as SBS is concerned.

As already described above, Prodcom data are needed for supporting further disaggregation of SBS for “Metal ores”, “Non-metallic minerals” and for “Non-ferrous basic metals. The public Prodcom data which are required for disaggregating are also showing a high share of missing values (roughly 20 %), see Table 11.

Table 12: Data from Prodcom for disaggregating production values from the 64 FIGARO format to the format of 182 product groups of the EU RME-model - Data gaps for all EU member countries 2008-2016

	Metal ores	Non-metallic minerals	Non-ferrous basic metals (excl. copper and aluminium)	Total
Cells with missing values	332	1 703	2 075	4 110
Total cells	1 764	8 064	9 828	19 656
% share missing values	19%	21%	21%	21%

Source: Authors‘ calculations.

The considerations concerning gap filling for SBS are also holding for Prodcom. It therefore can be concluded that, as far as the use of Prodcom data is concerned, the chosen level of disaggregation level is not likely to have a significant impact on the costs of procurement of data.

Number of gap filling cases and level of disaggregation: With respect to **SBS, almost all relevant disaggregation levels are based on the same basic level of detail of that survey**. The difference is only that in cases of moderate disaggregation three digit or in some cases four digit level information of SBS is aggregated to some interim level. To give an example regarding non-metallic mineral products: For the full disaggregation, each individual 3-digit item has to be used. But 3-digit information is also required for compiling the moderate breakdown of the 117 classification. The 117 classification is using two subgroups (construction materials and others) for disaggregating the 2-digit level. However, those aggregated subgroups are not directly available from SBS, but can be obtained only by aggregating 3-digit information. That means, in case of the moderate breakdown the same level of detail (3-digit) has to be used as for the full breakdown. The requirement for gap filling is not reduced by going for a moderate instead of a full breakdown.

Prodcom data are only available at the most detailed 8-digit level. Thus, for obtaining higher aggregation levels the gap filling has always to be conducted at 8-digit level. That is, using higher aggregation levels will not save costs of gap filling.

A detailed description of the gap filling (SBS, Prodcom) requirements for different disaggregation levels is presented in Appendix III. The above conclusions are widely confirmed by the detailed analysis

British Geological Survey (BGS): Data of the BGS on domestic extraction of metal ores by country in tonnes metal content are required for supplementing the Prodcom data on metal ores for establishing a full breakdown with respect to the 182-classification.

The data are already being collected by country for the purpose of the EU RME-model and are combined with further information (USGS metal prices, Comext unit prices) for converting tonnes into EUR. That approach can be used for this project as well. That is, no additional effort is required for estimating disaggregated data for extraction of metal ores in EUR.

Data for hybridization: For selected sales structures the monetary units are replaced by physical units.

Following the approach of the EU RME-model, non-monetary sales structures are established for the following product groups: agricultural crops, forestry products, fishery products and all energy carriers.

As a minimum requirement for converting non-monetary sales structures, imports, exports and outputs in physical units are needed. Preferably information on full physical sales structures should be utilized.

Figures on imports and exports in tonnes can be derived from Comext. Output values are obtained from the following sources:

- Domestic extraction of EW-MFA: That source is applied for estimating the output in tonnes for the following sectors: agricultural crops, fish (wild), wood and non-metallic minerals (Eurobase).
- Statistics on aquaculture: That source is needed to estimate the output of aquaculture which is not covered by domestic extraction data, because it is the output of an economic activity and not extraction from the environment (Eurobase)
- Energy balance: That source is applied for estimating the output, the imports and the exports of all energy carriers in TOE (Eurobase). Beyond output, the energy balance is also providing complete physical sales structures.

The above data are easily accessible from Eurobase. The cost of data procurement for this purpose is not significantly influenced by the level of disaggregation of the model. No gap filling is required.

3.3.2.2.3 Reporting errors

Eurobase data are taken from an EU-wide statistical system which is well developed and well-coordinated. The plausibility of the data is checked thoroughly at each stage of production. Therefore, good quality and comparability of the auxiliary data can generally be assumed. However, our experience from running the EU RME-model and the country tool is that there can still be a number of reporting errors which need to be checked and removed, as far as possible.

However, it is neither necessary nor feasibly to duplicate the checking work which has already been done elsewhere. Therefore, a pragmatic approach is proposed for the purpose of establishing an intra-EU MRIO model. For limiting the amount of checking work, the initial checking should be conducted at the level of the 182 classification, as at higher levels of aggregation, non-plausible values might to be disguised.

It has to be considered that the quality of the calculation results will be improved, the more errors are corrected. Under that perspective, a level of resolution by 182 product groups could be seen as pragmatic approach. Starting point for checking could be to have a look at the developments over time. In order to automate the checking process, certain threshold should be defined for identifying potentially implausible cases.

The requirement of checking data at a rather detailed level of 182 sectors is irrespective of the chosen level of disaggregation of the model. That is, using a more aggregated model would not reduce the effort for detecting reporting errors.

3.3.2.2.4 Summary of the data procurement

The purpose of this Section 3.3 is to elaborate on the data issue with respect to intra-EU calculations in more detail. The focus is given on the issue of data requirement for establishing detailed country vectors for imports, exports, outputs and inputs.

This report shows that the required data for establishing a breakdown by 182 sectors at country level are easily accessible from Eurobase and BGS. The data extraction costs are comparatively low, irrespective of the intended level of disaggregation of the model. Closing data gaps and removing reporting errors requires some additional effort. However, the investigation also showed that the costs of this step cannot be diminished significantly by reducing the level of disaggregation of the model (the problematic product groups, such as metals and metal ores should be disaggregated even in the case of lower disaggregation levels).

With respect to cost-benefit considerations the above results show that the cost curve for intra-EU disaggregation is following a rather specific pattern. For illustration see Figure 10.

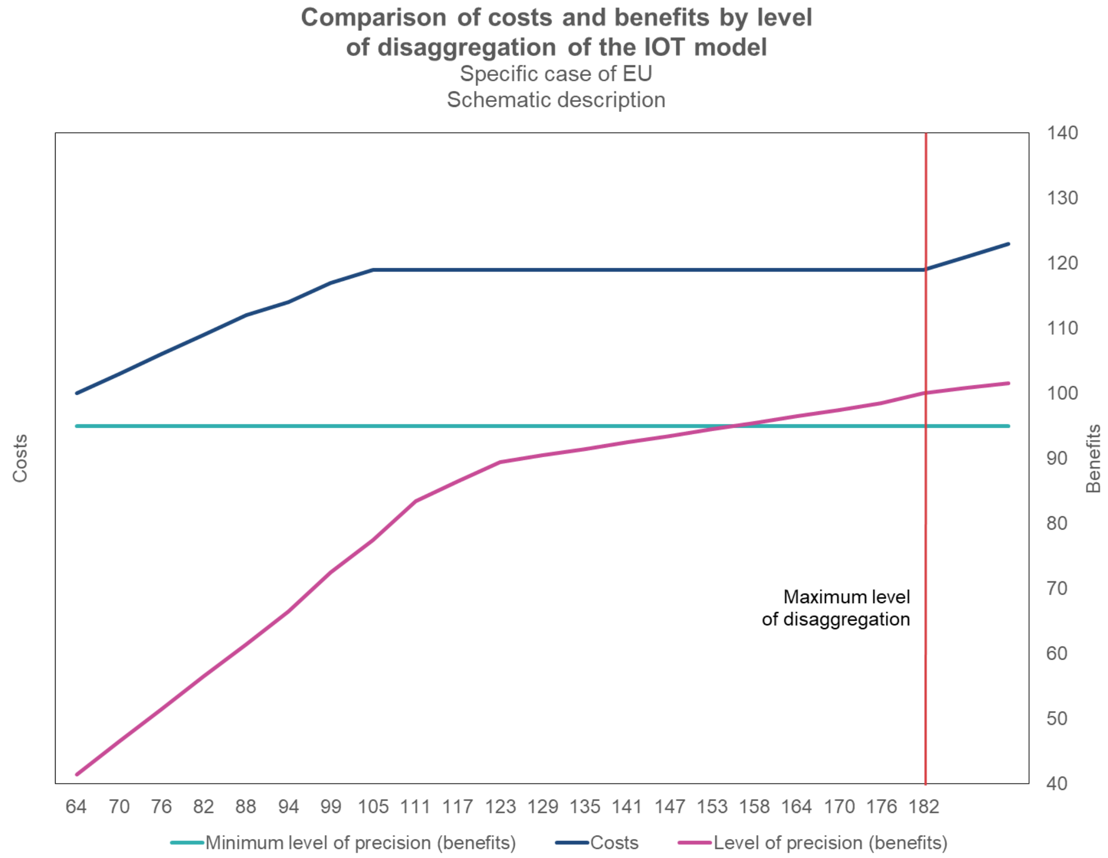

Figure 10: Comparison of disaggregation costs and precision of RME indicators as a function of disaggregation – a schematic description for the specific case of the EU

Source: Authors' illustration.

