Development of a System of Indicators for a Resource efficient Europe

DESIRE

Development of a System of Indicators for a Resource Efficient Europe

Physical/Hybrid supply and use tables

Methodological report

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About DESIRE

DESIRE is a FP7 project that will develop and apply an optimal set of indicators to monitor European progress towards resource-efficiency. The project runs from September 2012 to February 2016. We propose a combination of time series of environmentally extended input output data (EE IO) and the DPSIR framework to construct the indicator set. Only this approach will use a single data set that allows for consistent construction of resource efficiency indicators capturing the EU, country, sector and product group level, and the production and consumption perspective including impacts outside the EU. The project will:

- Improve data availability, particularly by creating EE IO time series and now-casted data
- Improve calculation methods for indicators that currently still lack scientific robustness, most notably in the field of biodiversity/ecosystem services and critical materials. We further will develop novel reference indicators for economic success.
- Explicitly address the problem of indicator proliferation and limits in available data that have a 'statistical stamp'. Via scientific analysis we will select the smallest set of indicators giving mutually independent information, and show which shortcuts in (statistical) data inventory can be made without significant loss of quality.

The project comprises further Interactive policy analysis, indicator concept development via 'brokerage' activities, Management, and Conclusions and implementation including a hand over of data and indicators to the EU's Group of Four of EEA, Eurostat, DG ENV and DG JRC.

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1 Introduction

Several environmental pressure indicators are based on information that can be obtained from physical supply and use tables (PSUTs). Examples are waste generation indicators, total material requirement (TMR), ecological rucksack, material intensity per product service (MIPS), carbon footprint. Further, when the PSUTs are combined with monetary and energy supply and use tables (MSUTs and EnSUTs), hybrid input-output tables (HIOTs) can be created. With the extensions of the PSUTs, the HIOTS can be used for calculating life cycle environmental pressure indicators for country/regional consumption, products, sectors and trade. The purpose of the current report is to present a generic methodology to create fully mass balanced multi-regional PSUTs.

Few PSUTs exist, and only one global multi-regional PSUT exists so far, i.e. the dataset created as part of the EU FP7 project CREEA (Schmidt et al. 2013; Merciai et al., 2013). The PSUTs created in the CREEA project were based on a procedure developed in a preceding EU FP6 project FORWAST. There are many similarities of the procedure developed in the FORWAST project and the principles introduced in the Waste Input-Output Table (Nakamura et al., 2007).

The presented methodology in this report, although strongly relying on the procedure provided by the FORWAST and the CREEA projects, shows many novelties. A very important property is that the current methodology produces PSUTs with homogenous activities. This means that each activity supplies the principal product and only co-products that are technologically linked to it. In addition, focus is on respecting conservation laws in processes that transform energy products, such as the production of electricity. Furthermore, the trade balance in mass units is a sub-procedure of the whole algorithm. As done in the CREEA project, to the PSUTs, which are usually accounted in mass units (Miller & Blair, 2008; Stahmer, 2000), are also added intangible goods that are accounted in other units of measurement. The ultimate scope is indeed that of accounting all the transactions of the world economies giving the priority to mass units, then to other units, such as energy and monetary units. This implies that the tables here presented go beyond the classical PSUTs and can be defined as hybrid (or mixed-units) supply and use tables (HSUTs).

The presented procedure has been used for creating HSUTs for 43 countries plus five rest-of-world regions for the period 1995-2011 in the EU FP7 project DESIRE. The concept of physical supply and use tables (PSUTs) is defined in the Systems of Economic and Environmental Accounts (SEEA) (SEEA Central Framework, 2012). It should be noted that it has not been possible to arrive at full mass balances for all flows in all countries. This is because of relatively poor data availability of product volumes and transactions in physical units in some countries. Most problems relating to imbalances and lack of data have been addressed by using an automated procedure to estimate mass flows and to reallocate raw material inputs from places with excess to places with deficit. However, there is still wide room for improvement both in terms of more detailed data collection and in terms of refining estimation procedures. The overall structure of the HSUTs is illustrated in Figure 1.

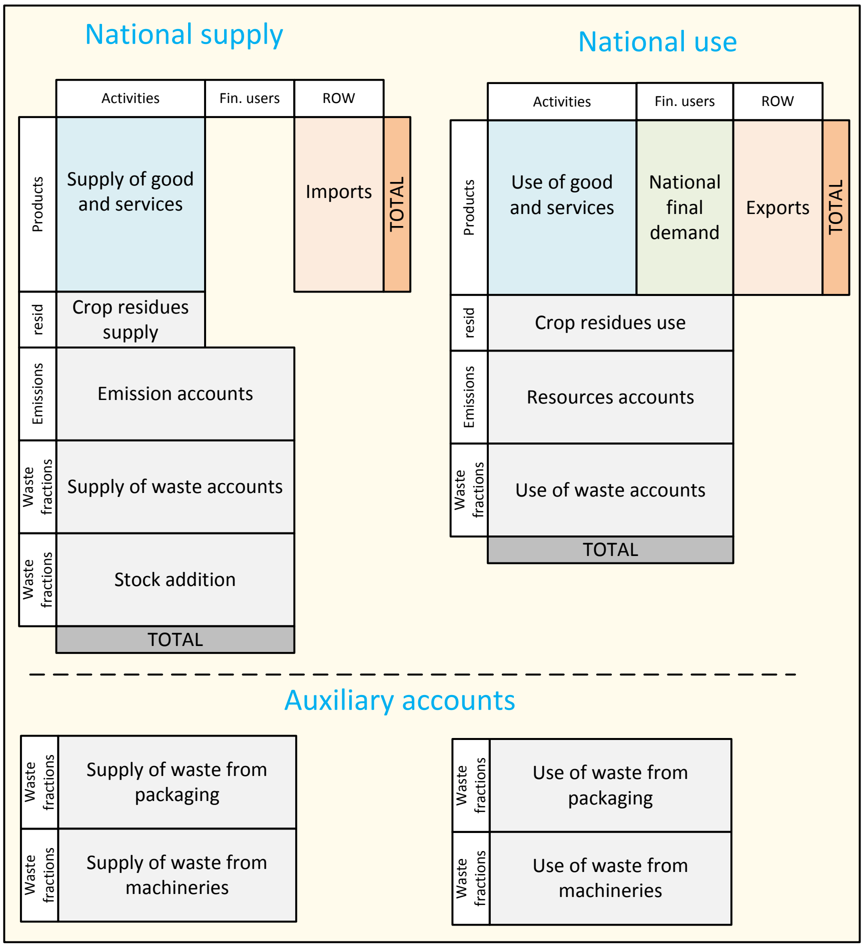

Figure 1 – Framework adopted for the construction of HSUTs. Notice that the waste treatment services are accounted in the transaction matrices (blue boxes). Waste accounts show the mass flows linked to waste treatment services.

2 Terminology

2.1 Variables

i=1 – 200 products (see 0)

a=1 – 164 (homogenous) activities (see 0)

w=1 – 18 waste fractions (see 0)

r=1 – 34 resources (see 0)

t=1 – undef *are the period of time/accounting periods*

2.2 Matrices, vectors and mathematical notation

Below it the presented a list of the major matrices and vector used in the reports.

Name	Short description	Dimension	Description
V'	Supply table	Products x activities	Subscripts Φ, T and E refer to the main units used in the hybrid framework, namely monetary (Φ), total physical dry matter mass (T) and energy units (E) respectively.
U	Use table		
FD	Matrix of domestic final demand	Products x domestic final demand categories	It shows the final demand of national consumers
M **m**	Matrix of imports Vector of imports (sum)	Products x country/region Products x 1	The matrices refer to a country, therefore sometimes it may be included in the text as M_C where C defines the country. All the matrix of imports (or exports) together give the trade cube.
E **e**	Matrix of exports Vector of exports (sum)	Products x country/region Products x 1	
q	Total supplied/used products	Products x 1	Sum of supplied products (domestic and exported) or used products (domestic and imported) for all human activities within a specified period and geographical area.
g	Total input/output of activities	1 x activities	Sum of the input or output of activities.
A	Coefficient transaction matrix	Products x activities	Subscripts: LCI: Input data with default coefficients T: Dry matter mass physical coefficient transaction matrix H: Hybrid coefficient transaction matrix
$\mathbf{D_o}$	Default product transfer coefficient matrix	Products x activities	The proportion of the input which is present in the products supplied by the activity. Allowed values ∊ [0,1].
$\mathbf{D_1}$	Feedstock specification with option for specifying specific proportion	Products x activities	Specifies which inputs to an activity become part of its supply. Zeroes indicate that the product is not a feedstock, ones indicate that the product is a feedstock but the proportion is unknown, and a value ∈]0,1[means that the product is a feedstock in the specified proportion.
D	Final Product transfer coefficient matrix	Products x activities	The proportion of the input which is present in the products supplied by the activity. Allowed values ∊ [0,1].
F	Final resource transfer coefficient matrix	Resources x activities	The proportion of the natural resources which is present in the products supplied by the activity.

			Allowed values $\in$ [0,1]. It is initialized by default values $\mathbf{F_0}$
T	Final waste transfer coefficient matrix	Waste fractions x activities	The proportion of the waste fractions which is present in the products supplied by the activity. Allowed values $\in$ [0,1]. It is initialized by default values $\mathbf{T_0}$
$\mathbf{f_{MMR}}$	Vector of material requirement	Products by 1	Indicates the minimum materials that must be available on the national market to allow given levels of production
N	Physical trade cube	Importer country x product x exporter country	Indicate the bilateral trade between all countries.
R	Matrix of resources	Resources x activities	Shows the resources extracted
B	Matrix of emissions	Emissions x activities	Shows the discharged emissions. The emissions can be due to: - Combustion of materials (B_{comb}) - Use of materials (B_{use}) - Supply of products (B_{supply})
CV	Matrix of calorific values	Product by activities	Shows the calorific values to convert energy flow accounted in TJ in mass flows, accounted in tonne
Q	Matrix of conversion input versus waste fractions	Waste fractions x inputs x activities	It shows how to convert an input (product, resource or waste fraction) in waste fractions
W	Waste accounts	Waste by activities	Subscripted *sup* indicates the supply side (i.e. W_{sup}), while subscripted *use* the use side (i.e. W_{use}). Instead, the subscripted *unreg* shows the supplied waste that is not processed by ordinary waste treatment services (i.e. W_{unreg}).
$\mathbf{\Delta S^{w}_{t+n}}$	Matrix of stock addition accounted in waste fractions	Waste fractions by activities	It shows the stock addition produced in the accounting period *t* and assumed to become waste in period *t+n*. The matrix can be also shown as follows $\mathbf{\Delta S^{w}_{m}(w,a)_{t-n}}$. It indicates the stock addition produced in the period *t-n* and become waste after *m* periods.
$\mathbf{\Delta S^{w}_{n}(w,a)_{t-n}}$	Matrix of stock addition accounted in waste fractions		
CW	Matrix of conversion of waste services into waste fractions	Products X activities	It shows the link between supply of waste services and use of waste fractions. It is built for waste treatment activities
dm	Vector of dry matter coefficients	Product X 1 (default)	Indicates the dry matter content of products. With a subscripted W and B indicates respectively the dry matter content of waste and resources,

Table 1 – List of main matrices and vectors used in the text

The methodology in this paper is focusing on physical mass supply and use tables. In order to avoid unnecessary use of the subscript referring to matrices (T), all matrices that can exist in different units (subscripts T, Φ, H), are in mass units (T) unless indicated with a subscript.

Table 2 shows the mathematical notation used in the report.

Notation	Short Description	Description
A	Matrix **A**	A matrix is indicated with capital and bold letters
a	Vector **a**	A matrix is indicated with small and bold letters
A(i,j)	Element of **A**	It is the element on the *i*-th row and on the *j*-th column of the matrix A
$\mathbf{A}_{ij}$	Element of **A**	Same of **A(i,j)**
A(i,:)	Row of **A**	*i*-th row of the matrix A
$\mathbf{A}_{i.}$	Row of **A**	Same of **A(i,:)**
A(:,j)	Column of **A**	*j*-th column of the matrix A
$\mathbf{A}_{.j}$	Column of **A**	Same of **A(:,j)**
a(i)	Element of **a**	*i*-th row of the matrix A
$\mathbf{a}_{i}$	Element of **a**	Same of **a(i)**
A·B	Matrix product	It is the common row by column matrix product.
A*B	Hadamard matrix product/element by element product	An *ij* element of A is multiplied by the *ij* element of B. A and B must have the same size. It is also used for the product of single elements.
diag(a)	Diagonalized matrix	It is the diagonal matrix where the elements of the vector a are down the main diagonal.
diag(A)	Diagonalized matrix	It is a diagonal matrix where only the elements of the main diagonal of A are included.
A(i,j)	Element of **A**	It is the element on the *i*-th row and on the *j*-th column of the matrix A
A(i,:)	Row of **A**	*i*-th row of the matrix A
A(i,:)	Column of **A**	*j*-th column of the matrix A
a(i)	Element of **a**	*i*-th row of the matrix A
$\breve{A}$	Estimate of A	The check accent is used to indicate initial estimates.
$\mathbf{a}_{ij}\cdot\mathbf{b}_{kl}$	Product of matrix elements	It is the product by *ij* element of matrix A and the *kl* element of matrix B

Table 2 – List of mathematical notation used in the text

3 Main input data

The main data sources used for the construction of MR-HSUTs are:

- Domestic production volumes in unit dry matter mass (see Table 11 in Appendix 2: Source data for physical flows).
- Multi regional monetary supply and use tables, i.e. MR-MSUTs (Stadler et al., 2015)
- LCI physical coefficients (main sources: Schmidt, 2010b; Merciai et al., 2013; www.ecoinvent.org)
- Energy supply and use table, i.e. EnSUTs (Stadler et al., 2015)
- Balanced trade in monetary units, i.e. monetary trade cube (Stadler et al., 2015)
- Material extensions (Stadler et al., 2015)

4 Methods and materials

The PSUT generation procedure starts from an uncomplete data collection and, by using all the available information, determines a full mass-balanced system. The algorithm can be divided in five blocks, where each of them describes the core data manipulation and elaborations applied to derive the desired outcome. The steps are summarized below in figure.

Step	Description
1. Revision, gap-filling and formatting of physical production data.	Data collection has two main limitations. From one side, it does not cover all the required flows; hence, some values need to be estimated. On the other side, collected data can be inexact and a revision is required. Finally data need to be rearranged to fit within a supply and use framework
2. Calculation of technical and distributive coefficients	Many productions convert raw materials into processed products and technical coefficients play a key role. Some technical coefficients are obtained from collected data, other from literature and, finally, from the monetary level of Exiobase 3.
3. Determination of national product minimum availability	Within each country, certain raw material product requirements are necessary to implement specific level of production/consumption. Otherwise, the risk is to determine a lack of raw materials/consumption goods that can imply an irrational distortion in the use/supply side, such as an enormous variation of change of inventories. This step relies on the calculation of technical coefficients.
4. Trade linking and inevitable revision of data	Once the first three steps are determined, it is necessary to specify the bilateral trade between different economies in order to assure that minimum required products are available in each market.
5. Mass balance within economies and extensions	The final step consists of an implementation of an algorithm in order to calculate the mass balance within activities and between supplies and uses. From these balanced tables extensions are determined.

The above steps are not always implemented simultaneously for all the products. For example, with regard to agricultural part, for practical issues in the writing of the algorithm code, step 1, 2 and part of 3 are performed before any other manipulation of the data. The logic behind this is to split the whole algorithm in *sectorial* modules and *general* modules. *A sectorial* module is a self-standing block that feeds its results to the general part but is independent. It is characterized by peculiar technological mechanism and is mostly fed by dedicated data source. For example, FAO provides most of the data on Agriculture. The advantage of this approach is dual. First, an update of a data source can be integrated without running all the other sectorial modules, saving computational time; second, it facilitates the contribution of experts. Indeed, a sectorial module includes specific relations and produces results that are isolated by the rest of system.

A *general* module has a double role. From one side runs generalized procedures for data not included in sectorial modules and, from the other side, implements operations where there is need of working with all the data simultaneously.

The following modules are included in the construction of the MR-HSUTs:

- Agri module (sectoral module)
- Energy module (sectoral module)
- Trade module (general module)
- Technical coefficients module (general module)
- Balancing module (general module)
- Final module (general module)

Figure 2 below shows the modules and the structure of the whole algorithm for the construction of MR-HSUTs. *Sectorial modules* are indicated in italic capital letters, while bold capital letter show *general modules*. In the current version, there are just two sectorial modules; agriculture and energy. This could be expanded in the future, e.g. with transport, waste treatment, and other sector specific modules.

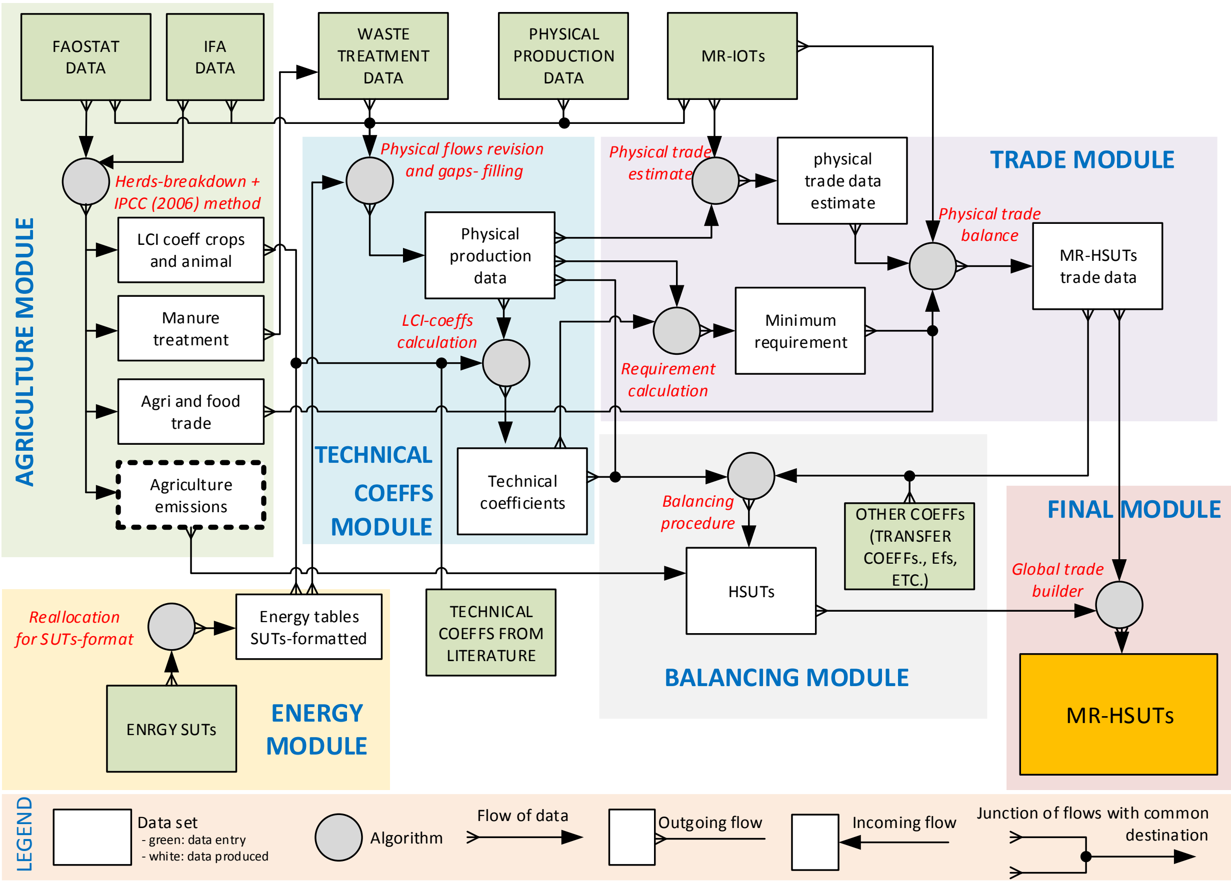

Figure 2 – MR-HSUTs algorithm. The green boxes show the data collected, while the white boxes the data calculated. The orange box shows the final delivered results.

