

Material footprints

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Material footprints

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Executive summary

In the transition to a more resource-efficient and circular economy, it's essential to measure material exposure and track consumption trends. Various indicators help identify problems and set goals for increasing resource efficiency. Many goods are produced in different countries than where they are used, impacting the environment beyond borders.

There is a growing need to develop measures for the material footprint for policy evaluation. The specific aims of this grant project include completing the existing Raw Material Equivalents (RME) tool provided by Eurostat, adapting in-house statistics of material flows into the Eurostat model framework, exploring other models, and finally developing the material flow data collection.

Our analysis begins by examining why domestic material consumption (DMC) and raw material consumption (RMC) patterns coincide over time. DMC and RMC tend to show similar trends as both follow the same economic activities, but RMC offers a broader perspective. Ongoing activities in the economy, such as construction, urbanization, economic growth, and technological development, increase the demand for various material types. Our analysis indicates a slight increase in Sweden's material footprint, especially for non-metallic minerals needed in construction, especially using EUROSTAT RME model. On the other hand, the corresponding input-output based raw material footprint measure don't show similar clear trends like the RME tools do, perhaps the revisions policy and now-casting of the material extensions from EXIOBASE database explain this.

Despite difficulties in showing detailed domestic material consumption at the industrial level, resource-intensive sectors in Sweden were found to have the highest impact on material consumption.

Introduction

In the transition to a more resource-efficient society and a circular economy, it is crucial to measure how much material we use and whether material usage is increasing or decreasing. Today, various indicators are used to measure the material usage of economies and countries. These indicators are important tools for identifying problems, setting goals, and monitoring measures aimed at increasing resource efficiency in society.

In today's global society, many goods are manufactured in a different country than where they are used. This results in many countries having an environmental impact in the form of carbon dioxide

emissions and material usage even outside their borders. Many products require a larger amount of material to be manufactured than what is visible in the final product. When countries and economies set goals for resource efficiency, it is important to consider the product's material footprint when calculating the total material usage of countries, regardless of where the material extraction occurs.

Material footprint estimates is part of the United Nations' Sustainable Development Goal 12, which focuses on sustainable consumption and production. Key targets can be summarized as:

- Sustainable Resources Management: By 2030, achieve the sustainable management and efficient use of natural resources.
- Waste Reduction: Reduce waste generation through prevention, reduction, recycling, and reuse by 2030.
- Chemicals and Waste Management: Achieve environmentally sound management of chemicals and all wastes throughout their life cycle to minimize adverse impacts on human health and the environment.
- Sustainable Practices: Encourage companies to adopt sustainable practices and integrate sustainability information into their reporting cycles.

These targets aim to reduce the material footprint by promoting efficient resource use, minimizing waste, and encouraging sustainable practices globally.

Statistics Sweden (SCB) has been producing material flow statistics since around 2010. Between 2020 and 2023 SCB was involved in a project financed by Vinnova (Sweden's innovation agency) where the possibility of using Eurostat's RME (Raw Material Equivalents) tool to produce data on material footprints was explored. The preliminary results from this project have been published on Statistics Sweden's website.¹ The project conducted by Vinnova together with SCB in 2020-2023 aimed to develop methods for measuring the material footprint, which is a measure of the total amount of raw materials used to meet a country's domestic consumption. The project contributed to creating a more comprehensive picture of resource use and identifying areas where improvements can be made to increase resource efficiency and circularity.

While the carbon footprint measure is well-developed, the material footprint measure needs further development. Specific goals for this grant funded project include:

¹ <https://www.scb.se/mi1306>

- Being able to fill in the RME table in the Eurostat EW-MFA questionnaire by 2024.
- Understanding the Eurostat RME model and adapting it to Swedish material flows data.
- Exploring other models like EXIOBASE and compare the results.
- Developing MFA data collection by breaking it down into industries.²
- Participating in Eurostat's work to extend the FIGARO input-output model with material flow accounts data.³
- Engaging with the Swedish National Board of Housing, Building and Planning on the results of this analysis.
- Being an inspiration for future works on regional material footprint statistics to integrate with our multiregional input-output model.

Furthermore, the ambition is to build up and strengthen our in-house expertise and create knowledge spillovers in the field of material flow accounts and input-output modelling.

Material flow accounts in the past

This section summarizes the most important work on developing the material flows account statistics. The sections also highlight on important conclusions and suggestions for a better understanding the measurement of industry specific resource management and circular economy.⁴

Statistics Sweden

An industry allocation has been made for Swedish material flow accounts, including domestic material consumption for the years 2008–2018, within a project in collaboration with Miljö & Avfallsbyrån (2020). Regarding the domestic extraction part of the material flows, industries have been assigned for each material category based on

² The interested reader may consult the link [Exiobase - Home](#) for further information.

³ The link to FIGARO system, [Database - ESA supply, use and input-output tables - Eurostat](#)

⁴ Material flow accounts are classified according to the NACE (Nomenclature of Economic Activities) system, which is the European standard for industry classification. This allows for detailed tracking and analysis of material flows by industry sectors.

expert assessment by the person responsible for SCB's material flow accounts. It was relatively straightforward to determine which sectors to distribute material flow to.

Regarding import and export statistics, the Miljö and Avfallsbyrån (2020) project applied data from Statistics Sweden on international trade in goods. This data includes the organization identification numbers of companies involved in imports and exports. These numbers were also existent in the business registers database (BR) too, allowing a matching procedure of industry specific NACE codes for these trading companies. Although many companies did operate in multiple sectors, we classify them based on their main sector in the BR. The current industry classification, SNI2007, was introduced in 2008, so the project classified imports and exports by industry for the years 2008–2018.

International work on material flows

According to Miljö and Avfallsbyrån (2020), several methods for the industry allocation of material flow accounts used in other countries were examined. Statistics Denmark has published a report describing their work with material flows and physical input-output tables within the circular economy, Ellen MacArthur Foundation (2015). However, according to the feasibility study the Danish method were not relevant for estimating the Swedish material flow within the Miljö and Avfallsbyrån project, as we do not have access to the type of detailed material flow accounts data used.

Similarly, Statistics Austria discusses their development work on material flows and physical input-output tables in a report, Baud (2011). Their approach involved building statistics based on material flow accounts, industrial production statistics, energy balances, energy accounts, and various other input sources. The Austrian experience revealed challenges in reconciling data sources that are not fully comparable, highlighting several issues in creating accurate physical input-output tables. One significant challenge they noted is the difficulty in converting materials into often complex products, a process that occurs continuously across all industries. This raises the question: how should a complex product be classified when it needs to be reported as a material?

Statistics Netherlands has published several reports outlining their method, including analyses by Van Berkel et al in 2019. Unlike the approaches in Denmark and Austria, the Dutch method does not start with existing material flow statistics. Instead, they reconcile statistics from supply-use tables. Monetary statistics are converted to physical measures in tons using various price indices. These physical values are then adjusted with more detailed information from other sources. They also add physical flows without monetary value, such as waste and air.

Finally, they balance supply and use, including emissions to air, which have weight even if they are in gas form and not visible.

