Deliverable 5.2: Report on test of routines and data set for 1-2 EU MS

21 January 2020

KAVA Reference (Number, Acronym, Full Title): PANORAMA: Physical AccouNts Of RAw MAterial stock and flow Information Service

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Version No: 1

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Content

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1. Executive Summary

This report presents the methodology and first prototype of the Physical AccouNts Of RAw MAterial stock and flow Information Service (PANORAMA) database. The PANORAMA database seeks to combine extensive data on material flows and stocks and that will be the basis for a web-based information service system to assess, for instance, current and future bottlenecks in the supply chain related to (critical) raw materials, specifically those that are currently not in the scope of existing tools and databases. This first prototype shows the methodology behind harmonizing, imputing, and balancing production, trade, and use statistics for a disaggregated (HS6-level) set of products containing copper and tantalum, at both product and element levels. The routine was applied to Denmark (year 2011). Results were then aggregated and compared to other physical stock-flow databases, including Exiobase and ProSUM.

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2. Introduction

The stable production and supply of raw materials is crucial for the resilience of the global economy. Furthermore, the extraction and movement of materials throughout the supply chain has strong implications for environmental health, where a better understanding of the entire raw material value chain can help minimize the impacts related to resource use. For this purpose, detailed assessments of materials stocks and flows are becoming increasingly crucial and are the end goal of the PANORMA project. This deliverable presents the theoretical basis for a transparent methodology to harmonize and balance global detailed production and trade data along with the existing aggregated supply and use tables (EXIOBASE) to better understand material movement through the economy. It furthermore applies this methodology to the Danish economy (a single region supply-use table) of two specific elements, copper (Cu) and tantalum (Ta) for the year 2011.

While the methodology is independent of the product aggregation level, in this deliverable we use the Harmonized Commodity Description and Coding Systems 6 digit code (HS6), which describes approximately 5300 articles/products. This product level showcases the level of material detail achievable with this routine, the harmonization concordances with other classification systems, the imputation procedure for missing values, and the balancing technique using uncertainty scores for each data system.

The final results are aggregated and compared to other available data, namely results from the H2020 ProSum project, EXIOBASE, and previous MFAs. This document concludes with a discussion on both the product- and element-level results, with a detailed discussion for future improvements to be implemented in the next versions of the model comprising the entire global economy, a full set of materials and elements to be targeted by the project.

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3. Classification & Data

3.1. Overview

Prior to the balancing procedures, complete structure of the physical SUT for Denmark must be prepared along with the necessary data for the initial estimations within such a structure. Hence, the following steps has been conducted along this exercise:

1. Harmonisation of the existing data on elemental compositions of products (goods) for Cu and Ta
2. Generating concordances between Exiobase product categories and existing products classifications (CPC, HS, PC)
3. Disaggregating existing Exiobase products classification to distinguish the identified elements containing products; finalizing a new HS2007-based Panorama products classification
4. Generating '1 to n' concordance between Panorama product categories and HS product classification.
5. Mapping detailed production (PC-based) and trade (HS-based) micro data for Denmark onto Panorama categories
6. Preparing the rest of the aggregated production and trade data for the SUT from Exiobase database
7. Assessing the uncertainty scores for all the data points
8. Balancing the resulting SUT for Denmark follows these steps
9. These steps have been divided accordingly between three independent development modules: Composition, Classification, and Data modules. All the main inputs and outputs of these modules are diagrammed in Figure 1.

Figure 1 Panorama D5.2 flowchart. Depicts major inputs (labelled red), modules (outlined), procedures (yellow labelled), outputs (rhombus), and related files.

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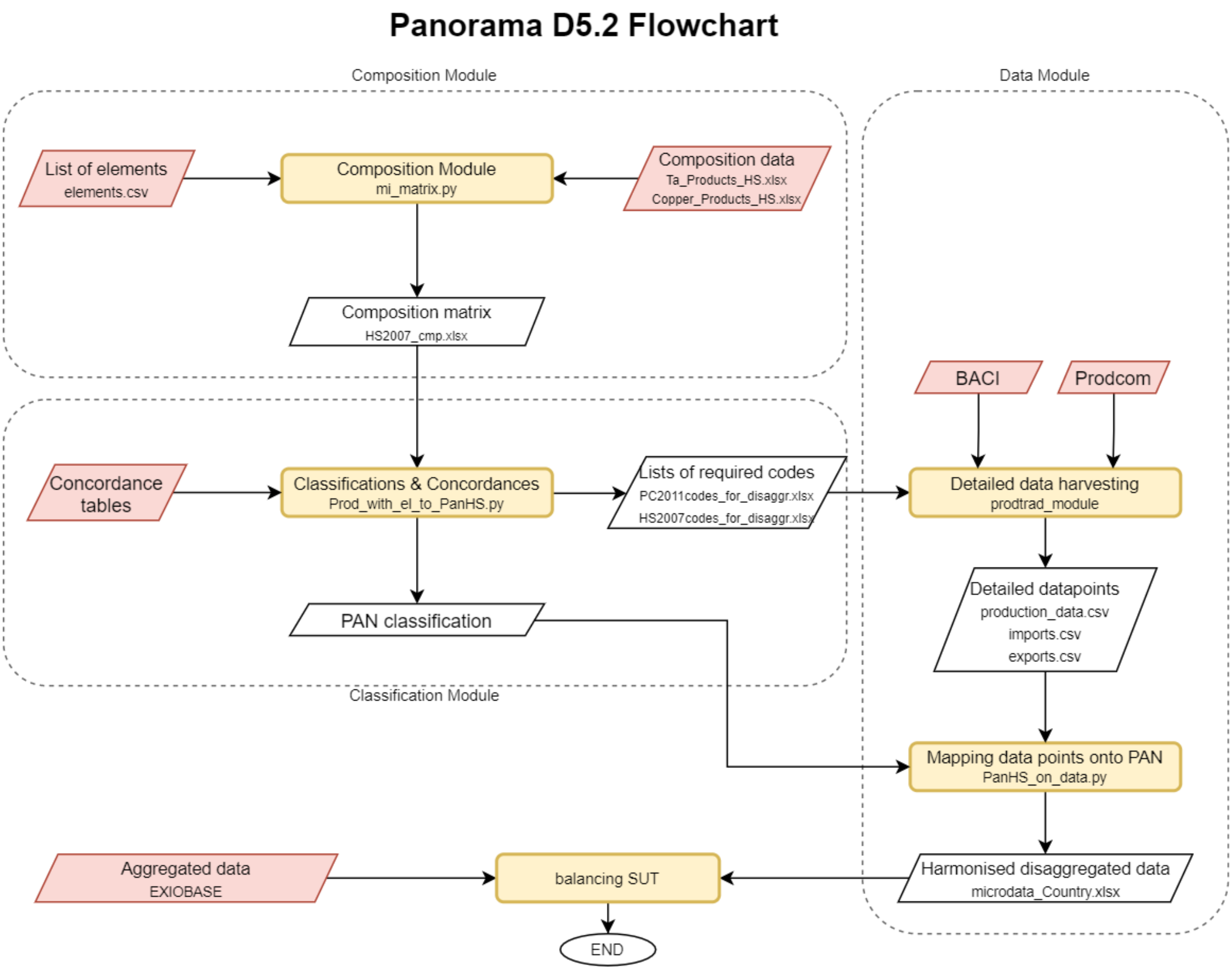

Figure 1 Panorama D5.2 flowchart. Depicts major inputs (labelled red), modules (outlined), procedures (yellow labelled), outputs (rhombus), and related files

3.2. Product Composition Module

The goal of this module is to collect existing data on the elemental product compositions (Ta and Cu), harmonise such data and to estimate the uncertainty scores of such values.
Tantalum composition of products (kg Ta/kg product) has been taken from the work of (Deetman et al. (2018) and have been manually assigned corresponding HS2017 codes. The uncertainty

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scores of such composition data points were assigned based on the evaluation of underlining assumptions (see Annex).
Copper content of products were taken from the study conducted by Soulier et al. (2018) along with the preliminary suggestion on the common uncertainty score for all the data points (2). The data was provided in the HS 1992 classification.
Harmonization of the both sources resulted in the output of the matrix (HS2007_cmp) with the elemental content and the uncertainty score (1-5) for each HS2007 good. It has been assumed that the products not covered in the input sources have zero content with the highest certainty (1). This concluded the operations within the Composition Module.

3.3. Classification Module

The goal of this module is to generate a new Panorama product classification (PAN) from the existing Exiobase v3.6 (Merciai & Schmidt, 2018; Stadler et al., 2018) product classification (EXIO) disaggregating such where required to distinguish specific elements containing goods.
Firstly, a consequential correspondence starting from the Exiobase product classification has been generated (see Figure 2). Concordance between EXIO and CPC product classifications has been manually assembled (see Annex) . The rest of the correspondences has been applied based on various officially published tables (UN Statistics Division , 2019). Based on the EXIO to HS2007 correspondence, element-containing EXIO categories were identified (yellow codes in Figure 2), and only such have been disaggregated on the HS level later (specific element containing HS goods plus single 'others' category; see Figure 3).

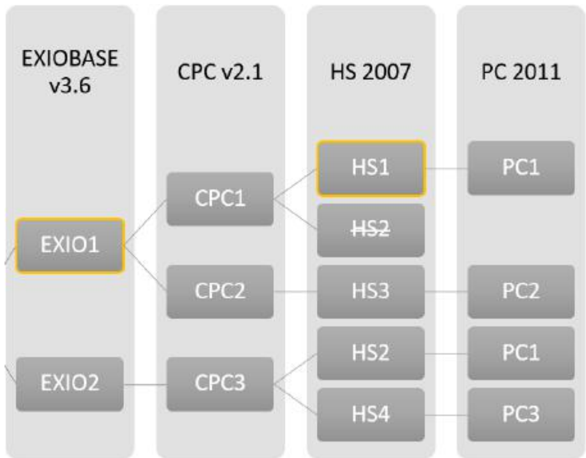

Figure 2 Model of the consequently generated concordances starting from Exiobase v3.6 classification (EXIO). EXIO to CPC is a 'one-to-many' correspondence. Since HS code could relate to several EXIO (CPC) categories, duplicate HS codes

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were removed, firstly from the element-containing categories (marked with yellow). HS to PC relation is not 'one-to-many'.

Exiobase to CPC correspondence is of a *one-to-many* type; however, the rest contain *many-to-many* connections. Hence, as a second step, the resulting EXIO to HS correspondence has been adjusted so that each HS code relates to one EXIO category only. It has been assumed that duplicate HS links to non-containing EXIO categories are prioritised to be kept (see Figure 2). This allows to avoid double counting while applying aggregated flows on the resulting PAN classification later in the process.
Finally, a new hybrid PAN classification (see Figure 3) has been generated applying the following logic:

- If EXIO category is NOT element-containing (as 'EXIO2') then:
  PAN category = EXIO category
- If EXIO category is element-containing (as 'EXIO1') then:
  PAN category = disaggregated EXIO category = list of the corresponding element-containing HS categories plus one 'EXIO_others' category. Such 'EXIO_others' is prepared for all kind of products related to the given EXIO category but not containing any of the elements.