In the rest of the report we describe each module of the algorithm, starting from the agriculture till the formation of multi-regional tables

4.1 Agri-module

In this module, data from FAOSTAT (FAO Statistic division, 2015) are manipulated in order to obtain technical coefficients, manure production, emissions and trade data in the mass units. FAOSTAT data undergo a gap filling procedure to assure that all the data of the time series are taken into account. For further information on the gap-filling procedure, see Section 4.3. Figure 3 shows a more detailed diagram of the module.

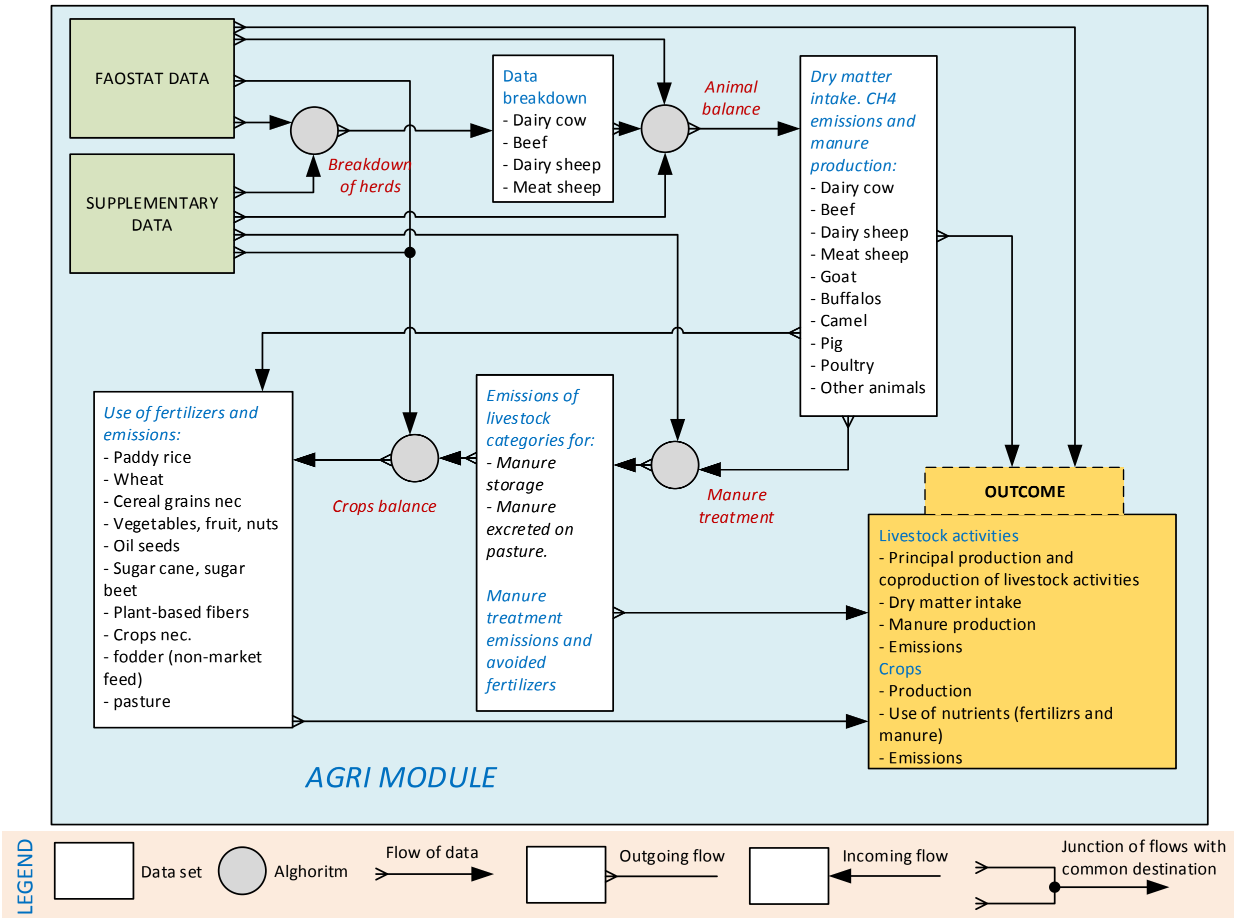

Figure 3 – Zoom in of the agricultural module. Green boxes show the data collected, while white boxes the data calculated. Yellow box shows the final delivered results.

The first procedure consists of splitting the cattle and sheep herds into dairy and meat activities, in order to meet the requirements of the adopted classification (see 'Appendix 3: Classifications'). FAOSTAT data do not make such a distinction, therefore an estimating procedure is applied. This procedure could be skipped if more detailed national data were available on the different livestock systems. When herds are split according to the classification, a mass balancing procedure is performed for livestock activities and, finally, for crop activities.

4.1.1 Breakdown of the cattle herd

Data available from FAOSTAT on the cattle herd, and used to split it between dairy and beef systems, are:

- Amount of dairy cows;
- Total stock of animals;
- Production of milk ;
- Yield of milk per cow;
- Meat supply.

These data are not exhaustive for our aims, hence supplementary data on cattle herd composition are taken from Dalgaard & Schmidt (2012), which refers to the Danish case. However, because of Denmark is a peculiar

self-sufficient and integrated system, the simple use of the Danish herd composition for all the countries would have generated many negatives values in the animal heads. Therefore, a generalized approach is implemented that links the herd composition to the peculiarities of each country.
The following formula shows the applied generalized procedure to get fractions of cows, heifers and bulls within the dairy herd. The sum of fractions gives 1.

$$\%CowD = \%CowD_{default} * \left(1 + \left(\frac{\#CowD}{\#CatHerd}\right)^2\right) * (1 + \%CatExp)$$
$$\%HeifD = (1 - \%CowD) * \%HeifD_{default} / (\%HeifD_{default} + \%BullD_{default})$$
$$\%BullD = (1 - \%CowD - \%HeifD)$$
$$where \quad \%CatExp = \begin{cases} 1 - \%IndCat_{slaughter} & if \quad \%IndCat_{slaughter} < 1 \\ 0 & if \quad \%IndCat_{slaughter} \geq 1 \end{cases}$$

Equation 1

Where
$\%CowD_{default}$, $\%HeifD_{default}$, $\%BullD_{default}$ are the default fractions within the dairy cattle herd of cows, heifers and bull, respectively (Dalgaard & Schmidt, 2012);
$\%CowD$, $\%HeifD$, $\%BullD$ are the calculated fraction within the dairy cattle herd of cows, heifers and bulls, respectively;
$\%CowD_{default}$ is the default fraction of dairy cows within the dairy cattle herd (Dalgaard & Schmidt, 2012);
$\#CowD$ is the amount of dairy cows in a country (FAOSTAT, 2015);
$\#CatHerd$ is total amount of herd in a country (FAOSTAT, 2015);
$\%CatExp$ is the estimate of the fraction of exported indigenous cattle animals;
$\%IndCat_{slaughter}$ is the fraction of slaughtered indigenous cattle animals. It is obtained dividing the number of slaughtered indigenous animals by the total number of slaughtered animals.

Danish diary and beef system are often integrated, therefore the default fractions are a consequence of this peculiarity. Because our objective is to separate these systems, the factor $\left(\frac{\#CowD}{\#CatHerd}\right)^2$ is introduced. Therefore, the dairy sector includes only animals that are functional to the reproduction or to the replacing of end-of-life animals. The rest is assumed to feed to the beef system or the meat industry. When the fraction of dairy cows is known, because the number of dairy cows heads is provided by FAOSTAT, all the remaining dairy animal heads can be directly calculated.

The residual cattle stock heads are obtained subtracting the dairy animals from the total cattle stock. The latter is then divided between types of animals as follows:

$$\%CowB = \%CowB_{default} * (1 + \%CatImp) * (1 + \%CatExp)$$
$$\%HeifB = (1 - \%CowB) * \%HeifB_{default} / (\%HeifB_{default} + \%BullB_{default})$$
$$\%BullB = (1 - \%CowB - \%HeifB)$$
$$where \quad \%CatImp = \begin{cases} \%IndCat_{slaughter} - 1 & if \quad \%IndCat_{slaughter} > 1 \\ 0 & if \quad \%IndCat_{slaughter} \leq 1 \end{cases}$$

Equation 2

$\%CowB_{default}$, $\%HeifB_{default}$, $\%BullB_{default}$ are the default shares within the beef cattle herd of cows, heifers and bull, respectively (Dalgaard & Schmidt, 2012);
$\%CowB$, $\%HeifB$, $\%BullB$ are the calculated share within the beef cattle herd of cows, heifers and bulls, respectively.

The relations showed in Equation 1 and Equation 2 have produced quite reasonable results for all the DESIRE regions. With reasonable results we indicate the respect of some specific targets.

One obvious desired outcome is always to have positive fractions. A second check is to get reasonable lifetime of animals. Lifetimes are initially default values, taken from Dalgaard and Schmidt (2012). Later, these values are endogenously modified by the algorithm. Figure 4 shows the results obtained for 2011. It can be seen that the share of dairy cows and the lifetime are strongly related. This is an obvious result because a long productive lifetime implies less replacing animals.

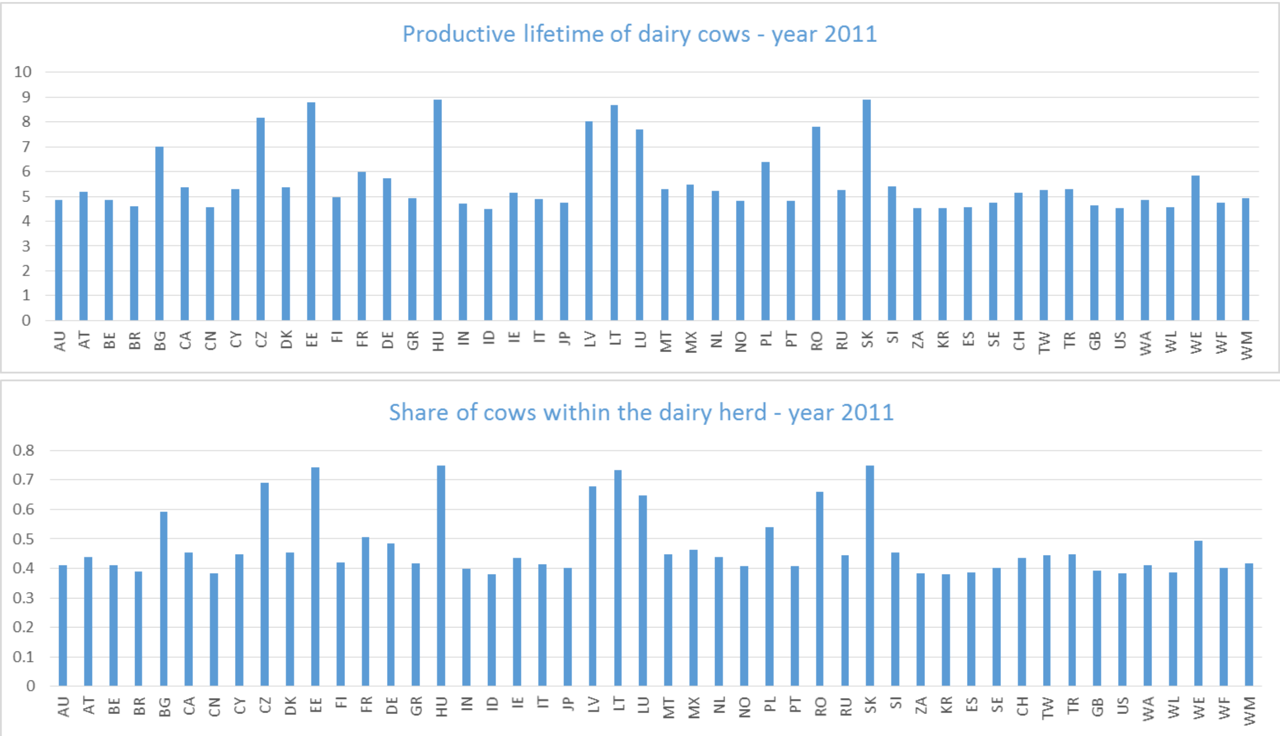

Figure 4 – Results of the cattle herd breakdown for the dairy system

A beef-system check consists of calculating the average weight of slaughtered animals and see whether it falls within a reasonable range. This is done in Figure 5. As it can be seen all the results can be considered acceptable.

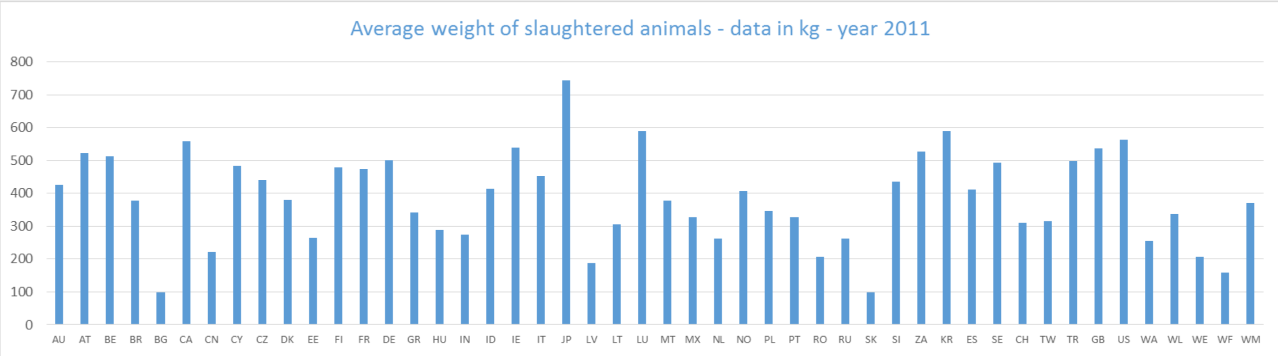

Figure 5 – Results of the breakdown of beef sector.

Final data obtained from this procedure and used in the rest of the algorithm are:
- Heads of cattle in diary and beef systems
- Weight of animals
- Weight and amount of live animals leaving the dairy system.

4.1.2 Breakdown of the sheep herd

The procedure to get the sheep herd composition is different from what is applied to the cattle because no default data were available on the herd composition. Input data from FAOSTAT are:
- Total sheep stock
- Ewes producing milk
- Total slaughtered animals
- Production of milk
- Production of meat
- Milk yield
- Production of wool

In addition to these data, some assumptions are adopted (Claeys & Rogers, 2003):
- 1 ram out of 35 ewes[1]
- Lifetime of a sheep is set to 7.5 years
- Birth rate is set to 1.15 (number of newborn lambs per pregnant ewe)
- Dressing percentage is 0.5

The sheep dairy and beef activities are more integrated than the cattle. We have assumed that the diary sectors are activated only if the annual milk yield per ewe is above 150 kg[2] and the revenues from milk are higher than meat for at least five years in the period from 1995 till 2011. If these conditions are met, then:
- the amount of diary ewes is equal to the animals producing milk directly from FAOSTAT;
- the number of rams is equal to the dairy ewes divided by 35;
- the number of lambs is then equal to the diary ewes times the birth rate.

[1] We refer to ram as the animals kept in the herd for reproductive purposes.
[2] Specialized dairy breeds produce from 180 to 490 kg of milk per lactation (http://www.sheep101.info/dairy.html). Assuming that some milk could be used for internal uses and that one lactation occurs per year, 150 kg/year as average yield seamed a reasonable threshold.

The sum of dairy animals is subtracted from the total sheep stock. If the outcome is positive, the meat system is also activated; otherwise only milk system is taken into account and the number of lambs is reduced to match the dairy stock with the total sheep stock. The procedure reduces the number of lambs until a certain low limit is reached that assure a certain amount of replacing animals. To respect this low limit, an iterative algorithm, from one side, reduces the number of rams and, from the other, reduces the birth rate.
For the meat system, we have that:

- The amount of ewes is obtained dividing the residual slaughtered animals by the birth rate. The residual slaughtered animals are equal to the total slaughtered animals less the slaughtered end-of-life dairy animals and less the lambs not used for replacing in the milk system. Of course, if the diary sector is not activated, all the subtracted values will be null. Only when the meat system is activated, the number of ewes cannot be lower than the value of ewes provided by FAOSTAT.
- The amount of rams is always equal to the number ewes divided by 35;
- The rest of animals of the total stock are then assumed to be lambs. The number of lambs cannot be lower a certain threshold. The same mechanism described above for the lambs in the dairy system is activated to assure a minimum of replacing animals.

A check of the procedure is performed to assure that reasonable results are obtained. Because of the many constraints from FAOSTAT data, it has been decided to take the weight of slaughtered lambs as sanity check. It is required that the weight should fall within a reasonable range. Here lambs is referred to any animal other than ewe or ram. Figure 6 shows the results. It can be seen that all the data fall in a reasonable range.

