Documentation of the EU RME model

October 2024

Preface

Eurostat has developed the EU RME model to estimate raw material consumption (RMC) and other raw material equivalent-based indicators for the EU economy. Material flow accounts in raw material equivalents (MFA-RME) are an extension to the economy-wide material flow accounts (EW-MFA). In the latter, trade flows are measured in actual physical quantities, whereas in the former, trade flows are recorded in terms of the raw material extraction that was needed to produce the traded products. The following indicators are estimated with the model:

- Imports in Raw Material Equivalents (IMP_RME)
- Raw Material Input (RMI)
- Exports in Raw Material Equivalents (EXP_RME)
- Raw Material Consumption (RMC)

The purpose of the documentation is to provide background information on the methodology and computations underlying the EU RME model to advanced users of the MFA-RME, to compilers of MFA-RME and to others interested.

The RME estimates are published in Eurostat's database in two datasets:

1) Material flow accounts in raw material equivalents - modelling estimates (online data code: env_ac_rme), which contains indicators in RME by material and

2) Material flow accounts in raw material equivalents by final uses of products - modelling estimates (online data code: env_ac_rmefd), which contains raw material consumption estimates by material, by final product and by type of final use.

For compiling estimates at the country level, Eurostat has published the country RME tool accompanied by a handbook and a set of data input files. This documentation, the tool and the supporting information can also be found on the methodology page of Eurostat's online dedicated section on Environment.

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Version

The original version of the documentation was published in 2012 with the title “Conversion of European Product Flows into Raw Material Equivalents”.[1] The handbook has been updated in December 2016 to reflect the major changes of the model including an update to NACE Rev. 2. In 2017, only minor changes were made to reflect small methodological adjustments. In 2018, Chapter 2.9 was added, the reference results were updated and some minor editing took place. In 2019, the reference results were updated. In 2020, against the backdrop of UK leaving the European Union, the EU RME Model was shifted from a EU28 model to a EU27 based model. Further, methodological changes were incorporated into the energy balance, which are described in chapter 2.4.2. Since 2023, the FIGARO IOTs are incorporated and reference results are updated annually.

[1] Eurostat’s successive projects for development of the EU RME model were 1) “Conceptual framework for measuring the environmental impact of the use of Natural Resources and Products (2008/S 149 – 199643/EN)”, 2) “Assistance in the development and maintenance of Raw Material Equivalents conversion factors and calculation of RMC time series (2010/A 127 – 193618)” , 3) "Regular up-dating and further methodological development of Eurostat’s RME model (2013/S 122-208385)” and 4) "RME Model (2016/S 151-272611) . The original version of the documentation was the final report of project two.

Table of contents

Preface ... 2

Acknowledgements ... 2

Version ... 3

Table of contents ... 4

List of figures ... 6

List of tables ... 6

Abbreviations and acronyms ... 7

1 Introduction ... 9

1.1 Background of calculating raw material equivalents ... 9

1.2 Central approach of the model ... 12

2 The calculation model ... 15

2.1 Introduction and overview of the calculation model ... 15

2.2 Leontief's input-output analysis ... 18

2.2.1 Concept ... 18

2.2.2 Application to Eurostat's RME model ... 19

2.3 High-resolution monetary IOT ... 20

2.3.1 Concept and rationale ... 20

2.3.2 Calculation method and data sources ... 21

2.3.3 Structural information based on the German high-resolution IOT ... 21

2.4 High-resolution hybrid IOT ... 23

2.4.1 Concept and rationale ... 23

2.4.2 Calculation method and data sources ... 24

2.5 External regionalised information for estimating the RME of metal imports ... 24

2.5.1 Concept and rationale ... 24

2.5.2 Calculation method and data sources ... 25

2.6 Revaluation of imports at domestic prices ... 26

2.6.1 Concept and rationale ... 26

2.6.2 Calculation method and data sources ... 26

2.7 Regionalised information for estimating recycling ratios for indirect metal imports ... 26

2.7.1 Concept and rationale ... 26

2.7.2 Calculation method and data sources ... 27

2.8 Regionalised information for estimating the energy mix of direct and indirect imports of electricity 27

2.8.1 Concept and rationale 27

2.8.2 Calculation method and data sources 27

2.9 Regionalised steel LCA-coefficients for energy use of steel imports....28

2.9.1 Concept and rationale 28

2.9.2 Calculation method and data sources 28

2.10 RME of imports – quality assessment 29

2.11 Numerical example of calculation of RME of imports in RME by the ADTA-IO model ..33

2.12 Calculation of the time series for the RME from 2000 onwards 40

3 MFA-RME at country level 41

4 Reference results....42

5 Annex 47

5.1 Literature 47

5.2 Data sources 48

5.3 Classifications....50

5.3.1 Classification of the high-resolution hybrid IOT 50

5.3.2 Expanded EW-MFA classification for materials (domestic extraction)....56

List of figures

Figure 1: Comparison of EW-MFA and MFA-RME 2022 13
Figure 2: Calculation steps and data sources for the RME calculation 17
Figure 3: Example of an input-output table 18
Figure 4: Impact of "method mix" on the quality of the estimates for RME of imports 32
Figure 5: EW-MFA vs. RME indicators per capita for the year 2022 42
Figure 6: Raw Material Consumption in the EU 2022 by main raw material categories 43
Figure 7: Raw Material Consumption per capita 2008-2022 43
Figure 8: Resource productivity vs. GDP 44

List of tables

Table 1: Method mix for estimating RME of imports 16
Table 2: RME of imports by aggregated product groups and main material categories 23
Table 3: Method mix for calculation of RME of imports 31
Table 4: Numerical example IOT 33
Table 5: Results of the RME model 2022 by material flow indicators 45

Abbreviations and acronyms

ADTA-IO	Adapted domestic technology assumption input-output model
CN8	Combined nomenclature 8-digit detail
COMEXT	Eurostat statistical database on trade of goods
CPA	Classification of products by activity
DE	Domestic extraction
DeteRess	German research project on determinants of future raw material use
DMC	Domestic material consumption
DMI	Direct material input
DTA	Domestic technology assumption
ECOINVENT	Database with lifecycle inventory data
EU	European Union
EUR	Euro
EW-MFA	Economy-wide material flow accounts
ESA	European system of national and regional accounts
EXP	Exports
FIGARO	Full international and global accounts for research in input-output Analysis
GCV	Gross calorific value
GDP	Gross domestic product
IMF	International Monetary Fund
IMP	Imports
IO	Input-output
IOT	Input-output table
ISO	International Organization for Standardization
LCA	Life-cycle analysis
LCI	Life-cycle inventory
M3	Cubic metres
MFA-RME	Material flow accounts in raw material equivalents

MIOT	Monetary input-output table
MRIO	Multi-regional input-output model
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne (Statistical classification of economic activities in the European Community)
n.e.c.	Not elsewhere classified
NGL	Natural gas liquids
PRODCOM	Production Communautaire, survey on industrial production in the EU
RAS	Iterative algorithm for estimating cell values of an input-output table
Rev.	Revision
RMC	Raw material consumption
RME	Raw material equivalents
RMI	Raw material input
SBS	Structural business statistics
SEEA	System of environmental-economic accounting
SIOT	Symmetric input-output table
SUT	Supply and use tables
t	Tonne
TOE	Tonnes of oil equivalent
TJ	Terajoule
UN	United Nations
USGS	United States Geological Survey

1 Introduction

1.1 Background of calculating raw material equivalents

In 2019, the European Commission released the European Green Deal. The framework of the Green Deal sets out a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy. The transition of the EU also implies that there are no net emissions of greenhouse gases in 2050 and that economic growth is decoupled from resource use.[2]

The Green Deal is an integral part of the European Commission's strategy to implement the United Nation's 2030 Agenda and the sustainable development goals (SDGs). SDG 8 and 12, amongst others, specifically include material footprints as an indicator to monitor the development.[3]

Further, the EU set out a new circular economy action plan that will help modernise the EU's economy and draw benefit from the opportunities of the circular economy domestically and globally. A key aim of the new circular economy policy framework will be to stimulate the development of lead markets for climate neutral and circular products, in the EU and beyond. The action plan will focus in particular on resource-intensive sectors such as textiles, construction, electronics and plastics where the potential for circularity is high.[4]

In October 2019, the Council of the European Union adopted a set of conclusions regarding the development of an eight (8th) Environment Action Plan (EAP). The 8th EAP will be guiding European environment and climate change policies for 2021-2030.[5] One key objective of the 7th EAP, that expired in 2020, was the transition of the European Union into a resource-efficient, green, and competitive low-carbon economy.[6]

Against this backdrop, and in order to monitor the European Commission's resource use, Eurostat has established an indicator scoreboard in which resource productivity is the lead indicator.

To measure resource productivity, domestic material consumption (DMC) is related to gross domestic product (GDP). DMC is derived from economy-wide material flow accounts (EW-MFA) covering all material inputs into national economies, the changes of stocks and their respective outputs. It is defined as the total amount of material directly used in a given economy. DMC is calculated by subtracting the exports from the direct material input (DMI) of an economy with DMI being the sum of domestic extraction (DE) and imports.

Several research projects and expert groups pointed out that the value of the DMI as a basis for the DMC depends strongly on the origin of the input. If e.g. metal ore is extracted domestically the total amount of ore is accounted for, but if metals are imported, only their imported mass (product weight) is used. This asymmetry led to the proposal to express all imported goods and exported goods in terms

[2] https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF
[3] https://sustainabledevelopment.un.org/post2015/transformingourworld
[4] https://ec.europa.eu/environment/circular-economy/
[5] https://www.europeansources.info/record/8th-environment-action-programme-council-adopts-conclusions/
[6] https://ec.europa.eu/environment/action-programme/

of raw material content. Consequently, all imported and exported semi-finished and finished goods are expressed in raw material equivalents (RME).

Also the European Commission has expressed the aim to integrate indirect or embodied material consumption into the lead indicator measuring resource productivity (see Section 3.4 of [Commission Staff Working Paper SEC(2011) 1067 final]).

Eurostat's aim was to provide an alternative to the DMC indicator: raw material consumption (RMC) which is expressed in raw materials equivalents. Conversion factors were needed to translate the masses of imported and exported goods into RME. A methodology had been developed in a past project to estimate material flow accounts in RME (MFA-RME) with a reasonable effort.[7,8] The methodology is based on an integration of data from input-output-tables (IOTs) and life-cycle-inventory data.

In the former project, a first set of RME conversion factors were developed and applied for selected import and export product categories for the EU-27 and for Germany as a pilot country. The set of RME factors was regarded as a first estimate. It was the aim of this project to consolidate the method and the results and to develop an approach for calculating time series of RME-accounts by an automated procedure. A major element of the methodological consolidation was to develop an empirically more broadly founded world metal model for estimating raw materials coefficients for imported metals.

The environmentally-extended input-output modelling approach for calculating RME presented in this report is consistent with the system of Integrated Environmental Economic Accounting (SEEA)[9] which is designed for depicting the interaction between the economy and the environment in a systematic and coherent manner. The economic system at European level is described by the European economic accounting system of ESA[10]. Input-output tables (IOTs) are an integral part of the ESA[11,12]. Applying an IOT-based approach for estimating RME supports the objective of embedding those indicators into the accounting system. A specific IOT-based calculation model was developed which we denote ADTA-IO model (adapted domestic technology assumption input-output model). The type of approach is sometimes also referred to as a hybrid life cycle analysis (LCA) in the literature.[13] It has to be noted that the LCA method is conceptually not aligned with ESA and SEEA. That is, the environmentally-extended input-output model is supplemented by external information, which is partly based on life cycle inventory (LCI) data, in order to integrate regionalised information to the

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7 Schoer et al. (2012a): Conversion of European Product Flows into Raw Material Equivalents, Final report of the project: Assistance in the development and maintenance of Raw Material Equivalents conversion factors and calculation of RMC time series, Heidelberg.

8 Schoer et al. (2012b): Raw Material Consumption of the European Union–Concept, Calculation Method, and Results. Environmental Science & Technology 46, 8903-8909.

9 UN, European Commission, UN FAO, IMF, OECD, World Bank, 2014: System of Environmental-Economic Accounting 2012: Central Framework. United Nations, New York.

10 Eurostat (2010): European System of Accounts, ESA 2010, Luxemburg

11 Eurostat (2008): Eurostat Manual of Supply, Use and Input-Output Tables, 2008 Edition http://ec.europa.eu/eurostat/documents/3859598/5902113/KS-RA-07-013-EN.PDF/b0b3d71e-3930-4442-94be-70b36cea9b39?version=1.0.

12 The Input-Output approach is a sub-module of the ESA framework. The input-output framework consists of three types of tables: a) supply and use tables, b) tables linking the supply and use tables to the sector accounts and c) symmetric input-output tables. Supply and use tables are matrices by industry and product describing the domestic production processes and the transactions in products of the national economy in great detail. Symmetric input-output tables show those relationships either in a product-by-product or in an industry-by-industry format. For the purpose of this RME model the symmetric product-by-product table is applied.

13 Joshi, S. (2000): Product environmental life-cycle assessment using input-output techniques. Journal of Industrial Ecology 3(2-3): 95–120.

model. However, the LCA method as defined by the International Organization for Standardization (ISO) is actually not applied. Only LCI data is used.

This report presents the **annual automated calculation model** for converting product flows into raw material equivalents (RMEs). The calculation approach provides detailed annual results on product flows in RME in a breakdown by the following dimensions:

- Categories of final uses and imports
- 182 product groups
- 51 raw material categories (without aggregates)

A previous version of this model, which was based on the NACE Rev 1.1 classification, was published in 2012 (see Schoer, K. et al., 2012a). The results of that model (2000-2013) were annually updated and published on Eurostat's online database. The model that is described in this documentation represents a revised version of the NACE Rev 1.1 based model. The major change is the migration from the NACE Rev 1.1 to NACE Rev. 2 classification. In addition, a number of methodical improvements were introduced with the primary aim of improving the estimates for RME of imports, such as increasing the degree of resolution of the IOT, improving the price concepts and the utilisation of further regionalised information.