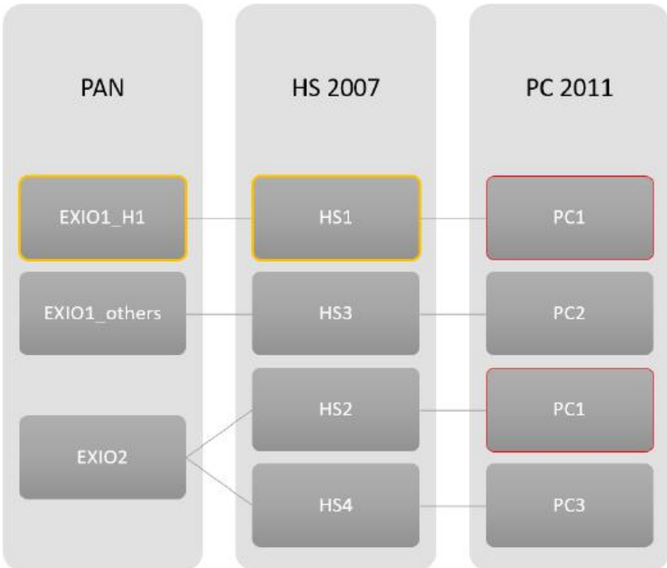

Figure 3 HS-based Panorama product classification (PAN). Yellow categories contain elements under consideration. Duplicated PC codes (red links) should be approached later in this Data Module to avoid double counting when mapping production data over PAN categories.

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Even though such hybrid PAN classification is sensitive to the set of elements of interest, it keeps the resulting SUT as compact as possible (emphasising the element-containing goods only) and allows for much easier and more aggregated data harvesting for the rest of the not detailed product categories.

As a result, new PAN classification, its description, and the concordance tables between PAN and other product classifications (HS2007, EXIO, PC2011) have been generated. Additionally, two lists of all the required HS and PC codes from the disaggregated PAN categories for the following data harvesting have been generated as main outputs of this module (see Figure 1). As a reminder, production and trade data for the aggregated (non-containing) PAN categories will be rather harvested from the Exiobase database itself.

3.4. Data Module

The goal of this module is to harvest, pre-process, harmonize and assess the uncertainty of the disaggregated (detailed) and aggregated (not containing elements) data for the SUT under construction.

Disaggregated data

The *prodtrad_module* (see Figure 1) is responsible for generating harmonized production (Prodcom) and trade (BACI) data and their respective uncertainty scores exclusively for the disaggregated PAN product categories. The procedure is applied for the required Prodcom Codes and HS codes that are provided by the Composition Module. Aggregated PAN product categories are covered by data from Exiobase.

Production (supply) micro data

The Prodcom manufacturing data was harvested from Eurostat for the year 2011. The dataset contained monetary and physical production statistics of 3852 for the EU-28 countries plus Iceland, Norway, Turkey, Bosnia and Herzegovina, Montenegro, Macedonia and Serbia.

For the Denmark case, most of the Prodcom codes that were required - 1766 out of 2033 – are present in the dataset. However, there was a need to estimate some of the data that were either missing or unavailable due to confidentiality issues. In addition, conversion of non-null data that was not reported in mass (kg) was performed for several codes. The Figure 4 represents the distribution of the different cases.

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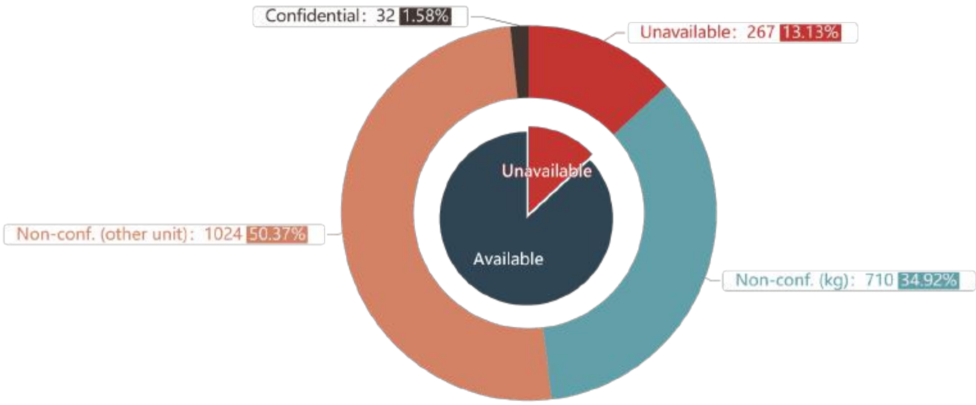

Figure 4 Distribution of production data by type

Estimation of missing data

Denmark reports most of their manufacturing statistics, which facilitates the creation of the disaggregated SUT for this country.
Most missing data is due to the absence of the required Prodcom codes in the dataset. These were simply set to 0, as there is no evidence that they are produced in Denmark or even Europe. Such logic was applied to 267 codes.
The second type of missing data derives from the confidentiality of the country or Europe. In such instances however, the total of EU-28 production statistics is available. The estimated Danish production of these codes were based on Denmark, the EU-28 exports, and the EU-28 total production according to the following equation:

$$P_{Den,i} = \frac{E_{Den,i}}{E_{EU28,i}} . P_{EU28,i}$$

Where:

$P_{Den,i}$ is the estimated Danish production of commodity i

$E_{Den,i}$ is the Danish exports of commodity i

$E_{EU28,i}$ is the total EU-28 exports of commodity i

$P_{EU28,i}$ is the total EU-28 production of commodity i

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The exports for both Denmark and EU-28 were derived from the BACI database. In order to combine the same commodities between Prodcom and BACI, the appropriate correspondence table between their classification systems was used. This was applied to only 32 codes.

Conversion of the production data to mass

After the estimation procedure, the dataset is complete. However, Prodcom contain records in different units, such as ce/el (number of elements), m2, p/st (number of items). The non-zero records must be converted into a common mass unit in order be fed into the balancing module. These codes are grouped by unit and presented in Table 1. Note that some the units are reported in mass, but substance base.

Table 1 Number of commodities produced in Denmark by unit

Unit	Description	Instances
p/st	Number of items	524
kg	Kilogram	370
kg act. Subst.	Kilogram of activate substance	15
kg N	Kilogram of nitrogen	6
m^3	Cubic metre	5
kg SiO_2	Kilogram of silicon dioxide	2
kg P_2O_5	Kilogram of phosphorus pentoxide (phosphoric anhydride)	2
kg K_2O	Kilogram of potassium oxide	2
kg $Na_2S_2O_5$	Kilogram of sodium pyrosulphide	1
kg H_2O_2	Kilogram of hydrogen peroxide	1
kg Al_2O_3	Kilogram of dialuminium trioxide	1
kg F	Kilogram of fluorine	1
kg HCl	Kilogram of hydrogen chloride	1
kg KOH	Kilogram of potassium hydroxide (caustic potash)	1
kg NaOH	Kilogram of sodium hydroxide (caustic soda)	1
kg TiO_2	Kilogram of titanium dioxide	1
m^2	Square metre	1
ce/el	Number of elements	1
kg Na_2CO_3	Kilogram of sodium carbonate	1
kg SO_2	Kilogram of sulphur dioxide	1
L	Litre	1
kg Cl	Kilogram of chlorine	1
G	Gram	1

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Two different approaches were used in order to convert the units into mass.
The first approach utilized estimates from the Comtrade database. In this database, it is possible to find trade reported both in number of units and mass (kg). Thus, the weight per unit can be estimated for a few commodities traded globally. The Prodcom codes that were reported in "p/st" were converted into the respective HS codes in order to retrieve the necessary data from Comtrade. These were done using appropriate correspondence tables. Since a commodity can be traded amongst several countries, only the median estimated weight was utilized for the conversion. This procedure was applied to convert 425 records that were reported in "p/st" in Prodcom.
In the second approach, the mass per unit of the remaining commodities were researched using online sources or contacting manufacturing representatives. This was done for 146 codes.
In Exiobase, produced ores are displayed in metal base, i.e. the total mass of metal contained in the ore. For this case study, only the Prodcom code 08911200, referring to Unroasted iron pyrites; crude or unrefined Sulphur (including recovered Sulphur) was relevant. Since this ore is rarely used to produce iron metal (Istanbul Mineral Exporters' Association (IMIB), 2019), the production of this commodity was set to zero.
Overall, the aforementioned procedures have to be accurately revised for misalignments in unit conversions in the coming work.

Production micro data: uncertainty scores

Quality flags (uncertainty scores) were generated according to the level of manipulation that were applied to the originally harvested Prodcom data. The quality flags vary in a 1 to 5 scale, where 1 represents the lowest uncertainty score and 5 the highest. For each record, the quality flags are set according to the following logic:

- Flag 1: data is readily available in kg or codes not found in the dataset;
- Flag 2: data is readily available and converted using Comtrade weight data
- Flag 3: data is readily available and converted using other sources
- Flag 4: data is estimated, but not converted
- Flag 5: all other cases

Trade (supply and use) micro data

The BACI trade data based on the HS 2007 classification system was harvested from CEPII for the year 2011. The dataset is a reconciled version of the Comtrade database and contained both monetary and physical flows amongst 216 countries. Contrary to the production data, it was not necessary to estimate any missing data. In order to make the database compatible with the requirements of the balancing module, two procedures were applied. These are conversion and generation of uncertainty scores.

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Conversion of ore trade to the metal base

In Exiobase, traded ores are also presented in metal base. Consequently, it was necessary to convert the total traded flows into the metal base.
Similarly to what has applied with the production data, the commodity trade of the code 260120 Iron pyrites; roasted was set to zero, as these are not used for metal production. For the other ores, concentration values were retrieved from the Global Material Flows Database. These can vary depending on where the ore has been mined. It was assumed that the concentration of the ore produced domestically was the same as exported. For those countries where the concentration of the particular trade ore was not available, a global average was adopted.

Trade micro data: uncertainty scores

The BACI database reconciles Comtrade's international trade statistics based on the reliability of the reporting countries. These are used to mirror the data of two reporting countries recording the same commodity flows (Gaulier & Zignago, 2012).The BACI database contains such reliability scores for 173 countries both as importers and exporters. Values close to zero represent more reliable reporting countries.
A geometric average was applied to combine the reliability score of the exporting country with the reliability score of the importing country. For the countries where such score was not available, the maximum value of all country scores was used. The distribution of the combined score can be seen in the Figure 5. Note that most of the trade records are a combination of countries with good reliability scores.