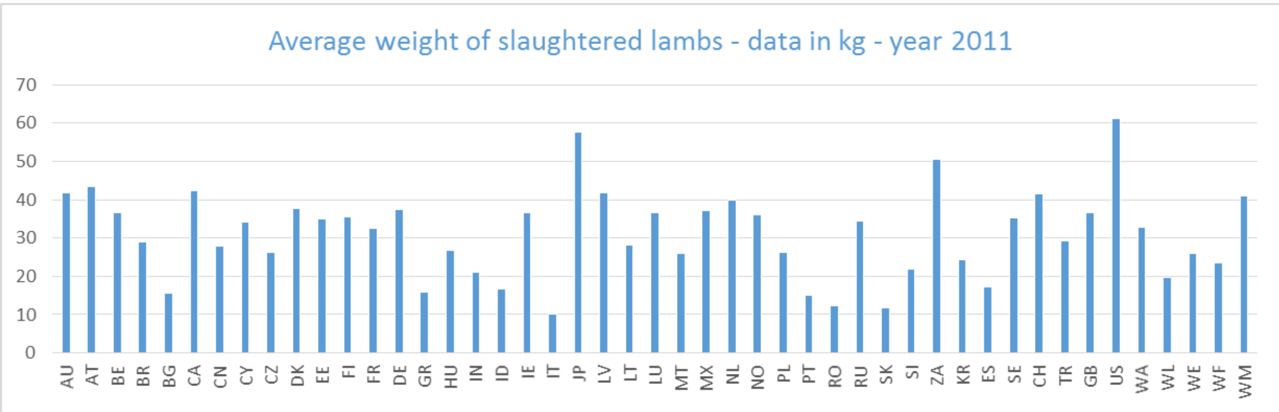

Figure 6 – Results of the breakdown of sheep herd.

The wool system is activated only for Australia, where the revenues from wool exceed that of meat and milk (FAO Statistic division, 2015). The meat system in Australia, calculated with the procedure above described, is then moved to the wool sector. For all the other countries, the production of wool is a coproduction of dairy and meat systems, and it is distributed using the animal heads as distribution factors.

Final data obtained from this procedure and used in the rest of the algorithm are:

- Heads of the diary, meat and wool systems;
- Weight of animals;
- Weight and amount of live animals leaving the milk system.

4.1.3 Animal balancing procedure

Data coming from the breakdown of cattle and sheep herds enter into animal balancing procedure. In addition to that, all the FAOSTAT data related to livestock are used in the algorithm. The IPCC guidelines (Intergovernmental Panel on Climate Change, 2006a) are chosen for the calculation of the feed intake, emissions and manure production. This procedure is applied for:

- Dairy cow system
- Beef system
- Dairy sheep system
- Sheep meat system
- Wool system

All the parameters and coefficients necessary for implementing the IPCC guidelines (Intergovernmental Panel on Climate Change, 2006a) are taken from the same report. The results obtained by cattle and sheep balances are then extended to:

- Goats (assumed as sheep)
- Buffalos (assumed as cattle)
- Camels (assumed as cattle)

For goats, buffalos and camels, it is assumed that there is either a milk or a meat system. An analysis of the supplied quantities is performed to determine the principal production. When a clear decision cannot be taken, FAOSTAT data on monetary productions are used for determining which production generates more revenues; the most profitable revenue is assumed as principal.

For all the remaining animal farming activities, i.e. pigs, poultry meat and eggs and other animals (horses, mules, asses, rabbits and hares), feed intake data from Krausmann et al. (2008) are used. Then, the IPCC procedure (Intergovernmental Panel on Climate Change, 2006a) is used for the calculation of methane emission, and parameters calculated in the FORWAST project (Schmidt, 2010a, 2010b; Schmidt, Weidema, & Suh, 2010) for the manure production. The final results obtained from the animal balancing procedure are:

- Dry matter intake;
- Emissions of methane for different animal herds;
- Production of manure.

4.1.4 Manure treatment procedure

The objective of this procedure is to estimate the total emissions emitted as consequence of the manure production and treatment. Further, the amount of nutrients added to the soil, which replace the use of fertilizers, is also calculated. The main ideas underlying this procedure are:

a. Emissions due to storage of manure are allocated to livestock activities;
b. Emissions generated from manure excreted outdoor are also allocated to livestock activities;
c. Emissions due to the spread and any other treatment of manure are allocated to manure treatment activities;
d. Manure treatments activities have a coproduction of fertilizers;
e. Livestock have coproduction of fertilizers if the manure is excreted on areas where fertilizers are applied to. However, this coproduction is implicitly taken into account.

For the calculation of emissions, the IPCC (2006) procedure is applied, using mostly default parameters and coefficients there included. See Dalgaard and Schmidt (2012) for a better explanation of the adopted procedure.

4.1.5 Crop balance procedure

The balance of nitrogen and phosphorus for crop activities is explained in this this section. The data inputs to the procedure are:

- Fertilizers, which can be from mineral sources or from manure treatment,
- Annual crop yields,
- Crop specific parameters concerning N content of crop and residues as well as crop-to-residue ratios,
- Use of land.

Emissions are the outcomes of the procedure.

Production of crops and land use data are taken from FAOSTAT (FAO Statistic division, 2015). Data on the fertilizers use are taken from IFA (2015) and from the manure treatment procedure (see 4.1.4). The total nitrogen input is distributed on crops according to their individual nutrients needs and several harvests per year are adjusted to ensure that the harvested area per crop from FAOSTAT (incl. several harvests per year) matches the total 'arable land' and 'permanent meadows and grassland' areas in FAOSTAT.

The balance is implemented for the eight crop activities included in DESIRE:

- Paddy rice
- Wheat
- Cereal grains nec
- Vegetables, fruit, nuts
- Oil seeds
- Sugar cane, sugar beet
- Plant-based fibers
- Crops nec.

Other two non-market activities are taken into account, which will be later integrated in the livestock activities:

- Non-market feed – fodder crops (excl. grazing grass)
- Pasture.

The first step consists of aggregating the FAOSTAT data according to the above listed crops activities. For each DESIRE crop category, production and land use are known. The yields of crops are simply derived from these data. Differently, values for pasture and non-market feed are endogenously calculated by the algorithm.

For non-market activities, the land use has to be calculated. In addition, the 'harvested' production of grass, which consists of the total grass eaten by animals on pasture, has to be determined. The land for non-market crops is obtained in two different ways:

a. If the residual land, which is the total arable land less that used by crops, is positive then it is allocated to non-market activities;

b. If the residual land is negative, it is assumed that several crop rotations take place per year.

The yield of non-market crops is then the total fodder production divided by this residual land. The production of pasture is assumed to be equal to the total dry-matter intake of animals (see 4.3.1.1) less the total known animal feed, which the sum of fodder, crop residues and market feed. The yield of pasture is then calculated. Checks are performed to allow reasonable values of yields.

The next step consists of distributing available nutrients to crops. Available nutrients consist of chemical fertilizers plus manure. Manure content of nutrients is determined using data from Penn State (2016). Efficiency of the manure absorption by plants is taken from MFVM (2001)

The procedure for nitrogen is performed using distribution factors (FAO, 2006), which give rough estimates of the use of N-fertilizers by crops for each country. Instead, the other-nutrients distribution factors are obtained multiplying the nitrogen factors for coefficients obtained in Heffer (2009; 2013). The algorithm reprocesses these distribution factors, making use of properties mentioned above (yield, land use, etc.), until all the nutrients are distributed to crops.

The manure excreted on pasture is here a constraint. The algorithm, based on the initial nutrients distribution factors, determines the quantity of nutrients needed on pasture land. If that amount is lower than the total nutrient-equivalent released by the excreted manure on land, it is assumed that no extra-fertilizer is applied to pasture land. Otherwise, chemical fertilizers are spread on the pasture land, of course for those countries where this option is assumed (see Table 3).

Countries: 32 of 42 countries			
Austria	Finland	Lithuania	Russian Federation
Belgium	France	Luxembourg	Slovakia
Bulgaria	Germany	Malta	Slovenia
China	Greece	Netherlands	South Africa
Cyprus	Hungary	Norway	Spain
Czech Republic	Ireland	Poland	Sweden
Denmark	Italy	Portugal	Switzerland
Estonia	Latvia	Romania	United Kingdom

Table 3 – Countries where it is assumed that fertilizers may be applied to the pasture land.

Once this step is finalized, the input of nutrients is determined and a mass balance is implanted. The nitrogen absorbed by plant is obtained based on protein content of the crops that is estimated from Moeller et al. (2005). The protein is converted to nitrogen using a protein to nitrogen ratio at 6.25 kg protein/kg N (European Commission, 2006). Then, the IPCC (Intergovernmental Panel on Climate Change, 2006b; Sass, 2003) procedure is implemented to calculate N-related emissions, which are N2O (direct), NOx, NH3, NO3 for the eight DESIRE crop categories. Finally, N2 is obtained as residual value. When the calculated N2 turned out to be negative, the protein content of the crop has been adjusted to ensure a consistent N-balance.

With regard to phosphorus, given the quantity spread on land, it is assumed that all the phosphorus not absorbed by crops is emitted. Crops-specific phosphorus contents have been collected from DTU (2009) and Cornell University (2007). The residual emitted quantity of phosphorous is then split into two categories according to a general procedure. It is assumed that 2.9% leaches into water whilst the rest is emitted to soil (Dalgaard et al., 2006), which, in reality, should be meant as the quantity accumulated in the soil.

Emissions produced by fodder cultivation and pasture are allocated to livestock activities later in the algorithm, when the grazing gap is split by animal categories and fodder crops are allocated (see 4.3.1.1).

The modelling of emissions from nutrients needs some more words because special assumptions are adopted. The objective is to assure homogeneity of products in the rows of the supply and use table and, at the same time, to maintain the mass balance of activities when analyses are implemented.

Firstly, it is important to have in mind that the emissions generated from the application of one unit of nitrogen from chemical fertilizers are not the same if an equal amount of nutrient from manure is spread. Usually manure produces more emissions due to different absorption efficiencies. At the same time, the nutrient content of a dry-matter unit of manure and fertilizer differs.

In order to maintain the homogeneity of products, the manure applied to land, which in reality substitutes chemical fertilizers, is converted into fertilizers according to the nutrient content (Penn State, 2016) and efficiency factors (MFVM, 2001). This is what will be included in the supply table as an off-diagonal production, i.e. a by-product. Thus, it is assumed that chemical fertilizers are the only source of nutrients to crops. In other words, the input of nutrients that should be from manure is assumed to come also from chemical fertilizers. It follows that the emissions in the agricultural activities are modified assuming that all the nutrients are from chemical fertilizers.

At the same time, the emissions from manure application to crops are all accounted in the manure treatment activity. This way of proceeding implies a double counting because the emissions from manure application are included in the agricultural activities, in the form of chemical fertilizers, but also in the manure treatment activity. Therefore, to avoid the double counting, the emissions determined by the application of chemical fertilizers replaced by the use of manure are subtracted in the manure activities. These subtracted emissions are defined as "avoided emissions" (see Figure 7)[3].

The adopted approach assures the mass balance of all the activities[4] and, at the same time facilitates the implementation of scenarios analyses in the agricultural activities.

If we had decided to calculate the emissions of crops based on a given mix of chemical/organic nutrients occurring in a given year, the consequence would be that we will always have a fixed mix of chemical/organic nutrients. Therefore, no matter which scenarios are implemented, or said differently how much manure will be produced, the manure utilization in crops would have been always the same.

[3] In the published extensions, there is a special section that includes the "avoided emissions".

[4] As said, the by-product of manure treatment is accounted in fertilizers according to nutrients content. Therefore, the mass is not the same of the manure produced. The inclusion of avoided emissions counterbalance this difference, assuring the mass balance.

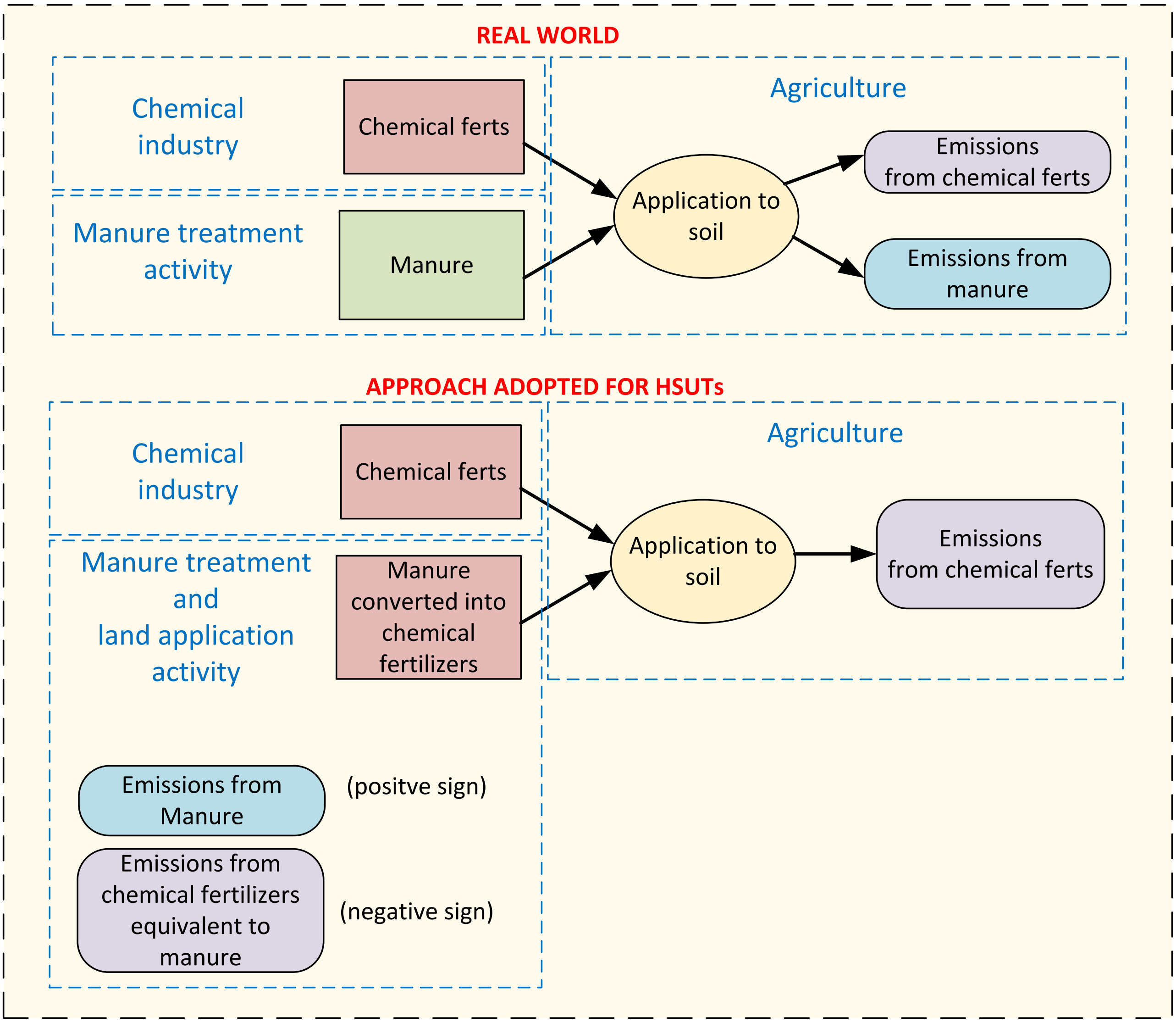

Figure 7 – Approach used for calculation of emissions of crops from input of fertilizers. In the real world (upper part) manure is applied on land together with chemical fertilizers. From these two inputs, emissions are produced. In the HSUTs (lower part) the 'manure treatment and its land application' is a separated activity from crops, therefore a different approach is implemented. Manure is treated as an organic fertilizer that substitutes chemical fertilizers. This means that the manure activity produces fertilizers and this coproduction is determined converting organic fertilizers into chemical fertilizers (lower box on the left). Homogeneity of products along the supply rows is so respected. On the use side (agriculture box), this manipulation implies that crop activities use the same quantity of nutrients but all comes from chemical fertilizers. The emissions in the crop activities are then modified following this assumption. At the same time, in the manure activity (lower box on the left), the conversion from organic to chemical fertilizers determines a violation of the mass balance. Therefore, in order to respect the mass balance, some emissions must be inserted in the manure activity. These emissions are equal to the sum of all the emissions from the application of manure to crops less the emissions that would occur if the quantity of chemical fertilizers substituted by organic fertilizers were applied to crops. The latter emissions, which are subtracted, are defined as "avoided emissions".

4.2 Energy module

The aim of the energy module is to convert data obtained by the En-SUTs (Stadler et al., 2015) in a format that is more suitable for the needs of HSUTs. Indeed, the approach followed by En-SUTs is different from that here applied. Roughly speaking, En-SUTs are strongly bound to the classification of energy sectors (OECD/IEA, 2004), which could be hastily defined as *descriptive.* Instead, the HSUTs here aims to trace the cause-effect mechanism, hence the approach could be meant as *analytical*, more suitable for analyses, exploiting the potentialities of the input-output tables, e.g. decomposition, scenarios analyses, etc. The differences fall into the following cases:

- Allocation of energy products from waste combustion (and combustion of other materials for treatment);
- Treatment of biogas from waste bio-gasification;
- Treatment of combined heat and power production;

Specific procedures have been written to address the above bullets. These procedures can be meant as practical ways of a more generalized approach to move from a descriptive to an analytical approach, given the constraint implied by pre-determined level of aggregation (system of classification).

Allocation of energy products from waste combustion: In the HSUTs, the supply of energy from waste incineration is allocated directly to the waste activities, no matter if the energy is a principal or a secondary production in economic terms; contrarily, in the En-SUTs it is either a production of the electricity sector, i.e. ‘electricity from biomass and waste’, or it may be a secondary production of any sector that burns waste. In the latter case, the produced energy is entirely consumed by the sector. An example can be the heat produced by wood waste in industries producing furniture. Figure 8 shows the different approach applied in the two procedures.

In practical terms, in this module, addressing the first bullet means that the total production of electricity and heat from combustion of waste is calculated and removed from non-waste activities. Below in the algorithm, this production will then be distributed to the different incineration activities, as described in section 4.3.2. This because the waste treatment services have to undergo a revision procedure (see 4.3.1) and only then will be ready for the by-product modelling.

Moving to the use side, within this module the demand by activities of heat produced from waste incineration is calculated. This demand will be directly used to build use coefficients (see 4.3.2).