The current version of the model represents the EU27 economy as of March 2020 (i.e. excluding the UK).

1.2 Central approach of the model

The main purpose of establishing estimates in RME is to extend the EW-MFA and offer an alternative to the indicator DMC.

The term **raw materials equivalent** (RME) corresponds conceptually to the term domestic extraction (DE) of the EW-MFA system. The RME model converts product flows into raw material equivalents. RME is the unit used to express product flows in their equivalent domestic extraction instead of using the simple product weight. The RME concept thus takes the perspective of raw materials embodied in products. The RME of a product indicates how much extraction of material was necessary over the whole production chain for manufacturing that specific product, irrespective of whether those raw materials were extracted domestically or in the rest of the world.

One important aim of physical flow accounting within EW-MFA is to derive indicators – one of the most important indicators being the DMC - which are used for the purpose of European policies such as Sustainable Development Goals (SDGs), the European Green Deal, circular economy, Europe 2020 and the resource efficiency scoreboard.

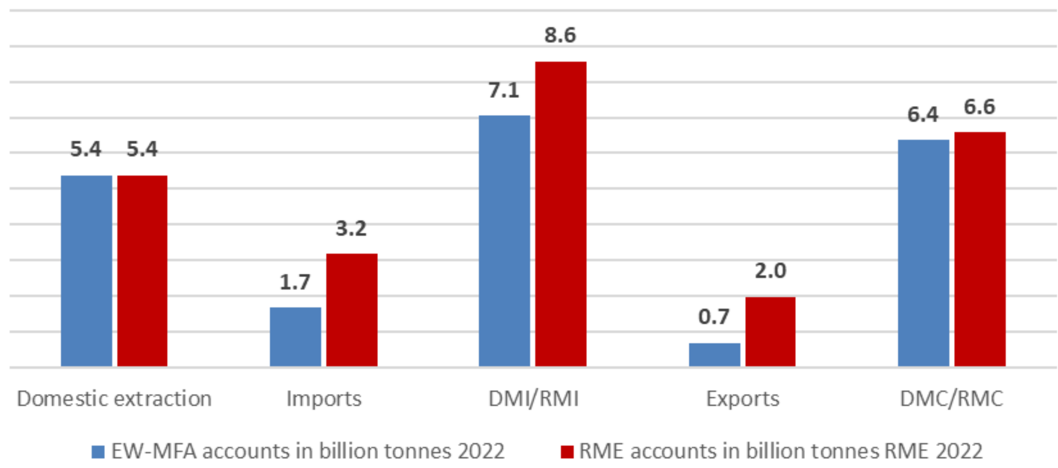
However, the DMC indicator inherently bears two major asymmetries:

1. The imports and export are measured in a different "unit" than the domestic extraction (DE). The latter is measured in virgin raw material extraction (e.g. tonnes of gross iron ore which is much heavier than the resulting steel). Trade is measured in simple product weight only (e.g. tonnes of steel).
2. The composition of imports and exports can differ leading to a further asymmetry. For the EU, one knows that products with a rather low degree of processing, like metal ores or primary energy carriers, dominate the imports. These raw or semi-manufactured products have a relatively low value of tonne RME per tonne of product in comparison to more finished products. EU exports are rather dominated by finished products, like cars, machinery etc. The weight of the finished products usually represents only a fraction of the weight of raw materials that were originally extracted for their manufacturing. This means that 1 million tonnes of imported products – measured in simple product weight – have a significant lower RME than 1 million tonnes of exported products.

The RME concept overcomes these asymmetries by considering the imports and exports measured in raw material equivalents, which represent the same "unit" as domestic extraction (DE).

Figure 1 illustrates the differences between original EW-MFA values and the corresponding RME results. It shows that imports expressed in RME are more than twice as high as the values provided by EW-MFA. For exports, the difference is even more pronounced: exports in RME are three to four times as high as the original EW-MFA results.

Figure 1: Comparison of EW-MFA and MFA-RME 2022



Eurostat aims to establish economy wide indicators whose trade components are "converted" from product weight into RME. The following accounting rule shows how the indicators – following the RME concept – are derived:

Domestic extraction (DE)

\+ Imports in raw material equivalents (IMP_{RME})

= Raw material input (RMI)

\- Exports in raw material equivalents (EXP_{RME})

= Raw material consumption (RMC)

It has to be pointed out that it is an important property of the RME accounting system that the above accounting identity is not only valid for total materials, but also at the level of individual raw material categories. In contrast, the DMC can only be disaggregated to the level of aggregated raw material categories (biomass, metal ores, non-metallic minerals and fossil energy resources) as semi-finished and finished imported and exported products can only be lumped together into rather broad material categories such as “products mainly from biomass” or “products mainly from metals”.

Besides the **Improvement of the mass flow indicator DMC** by converting product flows into flows of raw material equivalents the detailed RME model is able to serve further analytical purposes.

- **Establishing an ecological link** by a detailed disaggregation of RMEs by 51 material flow categories. A detailed disaggregation by material flow categories accounts for the fact that different raw material categories can have extremely different characteristics in terms of their environmental impact. The disaggregation is therefore a precondition for a meaningful ecological analysis and interpretation of material flows.
- **Establishing an economic link** by relating the direct and indirect demand for raw materials by 51 material flow categories to the final use of products by 182 product groups. Further, the underlying IOT establishes a link between the final use of products and the direct economic production and consumption activities. That link is essential for embedding the material flow indicator into an environmental-economic context that is able to relate the demand for raw materials to the economic driving forces.

The following chapter continues with a detailed description of the RME calculation model. It starts with some general considerations and a short overview of the steps and the data sources of the calculation model. In the following subsections, the principal steps of the calculation model are described in a more detailed manner.

2 The calculation model

2.1 Introduction and overview of the calculation model

The RME model for converting product flows into raw material equivalents is based on Leontief's input-output analysis[14]. Raw material inputs into an economy (environmental extension) are allocated to product groups by using the information of an input-output table (IOT). The IOT is depicting the interrelationships between economic production activities.

The core of the RME model is a high-resolution IOT with 182x182 product groups (see Annex 5.3.1: Product classification of the high-resolution hybrid IOT). In comparison, Eurostat's monetary standard IOT (discontinued in 2022) distinguish 64 products groups. Further for selected product groups the sales structures (the rows of the table) are expressed in physical instead of monetary units (hybrid IOT), as indicated in Annex 5.3.1. The replacement of monetary sales structures by physical structures accounts for the fact that for some product groups, such as raw products and firstly processed raw products, flows of embodied raw materials are represented more accurately by physical than by monetary relationships. The higher resolution in conjunction with hybrid sales structures ensures an improved depiction of the raw material content of product groups.

Finally, a crucial issue for the quality of the results is how the RME of imports are estimated, which account for about 40% of total RMI. In the basic model, the RME of imports is estimated under the assumption that the imported products are manufactured with the same technology as analogous domestic products, also referred to as the domestic technology assumption (DTA). However, in reality it cannot be expected that the production technology in the countries of origin of imports is sufficiently similar for all product groups.

From a pure conceptual perspective, using a multiregional input-output model (MRIO) instead of a model relying on the DTA would be the perfect solution as a multiregional model estimates import coefficients that fully represent the production conditions of the countries of origin of imports. However, from a practical point of view it has to be regarded that implementing MRIO models is extremely resource and data demanding. Further, the accuracy of the currently available MRIO models and databases is still suffering from a low resolution of the model and/or insufficient quality of auxiliary data[15].

Therefore, for the purpose of Eurostat's RME model a pragmatic approach was developed for overcoming the insufficiency of DTA. The approach integrates a combination of different adjustments (calculation methods) for replacing or improving DTA-based estimates for individual elements of the RME matrix of imports. Table 1 gives a general overview of the methods applied for estimating adjusted RME of imports.

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[14] Miller, Ronald E and Blair, Peter D. (2009): Input-Output Analysis, Foundations and Extensions, Cambridge University Press, Cambridge, United Kingdom.

[15] Karl Schoer, Richard Wood, Iñaki Arto, and Jan Weinzettel (2013): Estimating Raw Material Equivalents on a Macro-Level: Comparison of Multi-Regional Input−Output Analysis and Hybrid LCI-IO, Environ. Sci. Technol. 2013, 47, 14282−14289.

Table 1: Method mix for estimating RME of imports

1	2	3	4	5	6
High resolution IOT 182	Physical sales structures for selected product groups	Regionalised external approach for metals	Valuation of imports at domestic prices	Regionalised adjustment of embodied metals for recycling ratio	Regionalised adjustment of embodied electricity for energy mix

Figure 2 schematically illustrates the steps and the data sources[16] of the RME calculation procedure.

The RME calculation procedure consists of the following principal steps:

RME model for calculation of 2010 and onwards (NACE Rev. 2 model)

- Establishing an annual **high-resolution monetary IOT** by expanding the monetary FIGARO standard IOT 64x64 to the size of 182x182
- Establishing a **high-resolution hybrid IOT**. The high-resolution monetary IOT is converted into an IOT with mixed units by inserting physical sales structures for selected product groups.
- Collecting and disaggregating (only for metal ores) data on **domestic extraction**
- Estimating the **RME of direct metal ore and basic metal imports** based on external regionalised information
- **Leontief inverse based on the DTA/LCA (metals)**, 1st loop
- **Revaluation of imports at domestic prices**
- Adding **further regionalised information** on metal recycling ratios and primary metal content of indirect metal imports
- Adding **further regionalised information** on the energy mix of electricity generation
- **Leontief inverse based on the adjusted matrix for the RME of imports,** 2nd loop, final results for RME 2010 and onwards

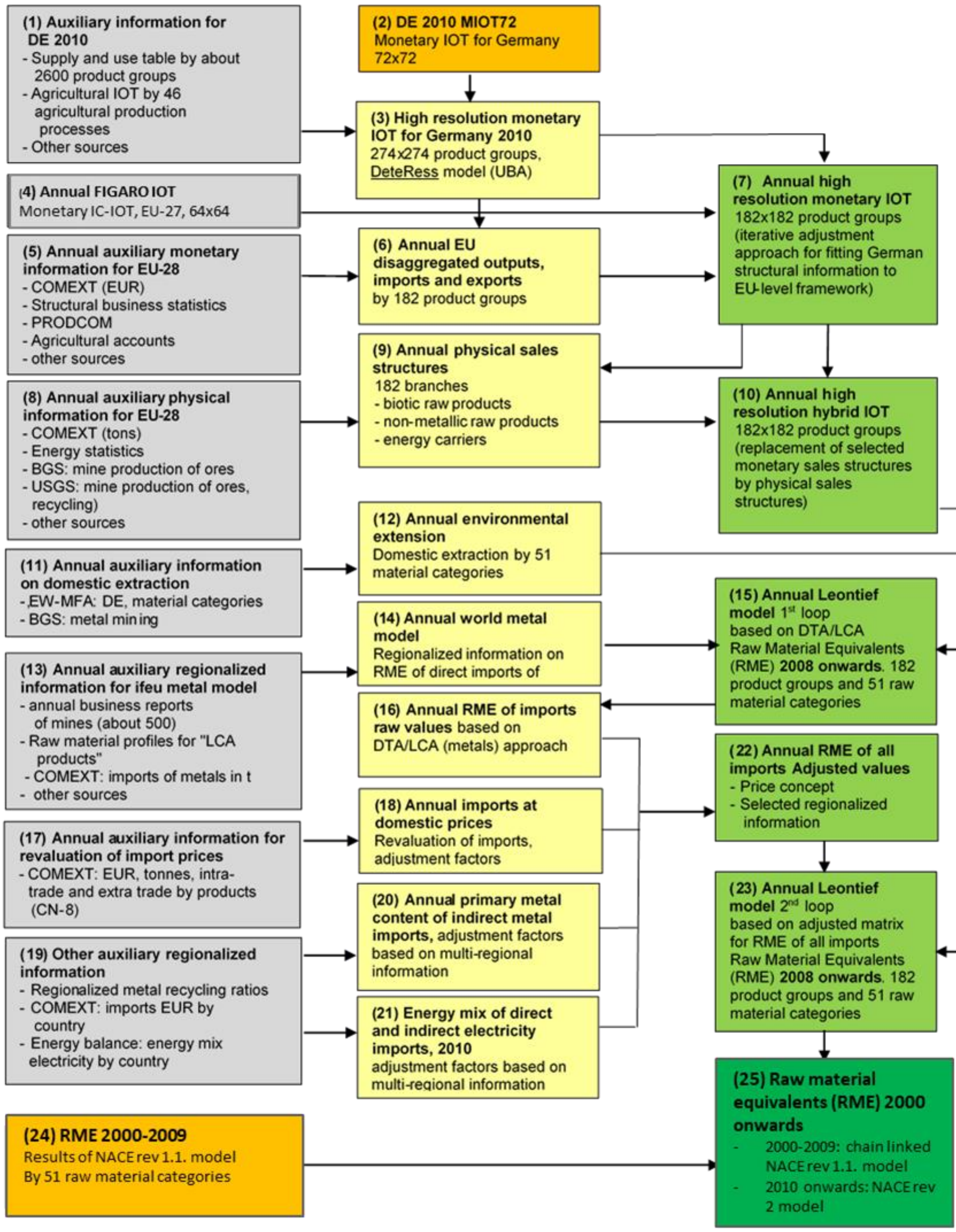
Full time series 2000 and onwards

- Chain linking RME results for 2000-2009 (NACE Rev 1.1 model) with the results of NACE rev 2 model at the level of 51 raw material categories.

In the following sections, the elements of the calculation procedure are explained in more detail. The description starts with an introduction into Leontief's input-output analysis as the underlying method and continues with describing the individual elements of the calculation procedure. In a concluding section, the quality of the results is assessed.