The conclusions from the Miljö & Avfallsbyrå (2020) feasibility study emphasize that the best way to analyse industry resource utilization, especially for the Swedish economy, is by using existing supply and use tables, as well as input-output tables. The national account statistics cover all industries and product groups and are available for several years, allowing for the study of trends.⁵ Based on the input-output systems, it is also possible to conduct sensitivity analyses to visualize how changes in the economy could impact the use and composition of different materials as demand conditions change.

The material flows accounts statistics with industry classification

Material flow accounts (MFA) cover the physical flow of materials into and out of the Swedish economy. This includes:

- Domestic extraction: Raw materials extracted within Sweden.
- Imports: Materials brought into Sweden from other countries.
- Exports: Materials sent from Sweden to other countries.
- Domestic material consumption (DMC): The total amount of materials used within Sweden, calculated as domestic extraction plus imports minus exports.

The definitions of material flows statistics are broken down into, a complete list of materials is provided in the appendix:

- Biomass: Includes wood, agricultural products, and other biological materials.
- Metals: Encompasses all metal ores and refined metals.
- Non-metallic minerals: Includes materials like sand, gravel, and other construction materials.
- Fossil fuels: Covers coal, oil, natural gas, and other fossil energy sources.

⁵ The integrated input and output statistics follows the CPA 2008 code system.

- Other products: Net imports of finished products composed of a mix of the above material categories.
- Waste: Imported or exported waste, categorized according to the European Waste Framework Directive.

According to the aim of the project, an industry assignment has been made for Swedish material flow accounts, including the measurement of domestic material consumption, for the years 2008-2022. The industry assignment methodology mainly follows the steps undertaken in the Avfalls and Miljöbyrån project (2020). For domestic extraction, a NACE code has been assigned to each material category based on expert assessment by the SCB expert in material flow accounts. It was quite natural to determine which industries would apply; the harvest of wheat reasonably comes from the agricultural industry, timber from the forestry industry, metal ore from the mining industry, etc. All our domestic extraction falls under the main NACE industry groups of A, B, and C, which are reported together in this report.

Calculation procedures of DMC

The domestic material consumption is calculated as:

$$DMC_{mi} = import_{mi} + DE_{mi} - export_{mi}. \quad (1)$$

meaning some sectors having no own extractions resulting in values of DMC hard to interpret. Unlike the traditional DMC measure, which can only be broken down into broad categories, the RME model allows for detailed disaggregation of material flow categories. This detailed breakdown is crucial for ecological footprint analysis and the interpretation of material flows. Therefore, the adjustment procedure is about to relocate the domestic extraction values from the primary sectors into using sectors using the share of traded materials via Leontief inverse matrix. The formulas were:

$$M_{mi} = m_{mi} L_{mij} y_{mi}. \quad (2)$$

The m_i values are as before the domestic extraction per million SEK output values, the next step is to calculation the trade share vector:

$$w_{mi} = \sum_i M_{mi} / \sum_i \sum_j M_{mij}. \quad (3)$$

The adjusted domestic material consumption formula is as follows:

$$DMC_{adj_{mi}} = import_{mi} + DE_{mi} \circ w_{mi} - export_{mi}. \quad (4)$$

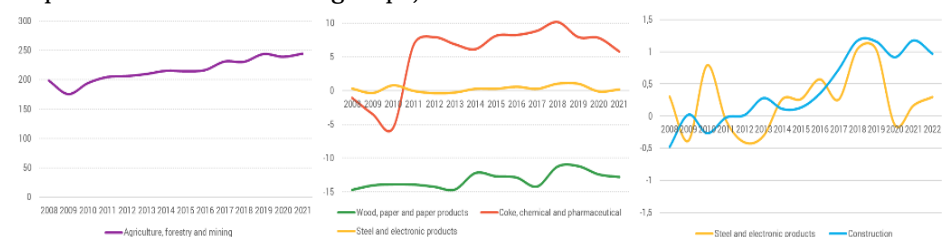
\circ the operator denotes elementwise multiplication.

Concerning imports and exports, the data is based on SCB's register of foreign trade in goods. In the trade statistics all trade enterprises report

by organization identification numbers. Organization identification numbers are also available in the business registers (BR) at SCB, which allows the matching procedure of NACE codes for these companies. Many companies operate in multiple industries, but for the purpose of this analysis, we have used the main industry listed for each enterprise based on the information available in the BR. The current industry classification, NACE rev.2 i.e., SNI2007 nomenclature, was introduced and applied in the reference year 2008. Hence, the domestic extraction, exports, and imports are divided into around 100 industries and 45 material categories. This process leads to some issues when matching business registers with trade statistics, as about 10 percent of companies don't get matched. This results in uncertainty in the final estimates.

As with all other statistics produced by Statistics Sweden, the information provided by companies regarding the foreign trade statistics is protected by statistical confidentiality. To produce official statistics governed by EU regulations, where results are reported on CN codes, SITC, or SPIN, so-called passive confidentiality applies, which means that companies are assumed to accept that the information is reported unless otherwise notified. A company that does not want its information to be disclosed must contact Statistics Sweden, and it will then be hidden in the reported statistics. Therefore, the results can only be reported at a more general level, see figure 1 below. Since material flows is reported as detailed as possible, the industry distribution for domestic extraction also needed to be aggregated to prevent indirect disclosure of information from foreign trade, see appendix for the industry classifications.

Figure 1: the domestic material consumptions for a selection of important domestic NACE groups, in millions of tons



Source: Statistics Sweden

Before extraction of raw materials and imports are made by the Swedish companies, they often change owners several times and are transformed into new products within the value chains. Such flows within a country's economy are not included in material flow accounts. Industry distributed material flow accounts (DMC) do not provide any information about industries or companies resource utilization; the series only show which industries ensured that the materials entered the Swedish economy. Internal flows within the country are not

captured, which can result in negative consumption in certain NACE categories.

Methods applied for estimating the Raw Material Consumption (RMC) footprint

Normally, statistical institutes produce material flow statistics using the RME tools developed by Eurostat. However, due to the high levels of aggregation in these models, there is growing interest in further developing material flow account statistics. By using detailed industry group information, the understanding of material usage in the economy can be improved.

Calculation procedures using Eurostat RME tools

The main purpose of establishing estimates in Raw material equivalents (RME) is to extend the EW-MFA questionnaire and offer an alternative to the DMC indicator. RME corresponds conceptually to domestic extraction (DE) in the EW-MFA system and converts product flows into raw material equivalents. This unit expresses product flows in their equivalent domestic extraction, considering the raw materials embodied in products. The RME of a product indicates the total material extraction necessary for its production, regardless of where the materials were extracted. According to Eurostat (2016) handbook defines a product RME as *“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.”*

Physical flow accounting within EW-MFA aims to derive indicators like DMC for European policies such as SDGs, the European Green Deal, and the circular economy. However, DMC has two major asymmetries: imports and exports are measured differently than domestic extraction (DE), and therefore the composition of imports and exports can differ significantly. The RME concept overcomes these asymmetries by measuring imports and exports in raw material equivalents, aligning them with DE.