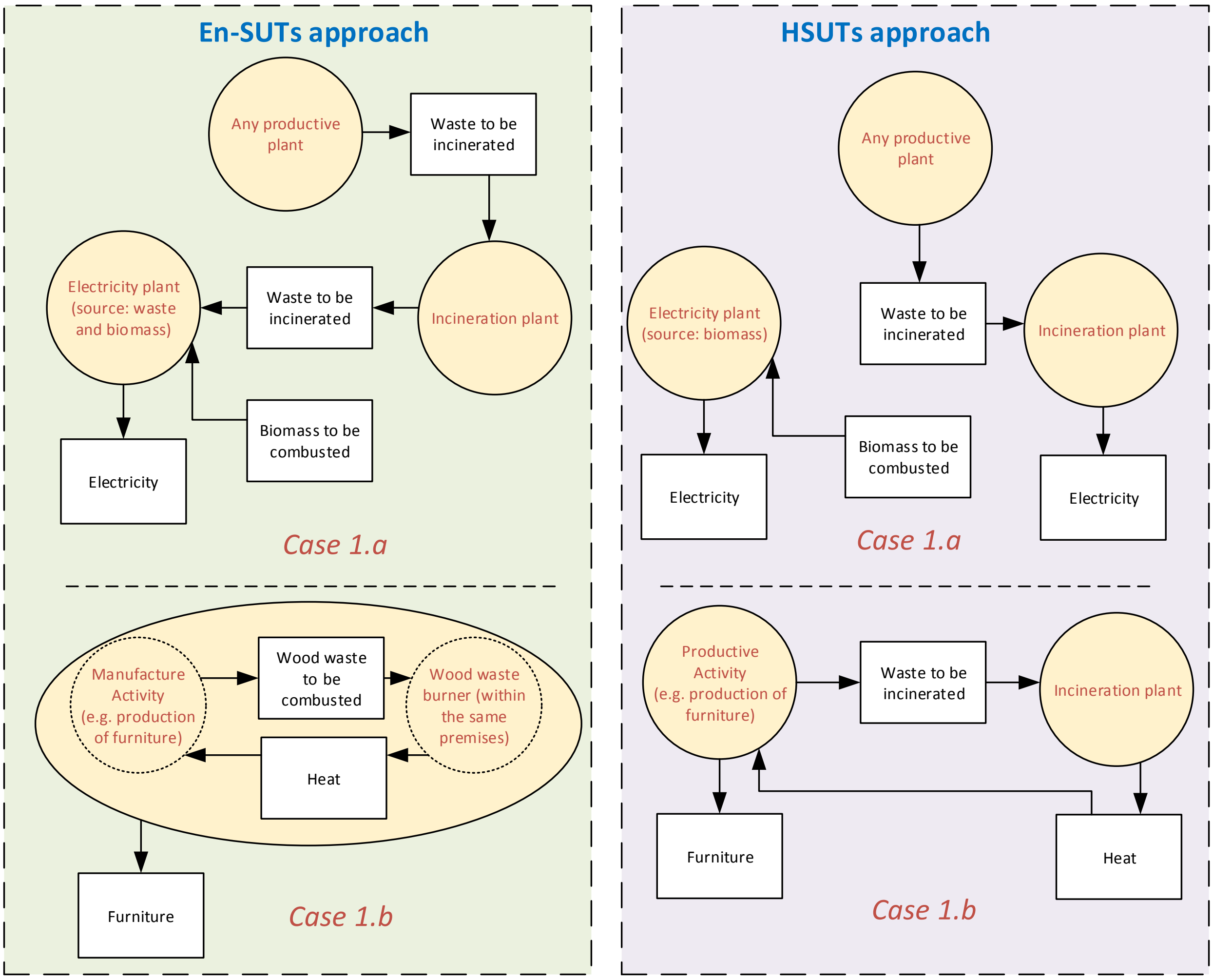

Figure 8 – Different approaches for the allocation of energy from waste adopted in the En-SUTs and in the HSUTs, respectively. Case 1.a refers to the different classification given to the producers of energy from combusted waste. In the En-SUTs incineration plants are just intermediators between producers of waste and electricity activities. The combustion occurs in the electricity activities. In the HSUTs, incineration plants burn waste and produce electricity as by-product. Case 1.b refers to the waste burned within the premises of productive plants, not classified as waste treatment activities. In the En-SUTs the production of heat from waste combustion and used for own uses may be a process embodied in any productive activity (for example in the furniture production). In the HSUTs, the process of waste combustion is always disaggregated and moved to waste combustion activities.

Treatment of biogas from waste bio-gasification: In the En-SUTs, all the production of biogas is accounted in the gas manufacture, no matter what raw material is used for. In addition to that, in some cases it is not clear which raw material is used for the production of biogas. Here again, because in the HSUTs what is produced in a plant that treats waste is always allocated to waste treatment activities, we have introduced some changes to data provided by our partners. We have identified two related instances in the En-SUTs to be addressed before entering the HSUTs.

The first is when the source of biogasification is a crop, but it is not sufficient for the total production of biogas. This is the case when a (raw material) crop multiplied with a biogas-transformation factor (AEBIOM,

2009) results to be considerably lower than the produced biogas[5]. Then, in order to respect conservation laws, an unspecified source must be added, which we thought to be waste (Case 2.a in Figure 9). The second case refers to situation where no crop feeds to the biogasification process at all. Iin this case we assume again that waste is the raw material entering the biogasification process (Case 2.b in Figure 9). Figure 9 illustrates the followed approach.

Like the first bullet, only the total production of biogas from waste biogasification is calculated and removed from the non-waste activities. Later this production will be distributed to waste treatment activities (see 4.3.2).

[5] The default biogas-transformation factors are taken from AEBIOM (2009).

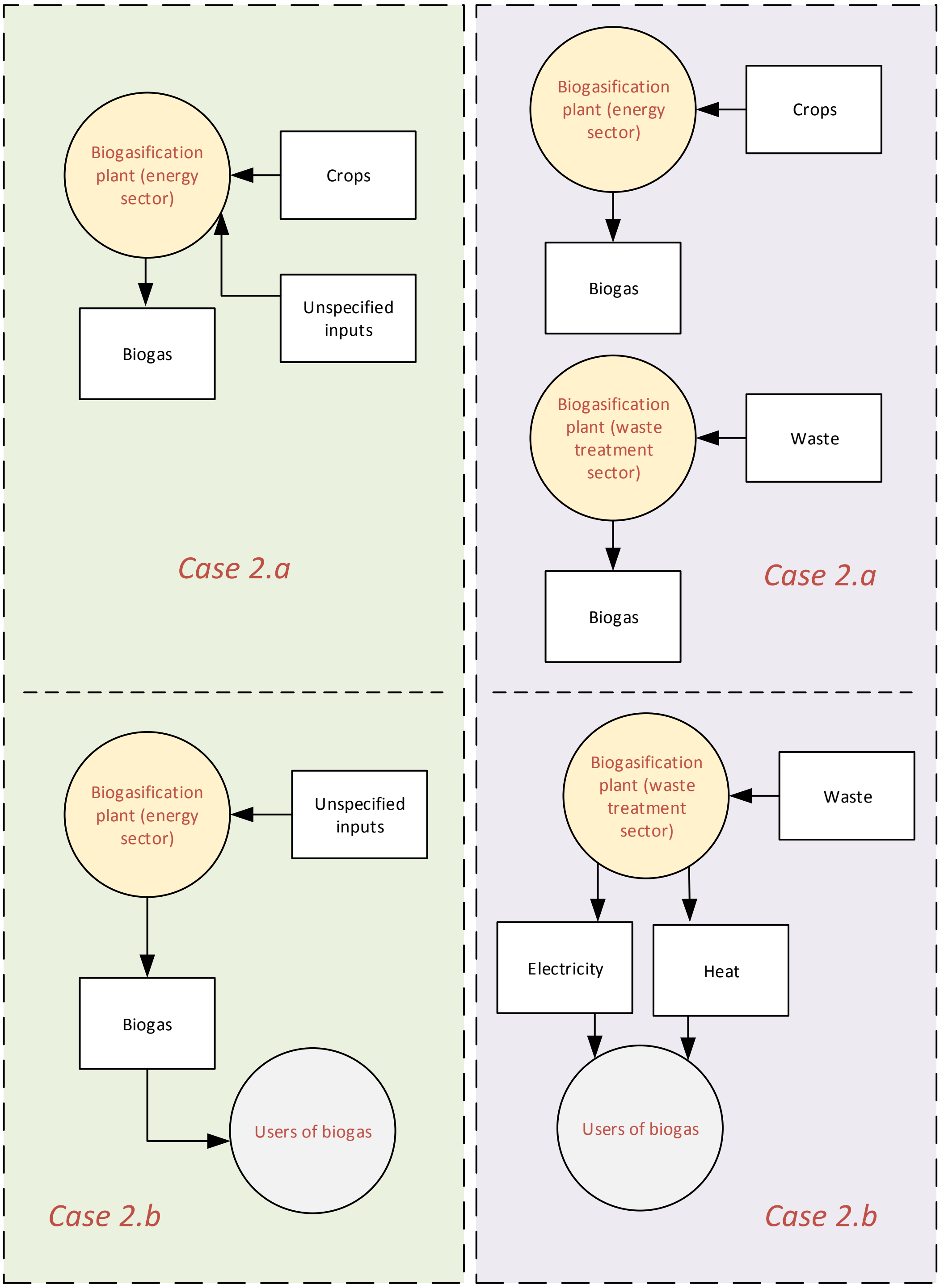

Figure 9 – Different approaches for the allocation of biogas. The En-SUTs assume that all the biogas is produced in the gas manufacture, which is part of energy sectors. The raw material for the production of biogas are in some cases crops. In some other cases, it is not clear which raw material is used. In the HSUTs, it is assumed that this unspecified source is waste, therefore the produced biogas is treated as an output of waste activities (case 2.a). When there is no input of raw materials at all, only waste activities produce biogas. Then, it is also assumed that thes waste activities transform biogas into electricity and heat before selling it (Case 2.b). Likewise, the input of biogas to activities is converted into electricity and heat.

Treatment of combined heat and power production: In the En-SUTs a plant that produces both heat and electricity (combined heat and power plant, CHP plant) is split into two different activities with two productive recipes, one producing heat and one electricity (OECD/IEA, 2004). In the HSUTs procedure, a CHP is usually considered as one activity with two outputs[6]. Hence, in the energy module, CHP plants are generally regrouped together using additional IEA data (International Energy Association, 2015). Figure 10 shows the general approach followed in the HSUTs. This approach allows us to better implement the energy balance of the CHP process.

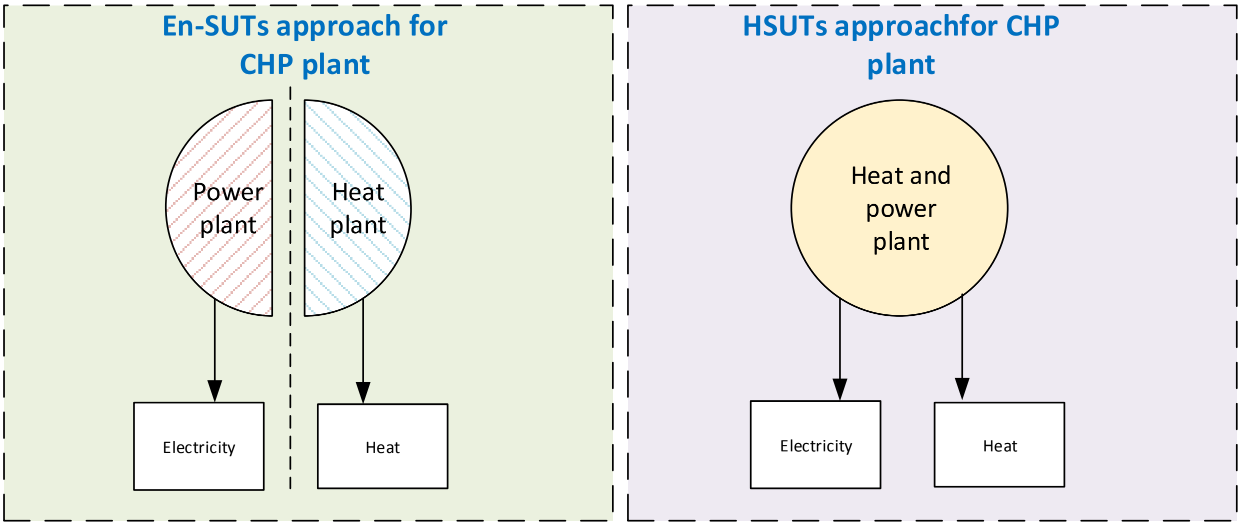

Figure 10 – Treatment of combined heat and power plant in the En-SUTs and HSUTs. Heat is assumed as princiapl production.

The default assumption for the rearrangement of CHP processes is that steam and heat are the principal production and electricity is a by-product. However, this assumption can be violated in some cases when the production of heat is low. Indeed, in some plants, or in some periods of the year, the request of heat may be low, then a CHP plant can be considered as a real electricity plant with a low production of heat. To take into account this case, we have decided to split the CHP in two activities that mimic the two extreme cases of a CHP plant management (see Figure 11), i.e. subdividing extraction plants into back-pressure mode CHPs and condensation mode power generation.

On the left side of the Figure 11 there is the case where the heat supply is very high so to be considered as main production, therefore a CHP plant is allocated to the 'heat and steam production' sector, with electricity treated as a coproduction (Case A). The ratio between production of heat and electricity is by default set to 2. This means that, in energy units, the supply of heat is at least the double of that of electricity. Then, if there is a residual part of electricity produced by CHP plants and not modelled as coproduction of the 'heat and stem process', it is assumed to belong to the electricity sector. This is represented by situation on the right side of Figure 11 (Case B).

[6] This is the classical example that in the industrial ecology community divides two schools of thought, i.e. the *attributional* and the *consequential* approaches (Weidema et al. 2013). The En-SUTs follows the former, while the HSUTs the latter.

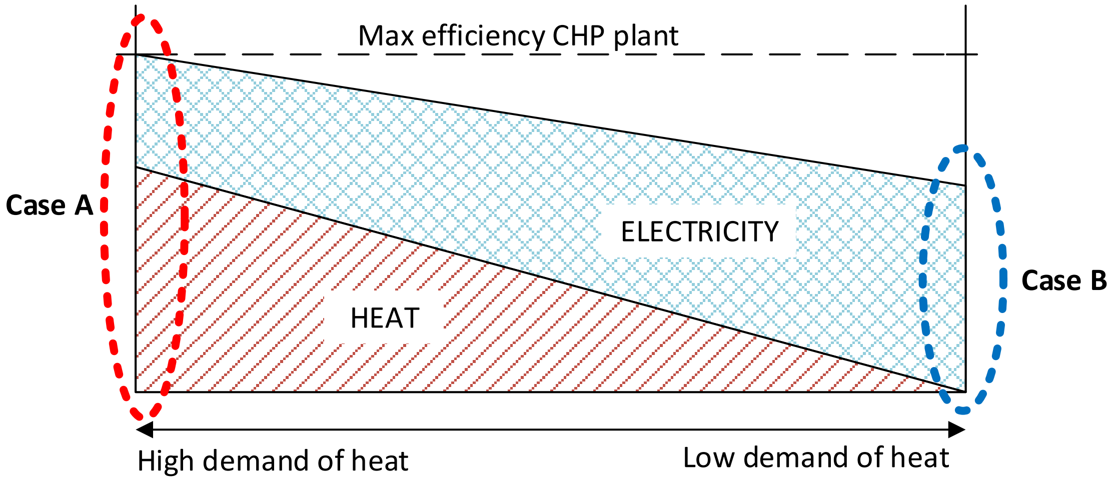

Figure 11 – Management of a CHP plant. When the heat demand is high, it is assumed that a CHP plant produces as much as possible heat and then electricity. Therefore, it is assumed that heat is the principal production (Case A). In this case, we have assumed that the ratio electricity-heat is 0.5. Instead, when the demand of heat is low or null, it is assumed that electricity is the principal production. Further, we have assumed that electricity has not coproduction of heat (Case B). Case A and Case B are treated as two different activities.

4.3 Technical coefficients module

The technical coefficient module is the first general module of the HSUTs procedure. The role of this module is double. Firstly, it performs a general revision of collected data, which also implies the calculation of missing values in the time series. The revision is applied to the total production and to trade flows. Secondly, it estimates technical coefficients, which are very important for the following modules. We can now look more in depth at each of these two tasks.

4.3.1 Revision of data

Collecting physical data on domestic productions and trade is a very difficult task for many economies of the world. Even when these data are available in statistical databases, a consistency check is necessary because they can be easily out of a reasonable range. In addition, there are missing data where specific procedures are developed. In this section we present the techniques aimed to revise the input data. Notice that the procedure applied in this part of the module does not occur for data coming from sectorial modules described above, but for all the remaining flow[7].

Initially, collected data are marked with high or low score depending on the reliability of the data source. Higher the score, higher the reliability. Mining ore data, for example, provided by partners from Wien University (WU MFA database version 2014), are considered very reliable, so as some food data from FAOSTAT. Only a gap-filling procedure is required for these data to complete the time series. For the low-scored products – manufactured products mainly – revision and estimation procedures are fulfilled, in addition to the gap-filling[8]. Table 4 shows what operations are applied to the different type of data.

[7] Data gap filling procedure, which is explained in this chapter, is fulfilled directly into the sectorial modules when needed (see 4.1). Therefore, all the data coming from sectorial modules do not need furter revisions.

[8] There are many data falling in this group. For example, the The United Nations Industrial Commodity Statistics Database (http://unstats.un.org/unsd/industry) provides data on glass production in many units of measurements, e.g. square meter. Therefore it is hard to convert the production in mass.

Type of data	Operations performed
Data with high score (e.g. mining products, agricultural products, etc.)	- Gaps-filling procedure
Data with low score not bound to local raw materials availability (e.g. plastic products, metal products)	- Reasonability check - Gaps-filling - Generalized data generation procedure
Data with low score strictly bound to local raw materials availability (e.g. cement)	- Linkage to specific raw material
Data missing from data collection (valid for manufactured products)	- Generalized data generation procedure (or price-based data generation)

Table 4 – type of data and performed operation

We try to better define each of the performed operations in the following. The order is the same of that implemented in the algorithm.