[16] A detailed overview of data sources is provided in Annex 5.2

Figure 2: Calculation steps and data sources for the RME calculation



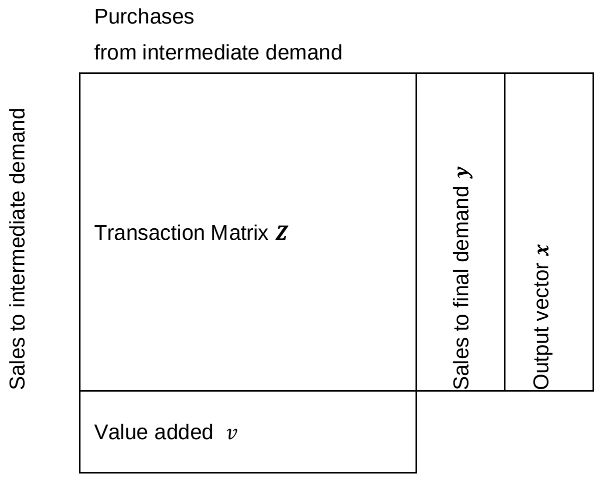
2.2 Leontief's input-output analysis

2.2.1 Concept

Input-output analysis was originally developed by Wassily Leontief in the 1930s, who was awarded with the Nobel Prize in Economics in 1973 for his contribution. Initially used for the monitoring of economic development of countries, it is now one of the most widely applied methods for economic and environmental analysis and accounting. Data on flows of products from each industrial sector to other sectors and itself is used to construct so-called input-output tables (IOTs) representing economic activities of a region, usually in monetary terms. Since the mathematical structure of an IOT is in its core a set of linear equations, matrix representations are used for the calculations.

In the following, a brief explanation of the general approach is given. Assume that the economy is represented by n sectors each producing a homogeneous product. The inter-sectoral flows within an economy then form a $n \times n$ matrix $\boldsymbol{Z}$, sales to final demand constitute a n x 1 vector $\boldsymbol{y}$ and total output of each sector is given by a $n \times 1$ vector $\boldsymbol{x}$.

Figure 3: Example of an input-output table



The input-output table in Figure 3 represents the following economic relationship:

$$\boldsymbol{x} = \boldsymbol{Zi} + \boldsymbol{y} \tag{1}$$

where $\boldsymbol{i}$ is a vector of ones with the same length as the number of columns of $\boldsymbol{Z}$. The result of $\boldsymbol{Zi}$ is a vector with the sums of the elements in each row of matrix $\boldsymbol{Z}$.[17] If we divide each flow (i.e. each element of $\boldsymbol{Z}$) by the total output of the sector (i.e. the corresponding element of $\boldsymbol{x}$), the $n \times n$ matrix of direct input coefficients $\boldsymbol{A}$ (often denoted as technology coefficient matrix) is obtained. A diagonalised vector[18] of total output $\boldsymbol{x}$ is used to perform this computation:

$$\boldsymbol{A} = \boldsymbol{Z} \times \boldsymbol{diag}(\boldsymbol{x})^{-1} \tag{2}$$

[17] The equations in this section represent basic linear algebra operations on vectors and matrices; please consult for example Appendix A in Miller and Blair (2009) or any basic textbook on matrix algebra for more information.
[d] diag stands for this diagonalisation and it means that a square matrix is created from a vector, which values are placed on the matrix diagonal and all other elements are equal to zero.

The direct input coefficients (i.e. the elements of the matrix $\boldsymbol{A}$) denote the amount of industry input required to provide one unit of output by sector (direct industry input). Replacing $\boldsymbol{Z}$ in the Equation 1, we obtain:

$$\boldsymbol{x} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{y} \tag{3}$$

Solving Equation 3 for total economic output $\boldsymbol{x}$ introduces the Leontief inverse $\boldsymbol{L} = (\boldsymbol{I} - \boldsymbol{A})^{-1}$ where $\boldsymbol{I}$ is the identity matrix of the same extension as $\boldsymbol{A}$ matrix with ones on the diagonal and zeroes for all other values:

$$\boldsymbol{x} = (\boldsymbol{I} - \boldsymbol{A})^{-1} \times \boldsymbol{y} \tag{4}$$

The Leontief inverse $\boldsymbol{L}$ represents the industry amounts required to provide one unit of output to final demand (cumulative or total industry input coefficients). While the basic IOT captures inter-sectoral flows only, it is possible to extend IOTs to include additional in- and outputs in satellite accounts according to specific needs (see for example Chapter 13 of EC (2008) for more information). For environmental accounting (e.g. UN SEEA), the IOT is extended with data on resource use, emissions and/or other environmental information. If domestic extraction is taken, total domestic extraction is differentiated by resource m and sector/product group n to create an $m \times n$ matrix $\boldsymbol{DE}$. Analogously to the transaction matrix $\boldsymbol{Z}$, this can be transformed into a matrix of direct raw material coefficients $\boldsymbol{F}$ by dividing each raw material input by the total output $\boldsymbol{x}$ of the sector:

$$\boldsymbol{F} = \boldsymbol{DE} \times \boldsymbol{diag}(\boldsymbol{x})^{-1} \tag{5}$$

If we multiply the matrix of direct raw material coefficients $\boldsymbol{F}$ with the Leontief inverse $\boldsymbol{L}$, we get the matrix of cumulative raw material coefficients $\boldsymbol{FL}$.

$$\boldsymbol{FL} = \boldsymbol{F}(\boldsymbol{I} - \boldsymbol{A})^{-1} \tag{6}$$

Since the objective is to obtain the raw material inputs associated with final demand, the last step is to multiply the $\boldsymbol{FL}$ matrix with the vector of final demand $\boldsymbol{y}$:

$$\boldsymbol{e} = \boldsymbol{FL} \times \boldsymbol{y} \tag{7}$$

The vector $\boldsymbol{e}$ then provides final demand by sector in raw material requirements. By distinguishing different categories of final demand, one can further differentiate the raw material requirements e.g. for export. To obtain the raw material input associated with imports only, the $\boldsymbol{FL}$ matrix is instead multiplied with the vector of imports ($\boldsymbol{m}$).

$$\boldsymbol{e_m} = \boldsymbol{FL} \times \boldsymbol{m} \tag{8}$$

Note that with this step, it is assumed that the products are produced with domestic technology (DTA). Else, the $\boldsymbol{FL}$ matrix would not be a valid description of the production process.

In summary, an IOT containing inter-sectoral flows, a matrix of raw material inputs and a vector of final demands/imports can be used to calculate raw material requirements if it is assumed that the domestic technology is an adequate approximation for the technology with which the imports are produced.

2.2.2 Application to Eurostat's RME model

The standard Leontief model as explained above is based on the DTA. For the purpose of this project, however, the DTA-based estimates are improved using external LCI-based information from the so-called ifeu world metal model (for details see Section 2.5). The resulting model is labelled ADTA-IO (adapted DTA input-output model).

In order to introduce external information from the metal model, modifications are made to the $\boldsymbol{Z}$ and the $\boldsymbol{DE}$ matrix. For the $\boldsymbol{Z}$ matrix, these modifications include adding lines and columns for metal ores and basic metals in which imports are attributed to intermediate consumption while their import columns are set to zero. This means that imports of these products are technically treated as being produced by the domestic economy as far as the model mathematics is concerned. For the $\boldsymbol{DE}$ matrix, these modifications mean adding specific columns for metal ores and basic metals with information on cumulated raw material content of these products estimated by the metal model.

The ADTA-IO model applies a double-loop approach. The purpose of the 1st loop is to generate a preliminary matrix of RME of imports, which is amended by further multi-regional information on metal recycling, valuation of imports at domestic prices and region-specific information on the energy mix of electricity generation (for details see Sections 2.6-2.8) and feeds into the 2nd loop in order to calculate final RME of imports and exports, RMC and RMI. The two-loop approach is necessary, because RME of exports and RMC do not only originate from domestic EU resources and thus partly consist of RME of imports transformed into exported/consumed goods. The second loop therefore ensures that also RME of exports and RMC reflect the additional information incorporated into RME of imports.

As explained above the **1st loop calculation** (Figure 2, step 15) applies the DTA for all product groups, except for direct imports of metal ores and basic metals. The calculation is based on the following input elements:

- High-resolution hybrid IOT (10)
- Domestic extraction (12)
- Matrix of the RME of direct imports of metal ores and basic metals estimated by the metal model (14). It is used as an additional environmental extension for imported products.

The **2nd loop calculation** (Figure 2, step 23) differs from the 1st loop calculation by the type of environmental extension for imports as the RME of all imports and not only of metal ores and basic metals are estimated by external information. The IOT and the domestic extraction matrix (step 12) remain unchanged. However, the “adjusted matrix of the RME of imports” (22) is used instead of matrix (14). Matrix (22) was obtained by augmenting the RME of imports calculated in the 1st loop by additional information on metal recycling, evaluation of imports at domestic prices and region-specific information on the energy mix of electricity generation (for details see Sections 2.6-2.8). The overall calculation procedure is further illustrated by a numerical example in Section 2.11.

2.3 High-resolution monetary IOT

2.3.1 Concept and rationale

The ADTA-IO model is based on a high-resolution IOT with 182x182 product groups. As a first step, a high-resolution monetary IOT is estimated (Figure 2, step 7). In comparison to the standard monetary IOT with 64x64 product groups that is published by FIGARO, a high-resolution IOT improves the accuracy of the calculation results considerably.

The Leontief models are generally assuming homogeneity of underlying product groups. The high-resolution approach is reducing possible inhomogeneity of product groups, which is a precondition for the Leontief procedure to be able to provide fairly realistic results. The chosen disaggregation of the high-resolution IOT in comparison to the standard 64x64 IOT is especially designed for meeting the special requirements of RME accounting.

Flows of raw materials are usually related to rather specific production activities as far as the first steps in the production chain are concerned. Each raw material enters the economy by a specific production activity (extraction). In addition, the following steps of transformation are usually confined to one or a rather limited number of specific production activities (primary processing). Therefore, it is very crucial to depict those first steps with a sufficient degree of detail in the IOT.

The raw material input to the economy is reported in a breakdown by 51 raw material categories (see Annex 5.3.2). That breakdown follows the EW-MFA classification for materials, amended by some further disaggregation for metals. Accordingly, almost for each raw material category a corresponding product group (extraction branch) was defined in the sectoral breakdown of the IOT (see Annex 5.3.1). Furthermore, also the branches of primary processing of raw materials, like agricultural animal production, food production, basic metal production, other non-metallic mineral products and energy transformation were disaggregated. In addition, some further branches that are considered quantitatively important under the perspective of raw material consumption (e.g. chemical industry, metalworking industry) are also presented in a disaggregated manner.

With respect to imports, it has to be noted that the product groups resulting from extraction and first processing of raw materials account for about 80% of the RME of imports. That is, the chosen level of disaggregation of the IOT alone is already strongly supporting the quality of estimating RME of imports by DTA.

2.3.2 Calculation method and data sources

The annual EU-level disaggregated IOT is estimated by fitting more detailed structural information from a corresponding IOT for Germany (182 x 182 product groups) for 2010 to the EU-level set of tables and corresponding vectors by an iterative adjustment approach. The EU-level set consists of an annual monetary IOT with 64x64 product groups and annual disaggregated vectors for outputs, imports and exports by 182 product groups.

Until 2022, the model was relying on Eurostat's publication of the annual EU IOT at 64 levels. In 2023, there was a switchover to FIGARO. Therefore, for the calculation of the RME estimates for 2010-2022, the FIGARO IOTs (64 level) were incorporated into the model and replaced the EU IOTs. FIGARO IOTs are currently available until reference year 2022[19].

2.3.3 Structural information based on the German high-resolution IOT

Due to lack of suitable EU-level data, structural information for Germany was utilised, as the German data situation for disaggregation of the IOT is much more favourable. For the purpose of the DeteRess project of the German Environment Agency, a high-resolution IOT (274x274 product groups) was

[19] https://ec.europa.eu/eurostat/de/web/esa-supply-use-input-tables/information-data

estimated for the year 2010[20]. That IOT was aggregated to the level of 182 x 182 product groups for the purpose of the EU-model (Figure 2, step 3).

The most important elements for estimating the high-resolution German IOT are:

- The standard IOT of the German Statistical Office, 72 x 72 product groups
- The expansion of that IOT was predominantly based on detailed supply and use tables of the size: 2600 product groups by 64 industries and on supply and use tables for earlier years, which provide a more detailed breakdown of 3000 x 120 product groups. Those detailed tables are not published[21]. They are designed as an internal tool of the German national accounting department for tuning different parts of the national accounting system and for generating the published IOT. The relevant parts of those tables were made available to the DeteRess project by the German Federal Statistical Office.
- For disaggregating the intra-agricultural product flows a detailed agricultural IOT (not published) by 46 agricultural production processes for the year 2010 from Thünen Institute was used.[22,23]

Disaggregated outputs, imports and exports at EU level

The second element for expanding the MIOT64 for the EU is the set of disaggregated vectors of outputs, imports and exports (Figure 2, step 6). The disaggregation of outputs is based on European Structural Business Statistics (SBS).[24] As the SBS breakdown was not sufficient for disaggregation of outputs for metals and other mining and quarrying product additional sources were used e.g. production statistics (Prodcom).[25] The disaggregation of imports and exports is based on monetary data from the European external trade statistics (COMEXT).[26]

Iterative adjustment approach

The EU level MIOT182 (Figure 2, step 7) is estimated by fitting the structural information from the German MIOT182 to the European data set of the MIOT64 and the disaggregated vectors for outputs, imports and exports. For the adjustment procedure, an RAS-type approach[27] was applied. The disaggregation of individual cells of the European MIOT64 is done in two principal steps:

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[20] Monika Dittrich, Karl Schoer, Claudia Kämper, Sabrina Ludmann, Jürgen Giegrich, Christoph Lauwigi, Christian Sartorius, Thorsten Hummen, Frank Marscheider-Weidemann (2018): Strukturelle und produktionstechnische Determinanten der Ressourceneffizienz: Untersuchung von Pfadabhängigkeiten, strukturellen Effekten und technischen Potenzialen auf die zukünftige Entwicklung der Rohstoffproduktivität (DeteRess), Umweltbundesamt (https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2018-04-11_texte_29-2018_deteress.pdf) For further analysis on the impact of sectoral disaggregation see Schoer et al. (2018).