Eurostat aims to establish economy-wide indicators by converting trade components from product weights into RMC. In short, the formulas are:

$$\text{RMC}_{mi} = \text{rmeimp}_{mi} + \text{DE}_{mi} - \text{rmeex}_{mi} \quad (5)$$

“m” represents the material types and “i” and “j” using - respectively producing industries. Raw material equivalents of import (RMEIMP) and raw material equivalents of export (RMEEX) begin with import and export values from the official statistics, respectively. These values are then rescaled and transformed into physical units. Additional adjustments are made to account for the amounts of recycled metals in indirect imports and regional information to estimate the energy mix within direct and indirect imports of electricity. For more technical details, readers are advised to consult the Eurostat Handbook for Estimating Raw Material Equivalents [Handbook-country-RME-tool](#).

The calculation procedure with an input-output framework

The following section describes in short, the steps behind the calculation of the material footprints impact using either the EXIOBASE or FIGARO input and output tables. For more technical details the reader recommends reading the full Eurostat report *Producing environmental account with environmentally extended input and output analysis* (Brown et al., 2021) and Palm et al. (2019). EXIOBASE incorporates a family of closely related methods. Statistics New Zealand and Eurostat both use a single region input-output (SRIO) method, assuming domestic technology for imports. Statistics Sweden applies a simplified single country national accounts consistent (SNAC) method. These two approaches use the same method for the calculation of domestic material footprint pressures but differ in the calculation of material footprint pressures arising due to imported products.

The material footprints (or ecological footprint) arising from final demand in the economy RMC_{tot} can be expressed as the sum of those arising domestically, RMC_{dom} and those arising abroad (due to imports), RMC_{imp} :

$$\text{RMC}_{\text{tot}} = \text{RMC}_{\text{dom}} + \text{RMC}_{\text{imp}}, \quad (6)$$

In both methods, domestic material footprints as given in Equation 1 are calculated according to

$$\text{RMC}_{\text{dom}} = \mathbf{m}_{\text{dom}}(\mathbf{I} - \mathbf{A}_{\text{dom}})^{-1} \mathbf{Y}_{\text{dom}}, \quad (7)$$

where \mathbf{m}_{dom} is the domestic material extraction per unit gross output, \mathbf{A}_{dom} is the domestic intermediate demand, \mathbf{Y}_{dom} is the final demand for domestically produced products in the economy. Eurostat uses the same method to calculate domestic energy use.

In the single region input output model (SRIO) with data technology assumption (DTA), material footprint arising in total, both domestically and abroad can be calculated as

$$RMC_{tot} = m_{dom}(I - A_{tot})^{-1}Y_{tot}. \quad (8)$$

where A_{tot} is the total intermediate demand ($A_{tot}=A_{dom}+A_{imp}$) and Y_{tot} is the final demand of both domestic and imported products. Materials extraction arising abroad only, can then be calculated as the residual through:

$$RMC_{imp} = RMC_{tot} - RMC_{dom}. \quad (9)$$

Here, “RMC” can be as either a scalar (total material footprint pressure), a vector (material footprint pressure per product consumed) or a matrix (material footprint pressure per product consumed and per interpreted component of final demand, of which one of the components could also be exports).

The material footprints of imports are thus calculated as if the imports had been produced in the economy in question. One interpretation of this method is that these material extractions represent those avoided domestically by importing the products. Eurostat does not aim to include imports when calculating domestic energy use with EXIOBASE.

In the applied SNAC model, the material intensity for imported products is calculated using a global multiregional input and output tables MRIO (i.e, EXIOBASE or FIGARO). Denote elementwise multiplication and division by \circ and \oslash respectively. In a first step, production intensities around the globe are calculated as:

$$m_{world} = (m_{gmrio} \circ (I - A_{gmrio})^{-1} \circ y_{gmrio}) \oslash y_{gmrio}, \quad (10)$$

where m_{world} is the material extraction per unit gross output per product and country included in the MRIO, m_{gmrio} is the material intensity of gross output in the MRIO and A_{gmrio} is intermediate demand per unit of gross output in the MRIO. Note that matrices in Equation 10 are disaggregated both by product type and geographical area (in single countries or groups of countries). To derive import intensities for the importing nation, the following calculation is performed:

$$m_{imp} = B \circ m_{world} a. \quad (11)$$

Where “B” is a matrix of import shares from each geographical area in the MRIO by product group for the importing country or region and “a” is a simple summation vector. This gives m_{imp} as the import intensities by product group according to the specific import shares for the importing country and according to the material footprint intensities and economic structure of the MRIO used. According to the simplified SNAC method used, RMC_{imp} can then be calculated as:

$$\text{RMC}_{\text{imp}} = \mathbf{m}_{\text{imp}} \mathbf{A}_{\text{imp}} (\mathbf{I} - \mathbf{A}_{\text{dom}})^{-1} \mathbf{Y}_{\text{dom}} + \mathbf{m}_{\text{imp}} \mathbf{Y}_{\text{imp}}. \quad (12)$$

$$\begin{aligned} \text{RMC}_{\text{tot}} = & \mathbf{m}_{\text{dom}} (\mathbf{I} - \mathbf{A}_{\text{dom}})^{-1} \mathbf{Y}_{\text{dom}} + \mathbf{m}_{\text{imp}} \mathbf{A}_{\text{imp}} (\mathbf{I} - \mathbf{A}_{\text{dom}})^{-1} \mathbf{Y}_{\text{dom}} \\ & + \mathbf{m}_{\text{imp}} \mathbf{Y}_{\text{imp}}. \end{aligned} \quad (13)$$

Where \mathbf{A}_{imp} is the intermediate demand for imported goods per unit output and \mathbf{Y}_{imp} is the direct final demand for imported goods. Other terms are as before.

The statistical quality of material footprint

Currently, Statistics Sweden uses data from both the environmentally extended multiregional input-output database EXIOBASE and official Swedish input-output data to produce official statistics on greenhouse gas and other air emissions from a consumption perspective. As this report aims to investigate the possibilities of using other models than RME tool by Eurostat as input data for the statistics on material footprint, this chapter compares the statistical quality of the EXIOBASE with currently used RME-tool. For a more detailed description of data and statistical quality the reader is advised to read the earlier grants report by Statistics Sweden (2023). As the call grants request other input and output related sources, we present a summary of them.

The comparison includes both quantitative and qualitative aspects. Variations in input data, production methodologies and data processing steps are discussed considering the following:

- Geographical coverage and classification
- Industry/product classification
- Economic variables (major components of the input-output table i.e., matrices of intermediate use, production values, output, final demand, value added, international trade)
- Material vectors
- Reference year for real data

Eurostat RME-tool

The RME (Raw Material Equivalent) tool from Eurostat estimates the raw material consumption (RMC) and other related indicators for the EU economy. Developed by Eurostat, the statistical office of the European Union, the tool's main purpose is to monitor and estimate RMC and related indicators. It helps in understanding the raw material inputs required to produce goods and services, thereby providing insights into the resource efficiency and sustainability of the economy. The tool supports the EU's goals of decoupling economic growth from resource use and environmental degradation. The reference year for real data is regularly updated to ensure accuracy. The database, available in Excel formats, presents data with a two-year lag.