In the first part the costs curve is behaving in the same manner as for the general case which has been is described before in Figure 3. From a certain level of disaggregation, the cost curve is remaining almost at the same level. Only after the maximum disaggregation level, the curve is showing a further increase. The nearly constant branch of the curve is applying to all disaggregation levels which are being considered as relevant, ranging from at least 117 sectors to the maximum level of 182 sectors. The described pattern is widely confirmed by the empirical costs curves which are presented in Section 2.5.1. That is, the degrees of accuracy (benefits) are highest at the 182 level. However, whether the differences are in a relevant order of magnitude is depending on the analytical purpose and the country under consideration.

Considering the specific shape of the cost curve for the EU, there is no reason to refrain from selecting the 182 sectors level as the optimum solution for intra-EU disaggregation. The benefits include high precision of results for all countries (which is highly uncertain for any other disaggregation level due to potentially different product composition across countries) and all detail materials and products, which is of high importance for any analytical purpose of the model and sector specific policies. Therefore, we recommend the full HIOT182 product breakdown for the intra-EU model.

3.3.3 A disaggregated RME-model for Denmark

For the purpose of this report we have calculated a hybrid IOT by 182 sectors for Denmark for the year 2010, including environmental extension. However, that model is also a first concrete example for establishing country models by a variant of the approach, which is proposed in the reports.

That model for Denmark was required for complementing the models for EU and Germany. All three models are utilized for testing the effect of varying the level of sectoral resolution on the accuracy of the results in RME.

The calculation of the disaggregated IOT for Denmark is based on the official Danish use table for by 64 sectors. For disaggregation the methodical approach which had been developed for estimating a disaggregated IOT for total EU-28 was applied. That approach was working rather smooth in the case of Denmark, as all data which are used for total EU are also available at country level from the European statistical system. A considerable number of data gaps had to be filled. As we had no access to data which are suppressed for confidentiality reasons, data gaps were closed by provisional estimates. Comparatively difficult was the monetary disaggregation of the mining and quarrying sectors due to a rather high share of missing data. The quality could certainly be improved by using confidential data.

3.4 Creating physical use extensions

Creating physical use extensions is almost equivalent to the full disaggregation of the respective product groups. The only difference is that the source product column is not disaggregated. However, the rows of the physical use tables need to utilize the same data and procedures as the full disaggregation. Still this approach can be preferred as the resulting MRIO table is of a smaller size. However, no high benefits can be expected regarding the disaggregation costs.

The physical use extensions can be applied also to the full HIOT182 model due to potentially higher detail on the site of primary materials, such as crops – see e.g. (Weinzettel, Vačkář et al. 2018), who applied all crops as reported by FAOSTAT in a physical use extension approach utilizing FAOSTAT commodity balance sheets as additional information on the use structure.

4 Options to model non-EU material supply

4.1 Options for modelling non-EU supply chains

This report focuses on the FIGARO MRIO data and its application for estimating RME indicators for the EU and its individual countries. However, the FIGARO dataset does not cover the rest of the world. Therefore, the supply chains of extra-EU imports are missing and have to be modeled outside FIGARO. We propose to consider three options to model the supply chains of extra-EU imports (sorted according to expected costs from lowest to highest):

a) The adapted domestic technology assumption of the current EU RME model

b) A disaggregated input-output table for the rest of the world

c) A disaggregated MRIO of the rest of the world

Option a) is to utilize the approach of the current Eurostat RME model, i.e. to model the rest of the world through an adapted domestic technology assumption (ADTA). In principal, the domestic technology assumption (DTA) is applied for estimating the raw material content of imports. But in reality the products which are imported by EU are manufactured by the production technology of the individual countries of origin and not by domestic EU technology. The ADTA approach of the Eurostat RME model is designed for taking into account the most important discrepancies by adjusting the initial DTA results by using regionalized information on important differences in production technology, namely differences in:

- ore grades of extracted metal ores
- metal recycling ratios
- energy intensity of steel production
- energy mix of electricity generation.

For the purpose of the EU RME-model the adjustments for differences between domestic technology and the technology of the source countries are introduced by modifying the FL-matrix for imports accordingly. The FL-matrix carries the information on the cumulated raw material content of imported products. The differences between EU and non-EU with respect to metal recycling ratios, energy intensity of steel production and energy mix of electricity production can be regarded by modifying the relevant coefficients of the A-matrix.

The double loop approach applied within the Eurostat RME model may be kept in order to keep the possibility for adjustment of the RME of imports according to the specific characteristics of the country of origin, as done in the current model. The advantage of combining the Eurostat RME model with the FIGARO MRIO table would be reaching results for individual countries of the EU consistent with the EU total. However, the potential for a global inconsistency would be kept.

Approach a) requires, some additional regionalised data for RoW on metal recycling ratios, energy mix of electricity generation and energy intensity of steel production.

Option b) for modelling the extra-EU supply chains is to develop a disaggregated IOT for the (extra-EU) rest of the world. Preferably, the rest of the world could be sub-divided by major EU trade partners, e.g. by China, US, Japan, etc. .

As already mentioned, for non-EU countries data availability is different compared to EU countries. As a starting point, an IOT of the OECD-ICIO model or of the WIOD model could be utilized (this is already close to disaggregation of the OECD ICIO dataset, but here we suggest disaggregating only the major trading partners and not the whole dataset). Other sources than for the EU have to be used for establishing full vectors for outputs, imports and exports. At least for outputs not all product groups may need to be covered.

Option c) suggests the full MRIO approach of appropriately disaggregated non-EU countries. The product resolution and the use of hybrid units are the most costly characteristics of such an MRIO. A HIOT182 model for non-EU countries might be very difficult and costly, if even feasible at all. However, it could be considered on a country by country basis whether it is possible to apply a simplified disaggregation approach to the level of HIOT182, as it was roughly outlined in the DeteRess paper (see short description in Section 1.3). The major feature of that approach would be that we apply the full disaggregation approach to raw material extraction sectors. It was put forward in the DeteRess paper that the necessary data for that calculation step should be easily available from international data sources. Unlike for raw materials, for disaggregating primary processing of raw materials and probably other sectors, a simplified method is used which does not require additional data for establishing disaggregated output vectors. Applying the simplified approach would mean that we have to accept that the accuracy of the results might be impaired. However, that option would have to be investigated more thoroughly to make a solid decision.

It is also possible to combine different product resolutions within one MRIO dataset, as applied within the Eora MRIO dataset (KGM & Associates Pty. Ltd 2018). That could mean, to apply a breakdown by 182 sectors for intra EU and a lower level (e.g. HIOT117) for non-EU. Yet, a precondition is that the classification of the lower level is compatible with the 182 classification and that the disaggregation level is still able to generate sufficiently accurate results.

4.2 Disaggregation of non-EU countries

For the purpose of disaggregation of the non-EU countries we briefly review the potential methods and data sources in this section. The general disaggregation method suggested for EU countries can be applied for non-EU countries as well. The major difference is in the source of the data. While the data sources for disaggregating EU tables are rather comprehensive and uniform (mostly within Eurobase), this does not apply for most non-EU data. Therefore, a number of estimates and proxies would have to be used for non-EU countries.

Next to data inputs described for the disaggregation of EU countries, for non-EU countries we further suggest to collect national IO tables with higher product detail than available within the ICIO to be disaggregated (e.g. the OECD ICIO). For example, the US, Canada, Japan and Australia provide much more detailed country level input-output tables. Those tables should be utilized for disaggregation, as they provide official disaggregated primary data.

For calculating disaggregated IOTs for other non-EU countries or regions the suggested disaggregation can be applied accordingly. The OECD ICIO based IOT by 35 sectors is taken as the starting point. As for the FIGARO model, also the OECD-ICIO model is already a fully balanced system, as far as the trade link is concerned. Insofar, it should be possible to apply the country-by-country disaggregation approach as it was proposed for FIGARO also for that model.