The *reasonability check* aims to spot collected data that are considerably distant from other observations of the time series or from other cross-checked sources[9]. These values are considered as outliers, hence they are deleted. There are two different approaches used. One for values at the end of the time series, which could have been defined as 'not definitive' in the data source (Equation 3), and one for other values.

In the first case, whenever the leap in last year was too big, that value was deleted. In Equation 3, x_{t+1} indicates the variable in the last year of the time series.

Equation 3
$$x_{t+1} = \begin{cases} 0 & if\ \Delta(t+1;t) > 0.9 \\ 0 & if\ \Delta(t+1;t) < 0.9 \end{cases} \quad where\ \Delta(t+1;t) = \frac{x_{t+1}}{x_t} - 1;$$

In the second case, whenever a value (x_t) diverges considerably from the average values (μ), it is deleted. 5% is the threshold value.

Equation 4
$$x_t = \begin{cases} 0 & if\ \Delta(t;\mu) > 20 \\ 0 & if\ \Delta(t;\mu) < 0.05 \end{cases} \quad where\ \Delta(t;\mu) = \frac{x_t}{\mu};\ \forall t \neq last\ period$$

The *gap-filling procedure* consists of tracing a line between two existing values to estimate the missing value lying in the middle. However, it can be also used to estimate values at the beginning or at the end of time series. The procedure assumes that there is a linear trend throughout the years. This approach can be quite robust when few values are missing from a time series, while it may be simplistic in other cases. However, we leave to the future the possibility of developing a more accurate procedure.

[9] For instance, a country could have a production that is higher than the world production estimate taken form other sources.

The *linkage to specific raw material* regards low scored or missing products where it is assumed a one to one link between raw material availability and processed goods. Further, it is important that the production of processed goods, for technical and economic reasons, occurs within a short distance from the raw material plant. To give an example, the procedure is used for determining the production of cement, which meets the above mentioned requirements. Whenever the cement production does not match with the local availability of sand, limestone, clay, etc., the value is reduced so that it is reasonable according to the availability of raw materials. Of course, this procedure is applied only if the utilized raw material has a high score.

The *price-based data generation* derives the missing physical flow using the monetary productions and average prices. Initially it is calculated an average price dividing a proxy of the world total monetary production by a proxy of the world total physical production. Only those countries that have both monetary and physical values contribute to the world production. The resulting prices are then used for obtaining the physical flows for countries where only the monetary value is known. However, the use of this procedure is very limited. It was just used for few mine products that are extracted locally and that do not make use of raw materials, such as 'Sand and clay' and 'Stone'. When extended to more products, this procedure gave unrealistic estimates for many economies of the world[10]. Therefore, it was avoided.

A *generalized data generation procedure* estimates physical production flows relying on the availability of raw materials. It is applied both for missing data and for data that are not trustworthy so to be completely neglected. Furthermore, initial estimates of missing trade data are performed because they are functional to the determination of raw material availability.
The underlying idea is that raw materials are distributed to activities following the allocation shown in the monetary tables. This procedure can be considered as a generalization of the *linkage to specific raw material procedure.* Indeed, here the link to raw materials is not limited to one to one (one raw material and one processed good) and raw materials can be also imported; furthermore, the amount of available raw materials may have a low score, so to be endogenously calculated.

The first step of the *general data generation procedure* consists of estimating the missing imports in physical units.
Initially, missing imports are calculated as fractions of the global trade. Therefore, at this stage, because is necessary to calculate the world production, only imports of flows whose total domestic production is known for all the regions are calculated (see Equation 7). For the remaining missing import flows, another procedure is applied and will be explained at the end of the section.
Be k a generic product. $\breve{\mathbf{m}}_{\mathbf{T}}(\mathbf{k})_{\mathbf{C}}$ indicates the estimated import of the k-th good by the country C, while $\mathbf{V}_{\mathbf{T}}'(\mathbf{k},:)$ is the physical domestic supply. $\mathbf{h}(\mathbf{k})$ is a factor that, multiplied by the total domestic production, i.e. $\mathbf{V}_{\mathbf{T}}'(\mathbf{k},:)$**,** gives the total product availability within the national border, including the exports[11]. Equation 5 shows how it is calculated**.** The vector of factors $\mathbf{h}$ is determined by monetary values, hence fixed prices are assumed.

Equation 5 $$\boldsymbol{h} = \, diag(\boldsymbol{V}_{\boldsymbol{\Phi}}' \cdot \boldsymbol{i})^{-1} \cdot [(\boldsymbol{V}_{\boldsymbol{\Phi}}' \cdot \boldsymbol{i}) + \boldsymbol{m}_{\boldsymbol{\Phi}}]$$

[10] In the CREEA project, we experienced this problem.
[11] Re-export is not considered.

Where $\mathbf{V}'_{\Phi}$ and $\mathbf{m}_{\Phi}$ are the supply table and vector of imports, both in monetary units. Notice that $(\boldsymbol{h}(\boldsymbol{k})-\mathbf{1})$ multiplied by the domestic production gives the imports.
Now, be $\mathbf{w}(\mathbf{k})_{\mathbf{C}}$ a fraction of the k-th flow imported by the country C respect to the total world imports (or world total trade) of the same flow. Monetary tables are used to calculate $\mathbf{w}(\mathbf{k})_{\mathbf{C}}$ .Equation 6 shows how the fraction is calculated. The suffix *cnt* is another way to indicate a world region and it is introduced to avoid confusion with *C.*

Equation 6 $$\boldsymbol{w}(\boldsymbol{k})_C = \boldsymbol{m}_{\boldsymbol{\Phi}}(\boldsymbol{k})_C / \sum_{cnt} \boldsymbol{m}_{\boldsymbol{\Phi}}(\boldsymbol{k})_{cnt}$$

Given these two factors, the imports can be estimated as fractions of the total trade accounted in physical units.

Equation 7 $$\widetilde{\boldsymbol{m}}_T(\boldsymbol{k})_C = \begin{cases} \boldsymbol{m}_T(\boldsymbol{k}) & \textit{if it has been already collected} \\ \sum_{cnt}[(\boldsymbol{V}'_T(\boldsymbol{k},:)\cdot \boldsymbol{i}) * (\boldsymbol{h}(\boldsymbol{k})-\mathbf{1})]_{cnt} * \boldsymbol{w}(\boldsymbol{k})_C & \textit{when missing} \\ \mathbf{0} & \textit{elsewhere} \end{cases}$$

Where $\sum_{\mathbf{cnt}}[(\mathbf{V}'_{\mathbf{T}}(\mathbf{k},:)\cdot\mathbf{i})\cdot(\mathbf{h}(\mathbf{k})-\mathbf{1})]_{\mathbf{cnt}}$**is** the estimate of total trade.
Now that total physical supply is known for a certain amount of products (due to data collection, *gap-filling procedure* and the other operations*)* so as the imports in physical units, it is time to calculate the remaining production flows. The procedure is iterative so that new estimated productions can also become in turn feedstock for other productions. Five iterations were necessary to get reasonable estimates. A less interested reader can go directly to Figure 12 for a graphical explanation of the procedure.
Before showing the iterative procedure, we introduce two important elements, $\mathbf{U}_{\mathbf{distr}}$ and **z.**
$\mathbf{U}_{\mathbf{distr}}$ is a matrix of distribution factors that, for each product, show how much of the total national consumption is allocated to the activities. The default distribution fractions are based on the monetary use table, i.e. $\mathbf{U}'_{\Phi}$, as shown in Equation 8. Fixed prices are assumed.

Equation 8 $$\boldsymbol{U}_{distr} = \boldsymbol{diag}(\boldsymbol{U}_{\boldsymbol{\Phi}}\cdot \boldsymbol{i})^{-1} \cdot \boldsymbol{U}_{\boldsymbol{\Phi}}$$

However, some distribution factors were exogenously manipulated when the monetary use tables seemed inaccurate, given the fixed prices assumption. The logic behind the data corrections of these few special cases aimed to allocate the products mainly to the activities where they are feedstock. For example, this is the case of the product 'Chemical and fertilizer minerals, salt and other mining and quarrying products n.e.c.' which groups many different productions whose price differs. It is important to remember that these data corrections cause a divergence between the monetary and physical levels (see 4.3.1.1 for more information).
Then, be **z** is a vector of factors used to move from physical national supply to total national consumption. $\boldsymbol{z}(\boldsymbol{k})$ is very similar to the factor $\boldsymbol{h}(\boldsymbol{k})$ (Equation 5) but takes into account monetary exports ($\mathbf{e}_{\Phi}$) in the numerator as shown in Equation 9.

Equation 9 $$\boldsymbol{z} = \boldsymbol{diag}(\boldsymbol{V}'_{\boldsymbol{\Phi}}\cdot \boldsymbol{i})^{-1} \cdot [(\boldsymbol{V}'_{\boldsymbol{\Phi}}\cdot \boldsymbol{i}) + \boldsymbol{m}_{\boldsymbol{\Phi}} - \boldsymbol{e}_{\boldsymbol{\Phi}}]$$

We can now introduce the iterative procedure used for estimating the remaining physical production flows (for a graphical explanation see Figure 12).

Equation 10

$$\begin{cases} \breve{f}_T = \begin{cases} (V_T' \cdot i) * z & if\ (V_T' \cdot i) > 0 \\ \breve{m}_T & elsewhere \end{cases} \\ \breve{U}_T = diag(\breve{f}_T) \cdot U_{distr} \\ \dot{V}_T' = diag(i \cdot (\breve{U}_T * D_0)) \\ V_T' = V_T' + \dot{V}_T' \end{cases}$$

$\breve{f}_T$ **is** the of raw materials, which is obtained from the known production $(V_T' \cdot i)$ plus the imports $(\breve{m}_T(k)_C)$. $\breve{\mathbf{U}}_{\mathbf{T}}$ is the new derived matrix of transactions, while $\mathbf{D_0}$is the default matrix of transfer coefficient (see Table 1 and Table 2 for a better description of the elements of the equation). $\dot{\mathbf{V}}_{\mathbf{T}}'$ indicates the new data generated that were unknown.

It is important to mention that the total availability of raw materials includes only part of materials used as feedstock and so destined to be embodied in the final production. This is important when an input is the sum of the feedstock plus something else. For example, with regard to plastic, an input of natural gas may be used as raw material for producing plastic, but it may be also combusted for producing heat. Therefore, the input of gas does not consider the fraction that is combusted. This manipulation was possible because of in the information given by En-SUTs.

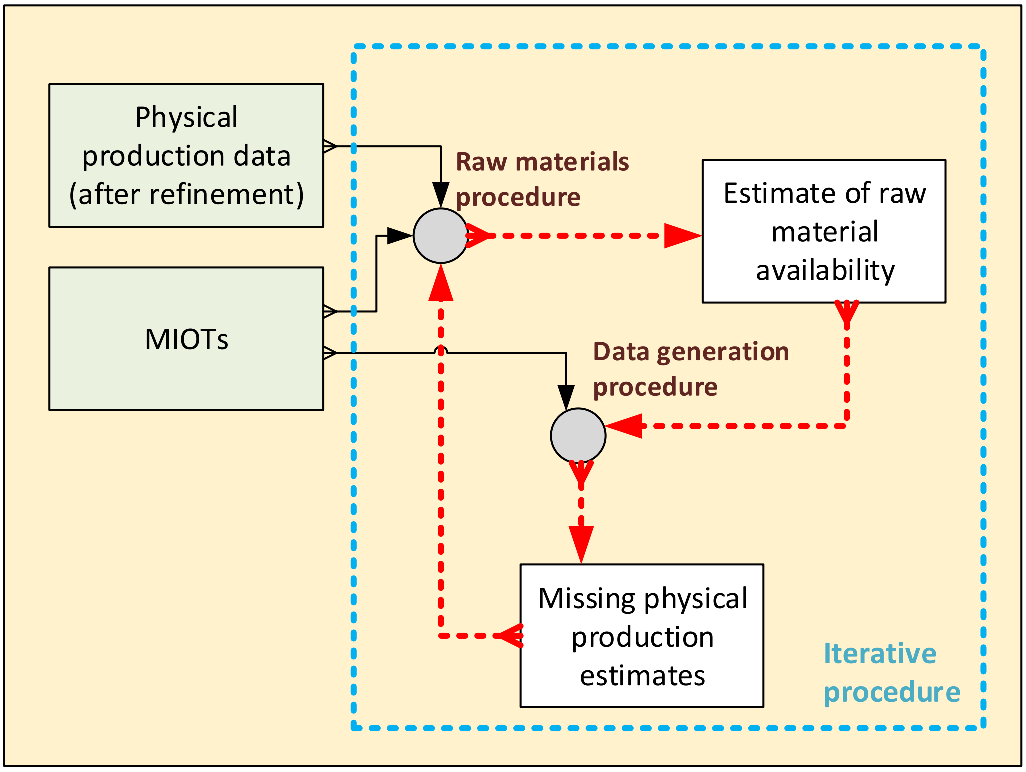

Figure 12 – The iterative data generation procedure for the assessment of missing physical production. Dotted red arrows show the new data flows generated in the iterative steps.

An implicit result of the iterative procedure is the calculation of remaining trade flows. Imports are calculated multiplying the new determined production flows by the factor $(\boldsymbol{h}(\boldsymbol{k}) - \mathbf{1})$.

Unknown exports are calculated multiplying the domestic production by the factors $\mathbf{x}$, which are derived as follows:

Equation 11 $$x = diag(V_\Phi' \cdot i)^{-1} \cdot e_\Phi$$

4.3.1.1 Additional revision of data redistribution

In this section it is presented a procedure for the distribution of some materials to activities that diverges from that indicated in the monetary and energy tables. This further revision was not planned when initially the algorithm was developed. Only in a second stage, when the database was ready and sanity checks were performed, this new part was included. For these reasons, we have decided to include this new section. These redistribution procedures will be added to those already planned in the initial writing of the MR-HSUTs algorithm and that have been described above[12].

When preliminary results of the HSUTs were analysed, we found out that, in some cases, the energy uses were far too high for some activities. In addition, we had some inputs that could be hardly justified in some production processes. We have tried to address many of these issues. However, we are aware that there is still wide room for improvement and that a more exhaustive data collection may overcome the following procedures.

The redistribution of inputs was performed for the following products:

- Food products, including agriculture products;
- Metals;
- Stone, sand and clay;
- Combusted products and electricity (energy inputs).

We have collected the total request of combusted products and electricity for all the activities included in the physical tables (www.ecoinvent.org; Merciai et al. 2010; tab. 3.1). The redistribution of energy inputs will be fulfilled using these new technical coefficients, which are indicated with $\mathbf{k}$. In practice, these coefficients will be the new weighting factors.

The activities are then divided in different groups, i.e. agriculture, mining activities, food production, manufacture, waste treatment, energy activities and, finally, services. The redistribution of energy products is fulfilled for any group separately, but it is not performed for energy activities and services. Therefore, the energy inputs to these two groups of activities follow what indicated in the En-SUTs. The same is for the final demand.

The redistribution is fulfilled as follows.

Equation 12

$$\boldsymbol{U_T}(\boldsymbol{e},\boldsymbol{j}) = \frac{\boldsymbol{k}(\boldsymbol{j}) * \boldsymbol{V_{T'}}(\boldsymbol{j},\boldsymbol{j})}{\sum_{h \in G}[\boldsymbol{k}(\boldsymbol{h}) * \boldsymbol{V_{T'}}(\boldsymbol{h},\boldsymbol{h})]} * \sum_{h \in G} \boldsymbol{U_E}(\boldsymbol{e},\boldsymbol{h}) * \boldsymbol{CV}(\boldsymbol{e}) \quad \forall \; group \; G$$

Where *h* and *j* are generic activities belonging to one of the group above listed, and here indicated with *G*. *e* indicates a generic energy product. $\mathbf{k}(\mathbf{j})$ is the collected LCI coefficient for the activity *j*. $\boldsymbol{U}_{\mathbf{E}}(\boldsymbol{e},\boldsymbol{h})$ is the use

[12] With these revisions, we do not want absolutely state that the MSUT, or En-SUTs, were inaccurate or give wrong results. We only want to alert the reader of the different results she may get using one or the other table. With regard to the En-SUTs, we could not have access to the distribution factors used by our partners. At the same time, En-SUTs were finalized much before MR-SUTs were calculated, therefore we did not succeed to harmonize the procedures. For all these reasons, we have decided to use own distribution procedure to redistribute energy products.

of energy product *e* by activity *h*, as indicated in the En-SUTs, and $\boldsymbol{CV(e)}$ is the caloric value of the product *e*[13].

For the other redistributed products, we have written a procedure that is partially similar to that indicated above for energy products (Equation 12) but with some differences. Indeed, the distribution coefficients are also calculated based on the MSUTs values. But, in addition to that, only some selected productive activities are allowed to use the inputs. These selected activities are split in real consumers and main consumers. The difference between these two categories will be clear soon. As for the energy products redistribution, final demand is not touched.

Table 5 shows the selected consumers chosen for the redistribution procedure.

With regard to food, the procedure implies that the residual flow that is not used as feedstock – either for feeding animals or to be processed in the food industry or used for internal uses in crop cultivations – may be purchased by only four activities (defined as real consumers) listed in Table 5. The distribution factors for these activities are based on the monetary tables and are shown in Equation 13.

Equation 13
$$\boldsymbol{DI(f,j)} = \frac{\boldsymbol{U_\phi(f,j)}}{\sum_{h\in C}[\boldsymbol{U_\phi(f,h)}]} * \frac{\sum_{l\notin C^*}\boldsymbol{U_\phi(f,l)}}{\sum_m[\boldsymbol{U_\phi(f,m)}]} \quad \forall \boldsymbol{j} \in \boldsymbol{C}.$$

Where *f* is a generic food flow, *j* and *h* are generic activities belonging to the group of real consumers, which is indicated with *C*. *l* and *m* are other generic activities. The group of activities using food as feedstock is indicated with C^*. $\boldsymbol{U(f,j)}$ is the use of the food flow *f* by activity *j*.

The first fraction on the right side of Equation 13 is the percentage share between real consumers, while the second fraction shows how much food is used as feedstock. Therefore, the second factor (always lower than 1) reduces the percentage shares of real consumers considering that a part of the food flow is already used as feedstock by some activities[14].

A similar procedure to food is applied to metals. The only difference is that all the intermediate use of metals is redistributed to the real consumers listed in Table 5. In mathematical terms, this means that the second fraction of Equation 13 is set to 1.