[21] Acknowledgement: We thank the national accounts department of the German Federal Statistical office (Destatis) for providing those detailed internal data.

[22] Schmidt, Th and Osterburg, B. (2013): Berichtsmodul „Landwirtschaft und Umwelt“ in den Umweltökonomischen Gesamtrechnungen – Tabellenband für die Berichtsjahre 1991, 1995, 1999, 2003, 2007 und 2010, Bericht des Thünen - Instituts für Ländliche Räume im Auftrag des Statistischen Bundesamtes, Braunschweig.

[23] Acknowledgement: We thank the Thünen Institut für ländliche Räume for providing detailed internal data.

[24] See http://ec.europa.eu/eurostat/web/structural-business-statistics/overview

[25] See http://ec.europa.eu/eurostat/web/prodcom/overview

[26] See http://ec.europa.eu/eurostat/web/international-trade/overview

[27] The general RAS method is an approach to reconcile inconsistencies in data that should match or sum up to the same amount. It is a bi-proportional adjustment algorithm that balances matrices in a mechanical way. For details see e.g. Lahr, M.L., de Mesnard, L., Biproportional Techniques in Input–Output Analysis: Table Updating and Structural Analysis. Economic System Research 2004, 16, (2), 115-134.

- Estimation of initial values by disaggregating individual cells of the European IOT by structural information from the German IOT,
- Iterative adjustment of the initial values gradually to the vector of total domestic uses (output + import – export) and to the corresponding cells of the MIOT64; each cell of the MIOT64 is regarded.

As a result, a fully coherent monetary IOT matrix of the format 182x182 is obtained. It has to be pointed out that the IOT represents to a large extent an approximation of the real European relationships and not of the German conditions, as the German structural information was not simply adjusted to the European vector of total domestic use. Due to the specific adjustment approach, the disaggregated IOT is fully carrying the information on the European average production technology as it is represented in the European MIOT64. Only below that level, German technological relations have been used, but even those have been adjusted to European domestic use totals.

2.4 High-resolution hybrid IOT

2.4.1 Concept and rationale

The high-resolution hybrid IOT (Figure 2, step 10) uses the high-resolution monetary IOT as a starting point. The only difference is that selected sales structures (rows of the matrix representing the sales of agricultural crops and products of forestry and fishery, fossil energy carriers, other mining and quarrying products) are replaced by physical relationships.

It is a specific feature of the raw product groups that are selected for hybridisation that the relationships between imports and domestic output in product weight are rather closely representing the relationships for raw material content. A high degree of representation is indicated by the fact that for raw products generally the bulk of the raw material content is determined by the corresponding raw material. For example, the raw material content of crude oil as a product is highly determined by the weight of the raw material crude oil. Table 2 illustrates that for the selected products the corresponding main raw material category is generally accounting for the bulk of the RME of imports.

Table 2: RME of imports by aggregated product groups and main material categories

EU-28 2010
%

		Aggregated product groups		
		Agricultural crops, products of forestry and fishing	Fossil energy carriers	Other mining and quarrying products
Main material categories	Total	100.0	100.0	100.0
	Biomass	77.9	0.3	0.2
	Metal ores	1.8	1.1	0.4
	Non-metallic minerals	13.3	2.2	97.5
	Fossil energy carriers	7.1	96.3	2.0

For fossil energy carriers and other mining products, the share of the corresponding raw material categories is quite close to 100%. Biomass is accounting for nearly 80% of RME of imports of biotic raw products. That is, the content of the corresponding raw material is well represented by the product weight, and the uncertainties of physical relationships based DTA estimates for those product groups are restricted to the remaining supplementary raw materials only. Hence, by using physical sales structures for those product groups the possible margin of error by applying DTA is likely to be rather low.

The effect may be illustrated by an example: For domestic production of fruits, comparatively low priced local fruits may prevail, whereas high priced tropical fruits dominate imports. If monetary relationships are applied for estimating raw material content of imports, the raw material content will be overestimated. Under the condition that raw material content is well represented by the physical relationships, applying physical relationships could avoid overstating.

2.4.2 Calculation method and data sources

Physical sales structures are estimated by the following methods:

- **Energy carriers:** Physical information from the energy balance is utilised, including information on sales structures of energy carriers in energy units.

  The energy balance is providing information on the full sales structures for energy carriers. However, as the level of breakdown by branches is not sufficient, further disaggregation was necessary by using the respective relationships of the monetary IOT.

  - In 2019, a conceptual change of the input data of the energy balance introduced additional flows, e.g. in order to improve the tracking of recycling operations. That is, there was a shift from net-booking to gross-booking. However, this change to gross-booking has had strong impacts on RME estimates of fossil energy carriers. Therefore, for the 2020 EU RME model version, it was changed back to net booking of energy flows. The isolated effect of this adjustments on fossil energy carriers is approximately +4,4 % on RMC in RME (average 2008-2018).

- **Others:** The monetary sales structures are fit into the physical benchmark values of outputs from Eurostat's EW-MFA domestic extraction data and imports and exports taken from Comext data[28].

2.5 External regionalised information for estimating the RME of metal imports

2.5.1 Concept and rationale

Instead of the DTA, regionalised information is used for estimating the RME of direct imports of metal ores, ore concentrates and basic metal products (Figure 2, step 14). The results of that external approach are used to replace the endogenous DTA based estimates, as domestic production technology for some metals is either lacking or not able to represent worldwide production conditions. The external estimates are derived by referring to information from the so-called ifeu world metal model.

[28] In this approach, physical information is used for outputs, imports and exports. Using information in physical units for those items is likely to improve the accuracy of the estimates for RME of imports and exports considerably. However, the disaggregation of domestic use in physical units is fully based on monetary relationships.

That metal model was developed for estimating a set of conversion factors for transforming imports of metal in tonnes to RME[29].

The following types of conversion factors are required:

- **Conversion of ore concentrates to RME**: Metal ores are usually not imported as gross ores but as ore concentrates. That is, factors are needed for converting the weight of concentrates into the weight of gross ores.
- **Conversion of total basic metal to primary metal**: A considerable share of basic metals originates from recycling (secondary metal). Flows of imported basic metals as reported in Comext, however, include primary and secondary metals. As only primary metals, which originate from extracted ores, have to be regarded according to the RME concept, the shares of primary metal in total metal flows have to be estimated. The recycling ratios differ by metal, country of origin and time. That is, primary metal imports factors are required which convert the total metal flows into flows of primary metal only.
- **Conversion of metal content to RME**: The product weight of basic metals, which widely reflects the content of pure metal, is representing only a fraction of the mass of the corresponding gross ore (RME). Moreover, the so-called ore grades (metal content per tonne of gross ore) are differing considerably by type of metal, mine of origin and time.
- **Full raw material vectors:** Further, if the DTA is not applied, information on the full raw material profile for each metal ore and basic metal category has to be provided from external sources. However, it has to be mentioned that, similar to the materials presented in table 1 the share of the corresponding raw material is rather dominant for metal ores and basic metals as well. That is, the impact of the estimate on other raw materials on total RME of imports of a metal can usually be considered to be rather low.

2.5.2 Calculation method and data sources

For each type of conversion factor, the metal model approach applies specific methods:

- The conversion factors for ore concentrates are measured by different approaches. In a few cases, the data could be taken from annual reports of mining companies. For iron and manganese, data on the metal content was available from the USGS database. Further, information from varying data sources like producer's association, scientific material reports or even information on the chemical composition or other assumptions is used.
- The regionalised conversion factors to primary metal content for direct and indirect iron, copper and aluminium imports are calculated based on regionalised primary metal shares in the countries of origin and the respective share of trade with the country of origin for the respective product group. For other metals, world average factors as a proxy for all countries of origin of basic metal imports are used.
- The conversion factors from metal content to RME are primarily based on the examination of about 500 annual reports for mines that are considered to be representative of the conditions in the major countries of origin of European metal imports. Further information originates from mining and metal industry associations. It turned out that a differentiation by country of origin did not provide

[29] For a more detailed description of the ifeu metal model see Karl Schoer, Jürgen Giegrich, Jan Kovanda, Christoph Lauwigi, Axel Liebich, Sarka Buyny, Josefine Matthias (2012): Conversion of European Product Flows into Raw Material Equivalents, Final report of the project: Assistance in the development and maintenance of Raw Material Equivalents conversion factors and calculation of RMC time series, Heidelberg

stable results. Therefore, for each metal category average conversion factor for all countries of origin where used.

- The first three factors are needed for estimating the content of metal ore of direct imports of metal products. However, besides metals other raw materials (e.g. fossil energy carriers) are also embodied in those products. The content of those raw materials of metal products is estimated by coefficients that are derived from the ECOINVENT database and some additional sources.

2.6 Revaluation of imports at domestic prices

2.6.1 Concept and rationale

For the revaluation approach (Figure 2, step 18), imports are valued at basic prices of domestic output. That calculation is based on the most detailed Comext data. According to the IOT concept, imports are not valued at prices of domestic output, but at CIF prices, i.e. the basic prices of the countries of origin plus trade and transport margin within the country of origin plus the costs for international transport

The revaluation approach serves two purposes:

- **Improving the coherence of the DTA approach**: Using DTA means in technical terms that the RME of imports for a product group is obtained by multiplying the import value with the domestic raw material coefficient vector (FL matrix). The denominator of the coefficient vector is valued at prices of domestic output. For obtaining coherent results, the imports also have to be valued at domestic prices.
- **Improving the physical representation of the monetary import flows**: This is achieved by the chosen revaluation method, which is based on mass relationships. The approach is using prices that are expressed in EUR per tonne at the most detailed level of disaggregation of Comext (see calculation approach below). That is, the revaluated prices are reflecting only differences in mass. Quality differences are not regarded. To give an example: It can be considered that the raw material content of an imported car is widely determined by the mass of the car disregarding that the domestic cars might incorporate a higher level of value added (quality).

2.6.2 Calculation method and data sources

The revaluation is based on annual Comext data at the most detailed level (about 12,000 relevant product groups). The average unit prices of intra trade imports + intra-trade exports + extra trade exports are taken as a proxy for prices of domestic output. The adjusted import values are obtained by multiplying the imports in tonnes with domestic prices (EUR per t) as proxy values. That method can only be applied for product groups that are covered by Comext. That is, the calculations for service products still have to be based on unadjusted import prices.

2.7 Regionalised information for estimating recycling ratios for indirect metal imports

2.7.1 Concept and rationale

The estimation of RME of indirect metal imports (metals which are embodied in imports of products, other than metal ores and basic metals) is in principle based on the DTA. That is, implicitly the domestic metal recycling ratios are imputed. However, especially regarding metal recycling ratios there can be vast diversities between countries. For example, the EU-recycling coefficients for iron and aluminium are much higher than for the rest of the world. Due to those significant differences, the results of the original DTA approach which is assuming domestic recycling ratios for indirect metal imports has to be adjusted accordingly.

Calculation step 20 (see Figure 2) is designed for adjusting the DTA based estimates by applying regionalised information on the differences between domestic recycling and recycling in the countries of origin of imports.

2.7.2 Calculation method and data sources

For establishing adjustment factors, information from the ifeu world metal model is used (see Section 2.5). Regionalised shares, i.e. the shares in the countries of origin multiplied by the respective share of trade, are calculated for iron, copper and aluminium, and products thereof; world averages are used as proxies for the averages for other metals. In a second step, adjustment factors for iron, copper, aluminium, lead, zinc, tin and silver were established that represent the relative difference between EU and world recycling ratios/primary metal shares. The amount of embodied metals of imports is adjusted for each product group by those factors (except for direct imports of ores and basic metals).

2.8 Regionalised information for estimating the energy mix of direct and indirect imports of electricity

2.8.1 Concept and rationale

RME of electricity imports are in principle estimated by DTA. That is, implicitly the domestic energy mix and efficiency of electricity generation is assumed for all direct and indirect electricity imports. The purpose of calculation step 21 (see Figure 2) is to adjust the DTA based estimates by applying regionalised information on the differences between energy mix and efficiency of electricity generation in the domestic economy and in the countries of origin of imports.

Electricity is embodied in almost every product. However, the energy mix of electricity, i.e. the content of fossil energy per unit of electricity, can be very different between countries, depending on natural conditions and political preferences and the efficiency of electricity generation. Switzerland and Norway contribute a high share of direct electricity imports to EU. For both countries, the share of fossil energy is much lower than for EU. On the other hand, as far as indirect electricity imports are concerned, the average share of fossil energy of the countries of origin of other imports is significantly higher than for EU, due to the lower importance of nuclear power. In both cases, the results of the original DTA approach assuming a domestic energy mix of electricity generation have to be adjusted in order to approximate the conditions in the regions of origin of imports.

2.8.2 Calculation method and data sources

The DTA results are corrected by adjustment factors. For establishing those adjustment factors, the following information was used:

- Energy balance data on energy mix of electricity generation by country for 2010[30]
- Imports of electricity and other products by country of origin

For the adjustment, the energy content of imported product has to be split into energy content of embodied electricity and other energy content. The embodied electricity is derived by the Leontief approach in analogy to embodied raw materials. The energy content of embodied electricity is primarily estimated by DTA.