It has to be decided what available structural information is most suitable; the structure for total EU or detailed relationships of another country. Furthermore, it may be suitable to utilize additional country specific information for disaggregation.

Data availability for disaggregation of non-EU countries seems to be much more restricted than for intra-EU disaggregation.

It is out of scope of this reports to discuss data in detail. That issue should be investigated in a later stage of the process. Therefore, the following description is only providing a short overview.

There are a number of international data bases which can be used for that purpose:

- United Nations (UN)-Comtrade for international trade(10)
- Food and Agriculture Organization of the UN (FAO) database(11): The database covers agricultural and partly food production in monetary and physical terms (outputs), crop balance sheets (information on broad input categories), international trade matrix for agricultural and food products.
- International Energy Agency energy balances(12)
- The UN Environment International Resource Panel database(13) for domestic extraction (raw materials)
- USGS database(14) on mining of metal ores and other minerals and production of major metals.
- BGS database(15) on mining of metal ores and other minerals and production of major metals and trade flows for metals and other minerals.

That is, international trade flows and production of raw materials seems to be rather well covered by international sources. With respect to disaggregation of outputs of other product groups one has to rely predominantly on rather heterogeneous and most likely incomplete national sources.

Therefore, it would most likely be difficult or even impossible to establish the 182 level. But it is possible to combine 182 level IOTs for EU countries with a set of lower level IOTs for non-EU countries in a joint MRIO model. An example is the EORA model. There, country-IOTs with many different levels of resolution are combined.

(10) https://comtrade.un.org/

(11) http://www.fao.org/faostat/

(12) https://www.iea.org/statistics/balances/

(13) https://www.resourcepanel.org/global-material-flows-database

(14) https://www.usgs.gov/centers/nmic/international-minerals-statistics-and-information

(15) https://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

5 Outlook – modelling substitution of primary raw materials

In the course of the UBA DeteRess project (Dittrich, M. et al. 2018) for Germany, an approach was developed and implemented for extending the conventional RME-accounting model with so called “substitutional factors” (RMES-model). The RMES-model is described in more detail in Schoer, K. et al. (2019), “An input-output model for simulating the substitution of primary raw materials – A case study for Germany”, forthcoming.

The conventional approach is confined to describe the use of primary raw materials. Substitutional factors of the RMES-model are comprising immaterial renewable energies, waste for recovery of energy (incineration) and waste for recovery of material (recycling). The use of those factors is substituting primary raw material consumption.

The conventional IOT-based RME accounting models are confined to describing the raw material content of products of final use in relationship to the economic driving forces. Resource efficiency is a major indicator for that accounting system.

Substitution of primary raw materials has a direct impact on the development of resource efficiency. The conventional approach is measuring the effect of replacing primary raw materials by substitutional factors only indirectly as a reduction of the use of primary materials. But, it is not visible whether and to what extend individual substitutional factors have contributed to the reduction.

It was the purpose of the DeteRess approach for an RMES-model to expand the analytical scope by explicitly showing the interaction of primary raw materials and substitutional factors.

5.1 Technical implementation

Technically the conventional model is modified by the following changes:

- Environmental extension: The environmental extension for the conventional model is exclusively comprised of primary raw materials. For the purpose of the RMES-model the above described substitutional factors are added to the environmental extension. Depending on the analytical purposes, different degrees of disaggregation for substitutional factors are conceivable.
- The IOT matrix is disaggregated accordingly by explicitly showing the corresponding product flows. That is, the following types of disaggregation are introduced:
    1. Electricity (CPA 35.1) is split into conventional electricity generation and electricity generation which is based on immaterial renewable sources (e.g. wind. hydro, solar voltaic).
    2. Heat (CPA 35.31) is split into conventional heat generation and on heat generation which is based on immaterial renewable sources (e.g. solar thermal, geo-thermal).
    3. The product group sewerage and waste (CPA 37, 38, 3) is disaggregated for accommodating waste for energy recovery and different sectors for recycling (waste for material recovery) and the remaining other sewerage and waste sector.

The RMES-model is assigning substitutional factors to products of final use in the same manner as for primary raw materials.

5.2 Data availability

With respect to the RMES-model for Germany for the year 2010, a rather comprehensive coverage of substitutional factors could be established due to the availability of various special studies on recycling.

In comparison, for implementing RME-model at the EU level, a number of data restrictions have to be regarded.

The data situation is favorable with respect to immaterial renewable energies and energetic recovery of waste. Those data are easily accessible from the energy balance for EU countries as well as for Non-EU countries.

Data availability is also comparatively favorable with respect to metal recycling. Currently, annual metal recycling ratios for five major metals (steel, copper, aluminium, lead and zinc) are already being collected for the purpose of the RME country tool in a breakdown by countries. That information is predominantly based on USGS data. The metal recycling ratio of an individual metal shows the share of secondary metal at the total production of unwrought metal. Probably, the coverage of metal could be extended to some more metals in near future and to Non-EU countries, if required. Metal recycling ratios are the most crucial information for establishing sales structures for individual basic metals, for ores and for recycled material.

However, with respect to other recycling, data availability for EU countries is currently rather limited. That is, a lot of data work will be needed for establishing a comprehensive coverage of recycling activities with a level of detail that can serve the purpose of the envisaged IOT based model.

6 Summary

Aggregation error is inherent to any input-output analysis including the current Eurostat RME model. The theoretical part of this report shows the complexity of the aggregation error, which makes it difficult to find the ideal disaggregation level. The results of testing different aggregation levels show that unacceptable deviations can be expected for monetary input-output models even with aggregation level equivalent to the current Eurostat RME model.

It was shown that pure monetary models are not able to provide accurate results sufficiently. Therefore, it is proposed to use a **hybrid model** (partly monetary sales structures are replaced by physical structures).

The relationship between precision and the level of disaggregation was checked by applying the model for Denmark, Germany and EU. It turned out that the minimum level of disaggregation is rather depending on the analytical purpose.

The precision level was defined as the standard deviation of the options from the reference approach HIOT182 (hybrid input-output table by 182 product groups). If exclusively **economy-wide RME indicators** are needed and if a precision level of 2-3 % is considered to be sufficient, the HIOT117 could be applied as the minimum disaggregation option. In case a **breakdown by detailed raw material categories** is needed, the HIOT134 can be considered as minimum level, if an accuracy threshold of 5 % is accepted. But if **results by product groups** are required, the investigation results are suggesting that only option HIOT182 would be sufficient.

The result stated above is predominantly applying to intra-EU disaggregation. But the above described minimum level might also be applied in case of non-EU disaggregation.

However, in the specific case of intra-EU disaggregation, which is the central focus of this report, an analysis of the costs curve for data procurement in relationship to different disaggregation options is showing a rather specific shape (see Figure 10). Usually, it could be expected that the costs are increasing with the level of disaggregation. Yet, that specific curve is remaining almost constant in the middle part. That constant branch of the curve is applying to all disaggregation levels which are being considered as relevant, ranging from at least 117 sectors to the maximum level of 182 sectors. The reason for that specific pattern goes back to the fact that almost all required data can be easily extracted from EUROBASE and that the efforts do not differ significantly for the considered range of disaggregation levels. Insofar, **option HIOT182 is representing the optimum disaggregation level** which is providing the highest level of precision in comparison to the other options without higher costs. Therefore, it is recommended to use HIOT182 as the preferred disaggregation option for the intra-EU model.

Furthermore, we provide results for a physical use extension approach on a more disaggregated model, which avoids disaggregation of most primary sectors. However, the effort of creating the use extensions is almost equivalent to the proper disaggregation regarding data and resources.

With respect to EUROBASE data, it has to be stated that there are considerable data gaps due to confidentiality reason. If this data is not disclosed, other methodological or organizational solutions need to be developed for gap filling in order to avoid significant impairment of the results.

For the disaggregation of the EU inter-county IOT from the level of 64 to 182 sectors a country-by-country approach is proposed. By that approach the country blocks of the model are disaggregated and balanced by keeping the already balanced system with coherent imports, exports, outputs and inputs. That task is quite different and much less complex than establishing a new MRIO model on the basis of non-harmonized national IOTs.

As an approach for balancing the IOT matrices for the purpose of intra-EU disaggregation we suggest a RAS-type approach as it was used for the EU RME model or alternatively an optimisation technique or other programming method.

Three different options are discussed for estimating the RME of imports of EU countries from non-EU countries. The simplest option would be to apply the ADTA approach of the Eurostat RME-model, but more appropriate yet feasible might be to establish a rest-of-the-world input-output table.