Finally, stone, sand and clay, when are not used as feedstock in productive activities (e.g. for glass or cement production), are assumed to be used for 98% by the construction sector (considered as main consumer). The remaining 2% is redistributed to all the other activities following the shares indicated by MR-MSUTs. In mathematical terms, with regard to construction activities, the first fraction on the right side of Equation 13 is set to 98%. Differently, with regard to the residual activities, a factor equal to 2% multiplies the two ratios on the right side of Equation 13 (see Equation 14).

Equation 14
$$\boldsymbol{DI(f,j)} = \begin{cases} \boldsymbol{0.98} * \dfrac{\sum_{l\notin C^*}\boldsymbol{U_\phi(f,l)}}{\sum_m[\boldsymbol{U_\phi(f,m)}]} & \textit{if } \boldsymbol{j} \textit{ is the construction sector} \\ \dfrac{\boldsymbol{U_\phi(f,j)}}{\sum_{h\in C}[\boldsymbol{U_\phi(f,h)}]} * \dfrac{\sum_{l\notin C^*}\boldsymbol{U_\phi(f,l)}}{\sum_m[\boldsymbol{U_\phi(f,m)}]} \cdot \boldsymbol{0.02} & \textit{if } \boldsymbol{j} \textit{ is not the construction sector} \end{cases}$$

>> Food
Hotel and restaurant services (C)

[13] As said above, the MR-HSUTs use different unit of measure. Mass units are the first choice, then energy units and euros. Energy tables only use energy units, hence the calorific values are inserted to convert these flows in mass units. For intangible energy product, e.g. electricity, calorific values are assumed to be 1.

[14] It is important to notice that a redistribution of food flows (but also of fertilizers) has already taken place in the agriculture module, where animal intake of different food categories was calculated. Hence, here only the redistribution of the non-feedstock part is fulfilled.

Public administration and defense services; compulsory social security services (C)
Education services (C)
Health and social work services (C)
All activities using food as feedstock, e.g. food industry, farming, etc.(constant)
>> Metals
Fabricated metal products, except machinery and equipment (C)
Machinery and equipment n.e.c. (C)
Office machinery and computers (C)
Electrical machinery and apparatus n.e.c. (C)
Radio, television and communication equipment and apparatus (C)
Medical, precision and optical instruments, watches and clocks (C)
Motor vehicles, trailers and semi-trailers (C)
Other transport equipment (C)
Furniture; other manufactured goods n.e.c. (C)
Chemicals n.e.c (C)
Food industries (C)
Internal uses
>> Stone, sand and clay
Construction sector (MC 98%)
All activities using stone, sand and clay as feedstock, e.g. glass production, excl. construction sector (constant)
Residual activities (C)

Table 5 – List of real consumers (C) and main consumers (MC) for the redistribution procedure. The bold text indicates the redistributed products. Constant in bold brackets indicates the activities not touched by the redistribution procedure.

4.3.2 Technical coefficients

The second part of this module aims to calculate an initial estimate of technical coefficients. Some coefficients are already shaped in the sectorial modules, all the others need to be calculated entirely. The coefficients calculated refer to the use of inputs and to the supply of co-productions. The first, defined as (*product) input coefficients* and indicated with **A**, show how much of the product *i* is necessary for the production of one unit of the principal output of *j*. The second, defined as *by-product coefficients* and indicated with **C**, show how much of off-diagonal production *i* is supplied per unit of the principal output *j*. Off-diagonal productions are here narrowed to by-products and to joint co-productions (European Commission et al. 2008; pp.514, def. 28.46.b and def. 28.46.c). In other words, only co-productions that are technologically linked to the principal production are off-diagonals.

The procedure starts with the calculation of *by-product coefficients*. The reason lies in the necessity to determine principal productions that will be the denominator in the calculation of *input coefficients.*

In the current version of Exiobase, the information necessary for the calculation comes from both *sectorial modules* and literature (www.ecoinvent.com; Merciai et al. 2013; Schmidt 2010b). From literature, coefficients on waste treatment activities co-productions are mainly taken. These coefficients, in particular, will be used for distributing the production of electricity, heat and biogas, which is derived in the energy

module (see 4.2). Some other b*y-product coefficients,* like the production of meat in dairy cows sector, are directly taken from the agriculture module[15].
Once reconstructed the *by-product coefficients* matrix*,* this information is used to split the total supply of commodity in two groups, principal productions and by-productions, as follows:

Equation 15
$$v_{princ} = (C + I)^{-1} \cdot (V_T' \cdot i) \qquad where\ v = V' \cdot i$$
$$v_{by-prod} = (V_T' \cdot i) - v_{princ}$$

C is the matrix of *by-product coefficients (product by activity),* $\mathbf{v_{princ}}$ is the vector of principal production, $\mathbf{v_{by-prod}}$ of by-productions and ***I*** the identical matrix. We can now mode to the *input coefficients.*
The matrix **A** is already partially filled with technical coefficients coming from sectorial modules. For the remaining flows, a procedure is thought that makes use of the distribution of the estimated available materials along the activities that was calculated in 10.
Initial estimates of *input coefficients* are simply determined by dividing the distributed inputs by the principal outputs, i.e. $\mathbf{v_{princ}}$. Afterwards, some consistency checks are fulfilled[16]. Indeed, coefficients are strongly dependent on the monetary distribution of inputs, therefore some drawbacks could rise because of:

1. inhomogeneous product prices that may be hidden in the monetary tables. Therefore, the distribution of the product in mass units may be not proportional to the monetary figure. This implies that *input coefficients* may be under or overestimated;
2. balancing techniques of the MSUTs (or MIOTs) rely on different requirements than those of physical tables. For example, a risk could be the misallocation of some inputs[17].

Of course, not all the input coefficients derived from monetary figure can be checked; first, because of limited amount of time, second, because this would require an enormous amount of information that is not available. Indeed, the use of the monetary distribution is also finalized to cover that lack of information.
Therefore, we only focussed on some specific input-coefficients, leaving out the others. We concentrate our effort on two types of possible revisions:

a. on relevant inputs to specific activities;
b. on the distribution of specific feedstock.

The first bullet covers the cases where there is a direct link between raw materials and processed products. For example the production of rice can be fulfilled processing paddy rice or by the further refining of some pre-refined rice. The consistency checks assure that there is enough raw material to produce the processed

[15] The inclusion of more sectorial modules and a better detailed system of classification could increase the presence and the consistency of by-productions. For example the animal feed coming from food processing could be better modelled.
[16] The idea to work with coefficients lies in the possibility to facilitate the process of revision. Indeed, it is easier to perform consistency checks on coefficients rather than absolute levels.
[17] The physical tables allow a wide range of checks that could be easily overlooked in a monetary-balancing procedure. One of the examples could be the exclusion of raw materials in an activity. For the monetary balance aims, it may be not important whether the raw material is included in a production recipe or not; one could get balanced activities anyway. Contrarily, when checking the mass balance, the absence, or the little usage, of a raw material will pop up. Hence, a series of checks on raw material requirements are necessarily introduced in the MR-HSUTs procedure.

product (case A in Equation 16). This means that the sum of inputs embodied in the final product, when accounted as coefficients, must be higher than 1. At the same time, a procedure is implemented to reduce coefficients that turn out to be too high (case B in Equation 16). $\mathbf{x_{eff}}$ is an indicator of the max allowed inefficiency when converting input to final products. The consistency checks are listed below in Equation 16.

Equation 16

$$\begin{cases} \sum_i (\boldsymbol{A(i,j)} * \boldsymbol{D_0(i,j)}) > \mathbf{1} & \text{case A} \\ \boldsymbol{A(i,j)} * \boldsymbol{D_0(i,j)} < (\mathbf{1} + \boldsymbol{x_{eff}}) & \text{case B} \end{cases}$$

Where $\mathbf{D_0(i,j)}$ is the default transfer coefficient of input *i* to *j*, while $\mathbf{x_{eff}}$ is an assumed efficiency factor. A transfer coefficient, which lies in the interval $[0,1]$, says how much of the input is embodied in the final product. Default transfer coefficient are taken from Forwast (Schmidt, 2010b).

The second bullet is mostly driven by conservation laws, technical constraints and so on. For example, beef animals usually enter the slaughterhouse that produce meat for human consumption. Therefore, for instance, it is assumed that the live beef animals destined for human consumption must enter the meat processing activities, therefore all the other coefficients are set to zero.

Once again, it is important to notice that the inclusion of these physical-based checks and revisions, implies a difference in the structure of the economies between the monetary and the physical levels. Such a difference will determine a divergence in the results of the analysis using one or the other level[18].

Finally, before concluding, it must be said that in this module the inputs coefficients for animal intake are also calculated. This procedure consists of partitioning the dry-matter intake, which is calculated in the agricultural module, in input of:

- market crops (cereals, seeds, flours, etc.);
- crop-residues;
- fodder;
- grazing grass.[19]

The portioning of animal feed is performed using monetary values as distribution factors.

4.4 Trade module

The trade module is one of the most important improvement in the construction of the PSUTs. In Exiobase v2 (Merciai et al., 2013) this procedure was not endogenous, therefore some trade flows were in conflict with other data used for the construction of the physical layers. To give some examples, in some countries where, according to FAO, no production of some agricultural products occurred, there could be an export higher than import. To solve this lack of domestic production, the inventories were assumed to provide the residual value.

Other cases could occur when there was very low raw material availability to justify a certain level of production. Here again, inventories played a key role.

[18] The difference will be only for those products accounted in physical units, which in the current data sets are restricted to mass and energy units. Here physical units are meant as conservative units different from the monetary ones. However, theoretically, the physical units could be extended to all the products supplied in the world economies. By doing that, all the checks and physical-based revisions of data, which are here shown, could be extended to all the transactions.

[19] Swine and poultry are excluded from this category.

To address all these limits, the trade module is added in the current version of Exiobase. Hence, trade flows are now endogenous results. The aim is to avoid the artificial manipulation of inventories and to have more reasonable results, closer to what observed in the real world[20].

4.4.1 Minimum material requirement and trade revision

The first step consists of calculating the *minimum material requirement feedstock* ($\mathbf{f}_{\mathbf{MMR}}$), which is the minimum availability of raw materials in order to justify certain levels of production. Said in other words, in order to carry out productions, the activities need certain amount of inputs, which may be products, resources or waste. This procedure is valid for all the activities in all the countries.

The calculation of the $\mathbf{f}_{\mathbf{MMR}}$ is very simple, it is equal to:

Equation 17

$$\boldsymbol{f}_{\boldsymbol{MMR}} = \left[\boldsymbol{diag}(\boldsymbol{A} \cdot \boldsymbol{v}_{\boldsymbol{princ}}) \cdot (\boldsymbol{I} + \boldsymbol{0.8} * \boldsymbol{diag}(\boldsymbol{d}_{\boldsymbol{interm}}))\right] \cdot \boldsymbol{i}$$
$$\textit{where} \quad \boldsymbol{d}_{\boldsymbol{interm}} = \boldsymbol{diag}(\boldsymbol{U}_{\boldsymbol{\Phi}} \cdot \boldsymbol{i})^{-1} \cdot (\boldsymbol{FD}_{\boldsymbol{\Phi}} \cdot \boldsymbol{i})$$

Where **A** is the matrix of *product input coefficients (see 4.3.1.1),* $\mathbf{v}_{\mathbf{princ}}$ the vector of principal productions and $\mathbf{d}_{\mathbf{interm}}$ is the ratio by the final demand ($\boldsymbol{FD}_{\boldsymbol{\Phi}} \cdot \boldsymbol{i}$) and the total use of intermediate uses ($\boldsymbol{U}_{\boldsymbol{\Phi}} \cdot \boldsymbol{i}$) in the monetary tables. $\mathbf{f}_{\mathbf{MMR}}$ indicates the quantity of feedstock that should be available for any economy. The coefficient 0.8 follows an assumption where the price paid by final consumers is 20% higher than that paid by activities.

The second step consists of a revision of the trade flows. The aim of this step is to assure that a country has access to what it needs. Initial estimates of imports and exports are already determined in *sectorial modules* (4.1 and 4.2), in the *Technical coefficients module* (4.3.1) and the rest, accounted in monetary units, is taken directly from MR-MIOTs. MR-MIOTs also provide data on the shares of bilateral trade. However, initial estimates of trade may already hide some drawback for the achievement of a balanced trade cube.

There are two feasible limits hidden in the data that are here addressed:

- A country needs to import a certain quantity of a material , but the countries from whom it imports do not export enough to satisfy such a requirement;
- A country does not produce enough to satisfy its requirement and, at the same time, the initial estimated import is null[21].

For the first case, other countries are inserted in the list of source countries. In this process, big exporters are preferred. In practice, this step implies that import shares are modified (so as the export shares of big exporters). The second case, instead, implies that import flows are created from scratch. In this case, the imports shares include only exporters with a trade in global terms above a predetermined threshold.

[20] However, for few cases, the current version still uses the inventories as residual balancing tool. This is the case for few energy products in some countries. The reason for that lies in impossibility to get balanced trade flows.

[21] We think that the main source of these inconsistencies should lie in the different use classification categories by the data source. For example beneficiated ores could be allocated either to mining sectors or to metal manufacture; it depends on the logic followed by the data provider. However, there could be many other reasons for such inconsistencies. For instance, the use of fixed prices when calculating initial estimates, errors in the data collection, and many more.

As said for previous cases, these revisions will imply a further divergence in the results between monetary and physical levels.

4.4.2 Physical trade cube

The core part of the trade module consists of a procedure that estimates the trade flows for each country. Hence the next step is the calculation of the bilateral trades for all the countries, which will shape the physical trade cube (**N**). The latter is a 3-dimensionals matrix $\text{country}_{\text{importer}}X\text{product}X\text{country}_{\text{exporter}}$.

An initial estimate of the physical trade cube is fulfilled using the trade flows calculated previously and the monetary trade quota derived from the revised monetary cube (4.4.1). This initial estimate of the trade cube is not balanced, hence a procedure is thought for such aim.

The physical balanced trade cube, indicated with **T**, is obtained solving a cross-entropy optimization problem subjected to the seven equations as shown in Equation 18 Equation 25. The objective function to minimize takes into account the variation of trade flows respect to the initial estimates.

Equation 18 $$OF = min\left\{\sum_{i,c',c''} \boldsymbol{N_i}(\boldsymbol{c'},c'') \cdot \left(log\left(\boldsymbol{N_i}(\boldsymbol{c'},c'') / \boldsymbol{\breve{N}_i}(\boldsymbol{c'},c'')\right)\right)\right\}$$

Equation 19 $$\boldsymbol{m_i} - \boldsymbol{e_i} + \boldsymbol{V_{i,i}} - \mathbf{U_{ii}} + \sum_{j\neq i}\boldsymbol{V_{i,j}} \geq \boldsymbol{f_{MMR,i}} - \boldsymbol{\hat{u}_i} \quad \forall\, product\ i\ and\ \forall\ country\ c$$

Equation 20 $$\boldsymbol{U_{i,i}} \leq \boldsymbol{V_{i,i}} * \boldsymbol{k_i} \quad \forall\, product\ i\ and\ \forall\ country\ c$$

Equation 21 $$\boldsymbol{\hat{u}_i} = \sum_h(\boldsymbol{U_{h,h}} * \boldsymbol{A_{ih}}) \quad \forall\, product\ i\ and\ \forall\ country\ c$$

Equation 22 $$\boldsymbol{m_i} = \boldsymbol{i} * \boldsymbol{N_i} \quad \forall\, product\ i\ and\ \forall\ country\ c$$

Equation 23 $$\boldsymbol{e_i} = \boldsymbol{N_i} * \boldsymbol{i} \quad \forall\, product\ i\ and\ \forall\ country\ c$$

Equation 24 $$\boldsymbol{V_{i,i}} * (\boldsymbol{1} - \boldsymbol{U_{i,i}}) + \sum_{j\neq i}\boldsymbol{V_{i,j}} > e_i \quad \forall\, product\ i\ and\ \forall\ country\ c$$

Equation 25 $$\sum_c \boldsymbol{e_i^c} = \sum_c \boldsymbol{m_i^c} \quad \forall\, product\ i$$

In the objective function, $\mathbf{N_i}(\mathbf{c'}, c'')$ is the final estimate trade flow of product *i* from country *c'* to country *c''*, while $\mathbf{\breve{N}_i}(\mathbf{c'}, c'')$ is the initial estimate.

With regard to constraints, Equation 19 states that the available material must be higher than the minimum material requirement. The available material can come from the net trade $(\boldsymbol{m_i} - \boldsymbol{e_i})$, from the domestic principal production$(\mathbf{V}_{i,i})$, which may be reduced of the increased direct internal use $(\boldsymbol{U_{i,i}})$, or from the by-productions $(\sum_{\mathbf{j}\neq\mathbf{i}} \mathbf{V_{i,j}})$. A decrease of the minimum material requirement may occur when other activities, which ask for *i* as input, are also shrunk due to internal uses. Therefore, they ask for less *i* (i.e. $\mathbf{\hat{u}_i}$ in Equation 21).

Equation 20 indicates an external upper limit for the internal uses. It shows that the direct internal use cannot be higher that a fraction of the total production. Equation 22 shows the national balance of imports and Equation 23 of exports. It is then assumed that that a country cannot export more than what produces (Equation 24). Finally, Equation 25 indicates the world trade balance.

The trade cube ***N*** obtained undergoes a further reprocessing that consists of a rearrangement of the trade flows. As indicated in Equation 24, it is assumed that a country cannot export more than it produces. This assumption could be quite unrealistic for some economies. Indeed, there could be a valid solution where a

country exports all the domestic production while importing everything that is consumed on the domestic market. We think that this case may be not realistic and needs to be fixed.
A solution to this problem could be found either in a revision of the trade fractions or in a rearrangement of the trade flows. We went for the latter. The underlying idea is that a country can export at most 75% of its production and keep the rest for domestic consumption, if the internal demand is high enough.
Be ***h*** a vector of ratios between exports and the domestic supply.

Equation 26 $\boldsymbol{h}(\boldsymbol{i}) = \boldsymbol{e}(\boldsymbol{i}) / \sum_j \boldsymbol{V}'(\boldsymbol{i}, \boldsymbol{j})$

Where ***i*** is a generic product, ***e(i)*** is the export and $\sum_j \mathbf{V}'(\mathbf{i}, \mathbf{j})$ is the domestic supply.