Geographical Coverage and Classification: The RME tool covers the EU economy, focusing on the EU27 countries. It provides estimates for raw

material consumption (RMC) and other RME-based indicators at both the EU and country levels¹.

Industry/Product Classification: The tool uses the NACE Rev. 2 classification system for industries and products. This ensures consistency and comparability with other economic and statistical data.

Economic Variables: The major components of the input-output table in the RME tool include:

- **Matrices of Intermediate Use**: These capture the flow of goods and services between industries.
- **Production Values**: The total value of goods and services produced.
- **Output**: The total production output of industries.
- **Final Demand**: The total demand for goods and services by households, government, and other final users.
- **Value Added**: The net output of industries after subtracting intermediate inputs.
- **International Trade**: The imports and exports of goods and services.

Material Vectors: Material vectors in the RME tool represent the raw material inputs required to produce goods and services. These vectors are used to estimate the raw material equivalents of imports and exports, raw material input (RMI), and raw material consumption (RMC).

Reference Year for Real Data: The reference year for real data in the RME tool is updated regularly to reflect the most recent and accurate data available. The latest updates incorporate data up to 2023.

EXIOBASE

EXIOBASE is an environmentally extended multi-regional input-output (EE MRIO) database developed through international collaborations within the EU projects EXIOPOL, CREEA, and DESIRE. The latest version, EXIOBASE 3.8.2, was released in September 2021 and includes data from 1995 to 2022, with recent years based on forecasts. Updates depend on financing, and no new updates have been made since 2021.

Geographical Coverage and Classification: EXIOBASE 3 covers the world economy, divided into 49 regions, including 27 EU Member States, 17 major economies, and five rest-of-the-world regions.

Industry and Product Classification: The database includes 163 industries and 200 product groups under the NACE rev 1 classification scheme. It provides supply, use, and input-output (IO) tables in current, basic prices (Million EUR).

Input Data and Methodology: EXIOBASE 3 uses rectangular supply-use tables to construct monetary MRIO tables. The methodology follows a top-down approach, ensuring consistency with macroeconomic data,

capturing structural changes, and aligning with international data sources. Data sources include Eurostat, national statistical offices, the UN National Accounts Main Aggregates Database, FAOSTAT, IEA, and BACI.

The database relies heavily on now-casting economic structures for recent years, with the last official data from 2011. The balancing of technical coefficients and trade data uses a cross-entropy approach.

Material Vectors: One advantage of using EXIOBASE is that the database provides environmental extensions to be used with the MRIO tables. Here, 417 emission categories are available as well as 222 material (used/unused) and resource categories.

The main data source for the compilation of the material extension in EXIOBASE 3 was the Global Material Flow Database compiled by the research group “Sustainable Resource Use” at the Vienna University of Economics and Business (WU 2015). This database currently covers more than 300 different types of biotic and abiotic raw materials for more than 200 countries. During the DESIRE project, updates of this database were performed to include the years 2010–2012, see Stadler et al (2018).

Compared to earlier versions of EXIOBASE, the list of material extensions has been broken down significantly to enable more detailed analysis. It now covers 222 items, including 193 biomass items (179 crops, seven forestry and four fishery items, two crop residues, and grazing), 12 metal ores, eight industrial and construction minerals, and nine fossil fuels. Unused extraction refers to materials that never enter the economic system and comprises overburden and parting materials from mining, by-catch from fishing, wood, and agricultural harvesting losses, as well as soil excavation and dredged materials from construction activities, for more information see Stadler et al (2018), see appendix for more details on the materials.

In EXIOBASE 3, the items of fodder crops, grazing, and crop residues were directly allocated to the respective animal production sectors which use these commodities. The AgroSAM database were used in Müller et al. (2009). However, no documentation regarding how these data have been nowcasted has been found within this project.

FIGARO

FIGARO (Full International and Global Accounts for Research in Input-Output analysis) is an MRIO database developed by Eurostat and the Joint Research Centre of the European Commission. It serves as a reference tool for policymakers on the economic, social, and environmental impacts of globalization. First published in May 2021, FIGARO is updated annually, with the latest edition covering 2010 to 2021. The database, available in CSV and Excel formats, presents data with a two-year lag.

Geographical Coverage and Classification: FIGARO includes 46 geographical areas, comprising 27 EU Member States, 18 other major economies, and one rest-of-the-world region. It features supply, use, and input-output tables classified by industry (NACE Rev. 2) and product (CPA version 2.1).

Input Data and Methodology: The input data for FIGARO tables consist of national accounts, supply and use tables, international trade data, and business statistics. These are used to construct balanced bilateral trade databases and national IO tables. Due to a two-year data lag, Eurostat now-casts missing data using macroeconomic aggregates. Data sources include Eurostat, OECD, and UN Comtrade.

Challenges and Adjustments: Constructing MRIO tables involves addressing asymmetries in reported bilateral trade flows due to different valuations, classifications, time lags, and third-country transits. FIGARO balances these discrepancies using a generalized RAS-balancing method (GRAS).

Material Vectors: The environmental vectors for use with FIGARO MRIO tables are today available, but nothing is reported on the availability of material vectors from Figaro website. ⁶

Results

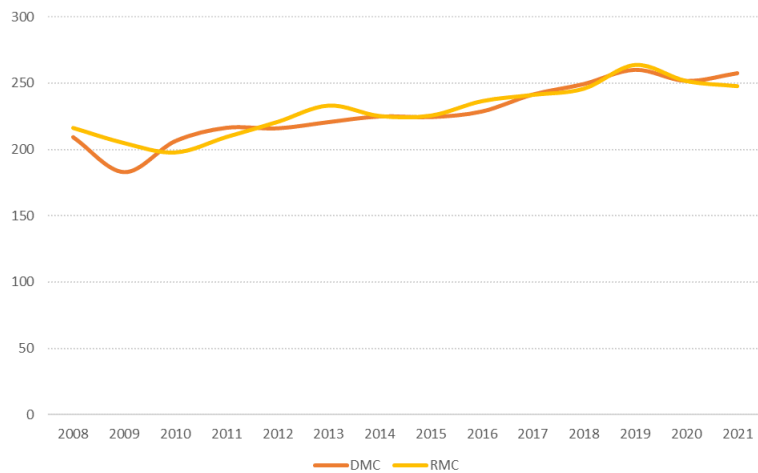
Why do the DMC and RMC series follow each other?

Our analysis starts with observed phenomenon on why pattern of domestic- and raw material consumption likely coincide over time. The made comparison stemming from data present within the prefilled Eurostat RME tool and Economy-wide material flows account (EW_MFA) questionnaire. The main model was summarized in the previous section.

Domestic material consumption measures the total amount of materials direct used by an economy. It includes the raw materials extracted domestically plus all physical imports, minus all physical exports. Raw Material Consumption on the other hand measures the total amount of raw materials required to produce the goods consumed by an economy.

Figure 2: the total values of material footprint measure RMC (“Raw material consumption”) and DMC (“Domestic material consumption”), expressed in millions of tonnes.