We suggest to estimate the MFA indicators in raw material equivalents with the current EU RME model([16]) until a reliable MRIO model with sufficient level of detail is available to take over this task.

([16]) See for the documentation of the EU RME model:
https://ec.europa.eu/eurostat/documents/1798247/6874172/Documentation+of+the+EU+RME+model/

7 Appendix I – Additional results

The complete results are attached in the following Excel files:

a) results_RME_aggregations_hybrid.xlsx (option a) in which the aggregation error of RME of imports enters the calculation of the other RME indicators)

b) results_RME_aggregations_original_RME_imports_hybrid.xlsx (option b) in which the original RME of imports is applied for the calculation of RME indicators, the aggregation error of RME of imports therefore does not enter the calculation of the other RME indicators)

c) results_RME_aggregations_PUext.xlsx (physical use extension approach)

d) results_RME_aggregations_original_RME_imports_PUext.xlsx

results_RME_aggregations_hybrid.xlsx   results_RME_aggregations_original_RME_   results_RME_aggregations_PUext.xlsx   results_RME_aggregations_original_RME_

Both files include two spreadsheets for each RME indicator, one for absolute values (xx_abs), one for relative values (xx_rel). Each column of the results is named according to a product bridge in the bridges_products_hybrid.xlsx and bridges_products_PUext.xlsx excel files:

bridges_products_hybrid.xlsx   bridges_products_PUext.xlsx

8 Appendix II – Classification for the EU RME-Model by 182 product groups, HIOT117 and HIOT155

Table 13: Classification for the EU RME-Model by 182 product groups ([17]) (non-disaggregated products are emphasized by green)

RME-code		RME-name
RME001	01.11.1-4, 01.12	Cereals
RME002	01.11.6, 01.13 (excl. 01.13.5, 01.13.7)	Green leguminous vegetables, vegetables and melons (excl. edible roots and
RME003	01.11.7	Dried leguminous vegetables
RME004	01.11.8, 01.11.9, 01.26.1	Soya beans, groundnuts and cotton seed, other oil seeds
RME005	01.13.5	Edible roots and tubers with high starch or inulin conten
RME006	01.13.7, 01.14	Sugar beet and sugar beet seed, sugar cane
RME007	01.15	Unmanufactured tobacco
RME008	01.16	Fibre crops
RME009	01.19.1, 01.11.5	Forage crops, incl. grazed biomass
RME010	01.2 (excl. 01.25.3, 01.26.1, 01.27, 01.28. 10.29)	Fruits
RME011	01.19.2, 01.19.3, 01.25.3, 01.27, 01.28, 01.29, 01.3	Other crop products
RME012	01.41.1, 01.42	Dairy cattle, liv,e other cattle and buffaloes, live and their semen
RME013	01.41.2	Raw milk from dairy cattle
RME014	01.46	Swine, live
RME015	1.43, 01.44, 01.45, 01.49	Other animals and animal products, incl. hunting and trapping and related
RME016	01.47.1	Poultry, live
RME017	01.47.2	Eggs, in shell, fresh
RME018	01.9	Farm manure and other agricultural waste products
RME019	01.6	Agricultural and animal husbandry services (except veterinary services)
RME020	02	Products of forestry, logging and related services
RME021	03	Fish and other fishing products; aquaculture products; support services to fishing
RME022	05.1	Hard coal
RME023	05.2	Lignite
RME024	06.10.1	Petroleum oils and oils obtained from bituminous minerals, crude
RME025	06.10.2	Bituminous or oil shale and tar sands
RME026	06.2	Natural gas, liquefied or in gaseous state
RME027	07.1	Iron ores
RME028	07.21	Uranium and thorium ores
RME029	07.29.11	Copper ores and concentrates
RME030	07.29.12	Nickel ores and concentrates

([17]) Note that item CPA 68 (real estate services is including the item „Imputed rents of owner-occupied dwellings“).

RME031	07.29.13	Aluminium ores and concentrates
RME032	07.29.14.a	Gold
RME033	07.29.14.b	Silver
RME034	07.29.14.c	Platinum MG
RME035	07.29.15.a	Lead
RME036	07.29.15.b	Zinc
RME037	07.29.15.c	Tin
RME038	07.29.19.a	Tungsten ores and concentrates
RME039	07.29.19.b	Tantalum ores and concentrates
RME040	07.29.19.c	Magnesium ores and concentrates
RME041	07.29.19.d	Titanium ores (Ilmenite) and concentrates
RME042	07.29.19.e	Manganese ores and concentrates
RME043	07.29.19.f	Chromium ores and concentrates
RME044	07.29.19.g	Other ores and concentrates
RME045	08.11.1	Ornamental or building stone
RME046	08.11.2	Limestone and gypsum
RME047	08.11.3	Chalk and uncalcined dolomite
RME048	08.11.4	Slate
RME049	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
RME050	08.12.13	Mixtures of slag and similar industrial waste products, whether or not incorporating pebbles, gravel, shingle and flint for construction use - recycling
RME051	08.12.2	Clays and kaolin
RME052	08.91	Chemical and fertiliser minerals
RME053	08.92	Peat
RME054	08.93	Salt and pure sodium chloride; sea water
RME055	08.99	Other mining and quarrying products nec
RME056	09	Mining support services
RME057	10.1	Preserved meat and meat products
RME058	10.2	Processed and preserved fish, crustaceans and molluscs
RME059	10.3	Processed and preserved fruit and vegetables
RME060	10.4	Vegetable and animal oils and fats
RME061	10.5	Dairy products
RME062	10.6	Grain mill products, starches and starch products
RME063	10.7, 10.8	Other food products
RME064	10.91	Prepared feeds for farm animals
RME065	10.92	Prepared pet foods
RME066	11	Beverages
RME067	12	Tobacco products
RME068	13	Textiles
RME069	14	Wearing apparel
RME070	15	Leather and related products
RME071	16	Wood and of products of wood and cork, except furniture; articles of straw and plaiting
RME072	17.1	Pulp, paper and paperboard
RME073	17.2	Articles of paper and paperboard
RME074	18	Printing and recording services
RME075	19.1	Coke oven products
RME076	19.2	Refined petroleum products
RME077	20.1, (excl. 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
RME078	20.15	Fertilisers and nitrogen compounds
RME079	20.16	Plastics in primary forms
RME080	20.2	Pesticides and other agrochemical products
RME081	20.3	Paints, varnishes and similar coatings, printing ink and mastics
RME082	20.4	Soap and detergents, cleaning and polishing preparations, perfumes and toilet
RME083	20.5	Other chemical products
RME084	20.6	Man-made fibres
RME085	21	Basic pharmaceutical products and pharmaceutical preparations
RME086	22.1	Rubber products
RME087	22.2	Plastic products
RME088	23.1	Glass and glass products
RME089	23.2	Refractory products
RME090	23.3	Clay building materials
RME091	23.4	Other porcelain and ceramic products
RME092	23.5	Cement, lime and plaster
RME093	23.6	Articles of concrete, cement and plaster
RME094	23.7	Cut, shaped and finished stone
RME095	23.9	Other non-metallic mineral products
RME096	24.1-3	Basic iron and steel and ferro-alloys
RME097	24.41.1, 24.41.4, 24.41.5, 24.41.9	Silver, unwrought or in semi-manufactured forms, or in powder form
RME098	24.41.2	Gold, unwrought or in semi-manufactured forms, or in powder form
RME099	24.41.3	Platinum, unwrought or in semi-manufactured forms, or in powder form
RME100	24.42	Aluminium
RME101	24.43.11, 24.43.21, 24.43.9	Lead
RME102	24.43.12, 24.43.22, 24.43.23	Zinc
RME103	24.43.13, 24.43.24	Tin
RME104	24.44	Copper
RME105	24.45.1, 24.45.2, 24.45.9	Nickel, unwrought; intermediate products of nickel metallurgy
RME106	24.45.3.a	Tungsten products
RME107	24.45.3.b	Tantalum products
RME108	24.45.3.c	Magnesium products