The rearrangement procedure is activated if the following conditions are met in a specific country:

1. $\mathbf{h(i)} > \mathbf{0.75}$
2. $\text{domestic demand} \geq \mathbf{0.25} * \sum_j \mathbf{V}'(\mathbf{i}, \mathbf{j})$

Then exports of the country and the imports to the same country B are both reduced, so that part of the domestic supply, i.e. $(\mathbf{h(j)} - \mathbf{0.75}) * \sum_j \mathbf{V}'(\mathbf{i}, \mathbf{j})$, can be used for the internal demand. In turn, new links between countries are constructed to compensated the trade flows reduction, so that the trade cube is still balanced. Figure 13 clarifies the manipulation fulfilled.

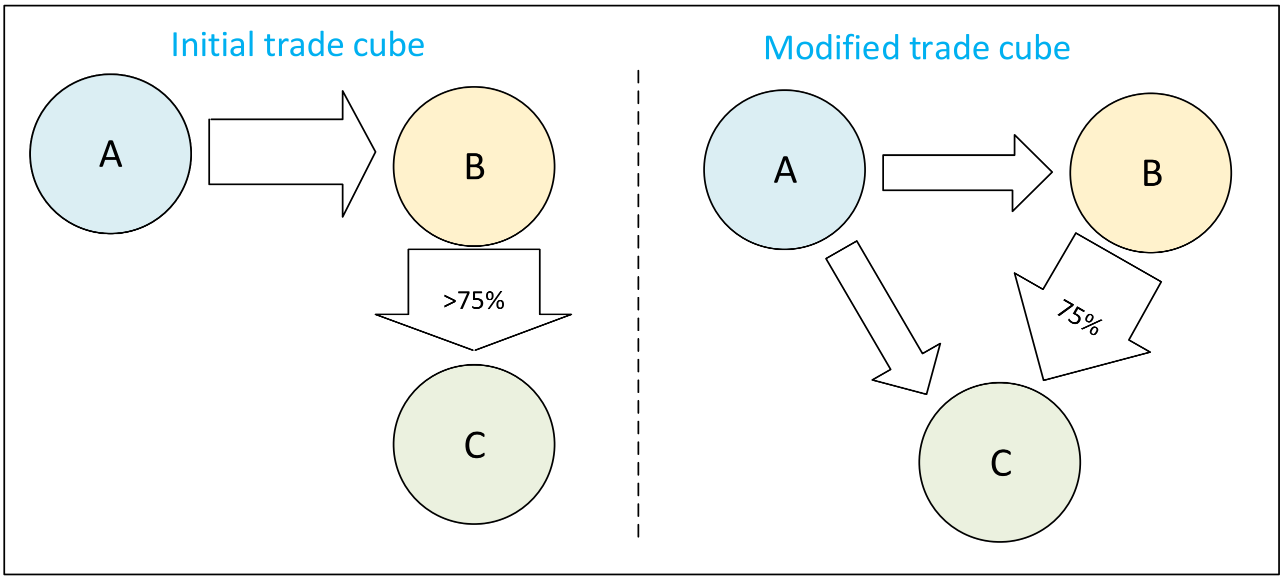

Figure 13 – Trade rearrangement procedure. Initially, Country B exports more that 75% of its production to country C and imports from country A. After the rearrangement, country B export less to country C (75% of its production) and import less from country A. Country C compensate its missing imports from country B by importing from country A. The trade flows are again balanced.

The choice of a threshold equal to 75% is purely arbitrary. We could improve this methodology with more country specific thresholds, but at the moment we don't have this information available.

The trade cube will be used in the last final module to construct the multi-regional tables. Instead, for the next module, which calculates the national balanced table, all this information is superfluous. What is needed is just the total imports (**m**) and exports (**e**) that, together with domestic supply, will shape the frame in which the national actors play their role.

4.5 Balance module

The core of the module consists of a procedure that, using all the information previously calculated, generates balanced tables. With balances tables we mean that supply and use of products are the same and, at the same time, the mass balance within activities is reached. In addition, we assure that in case of intangible processes accounted in energy units, e.g. production of electricity, supply of energy is obtained in accordance with predefined efficiency factor. These efficiency factors are mostly derived from En-SUTs[22].

4.5.1 National balanced tables

Initially, a draft version of HSUTs is constructed. This is obtained using data so far determined or taken from literature:

- physical production flows, disaggregated in principal and secondary production (4.3)
- trade data (4.4.2) ;
- technical coefficients (4.3.1.1).
- transfer coefficients for inputs of products, resources and waste (4.1; Merciai et al., 2013; Schmidt, 2010b);
- emissions coefficients, which indicate how much of input materials is discharged to the environment (Stadler et al., 2015)
- dry matter coefficients (Merciai et al., 2013; Schmidt, 2010b).

Next step consists of assuring that these HSUTs are finally balanced.

The procedure consists of a cross-entropy optimization problem subjected to constraints as shown in Equation 27-Equation 32. The main goal of the optimization problem is to redistribute the available products so that for each activity there is enough feedstock to justify given levels of production. Therefore, the objective function minimizes the variation of the use accounts respect to the initial estimates. The procedure is run for each country or region at time.

Equation 27 $$OF = min\left\{\sum_{i,j}\left(\boldsymbol{U}(i,j)\ \cdot log\left(\boldsymbol{U}(i,j)/_{\breve{\boldsymbol{U}}(i,j)}\right)\right)\right\}$$

Equation 28 $$\boldsymbol{U}\cdot\boldsymbol{i}+\boldsymbol{FD}\cdot\boldsymbol{i}+\boldsymbol{e}=\boldsymbol{V}'\cdot\boldsymbol{i}+\boldsymbol{m}$$

Equation 29 $$(\boldsymbol{dm}*\boldsymbol{i})'\cdot[(\boldsymbol{U}-\boldsymbol{U}_{comb})*\boldsymbol{D}]+(\boldsymbol{dm}_{\boldsymbol{R}}*\boldsymbol{i}_{\boldsymbol{R}})'\cdot(\boldsymbol{R}*\boldsymbol{F})+(\boldsymbol{dm}_{\boldsymbol{W}}*\ \boldsymbol{i}_{\boldsymbol{W}})'\cdot(\boldsymbol{W}_{\boldsymbol{U}}*\boldsymbol{T})\ =(\boldsymbol{dm}*\boldsymbol{i})'\cdot(\boldsymbol{V}')$$

Equation 30 $$\boldsymbol{U}\geq\boldsymbol{U}_{comb}$$

Equation 31 $$\boldsymbol{V}_{ener}\cdot\boldsymbol{i}_{ener}\geq\left[\boldsymbol{U}'_{ener-feed}\cdot\boldsymbol{i}_{ener}\right]*\boldsymbol{eff}_{ener}$$

Equation 32 $$\boldsymbol{D}_{low}\leq\boldsymbol{D}\leq min(\boldsymbol{1}-\boldsymbol{i}_{\boldsymbol{B}}\cdot\boldsymbol{B}_{\boldsymbol{Use}};\boldsymbol{D}_{\boldsymbol{up}})$$

In the objective function, $\mathbf{U}(\mathrm{i},\mathrm{j})$ is the final estimated use of material *i* by activity *j,* while $\breve{\mathbf{U}}(\mathrm{i},\mathrm{j})$ is the initial estimate. Moving to constraints, Equation 28 assures that there is a balance between what is demanded and what is supplied, including the trade. On the left side, ***U***, ***FD*** and ***e*** are respectively the transaction matrix,

[22] We do not take into account emission of heat, therefore energy balance is not performed. However, we assure that processes like electricity from fossil fuels or biomasses, have an input higher than output, respecting efficiency factors driven by technological threhold.

the matrix of final demand and the export vector. On the right side, ***V'*** and ***m*** are the supply matrix and the import vector, respectively. ***i*** indicate generic summation vectors.
Equation 29 establishes the mass balance within activities. Said in other words, each activity must have enough feedstock to allow its given level of production. $\mathbf{U_{comb}}$, ***R*** and $\boldsymbol{W_U}$ are the matrix of combusted inputs, matrix of natural resources and, finally, the use of waste matrix. ***dm*** indicates the dry matter vectors of the various inputs. ***D***, ***F*** and ***T*** are the transfer coefficients for goods, resources and waste fractions, respectively.
Equation 30 indicates that the use of a commodities must be higher or equal than the given input of combusted materials (see 4.2 and 4.3.1.1), which are here kept constant.
Equation 31 shows that in the electricity, steam and heat processes, whose consistency cannot be checked by mass balance, the output cannot be higher than predetermined process-efficiency ($\mathbf{eff_{ener}}$)(EURELECTRIC, 2003) times energy input ($\mathbf{U'_{ener-feed}} \cdot \mathbf{i_{ener}}$). Finally, Equation 32 defines the interval of the transfer coefficients. A transfer coefficient has a predefined lower limit ($\mathbf{D_{low}}$). Instead, the upper limit is the minimum value between a default value ($\mathbf{D_{up}}$) and the maximum feasible value, which is 1 less the emission factors due to the use of such material ($\mathbf{b_{use}}$).
In the optimization problem shown in Equation 28-27, the following variables are kept constant:

- supply of product (**V'**), excluding the supply of waste water treatment services,
- the trade (**N**)
- the dry matter coefficients (***dm***),
- the inputs of combusted materials ($\mathbf{U_{comb}}$),
- the efficiency of energy processes ($\mathbf{eff_{ener}}$),
- the inputs and the extensions calculated in the agri-module (e.g. input of fertilizers, animal feed intake, etc.).

This means that the variables determined by the procedure are:

- matrix of the uses (**U**),
- product transfer coefficients (**D**)
- supply of waste water treatment services.

The supply of waste water treatment services are endogenously calculated, because it is assumed that all the produced sewage, which is an endogenous variable, is handled[23].
In general, besides the change of inventories, all the values must be not negative.
When a solution is reached, production recipes are determined for each activities and for each country. Extensions have to be then calculated to complete the country tables. However, before calculating the final extensions, two other steps must be done. The first consists of creating the multi-regional table of transactions, including the purchases of the final consumers. Then, in the second step, the supply of waste fractions and the stock addition can be finally determined and so all the extensions.

[23] Notice the fact that invariable resources and uses of waste are a consequence of fixing the supply of good and services. All this information comes from data collection and, when necessary, by revisions applied in the previous modules. Only the supply of water waste treatment is assumed to be calculated endogenously, this because it is assumed that all the supplied wastewater is somehow treated. Different assumption is adopted for the other waste services, which are kept constant. Consequently, all the other waste may be also not treated, but illegally discharged or stocked somewhere.

In practice, what is still left out to be calculated is the waste from the use of packaging and from the use of heterogeneous goods, which can be calculated only when the multilateral transactions are reconstructed. Therefore, extensions will be calculated directly on the multi-regional table. This will be done in the next module.

4.6 Final module

In this section we show how the physical trade cube and the national balanced HSUTs are combined together to get multi-regional transaction tables, which are the core part of the MR-HSUTs. Once this is done, the total supply of packaging waste can be determined. Then, the total supplied waste can be calculated so as the use of waste treatment services. That would be the last step, afterwards everything is ready to calculate the final extensions, including the stock addition.

4.6.1 Multi-regional transaction tables

In order to construct the MR-HSUTs, the trade cube obtained in 4.4 is combined with national tables determined in 4.5. Figure 14 shows this step. This operation is quite straightforward.

For each country, the uses are split between domestic and imported products (lower part of Figure 14). The national table is moved on the multi-regional table without any adjustments. At the end, all the main diagonals of the countries will make the main diagonal of the global table.

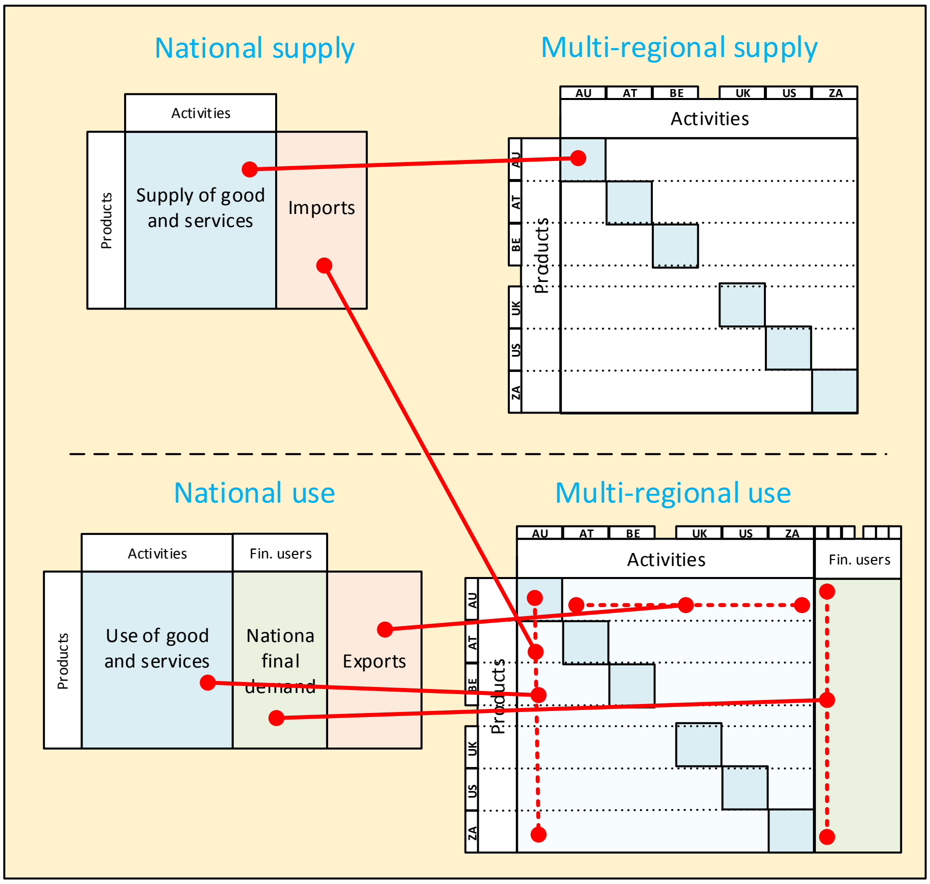

Figure 14 – From national to multi-regional transaction tables. The red lines indicate how the values obtained in the national balanced tables are redistributed in the multi-regional framework using the information of the physical trade cube.

There is, among many others, a consideration that is important to do.

We have assumed that each activity, so as final demand categories of a country, import the same share of products. This means that the fraction between domestic and imported products is the same for each economic actor of a country (*average import assumption*). The only exemption is done for live animal, where it is assumed that live animals may be imported by farming activities and food industry with a different fraction. This because, in the agri-module, it is assumed that some animals are imported and raised in the country before being slaughtered.

The *average import assumption* could be substituted with other assumptions that take into account the nature of each sector as done for live animals. However, because of limited time and lack of information, we have preferred to proceed in this way, being also aware that it is the most diffused assumption for multi-regional IO databases[24].

4.6.2 Auxiliary flows for waste accounts

Once determined the transactions within and between countries (see 4.6.1), some auxiliary flows are calculated in order to finally build waste accounts and other extensions. These flows are special cases because, contrarily to other flows calculated so far, need some further elaborations to be determined. They refers to:

- Supply/use of waste fractions from packaging;
- Supply/use of waste fractions as consequence of trade of heterogeneous products[25];
- Supply/use of waste fractions from vehicles[26].
- Supply/use of crop residues, energy crops and grass

Here, the use of the terms "supply" and "use" is slightly different from that of used in waste accounts, hence a clarification is necessary to avoid any source of confusion.

Supply of waste fractions from packaging (so as from heterogeneous products or vehicles) accounts the materials that are supplied by the producers that will be then purchased by consumers. The latter will then discharge these fractions as waste. Figure 15 illustrates the procedure for packaging and it can be also extended to the other two cases.

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[24] Another important remark refers to the by-production and is linked to analytic aspects. We have decided to put all the co-productions (off-diagonal production) in the row of the national product for maintaining the balance of products. This approach is suitable for a direct transformation of MR-HSUTs into MR-HIOTs by using the product or the industry technology assumptions. With regard to product technology assumption, problems could rise only if a country has some goods produced exclusively as co-productions. In that case, there is no recipe to subdivide multifunctional activities. Instead, when an analyst intends to use the by-product technology assumption (Stone's method), the coproduction should be divided according to the products that substitutes. Therefore, the co-productions should also cover imported products.

Likewise, when building the import fractions to be applied to use tables, only principal productions should be taken into account and not the co-productions.

[25] Heterogeneous products are made of many different materials. For simplicity are referred in the text as machineries. The list of these products can be found in 4.6.2.2.

[26] Vehicles are special heterogeneous products that are separated from heterogeneous products of the second bullet points because are accounted in monetary units. Further, part of vehicles are assumed to have different lifetime. For example, tyres of a car are usually changed more times during its lifetime.

The first three auxiliary accounts are not important extensions for the total mass balance of the economic system so we could have decided not to publish them. However, because they are very helpful for database users when performing certain types of analysis, such as the LCA of a product, we have decided to include them in the extensions[27].

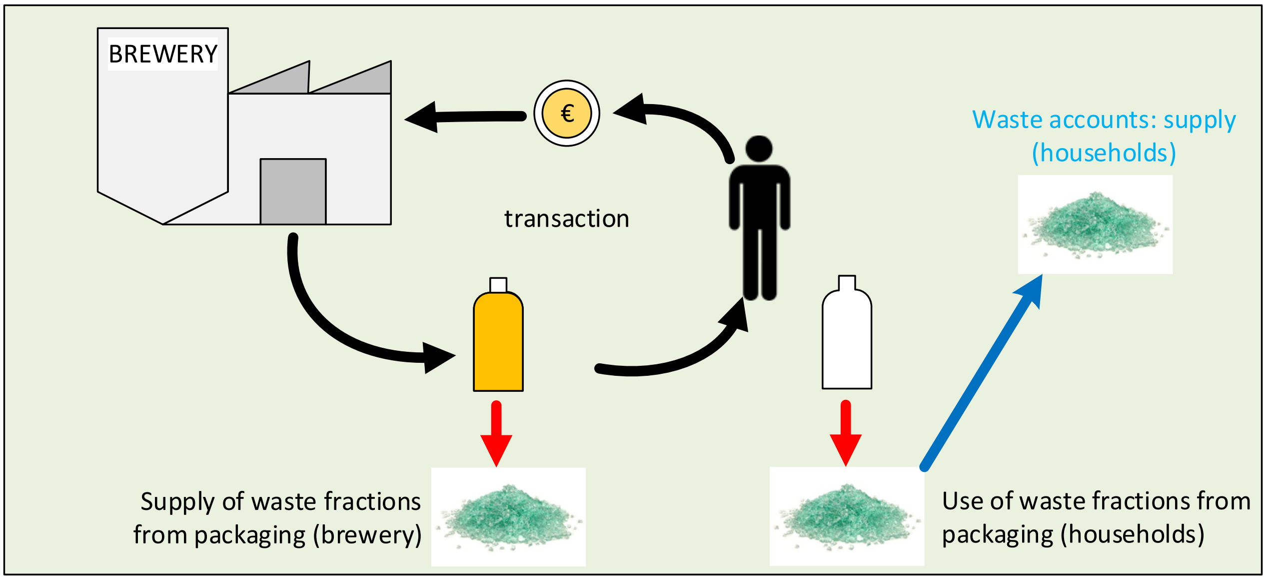

Figure 15 – Logic behind the construction of auxiliary accounts. Example of the packaging. The brewery produced bottled biers that sells to households. The glass of bottle is accounted as supply of glass from packaging in the beverage sector. Then, the household buys biers and the glass of bottles will be accounted in the in the households' category. The use of waste from packaging will be part of the waste accounts of households.