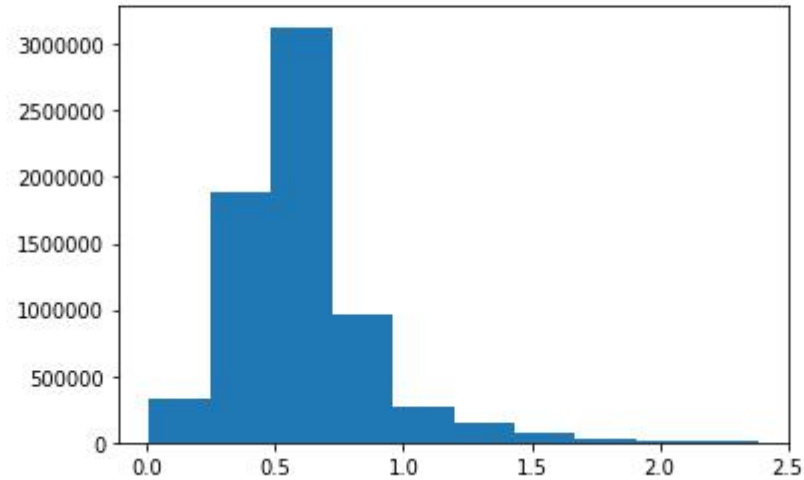

Figure 5 Distribution of the combined quality scores in BACI 2011 database.

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Such combined scores were distributed into 5 different categories to create the uncertainty scores, where 1 represents the highest quality and 5 the lowest.

Aa a result, the *prodtrad_module* harmonized and detailed production and trade data points along with their uncertainty scores have been output.

Mapping onto PAN product classification

As a following step, such detailed production and trade data points had to be properly mapped (summed) under the corresponding PAN product categories. This work is based on the outputs of the *prodtrad_module.*

Trade

Firstly, Imports (exports) of the same product from (to) different countries have been summed while the uncertainty scores of such were averaged using the weights (volumes) of the corresponding trade. Note, that such estimation of the cumulative uncertainty scores results in the implicit assumption of lower trade volumes having higher certainty.
Secondly, trade volumes of different products (HS 2007 codes) have been summed under the corresponding PAN product categories. Here, trade volumes of the PAN products consist either of a single HS product with the same uncertainty score (for the disaggregated PAN categories) or an accumulation of the related HS products (for aggregated and 'others' PAN categories) while applying the weighted average to obtain the uncertainty scores once again. Note, that because of the 'one-to-many' nature of the PAN to HS concordance, there was no double-counting problem present.
It has been assumed that absent data points are certain zeros (score 1).

Production

In contrast to HS-based trade data points, PC-based production values could be linked to several HS and consequentially PAN categories at the same time - the case when HS classification is more detailed on a single PC category. Hence, such double-counting problem had to be approached (see Figure 3). In particular, such production volumes have to be somehow reallocated between related more detailed HS categories. In this project, it has been assumed that missing detailed production values are proportional to the exports of such products (which are reported in BACI), and, hence, more general PC-based production volumes have been reallocated between linked HS products proportional to known trade volumes of such.

Other data

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Composition data from the Composition Module is HS based and, hence, has been simply assigned to the corresponding disaggregated PAN categories. The aggregated and 'others' categories automatically receive most certain zero-content values for all the elements.
Since *prodtrad_module* provides detailed production and trade data for disaggregated PAN categories only, the rest of the product categories are covered by data from Exiobase.

As a result of this work, detailed production, trade, and composition data with the corresponding uncertainty scores have been prepared (*microdata_Country*, see Figure 1) for the disaggregated PAN product categories.

Aggregated data (EXIOBASE)

Aggregated data is derived from the EXIOBASE hybrid supply and use table v3.3.18, which accounts tangible products in (dry) mass units, energy flows in TJ and services in millions of euro. Given the aim of this initial exercise limited to Denmark, the multi-regional EXIOBASE tables have been aggregated so to have two regions, Denmark and the rest of the world.
At the same time, for simplicity, each account in the extensions that is involved in the mass balance, i.e. resources, emissions, waste and stock addition, has been collapsed to one row.

The hybrid EXIOBASE tables are the result of the reconciliation of several data sources and of a broad estimation of missing data. In order to define the production recipes, micro data on productive processes have been collected from life-cycle inventories and internalized in the database. Mass, energy and monetary balances are performed for each product flow and for each activity.

These several steps in the construction of the hybrid EXIOBASE tables have a direct effect on the uncertainty scores of the data points which are the input parameters for the current PANORAMA algorithm. In particular, the logic behind the uncertainty is such that data collected from recognized statistical institution, such as FAO, IEA, EUROSTAT, and kept fixed in EXIOBASE obtains the lower uncertainty. In contrast, estimated data that are free to fluctuate because of less stringent constraints have higher uncertainty score assigned. In detail, each of the five levels of uncertainty scores are as follows:

- Fist level: exogenous data from highly recognized statistical institution which is included in EXIOBASE as a fixed parameter;
- Second level: exogenous data from highly recognized statistical institution which undergo a minor manipulated in EXIOBASE, such as unit conversion;

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- Third level: endogenous data estimated in the EXIOBASE algorithm obeying to stringent constraints, such as technological limits and constraints on raw material availability;
- Fourth level: endogenous data estimated in the EXIOBASE algorithm by a medium use of constraints;
- Fifth level: endogenous data estimated in the EXIOBASE algorithm applying uniquely general conditions on mass, energy and monetary balances.

4. Imputation and Balancing Procedure

The goal of this step of the deliverable was to develop a balanced set of element-specific flows across the Danish economy in the formal of a supply-use table (SUT), given the data inputs described in the preceding sections. To do so a procedure was devised that alternated imputation and balancing steps. We begin by describing the format of the target data, and then the alternating imputation and balancing steps, while new data elements are integrated. The mathematical details are described in the Annex.

4.1. Total mass supply-use table

A total-mass SUT describes the flows of mass of the goods supplied by industries and imported from abroad, which are then used by industries and domestic final consumers or exported. Besides, the SUT under consideration describes extractions from the environment, wastes, and emissions to the environment from both industries and final consumers. The objects that compose the SUT are:

- Make matrix (product outflows from the industries)
- Intermediate use matrix (flows of products into the domestic industries)
- Final use matrix (flows of products to the final demand categories; with positive terms)
- Final use matrix with negative terms (flows of products to final demand categories)
- Extraction by industries (flows from extraction activities to industries)
- Outflows from industries (flows from industries to outflows categories, depicted as negative numbers)

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- Extraction by final consumers (flows from extraction activities to final demand categories, in principle it contains only zeros but is kept because this block is present in the source data)
- Outflows from final consumers (flows from final demand to outflow categories, depicted as negative numbers)
- Total imports
- Total exports
- Total product output
- Total industry output

These objects are constrained by five types of accounting identities:

- 1) Total product output matches the sum of imports and the sum in columns of the make matrix
- 2) Total product output matches the sum of exports and the sum in rows of intermediate use, final use in positive terms and final use in negative terms
- 3) Total industry output matches the sum in rows of the make matrix
- 4) Total industry output matches the sum in columns of intermediate use, extraction by industries and outflows by industries
- 5) Sum in columns of final demand in positive and negative terms plus extraction and outflows by final consumers equals zero.

See the Annex for the mathematical symbols of each object and the equations that describe the constraints. Figure 6 provides a visual illustration of how the different components of a SUT are related and the letters used to designate the corresponding data blocks.

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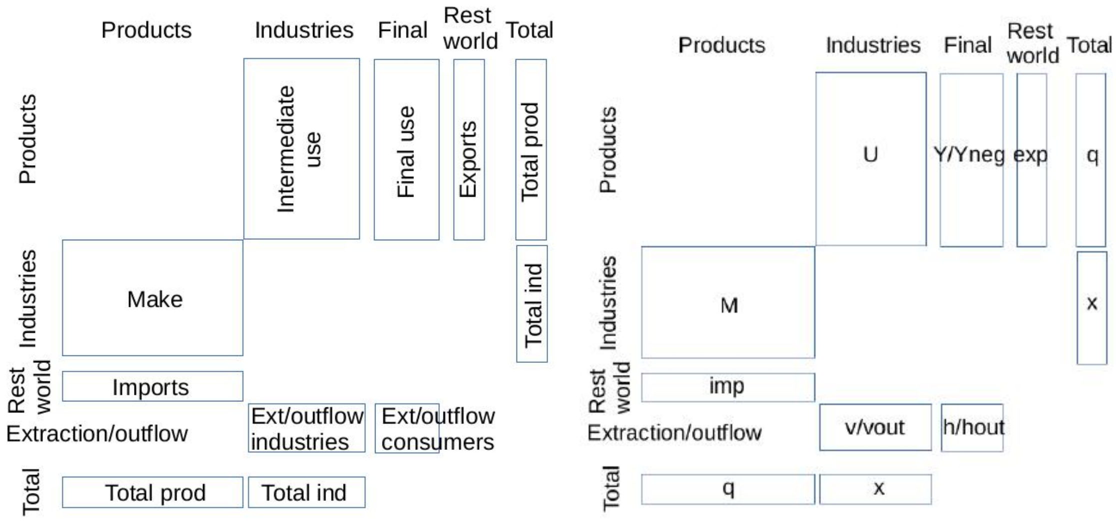

Figure 6 Structure of a domestic supply-use table (SUT)

4.2. Aggregated information

The first empirical data input used was the SUT of Denmark from the Exiobase hybrid tables, suitably converted to remove monetary and energy flows and keep only mass ones. It turned out that this system, which was supposed to be balanced, was not in fact balanced. The product constraints (constraints 1 and 2 from the preceding subsection) were only mildly inconsistent but the industry and final demand constraints (constraints 3 to 5) were very inconsistent. For example, in the changes in inventories category there were several negative entries, but no corresponding entry in the outflows to nature.

As such it was decided to balance the Exiobase data in two steps, first addressing constraints 3-5 and later constraints 1-2.

In the first step, all extraction categories were aggregated into a single category, and all outflow categories were aggregated into a single category. Then the difference in total industry outputs obtained from constraints 3 and 4 was allocated to either an extraction (if it was positive) or to an outflow (if it was negative). A similar procedure was performed to the column sums of final demand (constraint 5): if the difference was positive it was added as an extraction and if it was negative as an outflow (see Annex).

In the second step the whole system was balanced (see Annex).

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Once Exiobase was balanced, several blocks of it were used directly to build the Panorama mass-flow SUT of Denmark: extraction by industries, outflow by industries, extraction by final consumers and outflow by final consumers. The Panorama SUT has a more disaggregate set of products then Exiobase, so the remaining objects were further used as input for the disaggregation step: make, intermediate use, final use, negative final use, imports, exports, total product output and total industry output.

4.3. Disaggregated total mass information

Three blocks of disaggregated data are available with the Panorama level of product detail: total imports, total exports and total domestic production. However, this information is only available for some product categories that are disaggregated from the Exiobase product classification, and no information is available for product categories which are not disaggregated. As such it was decided to use this information to disaggregate the Exiobase objects of make, intermediate use, final use, negative final use, imports, exports, total product output and total industry output using proportional allocation. The following steps were followed, with mathematical details reported in the Annex (Appendix E).