RME109	24.45.3.d	Titanium products
RME110	24.45.3.e	Manganese products
RME111	24.45.3.f	Chromium products
RME112	24.45.3.g	Other non-ferrous metal products
RME113	24.46	Processed nuclear fuel
RME114	24.51	Casting services of iron
RME115	24.52	Casting services of steel
RME116	24.53	Casting services of light metals
RME117	24.54	Casting services of other non-ferrous metals
RME118	25.1	Structural metal products
RME119	25.2	Tanks, reservoirs and containers of metal
RME120	25.3	Steam generators, except central heating hot water boilers
RME121	25.5	Forging, pressing, stamping and roll-forming services of metal; powder metallurgy
RME122	25.6	Treatment and coating services of metals; machining
RME123	25.7	Cutlery, tools and general hardware
RME124	25.4, 25.9	Other fabricated metal products, incl weapons and ammunition
RME125	26	Computer, electronic and optical products
RME126	27	Electrical equipment
RME127	28	Machinery and equipment nec
RME128	29	Motor vehicles, trailers and semi-trailers
RME129	30.1	Ships and boats
RME130	30.2	Railway locomotives and rolling stock
RME131	30.3	Air and spacecraft and related machinery
RME132	30.4, 30.9	Transport equipment nec, incl military fighting vehicles
RME133	31	Furniture
RME134	32.1	Jewellery, bijouterie and related articles
RME135	32.2	Musical instruments
RME136	32.3	Sports goods
RME137	32.4	Games and toys
RME138	32.5	Medical and dental instruments and supplies
RME139	32.9	Manufactured goods nec
RME140	33	Repair and installation services of machinery and equipment
RME141	35.1	Electricity, transmission and distribution services
RME142	35.2	Manufactured gas; distribution services of gaseous fuels through mains
RME143	35.3	Steam and air conditioning supply services
RME144	36	Natural water; water treatment and supply services
RME145	37, 38, 39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services
RME146	41, 42, 43	Construction and construction works
RME147	45	Wholesale and retail trade and repair services of motor vehicles and motorcycles
RME148	46	Wholesale trade services, except of motor vehicles and motorcycles
RME149	47	Retail trade services, except of motor vehicles and motorcycles
RME150	49	Land transport services and transport services via pipelines
RME151	50	Water transport services
RME152	51	Air transport services
RME153	52	Warehousing and support services for transportation
RME154	53	Postal and courier services
RME155	55, 56	Accomodation and food services
RME156	58	Publishing services
RME157	59, 60	Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services
RME158	61	Telecommunications services
RME159	62, 63	Computer programming, consultancy and related services; information services
RME160	64	Financial services, except insurance and pension funding
RME161	65	Insurance, reinsurance and pension funding services, except compulsory social security
RME162	66	Services auxiliary to financial services and insurance services
RME163	68	Real estate services
RME164	69, 70	Legal and accounting services; services of head offices; management consulting services
RME165	71	Architectural and engineering services; technical testing and analysis services
RME166	72	Scientific research and development services
RME167	73	Advertising and market research services
RME168	74, 75	Other professional, scientific and technical services; veterinary services
RME169	77	Rental and leasing services
RME170	78	Employment services
RME171	79	Travel agency, tour operator and other reservation services and related services
RME172	80, 81, 82	Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services
RME173	84	Public administration and defence services; compulsory social security services
RME174	85	Education services
RME175	86	Human health services
RME176	87, 88	Social work services
RME177	90, 91, 92	Creative, arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services
RME178	93	Sporting services and amusement and recreation services
RME179	94	Services furnished by membership organisations
RME180	95	Repair services of computers and personal and household goods
RME181	96	Other personal services
RME182	97, 98	Services of households as employers; undifferentiated goods and services produced by households for own use

At the level of resolution by 182 sectors, the breakdown of activities of extraction of raw materials is already almost fully corresponding to the breakdown of domestic extraction. The disaggregation of primary processing of raw materials, which is also crucial for RME accounting, is widely following that level of breakdown.

Table 14: Classification of HIOT117

FIGARO	Proposed disaggregation for HIOT117
Agriculture (NACE 01)	- Cereals - Green leguminous vegetables, vegetables and melons (excl. edible roots and tubers and sugar beet) - Dried leguminous vegetables - Soya beans, groundnuts and cotton seed, other oil seeds - Edible roots and tubers with high starch or inulin content - Sugar beet and sugar beet seed, sugar cane - Unmanufactured tobacco - Fibre crops - Forage crops, incl. grazed biomass - Fruits - Other crop products - Dairy cattle (live), other cattle and buffaloes, live and their semen, aggregated with raw milk from dairy cattle; swine (live), aggregated with poultry (live), eggs (in shell, fresh), farm manure and other agricultural waste products, and agricultural and animal husbandry services (except veterinary services); Other animals and animal products, incl. hunting and trapping and related services
Mining and quarrying (NACE B)	- Hard coal - Lignite - Petroleum oils and oils obtained from bituminous minerals, crude - Bituminous or oil shale and tar sands - Natural gas, liquefied or in gaseous state - Iron ores - Uranium and thorium ores - Copper ores and concentrates - Nickel ores and concentrates - Aluminium ores and concentrates - Gold - Silver - Platinum MG - Lead - Zinc - Tin - Tungsten ores and concentrates - Tantalum ores and concentrates - Magnesium ores and concentrates - Titanium ores (Ilmenite) and concentrates - Manganese ores and concentrates - Chromium ores and concentrates - Other ores and concentrates - Ornamental or building stone - Limestone and gypsum - Chalk and uncalcined dolomite - Slate - Gravel and sand, excl. mixtures of slag and similar industrial waste products, whether or not incorporating pebbles, gravel, shingle and flint for construction use - Mixtures of slag and similar industrial waste products, whether or not incorporating pebbles, gravel, shingle and flint for construction userecycling - Clays and kaolin - Chemical and fertiliser minerals - Peat - Salt and pure sodium chloride; sea water - Other mining and quarrying products nec - Mining support services
Food, beverages and tobacco (NACE 10-12)	- Livestock food products (preserved meat and meat products and dairy products) - Processed and preserved fish, crustaceans and molluscs; Vegetable and animal oils and fats; Other food beverages and tobacco products (Processed and preserved fruit and vegetables, grain mill products, starches and starch products; Other food products, prepared feeds for farm animals, prepared pet foods, beverages, tobacco products)
Other non-metallic mineral products (NACE 23)	- Glass and porcelain (Glass and glass products, other porcelain and ceramic products) - Other nonmetallic mineral products (Articles of concrete, cement and plaster; refractory products, clay building materials, cement, lime and plaster, cut, shaped and finished stone, other nonmetallic mineral products)
Basic metals (NACE 24)	- Iron and steel (Basic iron and steel and ferroalloys,casting services of iron, casting services of steel) - Gold; Silver; Platinum - Copper - Nickel - Processed nuclear fuel - Other metals and services (Tin, magnesium products, tantalum products, titanium products, chromium products, casting services of other nonferrous metals, aluminium, lead, zinc, tungsten products, manganese products, other nonferous metal products, casting services of light metals)
Electricity, gas, steam and air-conditioning (NACE 35)	- Electricity and steam (Electricity, transmission and distribution services, steam and air conditioning supply services) - Manufactured gas; distribution services of gaseous fuels through mains

Table 15: Classification of HIOT155

FIGARO	Proposed disaggregation for HIOT155
Agriculture (NACE 01)	- Cereals - Green leguminous vegetables, vegetables and melons (excl. edible roots and tubers and sugar beet) - Dried leguminous vegetables - Soya beans, groundnuts and cotton seed, other oil seeds - Edible roots and tubers with high starch or inulin content - Sugar beet and sugar beet seed, sugar cane - Unmanufactured tobacco - Fibre crops - Forage crops, incl. grazed biomass - Fruits - Other crop products - Dairy cattle, live other cattle and buffaloes, live and their semen; - Raw milk from dairy cattle - Swine, live - Poultry, live - Eggs, in shell, fresh, - Farm manure and other agricultural waste products - Agricultural and animal husbandry services (except veterinary services) - Other animals and animal products, incl. hunting and trapping and related services
Mining and quarrying (NACE B)	- Hard coal - Lignite - Petroleum oils and oils obtained from bituminous minerals, crude - Bituminous or oil shale and tar sands - Natural gas, liquefied or in gaseous state - Iron ores - Uranium and thorium ores - Copper ores and concentrates - Nickel ores and concentrates - Aluminium ores and concentrates - Gold - Silver - Platinum MG - Lead - Zinc - Tin - Tungsten ores and concentrates - Tantalum ores and concentrates - Magnesium ores and concentrates - Titanium ores (Ilmenite) and concentrates - Manganese ores and concentrates - Chromium ores and concentrates - Other ores and concentrates - Ornamental or building stone - Limestone and gypsum - Chalk and uncalcined dolomite - Slate - Gravel and sand, excl. mixtures of slag and similar industrial waste products, whether or not incorporating pebbles, gravel, shingle and flint for construction use - Mixtures of slag and similar industrial waste products, whether or not incorporating pebbles, gravel, shingle and flint for construction userecycling - Clays and kaolin - Chemical and fertiliser minerals - Peat - Salt and pure sodium chloride; sea water - Other mining and quarrying products nec - Mining support services
Food, beverages and tobacco (NACE 10-12)	- Preserved meat and meat products - Dairy products - Processed and preserved fish, crustaceans and molluscs - Vegetable and animal oils and fats - Processed and preserved fruit and vegetables - Grain mill products, starches and starch products, - Other food products, - Prepared feeds for farm animals, - Prepared pet foods, - Beverages, - Tobacco products
Other non-metallic mineral products (NACE 23)	- Glass and glass products, - Other porcelain and ceramic products - Articles of concrete, cement and plaster - Refractory products - Clay building materials - Cement, lime and plaster - Cut, shaped and finished stone - Other nonmetallic mineral products