⁶ [Database - ESA supply, use and input-output tables - Eurostat](#)

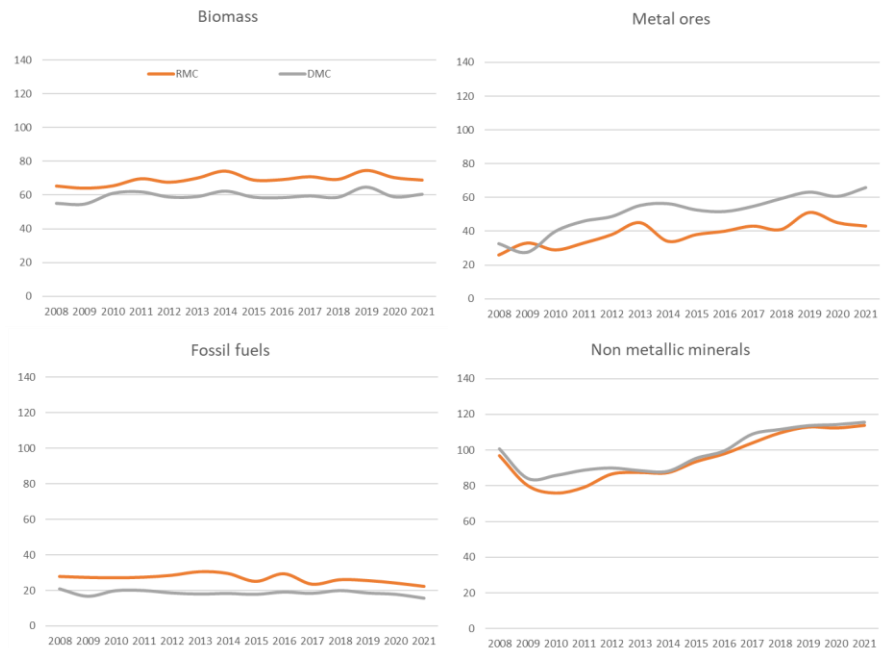


Source: Statistics Sweden, Eurostat database and EXIOBASE database.

According to the past research within the topic, DMC and RMC are often similar over time because they both measure the total amount of materials used by an economy, but with slightly different scopes. The main difference is that RMC accounts for the raw materials needed to produce imported and exported goods, providing a more comprehensive view of material use.

The coincidence of the series of domestic material consumption and raw material consumption at aggregate level may intuitively be explained by the similar definitions, see figure 2. Both indicators use trade flows (i.e., imports and exports) and domestic extractions, except for the RMC, which applies RME coefficients on trade volumes only, see equation 5. The fact that the main part of the Swedish domestic extraction derives from mining and quarrying activities provides therefore an intuitive and tentative explanation for the similarities. The applied RME coefficients on trade flows may be smoothed out due to the high level of aggregation of the data series and the effects of balancing import and export flows. The similarity seems to persist even after disaggregating the series into broadly defined material types.

Figure 3: the total values of RMC (“Raw material consumption”) and DMC (“Domestic material consumption”) allocated into different material categories, expressed in millions of tonnes.



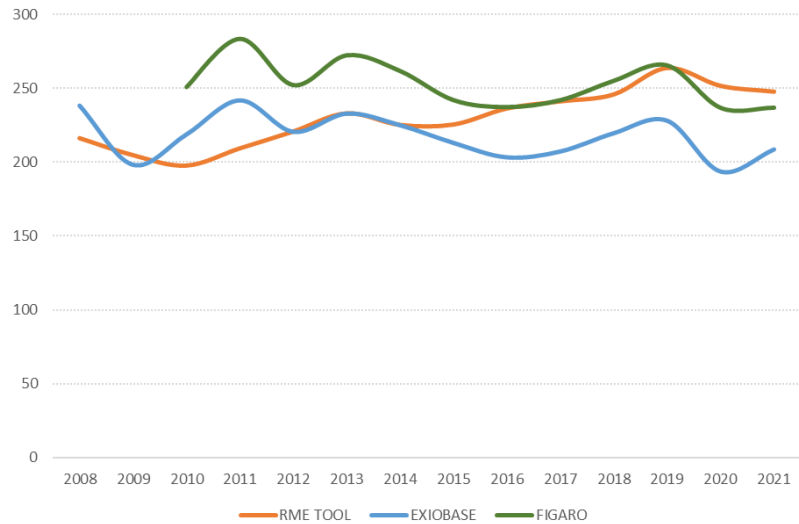
Source: Statistics Sweden, Eurostat database and EXIOBASE database.

The difference between the data series is more pronounced, especially when comparing DMC and RMC in the metal material group, see Figure 3. The Data Lab article (2018) highlights that the material footprint reallocates the mass of extracted materials to the countries that consume them. Net exporters of raw materials have a lower RMC compared to their DMC due to the deduction of indirect flows linked to exports. According to Figure 4, this indicates that the Swedish mining industry is a net exporter of metals and similar products.

RMC indicators – Eurostat RME tool vs Input and Output methods

In the following analysis we present analysis of measuring the RMC indicators using different methods and provide the reader with analysis on the coincidence of different perspectives. The RME tool provided by Eurostat is based on a slightly different LCA weighted IO hybrid approach as compared to the corresponding traditional Input and output based RMC indicators.

Figure 4: the totals of material footprint measure RMC (“Raw material consumption”), expressed in millions of tons.

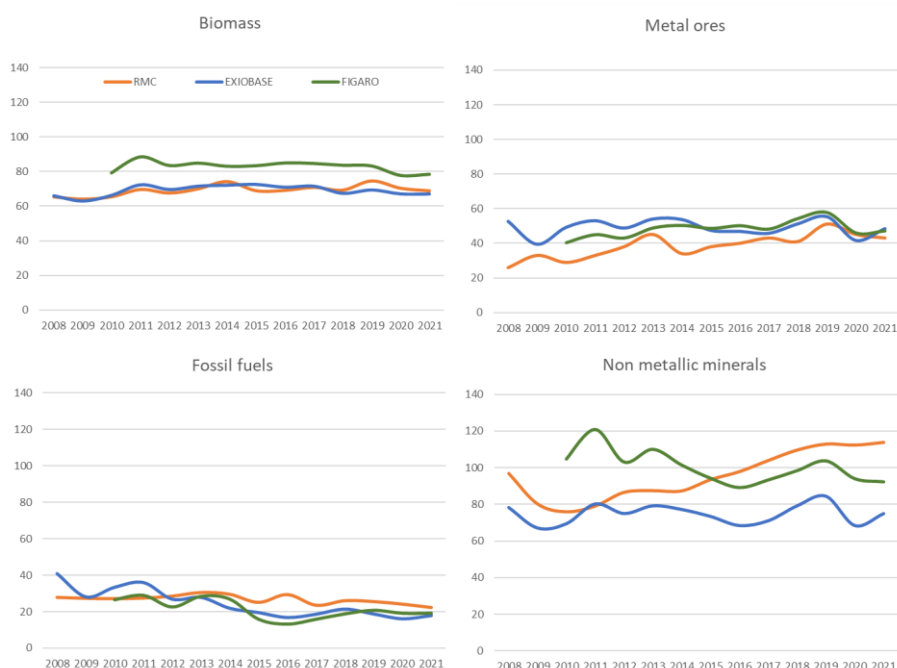


Source: Statistics Sweden, Eurostat database and EXIOBASE database.