That estimate has to be adjusted by taking into account differences in energy mix by countries. Average adjustment factors are obtained by weighting the country specific factors (relative differences between EU and country specific energy inputs to electricity generation) with the import quantities by country. The adjusted energy content of EU level embodied electricity is obtained by multiplying the DTA based values by those adjustment factors.

2.9 Regionalised steel LCA-coefficients for energy use of steel imports

2.9.1 Concept and rationale

Steel production is one of the most energy-intensive manufacturing sectors. It can be expected that for some countries of origin of imports the energy intensity of steel production is different from average global conditions. In order to take into account differences in energy intensity of steel production in different countries of origin of imports, the world LCA-coefficients for the production of basic iron that were used in the model before 2018 were replaced by regionalised, weighted coefficients.

2.9.2 Calculation method and data sources

The coefficients were calculated using data from the IEA World Energy Balances, USGS data on steel production and Comext trade shares for basic iron of the 14 major countries of origin of imports. As the base year for the calculation, 2013 was used. For the 14 major countries of origin of imports, country coefficients were calculated indicating the use of each energy carrier in TOE per tonne of crude steel. Electricity and heat use for steel production was converted into use of energy carriers using IEA data on energy transformation and the assumption that CHP-plants produce 50% heat and 50% electricity. The country coefficients were then summed up weighted by the trade share of the respective country. For the rest of the world (ca. 20 %), the world average use of energy carriers by ton of steel was utilised. The changes to the results in response to the adjustment were small (in the range of 1.000-10.000 tonnes of RME).

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[30] In principle, also annual data could be used for the adjustment. However, as energy mixes are considered to be changing only gradually, it is not likely that additional efforts for collecting and processing annual data would significantly improve the result. Countries included for direct electricity imports are Switzerland, Russia, Norway, Serbia, Macedonia, Ukraine, Bosnia and Herzegovina. Countries considered for indirect electricity imports are China, United States, Switzerland, Japan, Turkey, Republic of Korea, Russia, India, Taiwan, Singapore, Malaysia, Brazil, Norway, Indonesia, Canada, Mexico, Hong Kong, Israel, Vietnam, Argentina and Ukraine.

2.10 RME of imports – quality assessment

In the previous section, it was described that the RME model is comprised of a mix of methodical approaches (see Sections 2.3 to 2.8). The general purpose of applying a mix of methods is to improve the quality of the RME estimates in comparison to the "standard Leontief model". That standard model is based on the standard EU monetary IOT of the format 64x64 product groups and on pure domestic technology assumption (DTA).

The purpose of this section is to assess the specific impact of the applied method mix on the quality of the estimate for the RME of imports in quantitative terms.

Quantitative reference point for the quality assessment is the final matrix of the RME of imports by 182 product groups and 51 raw material categories (calculation result of the 2nd loop model). A specific method mix determines the value of each cell of that matrix. To give an example, the cell 'cereals' as a product and 'cereals' as a raw material is determined by the following methods:

- High-resolution IOT 182
- Physical sales structures
- Adjustment of embodied electricity for energy mix
- Adjustment of embodied metals for recycling ratio

By using the full 182 x 51 import matrix the method mix of nearly 9300 individual cells has to be analysed individually. In order to keep the analysis manageable, a simplified matrix was calculated for aggregated main raw material categories. The raw material categories are further broken down by aggregated product groups. The aggregation by product groups for each main raw material category follows the approach of assorting those product groups that share widely the same method mix profile. For the aggregated breakdown, see Table 3.

Table 3 shows 28 combinations of main raw material categories and aggregated product groups and 11 methodological approaches. Quality scores were assigned to each of the methods. The value of the quality yardstick (scores) of a method is reflecting the assumed specific improvements in accuracy. High quality scores indicate that a method is considered to have a high impact with respect to improving the estimate of RME imports of the relevant product groups.

Quality assessment of the methods:

- For the **high-resolution IOT** (see Section 2.3), which is in principle applying to all product groups of the IOT, three different score levels were established (1.a to 1.c). The highest level applies to those aggregated products for which all elements are disaggregated in comparison to the standard IOT. The medium score level was assigned to aggregated product groups which are only partly comprised of disaggregated elements. The lowest level is assigned to aggregated product groups, which completely consist of non-disaggregated elements. In the latter cases, quality is only improved by indirect effects (disaggregated input structures).
- High score values are assigned to **physical sales structures** for selected product groups (see Section 2.4). With respect to the selected product groups, it was explained above that the relationship between domestic production and imports in raw material equivalents (RME) is especially well represented by the corresponding relationship in traded weight.
- The **regionalised external approach** (Method 3.a and 3.b) receives a comparatively high score value as it is considered that the degree of accuracy achieved by this method is very high (see Section 2.5).

- By the **valuation of imports at domestic prices**, (see Section 2.6) the accuracy of the DTA based estimates (based on monetary sales structures) is improved.
- The method '**regionalised adjustment of embodied metals for recycling ratio'** (see Section 2.7) is supposed to have a high impact on the accuracy of the estimate on RME of indirect metal imports.
- The method '**regionalised adjustment of embodied electricity for energy mix'** (see Section 2.8) can be considered to have a high impact on the accuracy of the estimate on RME of direct and indirect electricity imports. Those adjustments are covering both, differences in the energy mix of electricity generation as well as general differences in the efficiency of electricity generation.

For each product group under consideration, the relevant quality scores are added up to total quality scores.

Table 3: Method mix for calculation of RME of imports

Method mix for calculation of RME of imports by main raw material categories and product groups

Main raw material categories	Aggregated product groups	RME of imports		Quality scores by method									
					1.a	1.b	1.c	2	3.a	3.b	4	5	6
				Total quality scores	High resolution IOT 182			Physical sales structures for selected product	Regionalized external		Valuation of imports at domestic prices	Regionalized adjustment of embodied metals for recycling ratio	Regionalized adjustment of embodied electricity for energy mix
					high impact on accuracy	medium impact on accuracy	low impact on accuracy		metal inputs	non-metal inputs			
	Quality scores				3	2	1	8	12	4	2	5	5
		Mio t RME	%	Scores									
Total		3,731	100.0										
Biomass	Total	217	5.8										
	Agricultural crops, forestry and fishery products	65	1.7	11	3			8					
	Animals and animal products	24	0.7	3	3								
	other food products	29	0.8	5	3						2		
	Wood products	4	0.1	3			1				2		
	Pulp and paper	4	0.1	3			1				2		
	Metal ores	0	0.0	4						4			
	Basic metals	0	0.0	4						4			
	Others: Import values measured at domestic prices	75	2.0	4		2					2		
	Others: Import values measured at cif prices	16	0.4	2		2							
Metal ores	Total	1,344	36.0										
	Metal ores	421	11.3	12					12				
	Basic metals	642	17.2	12					12				
	Others: Import values measured at domestic prices, adjustment for regional differences in metal recycling ratios	264	7.1	9		2					2	5	
	Others: Import values measured at cif prices, adjustment for regional differences in metal recycling ratios	17	0.5	6			1					5	
Non-metallic minerals	Total	420	11.3										
	other ming and quarrying products	58	1.5	11	3			8					
	Glass, ceramics	55	1.5	5	3						2		
	Chemical products	72	1.9	5	3						2		
	Metal ores	9	0.2	4						4			
	Basic metals	34	0.9	4						4			
	Others: Import values measured at domestic prices	150	4.0	4		2					2		
	Others: Import values measured at cif prices	43	1.2	1			1						
Fossil energy carriers	Total	1,750	46.9										
	Coal, oil and gas	1,110	29.8	11	3			8					
	Coke oven and refinery products	236	6.3	11	3			8					
	Metal ores	4	0.1	4						4			
	Basic metals	55	1.5	4						4			
	Others: Import values measured at domestic prices, embodied in electricity	88	2.4	9		2					2		5
	Others: Import values measured at domestic prices, not embodied in electricity	189	5.1	4		2					2		
	Others: Import values measured at cif prices, embodied in electricity	0	0.0	6			1						5
	Others: Import values measured at cif prices, not embodied in electricity	68	1.8	1			1						
Memo item: % share of methods[2)]				174.1	44.2	20.9	3.7	39.4	28.5	2.7	24.9	7.5	2.4

1)Extracted primary biomass, fossil energy carriers and for extrtacted primary non-metallic materials

2) Is including double counting

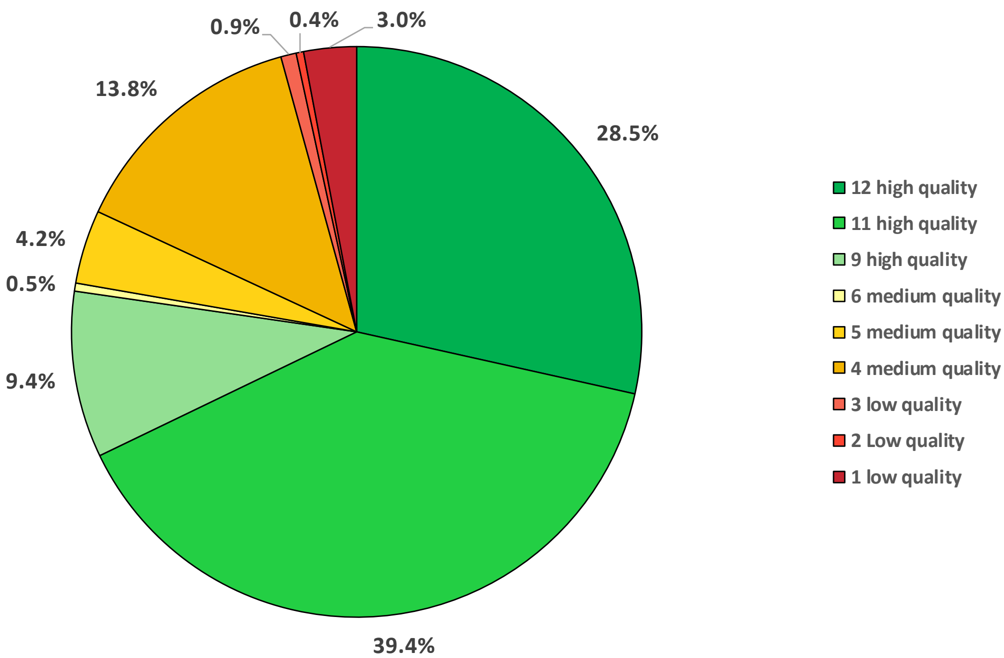
The RME of imports are widely dominated by direct and indirect imports of metal ores and fossil energy carriers, which account for 83% of all RME of imports. Most of those imports (75%) are direct imports of metals and fossil energy carriers, which are estimated with high quality approaches.

The bottom line of the table shows the share of the different methods. The figures on the share include double counting, as the methods usually apply to more than one product group.

The high-resolution IOT has an impact on 68.8 % of the RME estimate. 39.4% of the total estimate is influenced by physical sales structures. The regionalised external approach has a share of 31.2%. The method of valuation of imports at domestic prices has an effect of 24.9% of the total estimate. The impact of regionalised adjustments of metal recycling and electricity mix is comparatively small (7.5% and 2.4%).

Figure 4 summarises the quality assessment that Table 3 presented.

Figure 4: Impact of "method mix" on the quality of the estimates for RME of imports



The figure shows the aggregated shares of individual score classes at the total RME of imports. About 77% of all RME of imports are considered to be estimated by a “high quality” method mix. The “medium quality” mix is accounting for nearly 18% and only about 4% of the estimate is based on the “low quality” mix.

2.11 Numerical example of calculation of RME of imports in RME by the ADTA-IO model

The aim of this section is to illustrate the ADTA-IO model by a numerical example while a detailed description of the model is provided in the previous sections.

The table 4 below presents a standard IOT[31] – the numerical example of a hypothetical three-sector economy (A, B, C) extended by domestic extraction of raw materials by sectors (DE).

Table 4: Numerical example IOT

	A	B	C	final domestic demand (y_d)	exports (ex)	total use (q)
A	4	15	10	6	2	37
B	8	2	20	10	4	44
C	4	6	5	35	5	55
imports (m)	5	8	4			
domestic extraction (DE)	50	12	0			

Without the use of any additional LCI-based information, the calculation of RME of imports would be based on a standard Leontief model under the domestic technology assumption (DTA) and the following equations:

9) output (x) = q – m´

10) technology coefficient matrix (A) =intermediate consumption matrix (Z)*diag(x)$^{-1}$

11) F = DE*diag(x)$^{-1}$

12) L = (I-A)$^{-1}$

13) FL = F*L

14) RME of imports = FL* diag(m)

where ´ denotes vector transposition, diag stands for matrix diagonalisation and I is the identity matrix of the same dimension as the A matrix.

[31] Excluding the value added block, which is not relevant for this environmentally extended application of the IOT.

The respective numerical values would be as follows:

	x
A	32
B	36
C	51

A matrix	A	B	C
A	0.13	0.42	0.20
B	0.25	0.06	0.39
C	0.13	0.17	0.10

	A	B	C
F	1.56	0.33	0.00

Z matrix	A	B	C
A	4	15	10
B	8	2	20
C	4	6	5

L matrix	A	B	C
A	1.45	0.75	0.64
B	0.51	1.41	0.72
C	0.29	0.36	1.33

	A	B	C
FL	2.43	1.65	1.24

	A	B	C	Total RME of imports
RME of imports	12.17	13.17	4.98	30.32

The standard Leontief model is based on the domestic technology assumption (DTA) for the production technology of imports. For the purpose of this project, the DTA-based estimates are improved using LCI-based information on cumulated raw material content of imported metal ores and basic metals estimated by a metal model. This inclusion requires some modifications to Z and DE matrices as described in Section 2.2.2.