Basic metals (NACE 24)	- Basic iron and steel and ferroalloys - Casting services of steel - Casting services of iron - Gold - Silver - Platinum - Copper - Nickel - Processed nuclear fuel - Tin - Magnesium products - Tantalum products - Titanium products - Chromium products - Casting services of other nonferrous metals - Aluminium - Lead - Zinc - Tungsten products - Manganese products - Other nonferous metal products - Casting services of light metals
Electricity, gas, steam and air-conditioning (NACE 35)	- Electricity, transmission and distribution services - Steam and air conditioning supply services - Manufactured gas; distribution services of gaseous fuels through mains

9 Appendix III – Data availability for disaggregation in the case of SBS and Prodcom

9.1. SBS

9.1.1. Mining and Quarrying

Table 16: SBS classification for mining and quarrying

	Mining and quarrying
B05	Mining of coal and lignite
B051	Mining of hard coal
B0510	Mining of hard coal
B052	Mining of lignite
B0520	Mining of lignite
B06	Extraction of crude petroleum and natural gas
B061	Extraction of crude petroleum
B0610	Extraction of crude petroleum
B062	Extraction of natural gas
B0620	Extraction of natural gas
B07	Mining of metal ores
B071	Mining of iron ores
B0710	Mining of iron ores
B072	Mining of non-ferrous metal ores
B0721	Mining of uranium and thorium ores
B0729	Mining of other non-ferrous metal ores
B08	Other mining and quarrying
B081	Quarrying of stone, sand and clay
B0811	Quarrying of ornamental and building stone, limestone, gypsum, chalk and slate
B0812	Operation of gravel and sand pits; mining of clays and kaolin
B089	Mining and quarrying n.e.c.
B0891	Mining of chemical and fertiliser minerals
B0892	Extraction of peat
B0893	Extraction of salt
B0899	Other mining and quarrying n.e.c.
B09	Mining support service activities
B091	Support activities for petroleum and natural gas extraction
B0910	Support activities for petroleum and natural gas extraction
B099	Support activities for other mining and quarrying
B0990	Support activities for other mining and quarrying

The available breakdown of SBS for mining and quarrying is not sufficient for supporting the 182 classification, especially with respect to metal ores and non-metallic minerals. For that purpose, SBS has to be supplemented by more detailed results from Prodcom and some other sources.

The available breakdown of SBS might probably be sufficient for establishing a variant of a moderate disaggregation level. However, for metal ores, the breakdown by only three product groups which is offered by SBS, is likely to be insufficient in view of the very high differences between the RME intensities for the individual metals. That is, more disaggregation is needed even in case of a moderate breakdown. In that case, more detailed data from Prodcom are required (see Section 2.5).

9.1.2. Food, beverages and tobacco

Table 17: SBS classification for food, beverages and tobacco

	Manufacture of food products; beverages and tobacco products
C101	Processing and preserving of meat and production of meat products
C102	Processing and preserving of fish, crustaceans and molluscs
C103	Processing and preserving of fruit and vegetables
C104	Manufacture of vegetable and animal oils and fats
C105	Manufacture of dairy products
C106	Manufacture of grain mill products, starches and starch products
C107	Manufacture of bakery and farinaceous products
C108	Manufacture of other food products
C109	Manufacture of prepared animal feeds
C1091	Manufacture of prepared feeds for farm animals
C1092	Manufacture of prepared pet foods
C11	Manufacture of beverages
C12	Manufacture of tobacco products

The data requirement for disaggregating the food sector to the 182 level is fully met by SBS. Moderate disaggregation levels, like a subdivision into the sectors animal products and other products can only be obtained by aggregating 3-digit level data. That is, the costs of data procurement are not significantly different to the full breakdown of this sector.

9.1.3. Non-metallic mineral products

Table 18: SBS classification for non-metallic mineral products

	Manufacture of non-metallic mineral products
C231	Manufacture of glass and glass products
C232	Manufacture of refractory products
C233	Manufacture of clay building materials
C234	Manufacture of other porcelain and ceramic products
C235	Manufacture of cement, lime and plaster
C236	Manufacture of articles of concrete, cement and plaster
C237	Cutting, shaping and finishing of stone
C239	Manufacture of abrasive products and non-metallic mineral products n.e.c.

The data requirement for disaggregating non-metallic minerals to the 182 level is fully met by SBS. Moderate disaggregation levels, like a subdivision into the sectors construction materials and other products can only be obtained by aggregating 3-digit level data. That is, the costs of data procurement are not significantly different to the full breakdown of this sector.

9.1.4. Basic metals

Table 19: SBS classification for basic metals

	Manufacture of basic metals
C241	Manufacture of basic iron and steel and of ferro-alloys
C242	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
C243	Manufacture of other products of first processing of steel
C2441	Precious metals production
C2442	Aluminium production
C2443	Lead, zinc and tin production
C2444	Copper production
C2445	Other non-ferrous metal production
C2446	Processing of nuclear fuel
C2451	Casting of iron
C2452	Casting of steel
C2453	Casting of light metals
C2454	Casting of other non-ferrous metals

The requirement for disaggregation of basic metals to the level of the 182 level is only partly met by SBS. No further disaggregation is provided for “Precious metals production”, “Lead, zinc and tin production” and “Other non-ferrous metal production”. For disaggregating those sectors further information from Prodcom has to be utilized (see Section 2.5).

9.1.5. Electricity, manufactured gas and heat

Table 20: SBS classification for electricity, manufacture of gas and heat

	Electricity, manufacture of gas and heat
D351	Electric power generation, transmission and distribution
D352	Manufacture of gas; distribution of gaseous fuels through mains
D353	Steam and air conditioning supply

The data requirement for disaggregating the sector “Electricity, manufactures gas and heat” to the 182 level is fully met by SBS. Moderate disaggregation levels, like putting together electricity and heat, can only be obtained by aggregating 3-digit level data. That is, the costs of data procurement are not different to the full breakdown of this sector.

9.1.6. Disaggregation of other sectors

Table 21: SBS classification for other sectors

	Other sectors
C13	Manufacture of textiles
C14	Manufacture of wearing apparel
C15	Manufacture of leather and related products
C171	Manufacture of pulp, paper and paperboard
C172	Manufacture of articles of paper and paperboard
C191	Manufacture of coke oven products
C192	Manufacture of refined petroleum products
C201	Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms
C2015	Manufacture of fertilisers and nitrogen compounds
C2016	Manufacture of plastics in primary forms
C202	Manufacture of pesticides and other agrochemical products
C203	Manufacture of paints, varnishes and similar coatings, printing ink and mastics
C204	Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations
C205	Manufacture of other chemical products
C206	Manufacture of man-made fibres
C221	Manufacture of rubber products
C222	Manufacture of plastics products
C251	Manufacture of structural metal products
C252	Manufacture of tanks, reservoirs and containers of metal
C253	Manufacture of steam generators, except central heating hot water boilers
C254	Manufacture of weapons and ammunition
C255	Forging, pressing, stamping and roll-forming of metal; powder metallurgy
C256	Treatment and coating of metals; machining
C257	Manufacture of cutlery, tools and general hardware
C259	Manufacture of other fabricated metal products
C301	Building of ships and boats
C302	Manufacture of railway locomotives and rolling stock
C303	Manufacture of air and spacecraft and related machinery
C304	Manufacture of military fighting vehicles
C309	Manufacture of transport equipment n.e.c.
C31	Manufacture of furniture
C321	Manufacture of jewellery, bijouterie and related articles
C322	Manufacture of musical instruments
C323	Manufacture of sports goods
C324	Manufacture of games and toys
C325	Manufacture of medical and dental instruments and supplies
C329	Manufacturing n.e.c.