Focusing on figure 4, the initial impression is that the trends are at the same level concerning the material footprint pressure on over time. The RME tools seem to indicate a slightly upward trend in material footprint, but the values are found to be within the limits of the IO-based RMC indicators. Regarding the IO based material footprint measures, the values are found to be more rigid and indicate no upward pressure like the RME tool do. Since the material extensions provided by the EXIOBASE database are not regularly updated (the series have only been nowcasted since 2011) may explain the rigidity.

To better understand the movements of the time series evident at the aggregate level, Figure 5 that follows below, aims to present a set of sub-figures representing the traditionally used material group categories biomass, fossil fuels, metal ores, and non-metallic minerals.

Figure 5: the total values of RMC allocated into different material categories, expressed in millions of tons.



Source: Statistics Sweden, Eurostat database, EXIOBASE and Figaro database.

One striking trend in the RMC data can be found among non-metallic minerals. The divergence between the RME tool and the IO-based RMC measure in this category may be due to the yearly revision of the RME coefficients for both exports and imports. The domestic extraction data from EXIOBASE is only forecasted on a yearly basis, which may result in rigid movements of material usage. The upward trend observed in the RME tool may be explained by the ongoing expansion of the building sector in Sweden over the past few years, which has influenced the markets through upward pressure on demand for minerals and other intermediate products used in construction. The increase in Sweden's non-metallic material footprint can therefore be summarized as follows:

- **Increased construction activity:** the construction and infrastructure sectors demand enormous quantities of non-metallic minerals. As building projects for infrastructure, housing, and commercial buildings rise, so does the need for these materials.
- **Urbanization:** with more people moving to cities, there is a greater need for construction materials to build homes, roads, and other infrastructure.
- **Economic growth:** a growing economy often leads to increased consumption and production, which in turn raises the demand for raw materials.

- Technological development: certain technological advancements require specific materials, which can increase the demand for certain non-metallic raw materials.

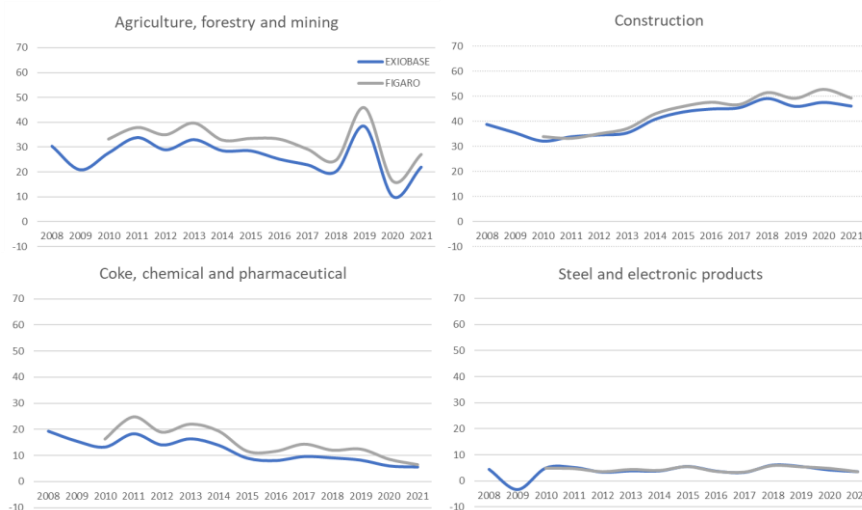
To finalize the analysis of RMC measures, the analysis has continuously undergone a validation of the RMC based on the input- and output models, specifically we inspected the statistical properties of variables within equations 10-13. The component m_{gmrio} indicate a few unrealistic values of domestic extraction per million EUR production, i.e., outliers, especially for some heavy coal-extracting countries like India. To mitigate and circumvent for the leveraging import multiplier effects in equation 12, we decided to proceed with median-adjusted country specific extraction intensities, especially for the fossil fuel part.

Reporting material flow accounts at the industry level

Given what was stated in Figure 5, the Swedish material footprint seems to differ slightly when comparing various material types and the impacts at the aggregate level. Regardless of the chosen models, the Swedish economy withdraws mostly non-mineral and biomass materials from our environment, both directly and indirectly via production value chains.

The next question is how this will translate if we turn our attention to the industry composition of the RMC measure. Because Eurostat RME tools are not yet available at industry level, our analysis is only based on the comparison of RMC measures by input and output models. To keep our analysis short and clear, the analysis focuses on industries that are resource-intensive in Sweden, in other words sectors that are highly dependent on domestic extraction sources.

Figure 6: The totals of RMC by industry aggregates, in millions of tons.



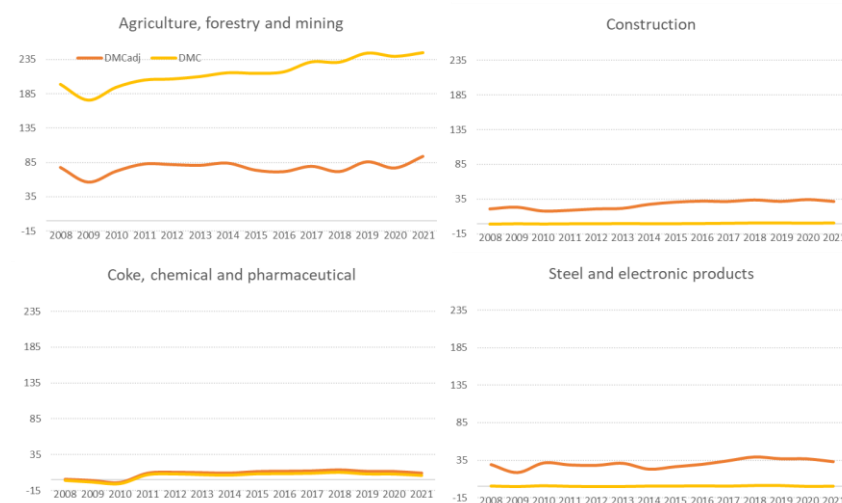
Source: Statistics Sweden and EXIOBASE database.

From Figure 6, one can see that the movements and trends over time seem to be highly collinear, even when comparing them by industry. The difference between the series stems from the estimation of the global material multipliers m_{imp} in Equation 11. The global multipliers are computed using either EXIOBASE or FIGARO database combined with the material extensions from EXIOBASE statistics.

When comparing the industry trends, one can find the highest impact on the Swedish material footprint is linked to the Swedish agriculture and quarrying mining activities. This phenomenon is partly due to Sweden's abundant supply of forest resources, timber, and wood, as well as the availability of iron ore, which creates conditions for more resource-intensive material extraction. Our production of domestic wood products, as well as products incorporating sand, gravel, and steel, is in demand by the building sector and other resource-intensive domestic manufacturing activities.

The previous analysis also shows that the RMC measure is relatively easy to allocate among industries since the raw data is already available at disaggregated sector codes (the reader is advised to read the data quality section for more details). Given what was stated from the RMC analysis, what tells the domestic material consumption statistics on the industry material consumption? The next figure therefore presents the DMC indicators over the same industries.