Let us assume that the A sector in the numerical example delivers metal ores and basic metals. The standard IOT is then modified as follows:

	A - import	A	B	C	final domestic demand (yd)	exports (ex)	total use (q)
A - import	0	5	0	0	0	0	5
A	0	4	15	10	6	2	37
B	0	8	2	20	10	4	44
C	0	4	6	5	35	5	55
imports adjusted (m_a)	0	0	8	4			
domestic extraction (DE)	30	50	12	0			

The light yellow in the table indicates a column and a row added for the imported A products. Red numbers and an arrow show the movement of imported A products from the import vector into the intermediate consumption matrix. The green number indicates the newly added information on cumulated raw material content of imported metal ores and basic metals.

The Leontief input-output model allocates direct and upstream requirements of products to their users. Therefore, upstream requirements of the imported product A, i.e. the DE information derived from LCI including the whole production chain, is allocated to product A and consequently together with the requirements of product A to all its users according to sales shares. Note that this assumes that the imported products A have the same structure as the domestically produced product A. While separate IO tables for imported and domestically produced products are available from national statistical institutes, it would be difficult to obtain this data on the level of product detail used within the RME model. Therefore, we only work with the total (domestic + import) IO table. Note that assuming that the LCI data provides the same cumulated DE per unit of imported product A as the domestic technology for product A yields the same result as the DTA. LCI data contains the DE from the whole production chain; no other inputs for production of imported product A are assumed within this model and the only user of imported product A is the domestic production of product A. This means that we virtually moved the production of the imported product A to the domestic economy without affecting any other product groups and with accounting for upstream DE through LCI data.

The set of equations used for the calculation of RME of imports shown above are applied on the modified matrices for the modified IOT: output (x) is calculated as total use (q) minus imports adjusted transposed (m_a'), RME of imports are calculated as FL multiplied by a vector of real imports diagonalised where A products are moved to A–import products row (m_m):

15) ***output (x) = q – ma′***

16) ***technology coefficient matrix (A) =intermediate consumption matrix (Z)*diag(x)-1***

17) ***F = DE*diag(x)-1***

18) ***L = (I-A)-1***

19) ***FL = F*L***

20) ***RME of imports = FL* diag(mm)***

The respective numerical values for the modified IOT are as follows:

	x
A - import	5
A	37
B	36
C	51

Z matrix	A - import	A	B	C
A - import	0	5	0	0
A	0	4	15	10
B	0	8	2	20
C	0	4	6	5

A matrix	A - import	A	B	C
A - import	0.00	0.14	0.00	0.00
A	0.00	0.11	0.42	0.20
B	0.00	0.22	0.06	0.39
C	0.00	0.11	0.17	0.10

	A - import	A	B	C
F	6.00	1.35	0.33	0.00

L matrix	A - import	A	B	C
A - import	1.00	0.18	0.10	0.08
A	0.00	1.37	0.71	0.61
B	0.00	0.41	1.36	0.68
C	0.00	0.24	0.34	1.31

	A - import	A	B	C
FL	6.00	3.09	1.99	1.54

	m_m'
A - import	5.00
A	0.00
B	8.00
C	4.00

	A - import	A	B	C	Total RME of imports
RME of imports	30.00	0.00	15.91	6.15	52.06

The ADTA-IO model applies a double-loop approach. The 1st loop calculation is carried out by the modified IOT and Leontief model shown above and delivers a preliminary matrix of RME of imports, which is amended by further multi-regional information on metal recycling, evaluation of imports at domestic prices and region-specific information on the energy mix of electricity generation. This additional information is implemented by multiplication of RME of imports resulting from the 1st loop by coefficients in this numerical example. The coefficients are applied to products calculated with the use of domestic technology assumption only (B and C products), as it is assumed that LCI-based information from the metal model used for calculation of A products already includes that additional information:

	B	C
RME of imports resulting from the 1st loop	15.91	6.15
Coefficients representing additional multi-regional information	1.1	1.05
RME of imports adjusted	17.50	6.45

The 2nd loop calculation is also based on the above described modified Leontief model, but as we have already calculated RME of imports for all product groups it is assumed now that all products (A, B, C) are calculated with the use of external information. Therefore, the IOT is modified as follows:

	A - import	B - import	C - import	A	B	C	Final domestic demand (y_d)	export (ex)	total use (q)
A - import	0	0	0	5	0	0	0	0	5
B - import	0	0	0	0	8	0	0	0	8
C - import	0	0	0	0	0	4	0	0	4
A	0	0	0	4	15	10	6	2	37
B	0	0	0	8	2	20	10	4	44
C	0	0	0	4	6	5	35	5	55
imports adjusted (m_a)	0	0	0	0	0	0			
domestic extraction (DE)	30.00	17.50	6.45	50	12	0			

Once again, the shaded cells in the table indicate added columns and lines. Red figures and arrows show the movement of imported products from the import vector into the intermediate consumption vector. Green figures indicate the information on cumulated raw material content of imported products, which equals RME of imports calculated in the 1st loop after their amendment by additional multi-regional information on metal recycling, evaluation of imports at domestic prices and region-specific information on the energy mix of electricity generation.

The respective numerical values for the 2nd loop are as follows:

	x
A - import	5
B - import	8
C - import	4
A	37
B	44
C	55

Z matrix	A - import	B - import	C - import	A	B	C
A - import	0	0	0	5	0	0
B - import	0	0	0	0	8	0
C - import	0	0	0	0	0	4
A	0	0	0	4	15	10
B	0	0	0	8	2	20
C	0	0	0	4	6	5

A matrix	A - import	B - import	C - import	A	B	C
A - import	0.00	0.00	0.00	0.14	0.00	0.00
B - import	0.00	0.00	0.00	0.00	0.18	0.00
C - import	0.00	0.00	0.00	0.00	0.00	0.07
A	0.00	0.00	0.00	0.11	0.34	0.18
B	0.00	0.00	0.00	0.22	0.05	0.36
C	0.00	0.00	0.00	0.11	0.14	0.09

	A - import	B - import	C - import	A	B	C
F	6.00	2.19	1.61	1.35	0.27	0.00

L matrix	A - import	B - import	C - import	A	B	C
A - import	1.00	0.00	0.00	0.18	0.07	0.06
B - import	0.00	1.00	0.00	0.07	0.23	0.11
C - import	0.00	0.00	1.00	0.02	0.02	0.09
A	0.00	0.00	0.00	1.31	0.54	0.48
B	0.00	0.00	0.00	0.38	1.27	0.58
C	0.00	0.00	0.00	0.21	0.25	1.24

	A - import	B - import	C - import	A	B	C
FL	6.00	2.19	1.61	3.11	2.04	1.56

	m_m'
A - import	5.00
B - import	8.00
C - import	4.00
A	0.00
B	0.00
C	0.00

	A - import	B - import	C - import	A	B	C	Total RME of imports
RME of imports	30.00	17.50	6.45	0.00	0.00	0.00	53.95

The influence of the ADTA-IO model design on the results can be shown on the RME of imports: They are 30.32 for the standard Leontief model that applies DTA for all products, but they increase to 52.06 after the introduction of LCI-based information for metal ores and basic metals. Another increase to 53.95 comes with the introduction of additional information on metal recycling, evaluation of imports at domestic prices and region-specific information on the energy mix of electricity generation. It should be noted, however, that these increases stem from LCI-based values used in this numerical example, which differ from reality.

In order to calculate final RME of exports, RMC and RMI, the FL matrix is multiplied by vectors of exports (ex), domestic final demand (y_d) and total final demand, i.e. sum of domestic final demand and exports (y_d + ex), respectively:

13) RME of exports = FL*ex

14) RMC = FL* yd

15) RMI = FL* (yd + ex)

	A - import	B - import	C - import	A	B	C	Total RME of exports
RME of exports	0.00	0.00	0.00	6.21	8.14	7.82	22.18

	A - import	B - import	C - import	A	B	C	Total RMC
RMC	0.00	0.00	0.00	18.64	20.36	54.77	93.77

	A - import	B - import	C - import	A	B	C	Total RMI
RMI	0.00	0.00	0.00	24.86	28.50	62.59	115.95

2.12 Calculation of the time series for the RME from 2000 onwards

The revised NACE Rev. 2 model provides results from 2010 onwards. In order to get a full time series from 2000 onwards the results of the previous NACE Rev 1.1 model for 2000-2009 and were chain-linked to the revised model. The relative differences for the year 2010 between the two models where used for adjusting the time series (2000-2007: unrevised model (NACE Rev 1.1); 2008-2009: EU RME model 2022) to the level of the revised model (NACE Rev 2). The adjustment was conducted at the level of final use categories and imports in a breakdown by 51 raw material categories.

3 MFA-RME at country level

In order to be able to supplement the MFA-RME on EU-level by corresponding information for Member States and EFTA countries, Eurostat developed a so-called country RME tool, which is coherent with Eurostat's EU RME model. The purpose of the country RME tool is to assist national statistical institutes (NSIs) to produce country-level estimates of MFA-RME with a manageable amount of effort.

The country RME tool is based on a so-called coefficient approach (estimates for RME of imports are based on EU-level import and export coefficients). The coefficients are adjusted to take into account significant country-specific differences in production technologies. For the calculation, annual EU-level RME coefficient matrices for imports and exports are combined with hybrid country-level import and export vectors. As data sources, country-level data from Comext, national accounts/supply and use tables, energy balances, EW-MFA data, United States Geological Survey (USGS) and structural business statistics are used in addition to results and input data from the EU RME model.

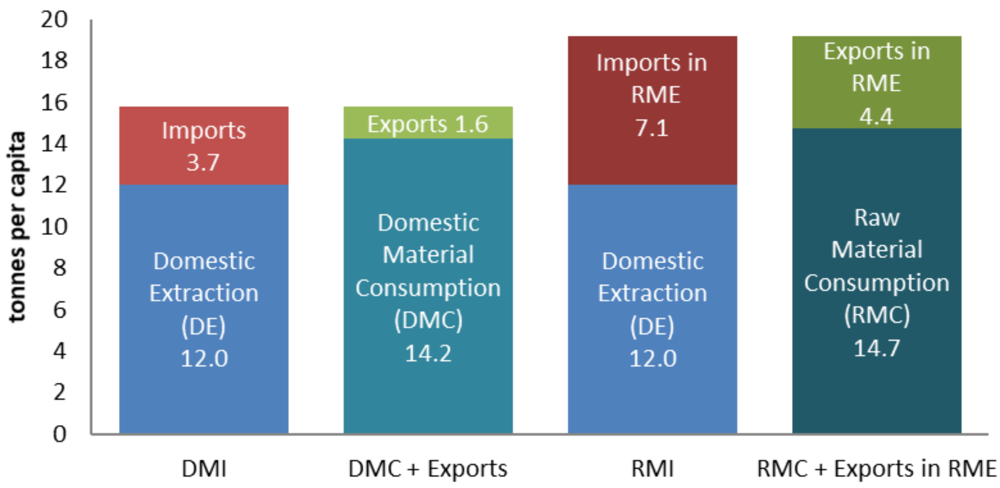
The country RME tool has been implemented as an Excel-based calculation tool (template). The country RME tool accompanied by a handbook and a set of data input files are available on the methodology page of Eurostat's online dedicated section on Environment.

The main objective for developing and publishing the country RME tool package, including the input files and the handbook, has been to facilitate the compilation of country-level MFA-RME with limited resources. To limit the resources needed, the country RME tool is necessarily a simplification of the EU RME model, even though it builds on the good practices and insights from the EU RME modelling projects. Establishing the full EU calculation model on a country-level would be rather resource consuming and may suffer from limited data availability. Developing and maintaining a national model with the complexity of the EU RME model is an option for a few countries only. Still, NSIs can develop more complex national models if wished so; the country RME tool only represents a recommended approach in case of limited resources.

4 Reference results

Eurostat's EU RME model provides highly disaggregated results on EU raw material input and consumption in tonnes of raw material equivalents. In the following, some exemplary results of the model are presented. Figure 5 illustrates the difference between EW-MFA accounts and MFA-RME calculated with the EU RME model (compare also Chapter 1.3). Both imports and exports in RME are considerably higher than imports and exports in actual product weight as the values expressed in RME incorporate the material required to produce a good. DMC and RMC, however, attain relatively similar values as the ratio between imports to exports in RME and in actual product weight is comparable within the EU (DMC = DE + imports - exports vs. RMC = DE + imports in RME – exports in RME).

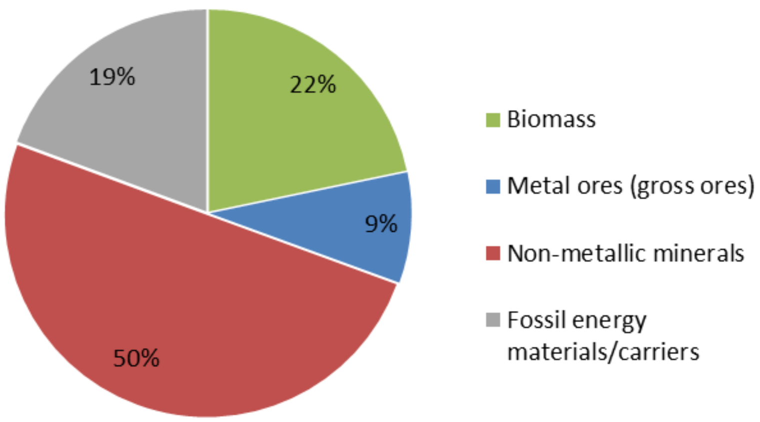
Figure 5: EW-MFA vs. RME indicators per capita for the year 2022



Source: EU RME model and Eurostat (env_ac_rme, env_ac_mfa, demo_gind)

In Figure 6, RMC by four main material categories is presented. The category 'Non-metallic minerals' mainly comprised of construction materials such as sand, gravel and limestone is clearly dominating while metal ores play a comparatively minor role. Biomass and fossil energy resources each account for roughly a fifth of total RMC.