The data requirement for disaggregating “Other sectors” to the 182 level is fully met by SBS. The alternative in this case would not be to go for a moderate disaggregation, but to refrain from disaggregating other sectors at all. However, as those data are easily available, the costs saving effect of skipping the disaggregation of other sectors will be close to negligible.

9.2 Prodcom

9.2.1 Mining of metal ores

Table 22: Prodcom classification for metal ores

	Metal ores
7101000	Iron ores and concentrates (excluding roasted iron pyrites)
7291100	Copper ores and concentrates
7291200	Nickel ores and concentrates
7291300	Aluminium ores and concentrates
7291400	Precious metal ores and concentrates
7291500	Lead, zinc and tin ores and concentrates
7291900	Other non-ferrous metal ores and concentrates

The Prodcom classification for metal ores is providing more detailed information on “Mining of non-ferrous metal ores” in comparison to SBS. However, that breakdown by the 8-digit level of the Prodcom classification is not sufficient for fully meeting the requirement for disaggregation up to the 182 level. For that purpose, supplementary sources have to be applied. See Section 2.6.

9.2.2 Mining and quarrying of non-metallic minerals

Table 23: Prodcom classification for non-metallic minerals

	Non-metallic minerals
8111133	Marble and travertine, crude or roughly trimmed
8111136	Marble and travertine merely cut into rectangular or square blocks or slabs
8111150	Ecaussine and other calcareous monumental or building stone of an apparent specific gravity >= 2.5
8111233	Granite, crude or roughly trimmed
8111236	Granite merely cut into rectangular (including square) blocks or slabs
8111250	Sandstone
8111290	Porphyry, basalt, quartzites and other monumental or building stone, crude, roughly trimmed or merely cut (excluding calcareous monumental or building stone of a gravity >= 2.5, granite and sandstone)
8112030	Gypsum and anhydrite
8112050	Limestone flux, limestone and other calcareous stone used for the manufacture of lime or cement (excluding crushed limestone aggregate and calcareous dimension stone)
8113010	Chalk
8113030	Dolomite, crude, roughly trimmed or merely cut into rectangular or square blocks or slabs (excluding calcined or sintered dolomite, agglomerated dolomite and broken or crushed dolomite for concrete aggregates, road metalling or railway or other ballast)
8114000	Slate, crude, roughly trimmed or merely cut into rectangular or square blocks or slabs
8121150	Silica sands (quartz sands or industrial sands)
8121190	Construction sands such as clayey sands; kaolinic sands; feldspathic sands (excluding silica sands, metal bearing sands)
8121210	Gravel and pebbles of a kind used for concrete aggregates, for road metalling or for railway or other ballast; shingle and flint
8121230	Crushed stone of a kind used for concrete aggregates, for road metalling or for railway or other ballast (excluding gravel, pebbles, shingle and flint)
8121250	Granules, chippings and powder of marble
8121290	Granules, chippings and powder of travertine, ecaussine, granite, porphyry, basalt, sandstone and other monumental stone
8121300	Mixtures of slag and similar industrial waste products, whether or not incorporating pebbles, gravel, shingle and flint for construction use
8122140	Kaolin, not calcined
8122160	Kaolinitic clays (ball and plastic clays)
8122210	Bentonite
8122230	Fireclay
8122250	Common clays and shales for construction use (excluding bentonite, fireclay, expanded clays, kaolin and kaolinic clays); andalusite, kyanite and sillimanite; mullite; chamotte or dinas earths
8911100	Natural calcium phosphates; natural aluminium calcium phosphates and phosphatic chalk
8911200	Unroasted iron pyrites; crude or unrefined sulphur (including recovered sulphur)
8911900	Other chemical and fertiliser minerals
8931000	Salt (including denatured salt but excluding salt suitable for human consumption) and pure sodium chloride, whether or not in aqueous solution or containing added anti-caking or free-flowing agents
8991000	Natural bitumen and natural asphalt; asphaltites and asphaltic rocks
8992100	Precious and semi-precious stones (excluding industrial diamonds), unworked or simply sawn or roughly shaped
8992200	Industrial diamonds, unworked or simply sawn, cleaved or bruted; pumice stone; emery; natural corundum, natural garnet and other natural abrasives
8992900	Other minerals

The Prodcom 8-digit classification for non-metallic minerals is providing full details for disaggregation of SBS information up to the level of the 182 classification. In case of a more moderate disaggregation no costs for gap filling could be saved.

9.2.3 Non-ferrous basic metals

Table 24: **Prodcom classification for non-ferrous basic metals (excl. copper and aluminium)**

	Non-ferrous basic metals (excl. Copper and aluminium)
24411030	Silver, unwrought or in powder form (including plated with gold or platinum)
24411050	Silver, in semi-manufactured forms (including plated with gold or platinum) (excluding unwrought or in powder form)
24412030	Gold, unwrought or in powder form for non-monetary use (including plated with platinum)
24412050	Gold, in semi-manufactured forms for non-monetary use (including plated with platinum) (excluding unwrought or in powder form)
24412070	Monetary gold (including gold plated with platinum)
24413030	Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form
24413050	Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)
24413070	Platinum catalysts in the form of wire cloth or grill
24414000	Base metals or silver, clad with gold, semi-manufactured but not further worked
24415030	Base metals clad with silver, semi-manufactured but not further worked
24415050	Base metals, silver or gold, clad with platinum, semi-manufactured but not further worked
24431130	Refined unwrought lead (excluding lead powders or flakes)
24431150	Unwrought lead containing antimony (excluding lead powders or flakes)
24431190	Unwrought lead (excluding lead powders or flakes, unwrought lead containing antimony, refined)
24431230	Unwrought non-alloy zinc (excluding zinc dust, powders and flakes)
24431250	Unwrought zinc alloys (excluding zinc dust, powders and flakes)
24431330	Unwrought non-alloy tin (excluding tin powders and flakes)
24431350	Unwrought tin alloys (excluding tin powders and flakes)
24432100	Lead plates, sheets, strip and foil; lead powders and flakes (excluding lead powders or flakes prepared as colours; paints or the like, insulated electric strip)
24432200	Zinc dust, powders and flakes (excluding zinc dust powders or flakes prepared as colours, paints or the like, zinc pellets)
24432300	Zinc bars, rods, profiles, wire, plates, sheets, strip and foil
24432400	Tin bars, rods, profiles and wires
24451100	Nickel, unwrought
24451200	Nickel mattes, nickel oxide sinters and other intermediate products of nickel metallurgy (including impure nickel oxides, nickel speiss, impure ferro-nickel)
24452100	Nickel powders and flakes (excluding nickel oxide sinters)
24452200	Nickel and nickel alloy bars, rods, profiles and wires (excluding prepared bars, rods or profiles for use in structures, insulated electric bars and wire, enamelled wire)
24452300	Nickel and nickel alloy plate, sheet, strip and foil (excluding expanded metal)
24452400	Nickel tubes, pipes and tube or pipe fittings
24453013	Tungsten (wolfram) and articles thereof (excluding waste and scrap), n.e.c.
24453017	Molybdenum and articles thereof (excluding waste and scrap), n.e.c.
24453023	Tantalum and articles thereof (excluding waste and scrap), n.e.c.
24453025	Magnesium and articles thereof (excluding waste and scrap), n.e.c.
24453027	Cobalt mattes and other intermediate products of cobalt metallurgy; cobalt and articles thereof (excluding waste and scrap), n.e.c.
24453030	Bismuth and articles thereof, including waste and scrap, n.e.c.; cadmium and articles thereof (excluding waste and scrap), n.e.c.
24453043	Titanium and articles thereof (excluding waste and scrap), n.e.c.
24453047	Zirconium and articles thereof (excluding waste and scrap), n.e.c.; antimony and articles thereof (excluding waste and scrap), n.e.c.
24453055	Beryllium, chromium, germanium, vanadium, gallium, hafnium (`celtium¿), indium, niobium (`columbium¿), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
24453057	Manganese and articles thereof, including waste and scrap, n.e.c.; cermets and articles thereof, including waste and scrap, n.e.c.

The Prodcom 8-digit classification for non-ferrous basic metals is providing full details for disaggregation of SBS information up to the relevel of the 182 classification. In case of a more moderate disaggregation no costs for gap filling could be saved.