First, it was necessary to expand the initial Panorama product classification so that there would be at least one product category for each Exiobase product category. Then a concordance matrix between the two classifications was delivered. In principle, in future iterations, this step may be skipped if the provided Panorama classification covers all Exiobase products.

The next step was to create disaggregation matrices, which would split a vector in the Exiobase product classification to a vector in the Panorama product classification. Such a disaggregation matrix would be constructed by using the concordance matrix and a vector of disaggregate quantities. This disaggregation matrix then disaggregates the aggregate quantity in the proportion of the disaggregate quantities. Note that since the originally provided disaggregated data was not complete, product categories which would not be disaggregated were added with a value of 1 in the disaggregate vector. Separate disaggregation matrices were created for imports, exports and domestic production.

The disaggregation matrices were then used to disaggregate the different data blocks: the import and export vectors were disaggregated directly. The columns of the make matrix were disaggregated using the domestic production disaggregation matrix. The disaggregation of the

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intermediate use, final use and negative final use matrices was performed using a disaggregate vector that was the difference between the sum of domestic production and imports minus exports. In some cases, the resulting value would become negative: in that case, a zero value was used instead. This assumption may be revised in the future.

The resulting fully disaggregated total mass SUT was then balanced. Currently, the balancing procedure uses the same data quality score for every entry. In the future data quality scores (1 to 5, with one being the best) will be assigned to the disaggregated SUT. The arithmetic average (rounded to the nearest integer) of the corresponding disaggregate and aggregate value will be used. In the case of the use matrices, the disaggregate value will itself be the integer-rounded arithmetic average of the three disaggregate data values.

4.4. Element composition information

The source data on the element composition was given on a product basis. Hence, every column of the make matrix and every row of the use matrices, as well as every entry of the import and export vectors were multiplied by the same fraction to determine the proportion of mass belonging to a given element. The mathematical formulas for this procedure and the one described in the following paragraph are reported in the Annex (Appendix F).

The extractions and outflows by/from industries and final consumers were obtained as the net differential between inputs and outputs of each industry, where total industry output was obtained as the row sum of the make matrix. This means that the resulting system is balanced for each of the five constraints for every element layer. The system is also balanced for every SUT entry in terms of total mass split by elements, except the extraction and outflow blocks. The sum across elements does not match total mass flows for extraction and outflow blocks because the element components were obtained as net differences while for the total mass a different approach was been taken (described above). Ideally, in the future this approach will be revised.

5. Results and Analysis

5.1. Results

The resulting physical SUT for the Danish economy in 2011 could be find in the Annex. Moreover, two physical SUTs (for Cu and Ta) of the same structure are given which describe the element-based mass flows of the economy. These tables cover 164 industries (from Exiobase) and 601 PAN product categories for these two elements which are described in the Annex as well. Out of those, 55 products contain tantalum and 375 contain copper.

To visualize the element-based flows of the resulting tables, two Sankey diagrams have been generated where PAN product categories have been aggregated back to Exiobase categories for simplicity of the representation (see Figure 7 and Figure 8).

As for an initial test of the validity of the resulting flows, such were compared to the volumes in the only found existing substance flow analysis (SFA) of copper in Denmark (Lassen & Hansen, 2000). The study reported 26-33 kilotonnes (kt) of the total copper mass imports into Danish economy into 1996, or 35-45 kt if projected into year 2011 with an average 2% GDP growth rate (CEIC Data, 2020). Meanwhile, 57 kt of the total copper mass inflow in 2011 results from our analysis. Similarly, the study reports 12-14 kt of the total recycling (projected onto year 2011) versus 16 kt obtained in our analysis.

The more comprehensive analysis of our results proceeds in this chapter.

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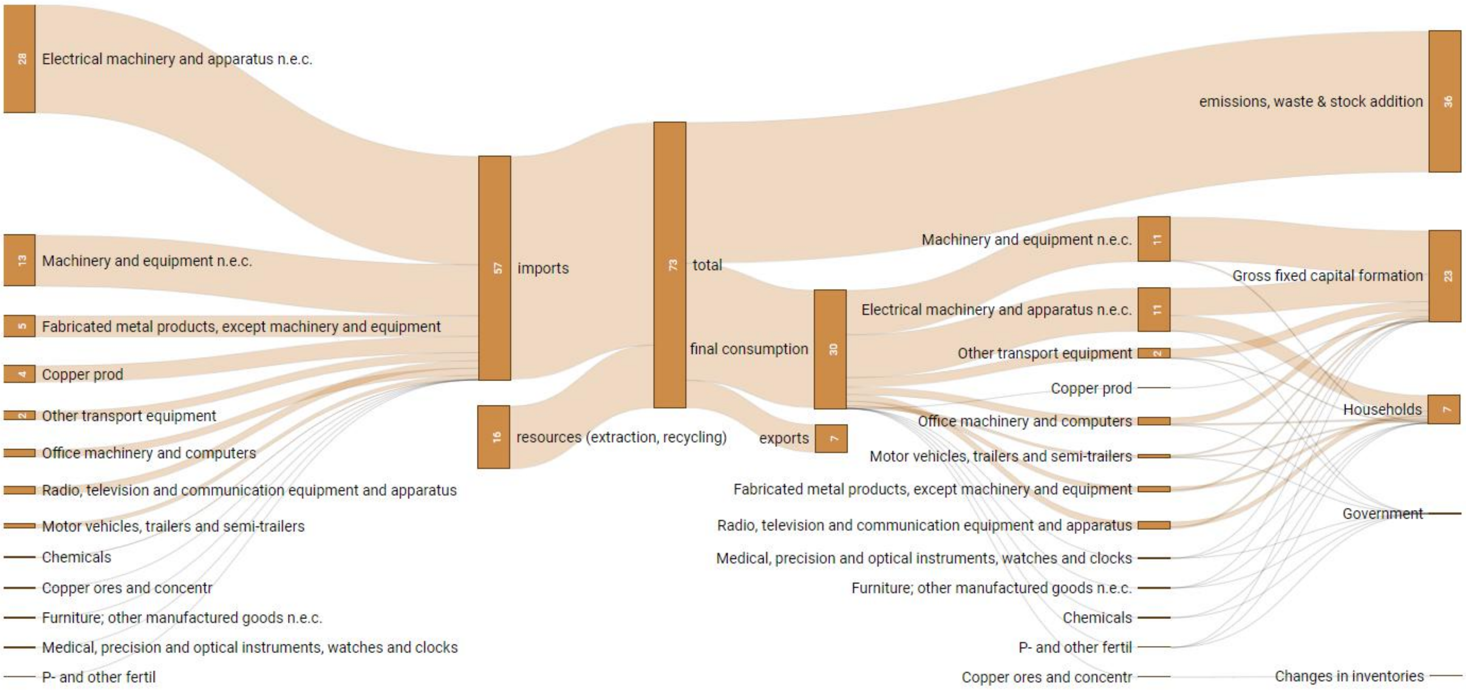

Figure 8 Annual copper (Cu) flows through Denmark in 2011 (thousand metric tonnes). Imports and the final demand flows are divided between corresponding Exiobase product and final demand categories. Resources' inflows and outflows (extraction, recycling, emissions, waste, and stock addition) have been collapsed into one values for this deliverable and are not separated under this diagram.

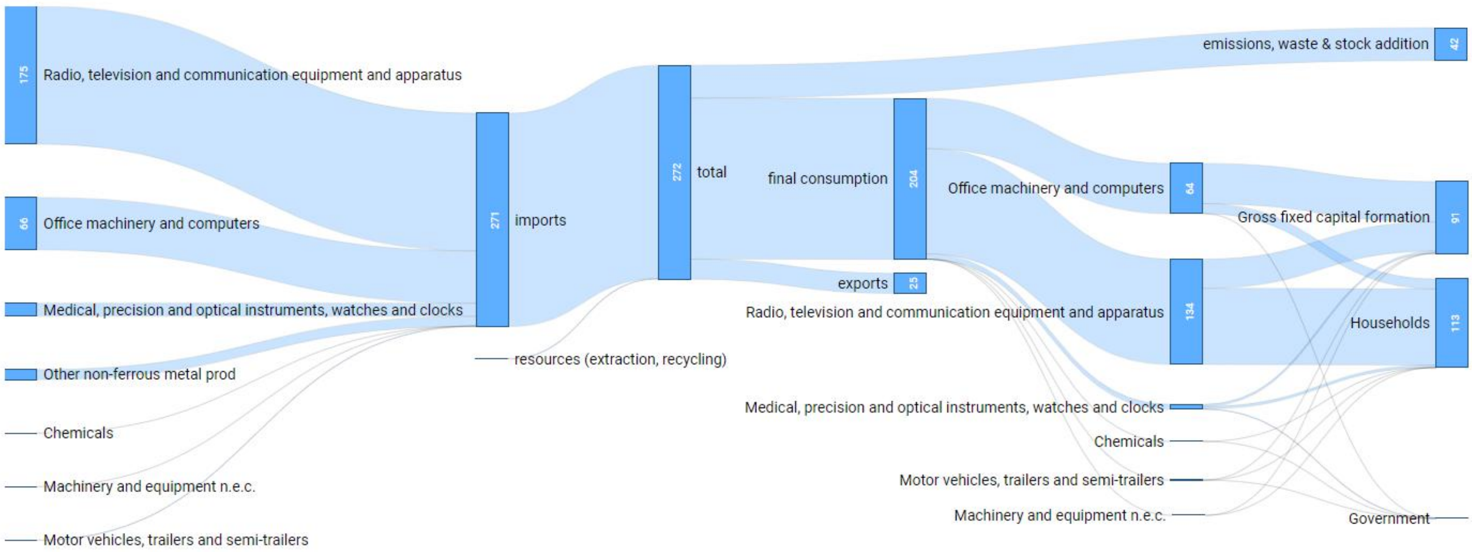

Figure 7 Annual tantalum (Ta) flows through Denmark in 2011 (metric tonnes). Imports and the final demand flows are divided between corresponding Exiobase product and final demand categories. Resources' inflows and outflows (extraction, recycling, emissions, waste, and stock addition) have been collapsed into one values for this deliverable and are not separated under this diagram.

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5.2. Analysis

To summarize, the following chart depicts four main SUT transformation phases along this deliverable with the final disaggregated Panorama SUT and its aggregated version:

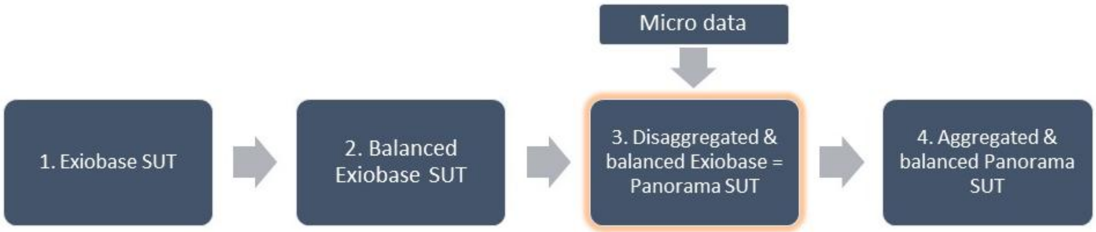

Figure 9 SUT phases along Panorama Deliverable 5.2: 1 - The original Exiobase SUT, 2 – balanced Exiobase SUT, 3 – Disaggregated (using proportions of the micro data) & balanced Panorama SUT, 4 – Panorama SUT aggregated back to Exiobase product classification for farther analysis.