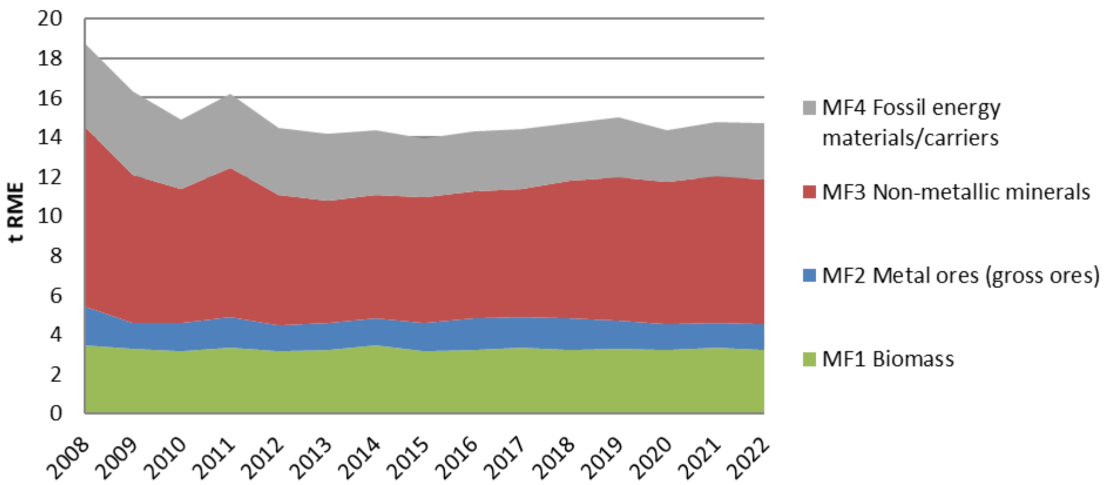
Figure 6: Raw Material Consumption in the EU 2022 by main raw material categories



Source: Eurostat (env_ac_rme)

Figure 7 shows the time evolution of raw material consumption per capita since 2008. The sharp drop observed in 2008 reflects the economic crisis and the resulting structural changes, which are among others due to the decline in investments in the construction and industrial sectors, in several European countries. In the period 2013-2019, RMC per capita has risen slightly. In 2020, RMC per capita drops due to the global pandemic and has since then increased to 14.7 tonnes per person in 2022.

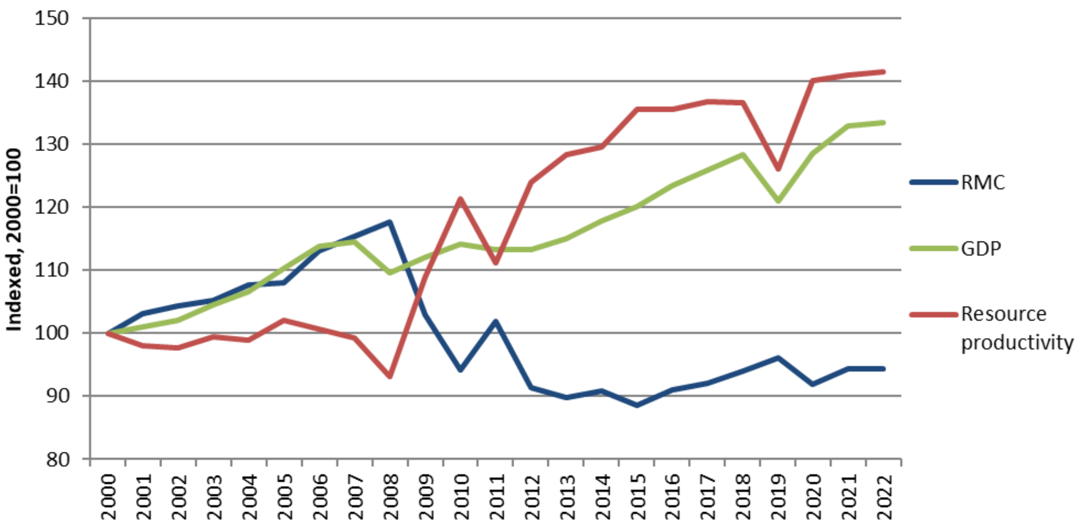
Figure 7: Raw Material Consumption per capita 2008-2022



Source: Eurostat (env_ac_rme)

Figure 8 looks at the time development of resource productivity with RMC as denominator. Since the year 2000, resource productivity has steadily been rising with an exception for the period 2010-2011. The significant increase after the crisis was caused by a severe drop in RMC as the crisis affected material-intensive industries such as construction more strongly than the services industry. In the period 2018-2019, resource productivity decreases mainly due to a drop in GDP. In 2020, against the backdrop of a renewed increase in GDP and a simultaneous decline in RMC, resource productivity increased and remains at this level in 2022.

Figure 8: Resource productivity vs. GDP



Source: EU RME Model and Eurostat (env_ac_rme, nama_10_gdp, demo_gind). Indexed with base year 2000. Note that the RMC values for the years 2000-2007 are calculated using chain linking. GDP in chain-linked volumes with reference year 2010.

A further differentiation of raw material use indicators is provided in table 5. Domestic extraction (DE), RMC, RMI as well as imports and exports for the year 2022 are disaggregated by all 51 raw material categories distinguished by the model. In addition, the EU RME model is able to provide results distinguishing 182 product groups (see Annex 5.3).

Table 5: Results of the RME model 2022 by material flow indicators

EU27, 1000 t RME		Domestic Extraction	Total Imports in RME	Total Exports in RME	Raw Material Consumption	Raw Material Input
TOTAL	Total primary raw materials	5,384,176	3,188,736	1,981,187	6,591,725	8,572,912
MF1	Biomass	1,442,183	304,682	314,004	1,432,861	1,746,865
MF2	Metal ores (gross ores)	229,465	903,557	550,132	582,891	1,133,023
MF3	Non-metallic minerals	3,289,219	549,939	540,144	3,299,015	3,839,159
MF4	Fossil energy materials/carriers	423,308	1,430,557	576,908	1,276,957	1,853,865
MF11	Crops (excluding fodder crops)	607,304	179,182	153,225	633,261	786,485
MF111	Cereals	271,842	67,031	89,716	249,157	338,873
MF112	Roots, tubers	49,104	2,579	4,422	47,260	51,683
MF113	Sugar crops	107,617	18,038	19,697	105,959	125,656
MF114	Pulses	4,080	2,402	1,598	4,884	6,483
MF115	Nuts	1,134	1,627	437	2,324	2,761
MF116	Oil-bearing crops	40,132	58,782	22,055	76,859	98,914
MF117	Vegetables	58,400	5,198	5,799	57,798	63,598
MF118	Fruits	67,428	13,346	6,107	74,667	80,774
MF119	Fibres	1,457	1,054	828	1,683	2,511
MF1110	Other crops n.e.c.	6,110	9,125	2,565	12,670	15,235
MF12	Crop residues (used), fodder crops and grazed biomass	523,121	60,919	80,660	503,380	584,040
MF121	Crop residues (used)	155,615	18,122	23,994	149,742	173,737
MF1211	Straw	119,410	13,906	18,412	114,904	133,316
MF1212	Other crop residues (sugar and fodder beet leaves, other)	36,205	4,216	5,582	34,839	40,421
MF122	Fodder crops and grazed biomass	367,507	42,797	56,666	353,638	410,304
MF13	Wood	307,481	61,120	79,059	289,542	368,601
MF131	Timber (industrial roundwood)	229,962	45,712	59,128	216,546	275,674
MF132	Wood fuel and other extraction	77,519	15,408	19,931	72,996	92,927
MF14	Wild fish catch, aquatic plants/animals	4,278	3,461	1,060	6,678	7,738
MF141	Wild fish catch	3,198	2,805	724	5,279	6,003
MF142	All other aquatic animals and plants	374	328	85	617	702
MF143	Hunting and gathering	706	327	252	781	1,033
MF21	Iron	:	213,815	101,241	:	:
MF22	Non-ferrous metal	:	689,742	448,891	:	:
MF221	Copper	114,513	241,652	169,698	186,467	356,165
MF222	Nickel	21,463	21,570	18,371	24,662	43,033
MF223	Lead	3,170	2,486	2,124	3,531	5,655
MF224	Zinc	17,966	19,889	15,493	22,362	37,855
MF225	Tin	1,268	15,105	6,554	9,819	16,373
MF226	Gold, silver, platinum and other precious metals	:	187,291	145,742	:	:
MF2261	Gold	:	164,223	126,329	:	:
MF2262	Silver	6,305	9,532	5,563	10,274	15,837
MF2263	Platinum and other precious metal ores	451	13,536	13,850	137	13,987

MF227	Bauxite and other aluminium	:	74,206	31,974	:	:
MF228	Uranium and thorium	0	3,716	823	2,893	3,716
MF229	Other metals n.e.c.	6,361	123,828	58,112	72,077	130,189
MF2291	Tungsten	112	5,219	1,960	3,371	5,331
MF2292	Tantalum	0	2,665	1,129	1,536	2,665
MF2293	Magnesium ores	0	1,088	405	683	1,088
MF2294	Titanium	0	37,501	18,886	18,615	37,501
MF2295	Manganese	2	5,828	2,317	3,513	5,830
MF2296	Chromium	442	4,570	1,907	3,106	5,013
MF2297	Other metal ores	5,805	66,956	31,507	41,253	72,760
MF31	Marble, granite, sandstone, porphyry, basalt, other ornamental or building stone (excluding slate)	:	60,381	64,289	:	:
MF32	Chalk and dolomite	:	29,296	18,830	:	:
MF33	Slate	:	170	233	:	:
MF34	Chemical and fertiliser minerals	23,638	21,688	18,786	26,540	45,326
MF35	Salt	42,061	23,015	24,598	40,479	65,077
MF36	Limestone and gypsum	:	108,881	119,116	:	:
MF37	Clays and kaolin	58,100	13,857	9,214	62,744	71,957
MF38	Sand and gravel	2,214,621	270,189	269,277	2,215,533	2,484,810
MF39	Other non-metallic minerals n.e.c.	:	22,462	15,801	:	:
MF41	Coal and other solid energy materials/carriers	370,985	393,131	204,802	559,315	764,116
MF411	Lignite (brown coal)	294,678	96,840	93,052	298,466	391,518
MF412	Hard coal	54,411	286,913	100,745	240,579	341,324
MF413	Oil shale and tar sands	11,184	5,691	5,572	11,303	16,876
MF414	Peat	10,712	3,687	5,433	8,966	14,398
MF42	Liquid and gaseous energy materials/carriers	52,323	1,037,426	372,107	717,642	1,089,749
MF421	Crude oil, condensate and natural gas liquids (NGL)	:	675,436	276,606	:	:
MF422	Natural gas	:	361,989	95,501	:	:

Source: Eurostat (env_ac_rme)

5 Annex

5.1 Literature

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5.2 Data sources

The table below shows a complete list of data which is used for annual update of the model:

Number	**General source**	**Description**
I-1	Data extraction ifeu	Primary metal coefficients for imports of basic metals (world average): valid for all years
		Annuals EU recycling coefficients for selected metals 2008
		Annual RME coefficients by products and raw materials 2009
		Annual RME coefficients by products and raw materials 2010
		Annual RME coefficients by products and raw materials 2011
		Annual RME coefficients by products and raw materials 2012
		Annual RME coefficients by products and raw materials 2013
		Annual RME coefficients by products and raw materials 2014
I-10	Data extraction Eurobase	MIOT 2008 EU27 (estimated)
		MIOT 2009 EU27 (estimated)
		MIOT 2010 EU27
		MIOT 2011 EU27
		MIOT 2012 EU27
		MIOT 2013 EU27
		MIOT 2014 EU27
		MIOT 2015 EU27
		MIOT 2016 EU27
		MIOT 2017 EU27
		MIOT 2018 EU27
		MIOT 2019 EU27
I-11	Data extraction Eurobase (Comext)	Exports extra-EU in EUR
		Exports extra-EU in tonnes

		Exports intra-EU in EUR
		Exports intra-EU in tonnes
		I-11-Comext conversion key 2008-2014
		Imports extra-EU in EUR
		Imports extra-EU in tonnes
		Imports intra-EU in EUR
		Imports intra-EU in tonnes
I-12	Data extraction Eurobase	Structural Business Statistics
	Data extraction Eurobase	Structural Business Statistics for Estonia on other mining. Estimation of extraction of oil shale and tar sands (as approximation for total EU)
I-13a	Data extraction Eurobase	I-13a-SBS short term trade
I-13b	Data extraction Eurobase	I-13b-SBS short term services
I-14	Data extraction Eurobase	Energy balance: Data extraction for all years
I-15	Data extraction Eurobase	Imports energy
	Data extraction Eurobase	Exports energy
I-16	Data extraction Eurostat internal	EW-MFA: DE by detailed raw material categories.
I-17	Data extraction Eurobase	Agricultural accounts
I-18	Data extraction Eurobase	Aquaculture
I-20	Data extraction Eurobase	National Accounts - Output and intermediate consumption
I.21	Data extraction Eurobase	National accounts -others
		National Accounts - Imports and Exports
I-22	Data extraction Eurobase	Prodcom
I-23	Data extraction Eurobase	Comext IMP by country
I-24	Data extraction Eurobase	EW-MFA main material categories
I-25	Data extraction Eurobase	Exports and imports by country, National Accounts
		Other aggregates, National Accounts
I-31	Data extraction BGS	BGS metal mining
I-32	Data extraction business report	Iron ore production Sweden: business report
I-34	Data extraction USGS	USGS: metal prices
I-35	Data extraction Eurobase	Exchange rate EUR-US$
I-37	Data extraction ifeu database	Energy mix electricity by country