10 Appendix IV – Selected results of the DeteRess report

The DeteRess report is has conducted analysis which is rather similar to this report (Schoer, Dittrich et al. 2018) for UBA (Germany) within the project DeteRess([18]). The aim of the document was to answer the following 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 of their report)?
- What method could be applied for estimating a detailed sectoral disaggregation of country IOTs (Sections 2.4 and 3.2 of their report)?
- Which principal approach and what level of regional resolution could be envisaged for a high-resolution MRIO model?

The below tables show some major results.

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 HIOT182 in %

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

	MIOT64	MIOT66	MIOT74	MIOT83	MIOT124	MIOT155	MIOT182	HIOT155	HIOT182
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
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	2.0	1.8	1.7	3.2	-1.9	0.0

Figure 11: Disaggregation error for EU and Germany in comparison to the HIOT 182 (%)

([18]) https://www.ifeu.de/projekt/deteress/

Degree of accuracy of RME of exports by disaggregation approach by main raw material categories and countries

Measured as differences to reference value MIOT182 in %

- 0 Reference value
- 1 Accurate: absolute deviation from the reference value not more than 3%
- 2 Sufficient: absolute deviation from the reference value more than 3% up to 5%
- 3 Insufficient: absolute deviation from the reference value more than 5% up to 10%
- 4 Highly insufficient: absolute deviation from the reference value more than 10 %

	MIOT64	MIOT66	MIOT74	MIOT83	MIOT124	MIOT155	MIOT182
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
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
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
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	-0.3	0.0
Fossil energy carriers	9.0	17.4	2.4	2.5	-2.3	-2.6	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
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

Figure 12: Disaggregation error of the major exporting countries globally in comparison to MIOT 182

Degree of accuracy of RME of exports by disaggregation approaches and detailed raw material categories

Measured as differences to reference value HIOT182 in %

0 Reference value
1 Accurate: absolute deviation from the reference value not more than 3%
2 Sufficient: absolute deviation from the reference value more than 3% up to 5%
3 Insufficient: absolute deviation from the reference value more than 5% up to 10%
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
Biomass	-8.9	-9.4	-11.6	-7.1	-11.7	-3.9	-0.8	-0.8	-0.2	0
Cereals	-20.5	-20.5	-21.1	-8.3	-21.2	-4.1	-2.3	-2.3	0.0	0
Roots, tubers	64.8	64.8	61.8	-4.7	61.9	-13.2	-13.2	-13.2	0.1	0
Sugar crops	21.8	21.8	20.0	83.1	20.2	89.1	86.8	86.4	0.5	0
Pulses	2.5	2.5	1.6	11.4	1.6	15.4	22.2	22.1	0.1	0
Nuts	-18.4	-18.4	-19.6	-18.4	-19.6	-21.4	-22.8	-22.0	-0.8	0
Oil bearing crops	-35.0	-35.0	-35.5	-33.9	-35.3	-31.9	-3.3	-4.5	2.2	0
Vegetables	32.1	32.1	30.1	18.9	30.3	2.7	-0.4	-0.3	0.0	0
Fruits	57.2	57.2	54.7	35.9	54.9	9.4	5.0	5.0	0.0	0
Fibres	-10.6	-10.6	-10.7	-10.6	-10.7	-5.6	-5.6	1.5	-7.3	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
Straw	-9.1	-9.2	-10.0	-9.2	-10.2	-2.8	-1.5	-1.6	0.1	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
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
Timber (Industrial roundwood)	-3.0	-4.7	-10.6	-10.7	-10.6	-10.5	-10.4	-9.8	-1.5	0
Wood fuel and other extraction	-1.2	-4.2	-14.3	-14.4	-14.1	-14.0	-13.8	-13.5	-1.6	0
Fish catch	-21.5	-23.0	-27.4	-27.5	-27.9	-27.9	-24.8	-24.4	-0.4	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
Hunting and gathering	-32.0	-32.0	-29.9	-8.9	-30.4	0.3	-0.5	-0.1	-0.4	0
Metal ores	-16.9	-8.4	-8.1	-8.4	-2.0	-2.4	0.7	0.8	-0.1	0
Iron ores	-21.1	-4.3	4.4	-4.3	3.5	3.5	3.5	3.4	0.1	0
Copper	-2.3	6.2	0.5	6.2	1.2	1.2	1.2	0.6	0.6	0
Nickel	3.2	5.9	4.2	5.9	-2.7	-2.2	1.3	1.7	-0.4	0
Lead	-27.6	-11.7	-10.2	-11.7	-11.4	-11.3	-0.1	0.3	-0.4	0
Zinc	2.6	9.7	10.3	9.7	8.7	8.6	1.7	0.6	1.1	0
Tin	1.3	1.3	1.3	1.3	0.0	0.0	-0.1	0.5	-0.6	0
Gold - gross ore	-32.3	-32.2	-32.4	-32.2	-7.6	-7.6	-0.2	-0.1	-0.2	0
Silver - gross ore	-13.8	-13.2	-14.4	-13.2	17.2	16.8	-0.7	0.0	-0.7	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
Bauxite and other aluminium	-5.2	0.8	3.9	0.8	-2.6	-2.6	-2.2	-2.6	0.3	0
Uranium and thorium	5.5	6.8	7.0	6.8	2.7	2.6	-4.4	-4.6	0.1	0
Tungsten - gross ore	8.3	9.0	9.2	9.0	4.2	2.8	3.8	3.4	0.5	0
Tantalum - gross ore	-10.9	-10.9	-10.9	-10.9	-24.1	-24.1	0.4	0.1	0.3	0
Mangnesium ores - gross ore	17.4	17.4	17.4	17.4	0.8	0.8	1.5	0.5	1.1	0
Titanium - gross ore	-37.6	-11.9	-6.4	-11.9	-14.6	-19.7	-2.2	0.1	-2.2	0
Manganese - gross ore	6.5	6.9	7.0	6.9	4.7	4.8	3.6	3.6	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
Other metal ores - gross ore	-10.5	-0.5	-2.8	-0.5	-8.7	-8.5	1.2	1.0	0.1	0
Non-metallic minerals	32.5	25.4	8.8	15.4	3.9	9.4	8.2	8.4	-0.3	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
Chalk and dolomite	1.3	0.8	-2.8	5.9	-6.3	2.4	1.4	1.7	-0.3	0
Slate	10.3	6.8	-2.5	9.5	-8.1	6.5	2.1	2.9	-0.8	0
Chemical and fertilizer minerals	-46.3	-48.3	-38.5	-15.8	-39.1	-7.2	-6.8	-7.9	2.1	0
Salt	-21.1	-25.4	-4.3	6.4	-5.7	11.6	12.3	11.9	1.4	0
Limestone and gypsum	2.3	-1.6	-13.3	4.1	-16.4	-3.1	-8.7	-7.8	-0.9	0
Clays and kaolin	-1.1	-5.8	-19.5	-23.0	-22.9	-27.0	-24.7	-24.2	-0.4	0
Sand and gravel	69.8	59.1	27.5	30.3	20.1	20.7	20.2	20.4	-0.5	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
Fossil energy carriers	-3.2	-5.1	0.3	-1.9	2.0	1.8	1.7	3.2	-1.9	0
Lignite (brown coal)	4.9	0.9	15.9	13.3	20.8	19.8	19.3	20.0	-1.2	0
Hard coal	-5.4	-7.3	0.3	-5.7	2.0	2.2	1.9	5.6	-5.3	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
Peat	-28.5	-30.3	-21.7	-30.3	-22.3	-17.6	-15.8	-16.5	0.3	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
Natural gas	-0.7	0.5	8.1	-2.4	7.8	7.8	8.1	9.7	-1.9	0

Figure 13: Degree of accuracy of RME of exports by disaggregation approaches and detailed raw material categories, measured as differences to reference value HIOT182 (%)

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Disaggregating input-output tables for the calculation of raw material footprints — Minimum requirements, possible methods, data sources and proposed method for Eurostat

KS-TC-21-002-EN-N

This report provides guidance on the use of the FIGARO multi-regional input-output dataset for estimation and in-depth analysis of material flow indicators in raw material equivalents (RME). The report reviews existing studies focused on aggregation error and disaggregation methods for input-output tables and it presents findings from our calculations based on the current Eurostat RME model. We conclude that monetary models are not able to provide sufficiently accurate results even at high sectoral disaggregation. We propose using a hybrid unit model in which monetary sales structures are replaced by physical sales structures for selected products.

For more information

https://ec.europa.eu/eurostat/

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