Based on that, two comparisons have been conducted: Microdata with the corresponding data from the resulting Panorama SUT and the original Exiobase SUT with the resulting Panorama SUT (aggregated version). In addition, comparison of the resulting Panorama data with the existing results of ProSUM project was made.

Panorama vs Micro data

The total mass SUT results for the Denmark case can be compared with the original micro data. These include production (sum in columns of the make matrix) and trade (imports and exports vectors). The comparison is made for those Panorama categories in which the micro data were available. This has also been aggregated back into Exiobase classification in order to facilitate the analysis.

In the production domain, the Panorama results related to the categories "*Copper ores and concentrates", "Other non-ferrous metal ores and concentrates",* and *"Chemicals nec" and "Copper products"* have relatively similar values or at least in the same order of magnitude than the micro data originally from Prodcom. However, the values can be vary from one to six orders of magnitude for the other categories. Additionally, the all Panorama figures are higher than those originated from the micro data (see Table 2).

In the trade domain, the Panorama results and micro data regarding the categories *"Fabricated metal products, except machinery and equipment (28)", "Machinery and equipment n.e.c. (29)", "Office machinery and computers (30)", "Electrical machinery and apparatus n.e.c. (31)", "Radio, television and communication equipment and apparatus (32)", "Medical, precision and optical instruments, watches and clocks (33)", "Motor vehicles, trailers and semi-trailers (34)",* and

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"Furniture; other manufactured goods n.e.c. (36)" displayed similar or in the same order of magnitude values for imports. For the exports, only the categories *"Copper ores and concentrates"*, *"Medical, precision and optical instruments, watches and clocks (33)"*, and *"Other transport equipment (35)"* fell under such conditions. All the remaining groups values were substantially different between Panorama and BACI (see Table 3 and

Table 4).

The discrepancies found illustrate the difficulties in merging Exiobase and the micro data to generate the Panorama results. In addition, there is no clear indication of categories that have more comparable values between sources.

Table 2: Comparison of production values between Panorama and Prodcom (all values in tons).

EX_code	Description	Prod_PAN	Prod_Micro
C_COPO	Copper ores and concentrates	0	0
C_ONFO	Other non-ferrous metal ores and concentrates	0	0
C_PFER	P- and other fertiliser	121,459	95
C_CHEM	Chemicals nec	821,786	150,847
C_COPP	Copper products	1	2
C_ONFM	Other non-ferrous metal products	108,333	0
C_FABM	Fabricated metal products, except machinery and equipment (28)	24,470	6,842
C_MACH	Machinery and equipment n.e.c. (29)	121,871	522
C_OFMA	Office machinery and computers (30)	2,513	0
C_ELMA	Electrical machinery and apparatus n.e.c. (31)	118,693	166
C_RATV	Radio, television and communication equipment and apparatus (32)	14,467	13
C_MEIN	Medical, precision and optical instruments, watches and clocks (33)	24,091	345
C_MOTO	Motor vehicles, trailers and semi-trailers (34)	153,427	296
C_OTRE	Other transport equipment (35)	382,168	6
C_FURN	Furniture; other manufactured goods n.e.c. (36)	64,137	296
	Total	1,957,416	159,430

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Table 3: Comparison of import values between Panorama and BACI (all values in tons).

EX_code	Description	Imp_PAN	Imp_Micro
C_COPO	Copper ores and concentrates	1	0
C_ONFO	Other non-ferrous metal ores and concentrates	4,661	367
C_PFER	P- and other fertiliser	91,882	359,211
C_CHEM	Chemicals nec	258,281	1,706,637
C_COPP	Copper products	5,340	36,065
C_ONFM	Other non-ferrous metal products	130,196	1,216
C_FABM	Fabricated metal products, except machinery and equipment (28)	488,781	721,207
C_MACH	Machinery and equipment n.e.c. (29)	516,250	706,670
C_OFMA	Office machinery and computers (30)	45,812	30,647
C_ELMA	Electrical machinery and apparatus n.e.c. (31)	224,899	267,401
C_RATV	Radio, television and communication equipment and apparatus (32)	50,495	67,113
C_MEIN	Medical, precision and optical instruments, watches and clocks (33)	65,038	37,747
C_MOTO	Motor vehicles, trailers and semi-trailers (34)	112,810	608,954
C_OTRE	Other transport equipment (35)	41,884	487,041
C_FURN	Furniture; other manufactured goods n.e.c. (36)	149,007	484,370
	Total	2,185,337	5,514,647

Table 4: Comparison of export values between Panorama and BACI (all values in tons).

EX_code	Description	Exp_PAN	Exp_Micro
C_COPO	Copper ores and concentrates	0	0
C_ONFO	Other non-ferrous metal ores and concentrates	0	11
C_PFER	P- and other fertiliser	10,058	118,208
C_CHEM	Chemicals nec	329,552	1,012,518
C_COPP	Copper products		5,833

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		16	
C_ONFM	Other non-ferrous metal products	24,124	432
C_FABM	Fabricated metal products, except machinery and equipment (28)	10,198	504,526
C_MACH	Machinery and equipment n.e.c. (29)	72,133	759,571
C_OFMA	Office machinery and computers (30)	3,731	14,083
C_ELMA	Electrical machinery and apparatus n.e.c. (31)	43,991	448,400
C_RATV	Radio, television and communication equipment and apparatus (32)	6,851	40,392
C_MEIN	Medical, precision and optical instruments, watches and clocks (33)	11,344	48,762
C_MOTO	Motor vehicles, trailers and semi-trailers (34)	98,324	326,151
C_OTRE	Other transport equipment (35)	381,035	521,310
C_FURN	Furniture; other manufactured goods n.e.c. (36)	23,792	511,502
	Total	1,015,147	4,311,701

Panorama vs ProSUM

The ProSUM database contains information of the total amount put on the market (apparent consumption) of electrical and electronic equipment (EEE), end-of-life vehicles, and batteries (Huisman et al., 2017). In addition, the amounts of a set of elements for these categories are available, including copper and tantalum. These figures can be compared with the results derived for the Denmark case.

The classification of Panorama follows a combination of Exiobase and HS classification. This is the case in which Cu or Ta are found in the HS code. However, if none of the elements are found in the commodity, then the Panorama code will assign the code 'others' to aggregate all the rest of the commodities that do not have flows of copper and tantalum in the SUT (see Section 3.3). Since the comparison between the two databases can be done via correspondence with the HS classification, it is possible that the total for Panorama values (when aggregate to ProSUM categories) are underestimated. This is especially the case for batteries, as no Cu nor Ta fractions were indicated in the composition module. For vehicles, the Panorama codes *C_MOTO_870421, C_MOTO_870390, C_MOTO_870333, C_MOTO_870332, C_MOTO_870331, C_MOTO_870324, C_MOTO_870323, C_MOTO_870322, C_MOTO_870321* were considered, since they refer to small vehicles.

In Table 5, all the Panorama and ProSUM data are aggregated into the latter categories. In Table 6, only products that are mutually inclusive in both databases were aggregated. This way, underestimation of the Panorama totals is avoided. Put on the market values for both copper and totals are improved in the latter for the large equipment and small equipment. This also illustrates the importance of compiling comprehensive composition data.

In the mutually inclusive case, the copper and total flows for cooling and freezing, large equipment, and small equipment are considerably similar. For screens, the differences fall within the same order of magnitude, whereas for lamps, small IT equipment and vehicles, these are an order of magnitude different. However, the results are not comparable for the tantalum flows, indicating possible problems with its composition data. Still, it is interesting that values match for a number of categories even though the micro data related to EEE deviated considerably from the Denmark case results (see C_MACH, C_OFMA, C_ELMA, C_RATV, C_MEIN in Table 2, Table 3 and Table 4).

Table 5: Put on the Market (in tons) for EEE and vehicles according to sources in 2011.

Category	Cu	Ta	Total	Source
EEE-CoolingAndFreezing	606.9	0.0	15108.50	Panorama
EEE-CoolingAndFreezing	636.4	0.0	20634.76	Prosum
EEE-Lamps	85.2	0.0	1136.55	Panorama
EEE-Lamps	29.1	0.0	1634.08	Prosum
EEE-LargeEquipment	1089.4	0.0	30452.79	Panorama
EEE-LargeEquipment	877.2	0.0	45057.39	Prosum
EEE-Screens	1049.0	6.6	23727.51	Panorama
EEE-Screens	230.1	0.5	14842.31	Prosum
EEE-SmallEquipment	1763.9	0.3	39898.04	Panorama
EEE-SmallEquipment	2523.9	0.0	48142.18	Prosum
EEE-SmallIT	1571.3	58.9	38389.58	Panorama
EEE-SmallIT	272.8	0.2	11366.04	Prosum
Vehicles	481.0	0.3	59702.71	Panorama
Vehicles	5765.5	0.6	226152.51	Prosum

Table 6: Put on the Market (in tons) for EEE and vehicles that are mutually inclusive on sources in 2011.

Category	Cu	Ta	Total	Source
EEE-CoolingAndFreezing	360.0	0.0	8552.4	Panorama
EEE-CoolingAndFreezing	350.3	0.0	12967.3	Prosum

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EEE-Lamps	85.2	0.0	1136.5	Panorama
EEE-Lamps	8.9	0.0	692.7	Prosum
EEE-LargeEquipment	1080.0	0.0	30218.5	Panorama
EEE-LargeEquipment	809.9	0.0	39462.3	Prosum
EEE-Screens	838.0	6.6	18453.5	Panorama
EEE-Screens	142.4	0.5	11033.1	Prosum
EEE-SmallEquipment	1203.7	0.3	25578.3	Panorama
EEE-SmallEquipment	1321.0	0.0	24510.8	Prosum
EEE-SmallIT	1554.9	58.9	37979.8	Panorama
EEE-SmallIT	198.6	0.2	10137.0	Prosum
Vehicles	481.0	0.3	59702.7	Panorama
Vehicles	5765.5	0.6	226152.5	Prosum

Panorama vs Exiobase

The Panorama tables have been re-aggregated to the EXIO classification in order to perform a comparison of the initial data source with final calculated results (Exiobase SUT has been initially balanced because some unbalances were spotted).
The new data collected have modified the main aggregates' total as can be seen below. Main differences can be spotted in the trade data, with the trade of Copper products (+2900%), Office machineries (+152%) and other transport equipment (+82%). Yet, only in the latter case the increase of export, associated with reduction of the domestic production (-23%), has implied a high reduction of the material availability (-87%) on the domestic Danish market. A reduction of domestic production in the 'P and other fertilisers' has been compensated by higher imports, therefore the domestic availability was barely modified. Another relevant increase of imports occurs in the Motor vehicles. But also in this case the domestic availability is slightly changed.