5.3 Classifications

5.3.1 Classification of the high-resolution hybrid IOT

RME-code	NACE Rev. 2	RME-code	Unit
RME001	01.11.1-4, 01.12	Cereals	1000 t
RME002	01.11.6, 01.13 (excl. 01.13.5, 01.13.7)	Green leguminous vegetables, vegetables and melons (excl. edible roots and tubers and sugar beet)	1000 t
RME003	01.11.7	Dried leguminous vegetables	1000 t
RME004	01.11.8, 01.11.9, 01.26.1	Soya beans, groundnuts and cotton seed, other oil seeds	1000 t
RME005	01.13.5	Edible roots and tubers with high starch or insulin content	1000 t
RME006	01.13.7, 01.14	Sugar beet and sugar beet seed, sugar cane	1000 t
RME007	01.15	Unmanufactured tobacco	1000 t
RME008	01.16	Fibre crops	1000 t
RME009	01.19.1, 01.11.5	Forage crops, incl. grazed biomass	1000 t
RME010	01.2 (excl 01.25.3, 01.26.1, 01.27, 01.28. 10.29)	Fruits	1000 t
RME011	01.19.2, 01.19.3, 01.25.3, 01.27, 01.28, 01.29, 01.3	Other crop products	1000 t
RME012	01.41.1, 01.42	Dairy cattle, live other cattle and buffaloes, live and their semen	million EUR
RME013	01.41.2	Raw milk from dairy cattle	million EUR
RME014	01.46	Swine, live	million EUR
RME015	1.43, 01.44, 01.45, 01.49	Other animals and animal products, incl. hunting and trapping and related services	million EUR
RME016	01.47.1	Poultry, live	million EUR
RME017	01.47.2	Eggs, in shell, fresh	million EUR
RME018	01.9	Farm manure and other agricultural waste products	million EUR
RME019	01.6	Agricultural and animal husbandry services (except veterinary services)	million EUR
RME020	02	Products of forestry, logging and related services	1000 t
RME021	03	Fish and other fishing products; aquaculture products; support services to fishing	1000 t
RME022	05.1	Hard coal	1000 TOE
RME023	05.2	Lignite	1000 TOE

RME024	06.10.1	Petroleum oils and oils obtained from bituminous minerals, crude	1000 TOE
RME025	06.10.2	Bituminous or oil shale and tar sands	1000 TOE
RME026	06.2	Natural gas, liquefied or in gaseous state	1000 TOE
RME027	07.1	Iron ores	million EUR
RME028	07.21	Uranium and thorium ores	1000 t RME
RME029	07.29.11	Copper ores and concentrates	million EUR
RME030	07.29.12	Nickel ores and concentrates	million EUR
RME031	07.29.13	Aluminium ores and concentrates	million EUR
RME032	07.29.14.a	Gold	million EUR
RME033	07.29.14.b	Silver	million EUR
RME034	07.29.14.c	Platinum MG	million EUR
RME035	07.29.15.a	Lead	million EUR
RME036	07.29.15.b	Zinc	million EUR
RME037	07.29.15.c	Tin	million EUR
RME038	07.29.19.a	Tungsten ores and concentrates	million EUR
RME039	07.29.19.b	Tantalum ores and concentrates	million EUR
RME040	07.29.19.c	Magnesium ores and concentrates	million EUR
RME041	07.29.19.d	Titanium ores (Ilmenite) and concentrates	million EUR
RME042	07.29.19.e	Manganese ores and concentrates	million EUR
RME043	07.29.19.f	Chromium ores and concentrates	million EUR
RME044	07.29.19.g	Other ores and concentrates	million EUR
RME045	08.11.1	Ornamental or building stone	1000 t
RME046	08.11.2	Limestone and gypsum	1000 t
RME047	08.11.3	Chalk and uncalcined dolomite	1000 t
RME048	08.11.4	Slate	1000 t
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	1000 t
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	1000 t
RME051	08.12.2	Clays and kaolin	1000 t
RME052	08.91	Chemical and fertiliser minerals	1000 t
RME053	08.92	Peat	1000 t
RME054	08.93	Salt and pure sodium chloride; sea water	1000 t
RME055	08.99	Other mining and quarrying products n.e.c.	1000 t
RME056	09	Mining support services	million EUR
RME057	10.1	Preserved meat and meat products	million EUR
RME058	10.2	Processed and preserved fish, crustaceans and molluscs	million EUR

RME059	10.3	Processed and preserved fruit and vegetables	million EUR
RME060	10.4	Vegetable and animal oils and fats	million EUR
RME061	10.5	Dairy products	million EUR
RME062	10.6	Grain mill products, starches and starch products	million EUR
RME063	10.7, 10.8	Other food products	million EUR
RME064	10.91	Prepared feeds for farm animals	million EUR
RME065	10.92	Prepared pet foods	million EUR
RME066	11	Beverages	million EUR
RME067	12	Tobacco products	million EUR
RME068	13	Textiles	million EUR
RME069	14	Wearing apparel	million EUR
RME070	15	Leather and related products	million EUR
RME071	16	Wood and of products of wood and cork, except furniture; articles of straw and plaiting	million EUR
RME072	17.1	Pulp, paper and paperboard	million EUR
RME073	17.2	Articles of paper and paperboard	million EUR
RME074	18	Printing and recording services	million EUR
RME075	19.1	Coke oven products	1000 TOE
RME076	19.2	Refined petroleum products	1000 TOE
RME077	20.1, (exc.l 20.15, 20.16)	Basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in excl. fertilisers and nitrogen compounds, excl. plastics in primary forms	million EUR
RME078	20.15	Fertilisers and nitrogen compounds	million EUR
RME079	20.16	Plastics in primary forms	million EUR
RME080	20.2	Pesticides and other agrochemical products	million EUR
RME081	20.3	Paints, varnishes and similar coatings, printing ink and mastics	million EUR
RME082	20.4	Soap and detergents, cleaning and polishing preparations, perfumes and toilet	million EUR
RME083	20.5	Other chemical products	million EUR
RME084	20.6	Man-made fibres	million EUR
RME085	21	Basic pharmaceutical products and pharmaceutical preparations	million EUR
RME086	22.1	Rubber products	million EUR
RME087	22.2	Plastic products	million EUR
RME088	23.1	Glass and glass products	million EUR
RME089	23.2	Refractory products	million EUR
RME090	23.3	Clay building materials	million EUR
RME091	23.4	Other porcelain and ceramic products	million EUR
RME092	23.5	Cement, lime and plaster	million EUR
RME093	23.6	Articles of concrete, cement and plaster	million EUR

RME094	23.7	Cut, shaped and finished stone	million EUR
RME095	23.9	Other non-metallic mineral products	million EUR
RME096	24.1-3	Basic iron and steel and ferro-alloys	million EUR
RME097	24.41.1, 24.41.4, 24.41.5, 24.41.9	Silver, unwrought or in semi-manufactured forms, or in powder form	million EUR
RME098	24.41.2	Gold, unwrought or in semi-manufactured forms, or in powder form	million EUR
RME099	24.41.3	Platinum, unwrought or in semi-manufactured forms, or in powder form	million EUR
RME100	24.42	Aluminium	million EUR
RME101	24.43.11, 24.43.21, 24.43.9	Lead	million EUR
RME102	24.43.12, 24.43.22, 24.43.23	Zinc	million EUR
RME103	24.43.13, 24.43.24	Tin	million EUR
RME104	24.44	Copper	million EUR
RME105	24.45.1, 24.45.2, 24.45.9	Nickel, unwrought; intermediate products of nickel metallurgy	million EUR
RME106	24.45.3.a	Tungsten products	million EUR
RME107	24.45.3.b	Tantalum products	million EUR
RME108	24.45.3.c	Magnesium products	million EUR
RME109	24.45.3.d	Titanium products	million EUR
RME110	24.45.3.e	Manganese products	million EUR
RME111	24.45.3.f	Chromium products	million EUR
RME112	24.45.3.g	Other non-ferrous metal products	million EUR
RME113	24.46	Processed nuclear fuel	1000 TOE
RME114	24.51	Casting services of iron	million EUR
RME115	24.52	Casting services of steel	million EUR
RME116	24.53	Casting services of light metals	million EUR
RME117	24.54	Casting services of other non-ferrous metals	million EUR
RME118	25.1	Structural metal products	million EUR
RME119	25.2	Tanks, reservoirs and containers of metal	million EUR
RME120	25.3	Steam generators, except central heating hot water boilers	million EUR
RME121	25.5	Forging, pressing, stamping and roll-forming services of metal; powder metallurgy	million EUR
RME122	25.6	Treatment and coating services of metals; machining	million EUR
RME123	25.7	Cutlery, tools and general hardware	million EUR
RME124	25.4, 25.9	Other fabricated metal products, incl weapons and ammunition	million EUR

RME125	26	Computer, electronic and optical products	million EUR
RME126	27	Electrical equipment	million EUR
RME127	28	Machinery and equipment n.e.c.	million EUR
RME128	29	Motor vehicles, trailers and semi-trailers	million EUR
RME129	30.1	Ships and boats	million EUR
RME130	30.2	Railway locomotives and rolling stock	million EUR
RME131	30.3	Air and spacecraft and related machinery	million EUR
RME132	30.4, 30.9	Transport equipment n.e.c., incl. military fighting vehicles	million EUR
RME133	31	Furniture	million EUR
RME134	32.1	Jewellery, bijouterie and related articles	million EUR
RME135	32.2	Musical instruments	million EUR
RME136	32.3	Sports goods	million EUR
RME137	32.4	Games and toys	million EUR
RME138	32.5	Medical and dental instruments and supplies	million EUR
RME139	32.9	Manufactured goods n.e.c.	million EUR
RME140	33	Repair and installation services of machinery and equipment	million EUR
RME141	35.1	Electricity, transmission and distribution services	1000 TOE
RME142	35.2	Manufactured gas; distribution services of gaseous fuels through mains	million EUR
RME143	35.3	Steam and air conditioning supply services	1000 TOE
RME144	36	Natural water; water treatment and supply services	million EUR
RME145	37, 38, 39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	million EUR
RME146	41, 42, 43	Construction and construction works	million EUR
RME147	45	Wholesale and retail trade and repair services of motor vehicles and motorcycles	million EUR
RME148	46	Wholesale trade services, except of motor vehicles and motorcycles	million EUR
RME149	47	Retail trade services, except of motor vehicles and motorcycles	million EUR
RME150	49	Land transport services and transport services via pipelines	million EUR
RME151	50	Water transport services	million EUR
RME152	51	Air transport services	million EUR
RME153	52	Warehousing and support services for transportation	million EUR
RME154	53	Postal and courier services	million EUR
RME155	55, 56	Accommodation and food services	million EUR
RME156	58	Publishing services	million EUR

RME157	59, 60	Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	million EUR
RME158	61	Telecommunications services	million EUR
RME159	62, 63	Computer programming, consultancy and related services; information services	million EUR
RME160	64	Financial services, except insurance and pension funding	million EUR
RME161	65	Insurance, reinsurance and pension funding services, except compulsory social security	million EUR
RME162	66	Services auxiliary to financial services and insurance services	million EUR
RME163	68	Real estate services	million EUR
RME164	69, 70	Legal and accounting services; services of head offices; management consulting services	million EUR
RME165	71	Architectural and engineering services; technical testing and analysis services	million EUR
RME166	72	Scientific research and development services	million EUR
RME167	73	Advertising and market research services	million EUR
RME168	74, 75	Other professional, scientific and technical services; veterinary services	million EUR
RME169	77	Rental and leasing services	million EUR
RME170	78	Employment services	million EUR
RME171	79	Travel agency, tour operator and other reservation services and related services	million EUR
RME172	80, 81, 82	Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	million EUR
RME173	84	Public administration and defence services; compulsory social security services	million EUR
RME174	85	Education services	million EUR
RME175	86	Human health services	million EUR
RME176	87, 88	Social work services	million EUR
RME177	90, 91, 92	Creative, arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services	million EUR
RME178	93	Sporting services and amusement and recreation services	million EUR
RME179	94	Services furnished by membership organisations	million EUR
RME180	95	Repair services of computers and personal and household goods	million EUR
RME181	96	Other personal services	million EUR
RME182	97, 98	Services of households as employers; undifferentiated goods and services produced by households for own use	million EUR

5.3.2 Expanded EW-MFA classification for materials (domestic extraction)

MF111	Cereals
MF112	Roots, tubers
MF113	Sugar crops
MF114	Pulses
MF115	Nuts
MF116	Oil-bearing crops
MF117	Vegetables
MF118	Fruits
MF119	Fibres
MF1110	Other crops n.e.c.
MF1211	Straw
MF1212	Other crop residues (sugar and fodder beet leaves, other)
MF122	Fodder crops (incl. biomass harvest from grassland)
MF131	Timber (Industrial roundwood)
MF132	Wood fuel and other extraction
MF141	Wild fish catch
MF142	All other aquatic animals and plants
MF143	Hunting and gathering
MF21	Iron
MF221	Copper
MF222	Nickel
MF223	Lead
MF224	Zinc
MF225	Tin
A.2.2.6.1	Gold
A.2.2.6.2	Silver
A.2.2.6.3	Platinum and other precious metal ores - gross ore
MF227	Bauxite and other aluminium
MF228	Uranium and thorium
A.2.2.9.1	Tungsten
A.2.2.9.2	Tantalum
A.2.2.9.3	Magnesium ores
A.2.2.9.4	Titanium
A.2.2.9.5	Manganese
A.2.2.9.6	Chromium
A.2.2.9.7	Other metal ores
MF31	Marble, granite, sandstone, porphyry, basalt, other ornamental or building stone (excluding slate)

MF32	Chalk and dolomite
MF33	Slate
MF34	Chemical and fertiliser minerals
MF35	Salt
MF36	Limestone and gypsum
MF37	Clays and kaolin
MF38	Sand and gravel
MF39	Other non-metallic minerals n.e.c
MF411	Lignite (brown coal)
MF412	Hard coal
MF413	Oil shale and tar sands
MF414	Peat
MF421	Crude oil, condensate and natural gas liquids (NGL)
MF422	Natural gas