Figure 7: The totals of DMC by industry aggregates, in millions of tons.



Source: Statistics Sweden and EXIOBASE database.

Regarding the DMC measure, the series of DMC and RMC are not quite as similar as initially stated in figure 2, when comparing the figure 6 and 7 over the given industries. The measures of DMC and RMC are harder to compare at the industry level because the DMC only measures the direct effects on consumption and does not rely on the underlying trade flows between sectors. Furthermore, not all sectors report values of domestic extractions, which means that the values of trades sometimes result in negative domestic material consumptions. This may serve as an indication of how difficult it is to apply domestic material consumption on the NACE codes.

Because we do not precisely observe the trade flows of raw materials at the enterprise level, the original DMC measure fails to show a plausible industry consumption mix of raw materials. Instead, the analysis must rely on industry-specific trade structures from the derived Leontief inverse matrix (see equation 2 in the previous section). To address this, we start with an industry-specific DMC measure (see DMCadj in equation 4) and re-weight the original domestic extraction values by the trade shares of materials from the domestic Leontief inverse. This allows us to trace and relocate the values of domestic extraction to the domestic industries demanding the raw materials. As presented in figure 7, the DMC measure decreases in the domestic extraction industry due to domestic trade flows. The materials are then transmitted via trade into other industries, resulting in higher DMC values than the original measures.

Concluding remarks

As mentioned in the previous sections, measuring material flows presents several statistical challenges encountered in this report. These challenges can be summarized as follows.

Accurate data on material flows is often lacking due to incomplete records and inconsistent methodologies across countries. The complexity of tracking material flows, which involves multiple industries and processes, requires detailed data collection and analysis. Additionally, the dynamic nature of material flows, influenced by technological, policy, and economic changes, necessitates continuous monitoring.

These challenges underscore the need for improved data collection methods, international collaboration, and standardized frameworks to enhance the accuracy of material flow accounts. Furthermore, potential measurement errors can arise when adjusting data to NACE standards, as trade statistics may not accurately reflect the producers and users of materials. This calls for a deeper evaluation of how to assign NACE codes to material flow accounts.

As part of understanding MFA statistics among industries, the RMC measure indicates a relatively straightforward way to represent the exposure of material extractions for industries. The analysis of using alternative methods to measure the total RMC on our environment shows options, with the only pitfall so far being the collection of worldwide material flows. As earlier research mentioned; material flow accounts are prepared for Sweden, making it possible to use domestic production-related data for the Swedish component of the model, while relying on EXIOBASE only for multipliers applied to imports. Consistency must be ensured between the treatment and categorization of Swedish data and EXIOBASE data for further implementation.

If EXIOBASE data were used solely for multipliers, it would be feasible to use available projections of material usage from EXIOBASE. Multipliers are simply intensity values that reflect changes in the efficiency of production, rather than levels of demand for imports. As such, these multipliers change slowly over time and are suitable for providing estimates for short time series updates of data, PRINCE (2022).

The challenges within the project have mostly been about how to best understand the dynamics of the distribution of the DMC at the industry level. Since domestic extraction only appears within the agriculture, fishery, and mining parts of the economy, it results in difficult interpretation of the domestic material consumption within specific industries. This is because the statistics do not account for the trade of

raw materials within the Swedish economy. The analysis suggests a hybrid solution measuring the total purchase of raw materials from specific industries to tackle the issues of underestimating the actual trade flows of raw materials from the primary sectors into sectors like manufacturing, energy, and more.

Since Statistics Sweden continuously participates in projects aimed at estimating the circular economy and developing waste statistics, the Swedish National Board of Housing, Building and Planning is continuously learning about the new methodologies developed from these projects, Statistics Sweden (2024). For example, there are constructive interaction efforts made between these kinds of grant projects and projects to measure the reuse of materials within the Swedish building sector. As a final word, the ambition of the statistics on material flow exposure was also to further broaden the understanding by incorporating not only flows over certain industries but also how regions extract the materials. This is an important aspect of the regionalization policy. Our effort to make such an analysis fell short due to the lack of multiregional domestic input-output tables. Since Statistics Sweden's original plan was to produce multiregional input-output tables over Swedish regions, this means that such an analysis must be forwarded into the future.

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Appendix

Table 1: Domestic extractions (used and unused)