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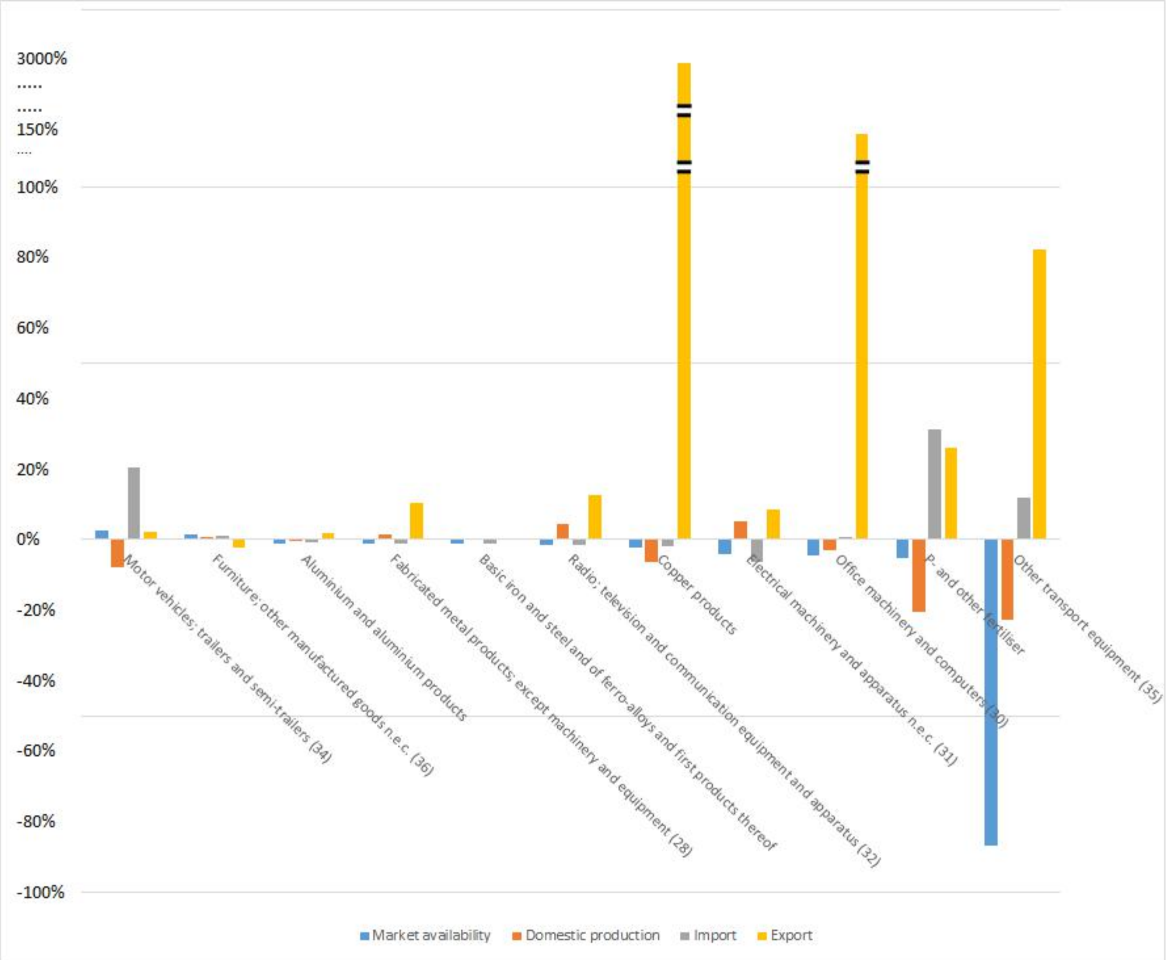

Figure 10 Change of the main aggregates' totals because of new data collection occurred in Panorama. Values are calculated as final value/initial value –1.

The second part of the analysis focuses on the behaviour of the balancing procedure. In Panorama an important role is played by the element composition mix of products. Therefore, the final data should be influenced by two factors, the change of the aggregate totals and a constrain in the element composition. This behaviour can be seen in the final data of Panorama with a simple linear correlation analysis (Table 7).

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Table 7: Correlation between the variations of the aggregate totals

Products used:	Variable 1	Variable 2	Slope	R squared
All EXIOBASE products	Market availability	Intermediate uses	0.3047	0.272
	Market availability	Final demand	0.298	0.231
	Intermediate uses	Final demand	0.886	0.696
Only Panorama products	Market availability	Intermediate uses	0.969	0.938
	Market availability	Final demand	1.045	0.92
	Intermediate uses	Final demand	1.036	0.905
Only Panorama raw materials	Market availability	Intermediate uses	0.982	0.897
	Market availability	Final demand	0.775	0.027
	Intermediate uses	Final demand	0.752	0.027

There is not a general systematic behaviour in the variation of the intermediate uses (IUs) and of the final demand (FD) when the market availability (MA) is modified due to new data collection. MA is calculated as domestic production plus imports and less exports. Instead, if we limit our analysis only to products modified in Panorama, it can be seen a strong positive correlation by the variation of MA and IU and FD. Yet, this correlation is dominated by the other transport equipment, which has high MA variation (see Figure 10). The latter is not a raw material but rather a final good, in other words it is not an input that is processed to produce other goods. Therefore, its uses are not highly constrained in the Panorama balancing procedure and so they are free to move following the behaviour of MA.

Different thing should be for raw materials. Raw materials are indeed processed in the activities to produce final product. Because of that, the condition on element composition mix should affect their use. Yet, in the Panorama results we still notice a strong correlation between the variation of MA and IUs as to indicate that the introduction of element composition mix for some products has not played a big role. Indeed, looking at the final results, it can be easily noticed that all the IUs of raw material are proportionally increased or decreased, so the element composition mixes have not caused an asymmetric reallocation of inputs between activities as should be expected.

The correlation between MA and FD is irrelevant. Therefore, the FD seems to be treated as a residual value. The balancing procedure seems to give priority to IUs and then the FD is readjusted to allow the balance. This approach could be different in the future developments of the Panorama database when constraints on the FD will be introduced.

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6. Limitations and Conclusions

6.1. Assumptions overview

Major assumptions behind the retrieved data and the balancing procedures are listed to be explicitly acknowledged and possibly reviewed in the following editions of the project:

- Uncertainty scores assigned to the data points are frequently subjective to the expert opinion of the evaluator and the underlying assumptions. Such scores are relative across datasets they describe and are hardly comparable between different data sources.
- It has been assumed that the products not covered in the original composition sources have zero content with the highest certainty (1).
- It has been assumed that duplicate HS links to non-containing EXIO categories are prioritised to be kept.
- Production volumes of products not being reported in Prodcom have been assumed to be zeros with the highest certainty (1).
- Confidential Prodcom data points were estimated based on the export volumes of the same goods.
- It was assumed that the concentration of the ore produced domestically was the same as exported.
- For those countries where the concentration of the particular trade ore was not available, a global average was adopted.
- Weighted average based estimation of the cumulative uncertainty scores results in the implicit assumption of lower trade volumes having higher certainty
- More general PC-based production volumes have been reallocated between linked HS products proportional to known trade volumes of such.
- Usage of proportions from micro data to disaggregate Exiobase aggregate flows.
- Treatment of domestic consumption disaggregate flows as a residual between domestic production and imports minus exports. An inconvenient consequence of this approach is that sometimes that value became negative and was exogenously set to zero.

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6.2. Conclusions & Future Steps

This report is based on the development of the activities of Task 5.2 (*Test routine for 1-2 EU countries*). The routine proposed in Task 5.1 (*Develop balancing routine out of existing routines in EXIOBASE*) has been therefore tested for Denmark and the year 2011.

In order to test the routine, a number of datasets had to be harvested and processed (Prodcom, BACI, Ta and Cu composition, Exiobase). A new Panorama product classification system with a HS 6 level of detail was generated to combined these datasets. As a result, SUT were created for the Panorama classification system, as well as their corresponding Exiobase aggregates. In addition, the same tables were also originated for copper and tantalum. These were then compared with both the original datasets (Exiobase, micro data), ProSUM database, as well as existing studies in the case of copper.

In the future editions, the consortium aims to incorporate additional data sources, improve the balance routine and revisit some of the listed assumptions. These are further explained below.

Initially, both extraction and waste data could potentially be imputed into the balancing procedure instead of treating extraction and outflows as residual terms, which would require having values of extraction and outflows by element type. This is more readily available for a set of elements from the IRP Material Flows Database. Even though such data has been already incorporated into Exiobase, it has not yet been formalized at Panorama due to time constraints.

Another issue that was not yet solved is the direct usage of the micro data instead of proportions to disaggregate Exiobase flows. Ideally, the data to be imputed in the procedure would be some average of both the Exiobase and the micro data absolute values. This is not yet the case until the discrepancies between Exiobase and the micro data aggregates (see section **Error! Reference source not found.**) are further analysed. Additionally, the usage of data quality information to pre-adjust these and the composition numbers is desired.

It has also been discussed the possibility of producing SUT not only on an element, but also on a material level. In Exiobase, the data is available for a set of 19 categories. However, the data on a micro level (e.g. HS 6) would be required, and it is not yet clear if the data to be harvested in Task 4.2. (*Estimation of composition and lifetimes*) will be also material base detailed.

Finally, the development of a reconciliation procedure for the composition data to be imputed in the balancing procedure should be realized. At this stage, only two references were used (see section 3.2). Although the results were comparable with the ProSUM dataset for some electrical and electronic equipment categories, there is a need to combine different composition data sources (such as ProSUM itself) to further improve the element-based physical SUTs.

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Additionally, micro date for manufacturing losses, final demand categories, and waste generation will be introduced in the coming work. This could come from life-cycle inventory databases, consumer surveys, and product lifetimes estimations.

References

Deetman, S., van Oers, L., van der Voet, E., & Tukker, A. (2018). Deriving European Tantalum Flows Using Trade and Production Statistics. *Journal of Industrial Ecology*, *22*(1), 166–179. https://doi.org/10.1111/jiec.12533

Gaulier, G., & Zignago, S. (2012). BACI: International Trade Database at the Product-Level (the 1994-2007 Version). *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.1994500

Huisman, J., Habib, H., Brechu, M. G., Downes, S., Herreras, L., Lovik, A. N., … Soderman, M. L. (2017). ProSUM: Prospecting secondary Raw Materials in the Urban Mine and Mining Wastes. *2016 Electronics Goes Green 2016+, EGG 2016*. https://doi.org/10.1109/EGG.2016.7829826

Lassen, C., & Hansen, E. (2000). Paradigm for Substance Flow Analyses Guide for SFAs carried out for the Danish EPA. *Environmental Project*.

Merciai, S., & Schmidt, J. (2018). Methodology for the Construction of Global Multi-Regional Hybrid Supply and Use Tables for the EXIOBASE v3 Database. *Journal of Industrial Ecology*, *22*(3), 516–531. https://doi.org/10.1111/jiec.12713

Soulier, M., Glöser-Chahoud, S., Goldmann, D., & Tercero Espinoza, L. A. (2018). Dynamic analysis of European copper flows. *Resources, Conservation and Recycling*, *129*(November 2017), 143–152. https://doi.org/10.1016/j.resconrec.2017.10.013

Stadler, K., Wood, R., Bulavskaya, T., Södersten, C. J., Simas, M., Schmidt, S., … Tukker, A. (2018). EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables. *Journal of Industrial Ecology*. https://doi.org/10.1111/jiec.12715

CEIC Data. (2020). *Denmark Real GDP Growth.* Retrieved from CEIC: Global Economic Data, Indicators, Charts & Forecasts: https://www.ceicdata.com/en/indicator/denmark/real-gdp-growth

Istanbul Mineral Exporters' Association (IMIB). (2019). *UNROASTED IRON PYRITES.* Retrieved from Turkish Minerals: http://www.turkishminerals.org/Mineral/1/UNROASTED-IRON-PYRITES

UN Statistics Division . (2019). *Classifications on economic statistics.* Retrieved from https://unstats.un.org/unsd/classifications/Econ

Annex

Concordance between EXIO and CPC

See the file in the appendices: D52_Appendix_section3.pdf

The mathematical details of balancing

See the file in the appendices: D52_Appendix_section4.pdf

There, Appendix A describes the notation, Appendix B describes the balancing method, and Appendix C provides the mathematical symbols of each object and the equations that describe the constraints. Appendix D describes the procedures from section: 4.2. Appendix E describes the procedures from section: 4.3. Appendix F describes the procedures from section: 4.4.

The resulting physical SUTs for the Danish economy in 2011

For the total mass flows,

See the file in the appendices: D52_Appendix_section5_total.xlsx

For two physical SUTs (for Cu and Ta) which describe the element-based mass flows of the economy,

See the file in the appendices: D52_Appendix_section5_elem.xlsx

Estimating uncertainty scores for Ta composition data

Table 2 describes tantalum containing products with the original kg Ta per kg product concentrations reported (Deetman et al., 2018). Such values have been adjusted for several products if the computational errors were found in the original study. For most of the products, related 6-digit HS codes have been identified. ‘Automotive (vehicles)’ product category covers all of the subheading of the listed 4-digit HS category. Code assignments for ‘Carbide tools’ and ‘Wave filters’ will have to be reviewed later in the project because of their relative complexity. Originally, all the data points have been assigned with an uncertainty score 2 (except primary tantalum ‘Articles’ with the highest certainty score). Any of the following features increased uncertainty score by one: market shares used in the original estimations; original source older than year 2000; unclear if the component is incorporated (PC, HDD); additional assumption made in the original study; values if given on a 4-digit level; derived as result of mass balancing (+2 scores).

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Table 8 Tantalum content of the HS-based goods along with the assigned uncertainty scores and adjusted values. Source: (Deetman et al., 2018)

Product	HS 2017	kg Ta / kg	Adjusted	Uncert. sc.
Concentrates	261590	0.00211456		4
Articles	810320	1		1
	810330	1		2
	810390	1		2
Carbides	284990	0.00006794		2
Capacitors	853221	0.367		2
HDD	847170	0.019		2
Artificial joints	902131	0.175		2
Camera lenses	900211	0.046		4
Vision correction lenses & other lenses	900130	0.00184		4
	900140	0.00184		4
	900150	0.00184		4
	900190	0.00184		4
Mobile phone	851712	0.00041		2
Laptop PCs	847130	0.00103	0.00079	3
Desktop PCs	847141	0.00088	0.00000066	3
Cameras	852580	0.00142	0.0015958	2
Hearing aid	902140	0.04667		3
Pacemakers	902150	0.0186		3
GPS	852691	0.0043		3
DVD players	852190	0.00001078		2
Furnaces	841710	0.000062		2
	841780	0.000062		2
	841790	0.000062		2
Carbide tools	382430	0.0007966		2
TVs	852842	0.000008	0.0000078	3
	852849	0.000008	0.0000078	3
	852852	0.000008	0.0000078	3
	852859	0.000008	0.0000078	3
Automotive (vehicles)	8703, 8704	0.0000058		4
Wave filters	854160	0.3305		3
Semiconductors (excl.	854110-	0.286		3

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

photovoltaic)	854130		
Aerospace	841111	0.00092	2
	841112	0.00092	2
	841121	0.00092	2
	841122	0.00092	2
	841191	0.00092	2

Appendix to section 3.3 of deliverable D5.2 of PANORAMA project

Manually assembled concordante from CPC to EXIOBASE product classifications.

CPC v2.1 code	EXIOBASE v3.6 code
33312	C_AGSL
41431	C_ALUM
41432	C_ALUM
41531	C_ALUM
41532	C_ALUM
41533	C_ALUM
41534	C_ALUM
41535	C_ALUM
41536	C_ALUM
14230	C_ALUO
11010	C_ANTH
24110	C_BEVR
24131	C_BEVR
24139	C_BEVR
24211	C_BEVR
24212	C_BEVR
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24230	C_BEVR
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24320	C_BEVR
24410	C_BEVR
24490	C_BEVR
35491	C_BIOD
11040	C_BKBP
37310	C_BRIK
37320	C_BRIK
37330	C_BRIK
37340	C_BRIK
37350	C_BRIK
37360	C_BRIK
37370	C_BRIK
37610	C_BRIK
37690	C_BRIK
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02112	C_CATL
02119	C_CATL
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34131	C_CHEM
34139	C_CHEM

34140	C_CHEM
34150	C_CHEM
34160	C_CHEM
34170	C_CHEM
34180	C_CHEM
34210	C_CHEM
34220	C_CHEM
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34232	C_CHEM
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33100	C_COKE
14210	C_COPO
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41412	C_COPP
41413	C_COPP
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41512	C_COPP
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32800	C_MDIA
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48323	C_MEIN
48329	C_MEIN
48341	C_MEIN
48342	C_MEIN
48351	C_MEIN
48352	C_MEIN

48353	C_MEIN
48354	C_MEIN
48410	C_MEIN
48420	C_MEIN
48430	C_MEIN
48440	C_MEIN
48490	C_MEIN
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Appendix to section 4 of deliverable D5.2 of Panorama project

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Details of the imputation and balancing procedure

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A Notation

In general a scalar is denoted by italic and a multidimensional object by bold, with lowercase denoting vector and uppercase matrix. (In fact most objects considered here will have additional dimensions when a multi-regional and multi-element setting is considered.)

Superscripts A and D denote, respectively, aggregate and disaggregate. In general an aggregate object is related to its disaggregate counterpart through an aggregation matrix of zeros and ones, which will be represented as $\mathbf{G}$, with annotations to distinguish different aggregation matrices. We assume aggregation to be unique, i.e., there is no instance of a disaggregate category corresponding to multiple aggregate categories.

We will need to use iterators to represent different categories of regions (r and s), economic products, sectors, primary input and final demand categories (i and j, respectively for input/row and output/column, usually), and elements k. As a rule iterators run from 1 to an n appended by an appropriate subscript (e.g., the total of regions is n_R). When necessary a total is also appended by a superscript to distinguish aggregate and disaggregate variants.

By definition, multiplication is the inner product. Hadamard product is denoted by $\#$ and Hadamard division by $\div$.

B Balancing algorithm

The disaggregate variables defined above (full domestic supply-use tables and international trade) are arranged in a single vector $\mathbf{t}$ of length n_T.

A balanced system, $\mathbf{t}_\infty$, satisfies:

$$\mathbf{G}\mathbf{t}_\infty = \mathbf{k}$$

whereas the initial estimate, $\mathbf{t}_0$, instead satisfies:

$$\mathbf{G}\mathbf{t}_0 \neq \mathbf{k}$$

The number of rows in $\mathbf{G}$ and length of $\mathbf{t}$ is n_K and together these two objects define the constraints that the balanced set of variables need to comply with. The algorithm proposed to balance the system from $\mathbf{t}_0$ to $\mathbf{t}_\infty$ is a modified form of the linear method of Rodrigues (2014), with the following steps:

$$\mathbf{t}_{k+1} = \mathbf{t}_k + \delta \hat{\mathbf{u}} \hat{\mathbf{t}}_k \mathbf{G}' \boldsymbol{\alpha}$$

In turn the vector of Lagrange multipliers, $\boldsymbol{\alpha}$, is determined as:

$$\boldsymbol{\alpha} = (-\mathbf{G}\mathbf{t}_k) \div \left(|\mathbf{G}| \hat{\mathbf{u}} \hat{\mathbf{t}_k} \right)$$

There might be a unique solution, otherwise a pseudo-inverse can be calculated. Finally, the adjustment step δ is calculated so that the relative adjustment is small for every variable.

$$\begin{aligned} \mathbf{t}^*_{k+1} &= \mathbf{t}_k + \hat{\mathbf{u}} \hat{\mathbf{t}}_k \mathbf{G}' \boldsymbol{\alpha} \\ \delta &= \min \left\{ 1, \epsilon \left| \frac{t_{i(k+1)}}{t^*_{i(k)} - t_{i(k)}} \right|_i \right\} \end{aligned}$$

where ϵ is a small number. In practice we shall use $\epsilon = 10\%$.

This procedure assumes a set of conditions:

- Variables are non-zero by definition, implying that empties are excluded from the set of variables.

- Variables are not allowed to shift signs. This could be handled by considering a pair of inflow-outflow terms. However, in practice, for the Panorama project it was decided not to incorporate this feature.

- Variables are strictly positive by definition. This means that outflow terms are handled by considering a -1 term in the appropriate position of the $\mathbf{G}$ matrix.

The last element of the algorithm is the vector of relative uncertainties or reliability factors, $\mathbf{u}$, with the same dimension as $\mathbf{t}$, whose entries take positive real values, such that the larger the value the larger the adjustment a particular variable is allowed to have. In practice we do not have different reliability factors for every element, but we consider five levels: 1 to 5 (from highest to lowest quality), and consider the corresponding u_i values to be 0.1, 0.2, 0.3, 0.4 and 0.5, respectively.

C Total mass flows

The different objects of a domestic total mass flow SUT are:

- Make matrix, $M^D_{i,j}$, for every industry $i = 1, \ldots, n_S$ and product type $j = 1, \ldots, n^D_P$.

- Intermediate use matrix, $U^D_{i,j}$, for every product type $i = 1, \ldots, n^D_P$, and industry $j = 1, \ldots, n_S$.

- Final use matrix with positive terms, $Y^D_{i,j}$, for every product type $i = 1, \ldots, n^D_P$, and final demand category $j = 1, \ldots, n_F$.