Crop residues	Feed	Non metallic minerals	Slate	Primary Crops	Cow peas, dry	Primary Crops	Okra
Crop residues	Straw	Primary Crops	Kapokseed in Shell	Primary Crops	Cranberries	Primary Crops	Olives
Fishery	Aquatic plants	Primary Crops	Honey	Primary Crops	Cucumbers and Gherkins	Primary Crops	Onions
Fishery	Inland waters fish catch	Primary Crops	Beeswax	Primary Crops	Currants	Primary Crops	Onions, dry
Fishery	Marine fish catch	Primary Crops	Abaca	Primary Crops	Dates	Primary Crops	Oranges
Fishery	Other (e.g. Aquatic mammals)	Primary Crops	Agave Fibres nes	Primary Crops	Eggplants	Primary Crops	Other Bastfibres
Fodder crops	Alfalfa for Forage and Silage	Primary Crops	Almonds	Primary Crops	Fibre Crops nes	Primary Crops	Other melons
Fodder crops	Beets for Fodder	Primary Crops	Anise, Badian, Fennel	Primary Crops	Figs	Primary Crops	Papayas
Fodder crops	Cabbage for Fodder	Primary Crops	Apples	Primary Crops	Flax Fibre and Tow	Primary Crops	Peaches and Nectarines
Fodder crops	Carrots for Fodder	Primary Crops	Apricots	Primary Crops	Fonio	Primary Crops	Pears
Fodder crops	Clover for Forage and Silage	Primary Crops	Arecanuts	Primary Crops	Fruit Fresh Nes	Primary Crops	Peas, Green
Fodder crops	Forage Products nec	Primary Crops	Artichokes	Primary Crops	Fruit, tropical fresh nes	Primary Crops	Peas, dry
Fodder crops	Grasses nec for Forage and Silage	Primary Crops	Asparagus	Primary Crops	Garlic	Primary Crops	Pepper
Fodder crops	Green Oilseeds for Fodder	Primary Crops	Avocados	Primary Crops	Ginger	Primary Crops	Peppermint
Fodder crops	Leguminous nec for forage and Silage	Primary Crops	Bambara beans	Primary Crops	Gooseberries	Primary Crops	Persimmons
Fodder crops	Maize for Forage and Silage	Primary Crops	Bananas	Primary Crops	Grapefruit and Pomelos	Primary Crops	Pigeon peas
Fodder crops	Other grasses	Primary Crops	Barley	Primary Crops	Grapes	Primary Crops	Pineapples
Fodder crops	Rye Grass, Forage and Silage	Primary Crops	Beans, dry	Primary Crops	Groundnuts in Shell	Primary Crops	Pistachios
Fodder crops	Sorghum for Forage and Silage	Primary Crops	Beans, green	Primary Crops	Hazelnuts	Primary Crops	Plantains
Fodder crops	Swedes for Fodder	Primary Crops	Berries nec	Primary Crops	Hemp Fibre and Tow	Primary Crops	Plums
Fodder crops	Turnips for Fodder	Primary Crops	Blueberries	Primary Crops	Hempseed	Primary Crops	Pome fruit, nes
Fodder crops	Vegetables and Roots, Fodder	Primary Crops	Brazil nuts, with shell	Primary Crops	Hops	Primary Crops	Poppy Seed
Forestry	Coniferous wood (Industrial roundwood)	Primary Crops	Broad beans, horse beans, dry	Primary Crops	Jojoba Seeds	Primary Crops	Potatoes
Forestry	Coniferous wood (Wood fuel)	Primary Crops	Buckwheat	Primary Crops	Jute and Jute like Fibres	Primary Crops	Pulses nec
Forestry	Kapok Fruit	Primary Crops	Cabbages	Primary Crops	Kapok Fibre	Primary Crops	Pumpkins, Squash, Gourds
Forestry	Natural Gums	Primary Crops	Canary Seed	Primary Crops	Karite Nuts	Primary Crops	Pyrethrum, Dried Flowers
Forestry	Non coniferous wood (Industrial roundwood)	Primary Crops	Carobs	Primary Crops	Kiwi Fruit	Primary Crops	Quinces
Forestry	Non coniferous (Wood fuel)	Primary Crops	Carrots	Primary Crops	Kolanuts	Primary Crops	Quinoa
Forestry	Raw materials other than wood	Primary Crops	Cashew nuts, with shell	Primary Crops	Leeks and other Alliac. Veg.	Primary Crops	Ramie
Fossil Fuels	Fossil Fuels	Primary Crops	Cashewapple	Primary Crops	Leguminous vegetables, nes	Primary Crops	Rapeseed
Grazing	Grazing	Primary Crops	Cassava	Primary Crops	Lemons and Limes	Primary Crops	Raspberries
Metal Ores	Bauxite and aluminium ores	Primary Crops	Cassava leaves	Primary Crops	Lentils	Primary Crops	Rice
Metal Ores	Copper ores	Primary Crops	Castor oil seed	Primary Crops	Lettuce	Primary Crops	Roots and Tubers, nes
Metal Ores	Gold ores	Primary Crops	Cauliflower	Primary Crops	Linseed	Primary Crops	Rye
Metal Ores	Iron ores	Primary Crops	Cereals nec	Primary Crops	Lupins	Primary Crops	Safflower Seed
Metal Ores	Lead ores	Primary Crops	Cherries	Primary Crops	Maize	Primary Crops	Sesame Seed
Metal Ores	Nickel ores	Primary Crops	Chestnuts	Primary Crops	Maize, green	Primary Crops	Sisal
Metal Ores	Other non	Primary Crops	Chick peas	Primary Crops	Mangoes, mangosteens, guavas	Primary Crops	Sorghum
Metal Ores	PGM ores	Primary Crops	Chicory Roots	Primary Crops	Mate	Primary Crops	Sour Cherries
Metal Ores	Silver ores	Primary Crops	Chillies and peppers, dry	Primary Crops	Melonseed	Primary Crops	Soybeans
Metal Ores	Tin ores	Primary Crops	Chillies and peppers, green	Primary Crops	Millet	Primary Crops	Spices nec
Metal Ores	Uranium and thorium ores	Primary Crops	Cinnamon	Primary Crops	Mixed Grain	Primary Crops	Spinach
Metal Ores	Zinc ores	Primary Crops	Citrus Fruit nec	Primary Crops	Mushrooms	Primary Crops	Stone Fruit nec,
Non metallic minerals	Building stones	Primary Crops	Cloves	Primary Crops	Mustard Seed	Primary Crops	Strawberries
Non metallic minerals	Chemical and fertilizer minerals	Primary Crops	Cocoa Beans	Primary Crops	Natural Rubber	Primary Crops	String beans
Non metallic minerals	Clays and kaolin	Primary Crops	Coconuts	Primary Crops	Nutmeg, mace and cardamoms	Primary Crops	Sugar Beets
Non metallic minerals	Gravel and sand	Primary Crops	Coffee, Green	Primary Crops	Nuts, nes	Primary Crops	Sugar Cane
Non metallic minerals	Limestone, gypsum, chalk, dolomite	Primary Crops	Coir	Primary Crops	Oats	Primary Crops	Sugar Crops nes
Non metallic minerals	Other minerals	Primary Crops	Cotton Lint	Primary Crops	Oil Palm Fruit	Primary Crops	Sunflower Seed
Non metallic minerals	Salt	Primary Crops	Cottonseed	Primary Crops	Oilseeds nec	Primary Crops	Sweet Potatoes
Primary Crops	Tallowtree Seeds	Primary Crops	Tea nes	Primary Crops	Tung Nuts	Primary Crops	Walnuts
Primary Crops	Tang, Mand Clement. Satsma	Primary Crops	Tobacco Leaves	Primary Crops	Vanilla	Primary Crops	Watermelons
Primary Crops	Taro	Primary Crops	Tomatoes	Primary Crops	Vegetables Fresh nec	Primary Crops	Wheat
Primary Crops	Tea	Primary Crops	Triticale	Primary Crops	Vetches	Primary Crops	Yams, Yautia

Source EXIOBASE 3.8.2

Table 2: Industry classification, NACE rev.2

Code	Description
A01-A05	Agriculture, forestry, and fishing
B05-B09	Mining and quarrying
C10-C12	Food products, beverages, and tobacco
C13-C15	Textiles, clothing, and leather products
C16-C18	Wood, pulp, paper, and printing industries
C19-C21	Manufacture of coal products, refined petroleum, chemicals, and chemical products, as well as pharmaceutical base products and medicines
C22-C23	Rubber and plastic products industry; and other non-metallic mineral products
C24-C25	Steel and metal production; and manufacture of metal products (excluding machinery)
C26	Computer, electronics, and optical products industry
C27	Electrical equipment industry
C28	Other machinery industry
C29	Motor vehicles, trailers, and semi-trailers industry
C30	Other transport equipment industry
C31-C33	Manufacture of furniture; other manufacturing; repair and installation of machinery and equipment
D35-E39	Supply of electricity, gas, heating, and cooling, as well as water supply, sewerage, waste management, and remediation
F41-F43	Construction activities
G45-G47	Trade
H49-H53	Transportation and storage
I55-I56	Hotels and restaurants
J58-J60	Publishing activities, film, video, TV, sound recording, phonogram publishing, programming, and broadcasting
J61	Telecommunications
J62-J63	Computer programming, consultancy, and information services
K64-K66	Financial and insurance activities
L68	Real estate companies and property managers
M69-M72	Legal and economic consultancy; head office and business consultancy services; architectural and engineering consultancy, as well as R&D
M73-M75	Advertising and market research, other activities within law, economics, science, technology; veterinary activities
N77-N82	Rental of real estate services, travel services, and other support services
P85	Education
Q86	Healthcare
Q87-Q88	Residential care, social work activities without accommodation
R90-R93	Culture, entertainment, and recreation
S94-T98	Other service activities and household employment, etc.