- Final use matrix with negative terms, $Yneg^D_{i,j}$, for every product type $i = 1, \ldots, n^D_P$, and final demand category $j = 1, \ldots, n_F$.

- Primary input matrix, $V^D_{i,j}$, for every primary input category $i = 1, \ldots, n_E$, and industry $j = 1, \ldots, n_S$. Primary inputs include extraction and absorption from nature.

- Matrix of outflows from industries, $Vout^D_{i,j}$, for every outflow category $i = 1, \ldots, n_W$, and industry $j = 1, \ldots, n_S$. Outflows (negative values) include additions to stock, emissions to atmosphere, sewage and physical waste.

- Primary inputs to final demand, $H^D_{i,j}$, for every primary input category $i = 1, \ldots, n_E$, and final demand category $j = 1, \ldots, n_F$.

- Outflows from final consumers, $Hout^D_{i,j}$, for every outflow category $i = 1, \dots, n_W$, and final demand category $j = 1, \dots, n_F$.
- Total imports, imp^D_i, for every product type $i = 1, \dots, n^D_P$.
- Total exports, exp^D_i, for every product type $i = 1, \dots, n^D_P$.

  The following data blocks are dependent on the preceding ones, but are convenient for the formulation of the balancing problem:
- Total product output, q^D_i, for every product type $i = 1, \dots, n^D_P$.
- Total industry output, x^D_j, for every industry $j = 1, \dots, n_S$.

These variables are constrained by the following accounting identities are:

$$q^D_i = imp^D_i + \sum_j M^D_{i,j} \tag{C.1}$$

$$q^D_i = \sum_j U^D_{i,j} + \sum_j Y^D_{i,j} + \sum_j Yneg^D_{i,j} + exp^D_i \tag{C.2}$$

$$x^D_j = \sum_i M^D_{i,j} \tag{C.3}$$

$$x^D_j = \sum_i U^D_{i,j} + \sum_i V^D_{i,j} + \sum_i Vout^D_{i,j} \tag{C.4}$$

$$0 = \sum_i Y^D_{i,j} + \sum_i Yneg^D_{i,j} + \sum_i H^D_{i,j} + \sum_i Hout^D_{i,j} \tag{C.5}$$

D Allocation of differences in industry and final consumer balances

The differences between inputs of industries and final demand consumers are:

$$\Delta x^D_j = \left(\sum_i U^D_{ij} + v^D_j + vout^D_j \right) - \sum_i M^D_{ij} \tag{D.1}$$

$$\Delta y^D_j = \sum_i Y^D_{ij} + \sum_i Yneg^D_{ij} + h^D_j + hout^D_j \tag{D.2}$$

Notice that it is assumed that the extraction and outflows of industries and final consumers now have a single category, so we are dealing with vectors, hence the lower-case symbol for these objects.

The differences are then allocated to extraction or outflow terms (now denoted with an asterisk superscript) depending on whether they are negative or positive. That is is:

- If $\Delta x_j^D < 0$ then $v_j^{D*} = v_j^D + |\Delta x_j^D|$.
- If $\Delta x_j^D > 0$ then $vout_j^{D*} = vout_j^D - |\Delta x_j^D|$.
- If $\Delta y_j^D < 0$ then $h_j^{D*} = v_j^D + |\Delta y_j^D|$.
- If $\Delta y_j^D > 0$ then $hout_j^{D*} = hout_j^D - |\Delta y_j^D|$.

Recall that the outflow terms are negative by definition.

E Disaggregation of aggregate flows using disaggregate information

Let every element in the aggregate SUT be denoted with superscript A, in the same way as D is used for the disaggregate system. Also, let imp_i^{D*}, exp_i^{D*} and m_i^{D*} be the source micro-data concerning the total mass imports, exports and domestic production of product i. The micro-data is incomplete, meaning that it only has values for products that are disaggregation of Exiobase products. Also, let $\mathbf{G}^{P*}$ be the product concordance matrix provided, connecting the Exiobase classification in rows and the Panorama classification in columns. This aggregation matrix was also incomplete, meaning that some Exiobase products did not match any Panorama product.

The first step was therefore to obtain a complete concordance matrix $\mathbf{G}^P$, that would connect every aggregate product to some disaggregate product. To do so we generate the row and the column sum of $\mathbf{G}^{P*}$ as $\mathbf{g}^{P*r}$ and $\mathbf{g}^{P*c}$ respectively. We checked that $g_j^{P*c} = 1$ for every disaggregate product j, meaning that all provided disaggregate products were linked to the aggregate classification. However, for some aggregate products the reverse did not hold, i.e., for some i it happened that $g_i^{P*r} = 0$. This was addressed by expanding the seet of disaggregate products with a one-to-one correspondence to every missing aggregate products. That is, if the original number of disaggregate products was n_P^{D*} and there were n_P^{A*} aggregate products for which the corresponding entry of $\mathbf{g}^{P*r}$ was zero, then the new number of disaggregate products is $n_P^D = n_P^{D*} + n_P^{A*}$, and for every column $j > n_P^{D*}$ in $\mathbf{G}^P$ the entry corresponding to a row in which $g_i^{P*r} = 0$ was set as $G_{ij}^P = 1$. For every column $j \leq n_P^{D*}$ the column of $\mathbf{G}^P$ is identical to the corresponding column of $\mathbf{G}^{P*}$. At the end of this procedure $g_i^{Pr} > 0$ for every i, where $\mathbf{g}^{Pr}$ is the row sum of $\mathbf{G}^{P}$.

The second step was to generate disaggregation matrices. Consider a general incomplete disaggregation vector $\mathbf{d}^*$. That is $d_j^* = 0$ for every j such that $G_{ij}^P = 1$ and $g_i^{Pr} = 1$. This disaggregation vector was made complete by setting $d_j = 1$ in a new vector $\mathbf{d}$ whenever the previous instance occurred, and setting $d_j = d_j^*$ when that was not the case. Then an auxiliary sum vector was obtained as $\mathbf{d}^{s*} = \mathbf{G}^P\mathbf{d}$. In some instances this sum vector exhibited zero entries, meaning that there the sum of disaggregate mass flows was zero. In those cases it was set to one, to avoid division by zero. That is, we defined a new sum vector $\mathbf{d}^s$ where $d_i^s = 1$ if $d_i^{s*} = 0$ and $d_i^s = d_i^{s*}$ otherwise. The allocation matrix proper was then constructed as $\mathbf{D} = \text{diag}(\mathbf{d}^s)^{-1}\mathbf{G}^P\text{diag}(\mathbf{d})$. The allocation matrix has the property that all of its rows sum up to one (meaning that every aggregate quantity is exhaustively split among a positive integer number of disaggregate quantities) and there is at most one nonzero entry in each column (as it is a strict disaggregation).

Initial (i.e., unbalanced) estimates of the missing disaggregate objects were thus obtained as:

$$(\mathbf{imp}^D)' = (\mathbf{imp}^A)'\mathbf{D}^{imp} \tag{E.1}$$

$$\mathbf{M}^D = \mathbf{M}^A\mathbf{D}^m \tag{E.2}$$

$$\mathbf{exp}^D = (\mathbf{D}^{exp})'\mathbf{exp}^A \tag{E.3}$$

$$\mathbf{U}^D = (\mathbf{D}^{alt})'\mathbf{U}^A \tag{E.4}$$

$$\mathbf{Y}^D = (\mathbf{D}^{alt})'\mathbf{Y}^A \tag{E.5}$$

$$\mathbf{Yneg}^D = (\mathbf{D}^{alt})'\mathbf{Yneg}^A \tag{E.6}$$

Note that the import matrix is in rows (hence the transpose symbol, $'$). We have used $\mathbf{D}^{imp}$, $\mathbf{D}^{exp}$ and $\mathbf{D}^m$ to denote the disaggregation matrices calculated taking as initial disaggregate vector $\mathbf{d}^*$, respectively $\mathbf{imp}^{D*}$, $\mathbf{exp}^{D*}$ and $\mathbf{m}^{D*}$. The alternative aggregation matrix applied to the transformation of the use matrices, $\mathbf{D}^{alt}$ was obtained by using as initial disaggregate vector $\mathbf{d}^*$, a vector that was took the value $d_j^* = 0$ if $imp_j^{D*} + m_j^{D*} - exp^{D*} < 0$ and $d_j^* = imp_j^{D*} + m_j^{D*} - exp^{D*}$ otherwise.

F Splitting of element flows

For every scalar component of the total mass disaggregate SUT there are now n_E components corresponding to each of the elements considered. Let these new element-specific flows be denoted by appending a subscript (k) to the corresponding component of the total mass SUT. Also, let C_{jk} denote the fraction of total mass of product j that consists of element k, satisfying $\sum_k C_{jk} = 1$. The composition matrix $\mathbf{C}$ is the new data input for this stage of the imputation and balancing procedure.

For every component of the total mass SUT related to a product j the following element-specific components are obtained as:

$$\begin{aligned} M^D_{ji(k)} &= C_{j(k)} M^D_{ji} \\ U^D_{ij(k)} &= C_{j(k)} U^D_{ij} \\ Y^D_{ij(k)} &= C_{j(k)} Y^D_{ij} \\ Yneg^D_{ij(k)} &= C_{j(k)} Yneg^D_{ij} \\ imp^D_{j(k)} &= C_{j(k)} imp^D_{j} \\ exp^D_{j(k)} &= C_{j(k)} exp^D_{j} \\ q^D_{j(k)} &= C_{j(k)} q^D_{j} \end{aligned}$$

Total industry output was obtained as:

$$x^D_{i(k)} = \sum_j M^D_{ji(k)}$$

Extraction and outflow of industries and final consumers were obtained as net differences. That is, we first define:

$$\Delta x^D_{j(k)} = \left(\sum_i U^D_{ij(k)} \right) - x^D_{j(k)} \quad \text{(F.1)}$$

$$\Delta y^D_{j(k)} = \sum_i Y^D_{ij(k)} + \sum_i Yneg^D_{ij(k)} \quad \text{(F.2)}$$

And then set:

- If $\Delta x^D_{j(k)} < 0$ then $v^D_{j(k)} = |\Delta x^D_{j(k)}|$ and $vout^D_{j(k)} = 0$.
- If $\Delta x^D_{j(k)} > 0$ then $v^D_{j(k)} = 0$ and $vout^D_{j(k)} = -|\Delta x^D_{j(k)}|$.
- If $\Delta y^D_{j(k)} < 0$ then $h^D_{j(k)} = |\Delta y^D_{j(k)}|$ and $hout^D_{j(k)} = 0$.
- If $\Delta y^D_{j(k)} > 0$ then $h^D_{j(k)} = 0$ and $hout^D_{j(k)} = -|\Delta y^D_{j(k)}|$.

References

J. F. D. Rodrigues. A Bayesian approach to the balancing of statistical economic data. *Entropy*, 16 (3):1243–1271, 2014.