The last account show flows with no market value, but anyway exchanged by activities. Crop residues are the only flows that are important for the mass balance of activities. The rest are simply auxiliary accounts.

4.6.2.1 Waste from packaging

The packaging is considered as materials that travel with products. Therefore, the supply of packaging is accounted in the country producing packaged goods, but it is discharged as waste by the purchasers that can be within the same borders of the producer or in another region.

It is assumed that a part of the input of materials entering into specific activities, and not used as feedstock, is converted to packaging. The activities that are supposed to deliver products wrapped in packaging are listed in Table 6. The products used for the packaging are instead shown in Table 7. The coefficients used for defining the amount of packaging supplied are based on own assumptions based on the nature of the products (see 0).

Vegetables, fruit, nuts	Fish products
Products of meat cattle	Wholesale trade and commission trade services, except of motor vehicles and motorcycles
Products of meat pigs	Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods

[27] We could have decided to include also the construction waste in these auxiliary accounts. However, we have assumed that construction works are not traded, but only construction services are, which do not imply a trade of materials.

Products of meat poultry	Fabricated metal products, except machinery and equipment
Meat products nec	Machinery and equipment n.e.c.
products of Vegetable oils and fats	Office machinery and computers
Dairy products	Electrical machinery and apparatus n.e.c.
Processed rice	Radio, television and communication equipment and apparatus
Sugar	Medical, precision and optical instruments, watches and clocks
Food products nec	Furniture; other manufactured goods n.e.c.
Beverages	

Table 6 – Activities assumed to use packaging to wrap its products

Glass and glass products
Basic iron and steel and of ferro-alloys and first products thereof
Aluminium and aluminium products
Plastics, basic
Rubber and plastic products
Paper and paper products
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials

Table 7 – Material used for packaging

It is assumed that a product has the same amount of packaging regardless where it is consumed. Hence, the use of packaging is distributed to purchasers according to the fraction consumed of the packaged product. It is assumed that the packaging becomes waste in the same period of the product consumption, therefore the use of packaging becomes directly supply of waste.

4.6.2.2 Waste from heterogeneous products

The need of introducing a special procedure for heterogeneous products, such as machineries, lies in the fact that there is not a one-to-one correspondence between these products and waste fractions. In addition, each country has its own composition for these products. Therefore, when a purchaser buys a machinery, it must be taken into account all the different materials that are also embodied in the imported items. Table 8 shows the list of heterogeneous products.

Foundry work services
Fabricated metal products, except machinery and equipment
Machinery and equipment n.e.c.
Office machinery and computers
Electrical machinery and apparatus n.e.c.
Radio, television and communication equipment and apparatus
Medical, precision and optical instruments, watches and clocks
Furniture; other manufactured goods n.e.c.

Table 8 – List of heterogeneous products. These products are made of different materials.

The material composition of heterogeneous products is calculated in the balance module (Equation 29).

Hence, the supply of waste fractions from the production of heterogeneous products is straightforward. Instead, the use of waste fractions requires the information on the mix of consumed products from national and foreign sources, which is determined in 4.6.1 following the adopted *average import assumption.* That information is used to weight the material composition of heterogeneous products calculated in Equation 29. The result is a country-specific material composition of used heterogeneous products. These country-specific factors will be used to transform the input of heterogeneous products in waste fractions.

It is assumed that all the materials embodied in the heterogeneous goods become waste at the same time, following a specific *lifetime function* calculated in Forwast (Schmidt, 2010b; Schmidt et al., 2010). A more detailed explanation of *lifetime functions* will be done in 4.6.3.

4.6.2.3 Waste from vehicles

Vehicles ('Motor vehicles, trailers and semi-trailers' and 'Other transport equipment') are special homogenous products that are accounted in monetary units in the HSUTs[28].

For these products the transfer coefficients are exogenous and not derived in Equation 29 (see 4.5.1).

It has been decided to set the transfer coefficients to 0.8 for each feedstock material. This means that the supply of waste fractions from the supply of vehicles is 80% of the input of feedstock materials.

These supplies waste fraction will be distributed to consumer following the procedure already applied for packaging and heterogeneous materials. The only difference with flows in 4.6.2.2 concerns the timing of the material disposal. It is assumed that tyres are substituted more times during the lifetime of a vehicles. Therefore there are two different *lifetime functions*, one for the tyres and one for all the rest of materials. See 4.6.3 for more information on the *lifetime functions.*

4.6.2.4 Crop residues, energy crops and grass

These accounts are calculated in order to show the by-productions of activities that may have not a market value but are exchanged by activities or internally used. They include supply and use of crop residues, use of grass and ensilage by animals and, finally, supply and use of energy crops.

The crop residues (FAO Statistic division, 2015) are taken into account in the mass balance of the activities. Indeed, extracted natural resources also consider the substances taken from nature in order to produce residues that are exchanged with other activities. In the activities using crop residues, these flows are treated by waste treatment activities.

The grass and the ensilage accounts are introduced just to give extra information on the diet of animal in the livestock activities. They are used elaborating data from FAOSTAT (FAO Statistic division, 2015).

Finally, the crop residues is just an additional information to show the supply and use of energy crops (Stadler et al., 2015), which are includes in the 'Crops nec', together with non-energy crops.

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[28] There is not a particular reason why these flows are accounted in monetary values after the improvement performed in the current version of Exiobase. We could have decided to account also vehicles in mass units, but in order to differentiate vehicles from other heterogeneous products, we have kept things as decided in Exiobase v2 and Forwast. However, the move towards mass units will be inevitable when more information on the mass per unit of monetary value will be available.

4.6.3 Use of waste treatment services and waste accounts

In the section 4.6.2, it has been shown how some special waste flows are derived from auxiliary accounts. For all those flows, because of some peculiarities, specific procedures have been developed. For all the other flows, instead, a general procedure is applied. This will be explained in the current section.

4.6.3.1 Potential waste

Waste supply, in the general procedure, is determined as a fraction of the total potential waste. The potential waste is made of all the materials that enter into an activity, or a final demand category, and are not embodied in final products (as feedstock) or emitted to the biosphere. With materials entering into the economy we refer to any product, natural resource or waste fraction. For example a potential waste may include scraps of a foundry, windows of a new construction, a new computer, manure excreted, etc. Equation 33 shows how to calculate the potential waste.

Equation 33

$$V'_{w;potenatial} = \begin{cases} (\boldsymbol{dm} * \boldsymbol{i}) \cdot [(\boldsymbol{U} - \boldsymbol{U}_{comb}) * (\boldsymbol{I}_{MP} - \boldsymbol{D}] + \boldsymbol{FD} & from\ input\ of\ products \\ (\boldsymbol{dm}_R * \boldsymbol{i}_R) \cdot (\boldsymbol{R} * (\boldsymbol{I}_{MR} - \boldsymbol{F})) & from\ input\ of\ natural\ resources \\ (\boldsymbol{dm}_W * \boldsymbol{i}_W) \cdot (\boldsymbol{W}_U * (\boldsymbol{I}_{MT} - \boldsymbol{T})) & from\ input\ of\ waste \end{cases}$$

Where ***U*** and ***FD*** are the transaction matrix and the matrix of final demand. $\mathbf{U}_{\mathbf{comb}}$, ***R*** and $\boldsymbol{W_U}$ are the matrix of combusted inputs, matrix of natural resources and, finally, the use of waste matrix. ***dm*** indicate the dry matter vectors of the various inputs and ***i*** summation vectors. ***D***, ***F*** and ***T*** are the transfer coefficients for goods, resources and waste fractions, respectively. $\mathbf{I}_{\mathbf{M}*}$ are matrices (of different shapes) with all 1s.

4.6.3.2 Supply of waste and stock addition

The potential waste $\mathrm{V}'_{\mathrm{w;potenatial}}$ shown in Equation 33 includes all the materials that soon or later will become waste. It has a format inputXactivity, where with input is meant a product, a natural resource or a waste fraction, while activity indicates both productive activities and final consumers.

However, only part of the potential waste will become waste in the same accounting period of the purchase, the rest is treated as stock addition that will become waste in future periods. We have assumed a *lifetime function* that takes into accounts these aspects.

A *lifetime function* indicates when a product will become waste. In practice, a lifetime function says how much of purchased products will become waste in each accounting period (years) since then on. Lifetime functions are assumed to be triangular functions and were developed in the FORWAST project (Schmidt, 2010b; Schmidt et al., 2010).

An example of *lifetime function* can be found in Figure 16 regarding textile products. It is assumed an average lifetime of 10 years. In the first period, which is the period of the transaction, it is assumed that 1% of the total purchased textiles becomes waste, the rest is stock addition. In the following accounting period, another 2% becomes waste reducing the stock. After 19 years, all the textile products become waste.

Equation 34 shows the breakdown of the potential waste in waste discharged in the same period of the transactions (period *t*), i.e. $V_w^{'}$, and in stock addition that will be degraded in the following periods, i.e. $\Delta S_{t+1}, \Delta S_{t+2}, \Delta S_{t+3}, \dots, \Delta S_{t+n}$[29].

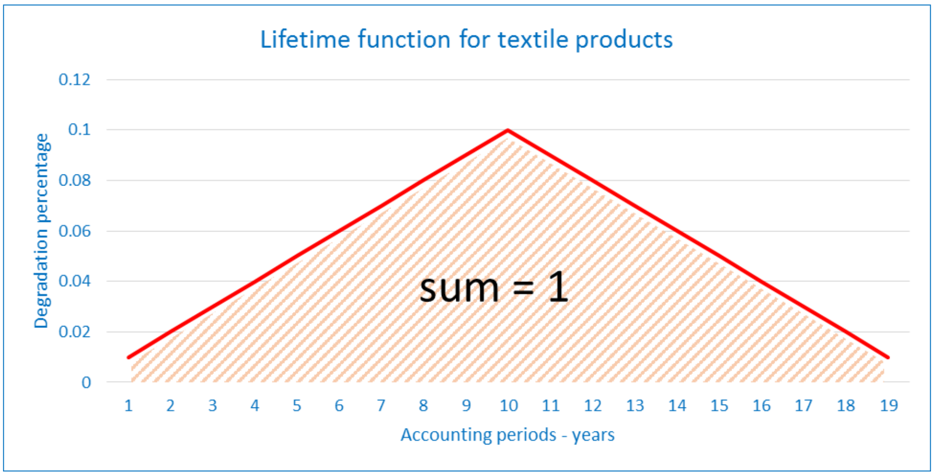

Figure 16 – Lifetime function for textile products. It is assumed a triangular function with average lifetime of 10 years.

Equation 34 $$V'_{w;potenatial} = V'_w + \Delta S_{t+1} + \Delta S_{t+2} + \Delta S_{t+3} + \dots + \Delta S_{t+n}$$

The various elements of the potential waste, which have a format inputXactivity, are then converted into waste fractions. This operation is performed by a transformation matrix ***Q*** as shown in Equation 35. Matrix **Q** is a 3 dimensional matrix that decomposes each input (*i*) of an activity (*a*) into discharged waste fractions (*w*) (see Figure 17). The list of waste fractions is shown in Table 9 at the end of the section.

Equation 35 $$\boldsymbol{W}_{sup}(\boldsymbol{w},\boldsymbol{a}) = \sum_i (\boldsymbol{V'}_w(\boldsymbol{i},\boldsymbol{a}) * \boldsymbol{Q}(\boldsymbol{i},\boldsymbol{a},\boldsymbol{w}))$$
$$\boldsymbol{\Delta S}^{w}_{t+n}(\boldsymbol{w},\boldsymbol{a}) = \sum_i (\boldsymbol{\Delta S}_{t+n}(\boldsymbol{i},\boldsymbol{a}) * \boldsymbol{Q}(\boldsymbol{i},\boldsymbol{a},\boldsymbol{w})) \ \ where\ \boldsymbol{n} \in \boldsymbol{Z}$$

$\mathbf{W_{sup}(w,a)}$ is the supply of waste concerning products purchased and discharged in the same accounting period (*t*); $\mathbf{\Delta S^{w}_{t+n}(w,a)}$ is the part of accumulated materials (stock addition) purchased in the period *t* that will become waste in a generic future period *t+n*. The format of all the matrices calculated in Equation 35 is waste fractionXactivity.
It is important to say that $\mathbf{W_{sup}(w,a)}$ shows only a part of the waste really treated in an accounting period *t*. The total supplied waste is indeed made of $\mathbf{W_{sup}(w,a)}$ plus the waste from products purchased in previous periods (*t-n*) and eventually discharged in the period *t*. To make a distinction, we define $\mathbf{W_{sup}(w,a)}$ as *ordinary supply of waste*.

[29] Equation 34 includes all the flows accounted in the previous sections from auxiliary accounts (4.6.2). Further, ash residues produced after the product combustion are also included in the total potential waste, although these flows will be presented in 4.6.4 when introducing the emissions from combustion.

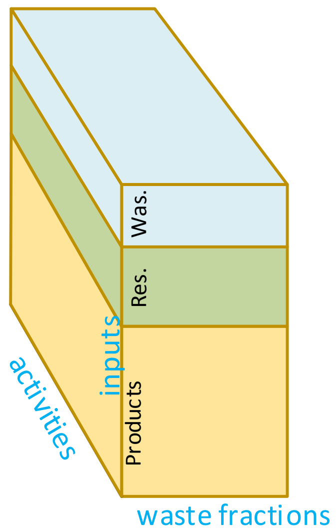

Figure 17 – Transformation matrix Q. It is a 3-dimensional matrix inputXactivityXwaste-fraction. It converts inputs (products, natural resources and waste of waste) to activities into waste fractions.

4.6.3.3 Waste conversion factors and use of waste

Once known the total supply of waste fractions, a conversion factor $\mathbf{CW}$ which links waste treatments $(\mathbf{i_w})$ to waste fractions (w) is determined. In other words, $\mathbf{CW}$ connect the supply of waste service accounted in the supply table to the use of waste in the waste accounts.
Just to remember the procedure to get waste flows, the supply of waste treatment services is collected from different statistical sources, undergoes a revision process and is kept constant in the balance module. Only the treatment of sewage is calculated endogenously based on the production of sewage by activities. The conversion factors are for most of the waste treatments exogenous because there is a one-to-one correspondence between waste treatments and waste fractions. For example the recycling of paper treats only paper waste, so as the incineration of plastic deals only with plastic waste. Things are less obvious for inert materials, a waste fraction that encompasses many materials, such as metals, construction waste, etc. Inert waste may be only incinerated or put in landfills.
The conversion factors for inert waste are then calculated within the MR-HSUTs procedure. They are based on the mix of residual materials that are not recycled. Therefore they are country specific.
The determination of the conversion factor allows the calculation of the use of waste as shown in Equation 36.

Equation 36 $$\boldsymbol{W_{use}}(\boldsymbol{w},\boldsymbol{a}) = \sum_{i_w}[\boldsymbol{V'}(\boldsymbol{i_w},\boldsymbol{a}) * \boldsymbol{CW}(\boldsymbol{i_w},\boldsymbol{w})]$$

4.6.3.4 Use of waste treatment service and the unregistered supply of waste

Once known the supply of waste from each activity $(\mathbf{W_{sup}}(\mathbf{w},\mathbf{a}))$ and the use of waste given the conversion factors, it is possible to move further determining the use of waste treatment services. In other words, it has to be derived how it is treated the waste supplied by each activity or final consumption category. This will be done using shares of waste treatment services.

First of all, it can be said that there is no difference between activities in sending waste to the different waste treatments. This means that if 50% of paper is recycled in a country, it will be so for any activity or consumers[30]. Said that, we can go more in depth into the adopted approach.
The underlying idea is very simple, the supply of waste treatment services shapes the use of them.
For any waste fraction, it is calculated how much in percentage is handled by the different treatments. For example, with regard to paper, it is calculated how much is recycled, incinerated or landfilled. Be $\boldsymbol{t}(\boldsymbol{w}, \boldsymbol{i_w})$ the percentage of waste fraction *w* handled by treatment service i_w. Equation 37 shows how to get it.

Equation 37 $$t(w, i_w) = \sum_a [V'(i_w, a) * CW(i_w, w)] / \sum_{j_w} \sum_{aa} (V'(ii_w, aa) * CW(ii_w, w))$$

Where $\sum_a V'(i_w, a)$ is the total supply of waste treatment service i_w, while $\sum_{j_w} \sum_{aa} (V'(ii_w, aa))$ is the total treated waste fraction w. *a* and *aa* indicate generic activities. $\mathbf{CW}(\mathbf{i_w}, \mathbf{w})$ is the conversion factor between waste treatments and waste fractions. It can be noticed that $\boldsymbol{t}(\mathbf{w}, \mathbf{i_w})$ does not rely on who produces waste because it is assumed that the waste scenario is the same for all the actors**.**
The shares of waste treatment services are then used to convert the ordinary supply of waste $\mathbf{W_{sup}}(\mathbf{w}, \mathbf{a})$ into demand of waste treatment services. However, before doing this step another check is necessary.
As said above, the supply of waste treatment services, or said differently the use of waste (Equation 36) is mostly exogenous while the ordinary supply of waste is endogenous (Equation 33-30), the two values can be hardly the same. If the use of waste is lower than the ordinary supply, it is assumed that there are ordinary unregistered waste flows. Instead, if the use is higher, it means that materials accumulated in previous years are treated in the current period. Be $\mathbf{z}(\mathbf{w})$ the ratio between total use of waste and total ordinary supply for a generic waste fraction *w*.

Equation 38 $$z(w) = \sum_a W_{use}(w, a) \ / \sum_a W_{sup}(w, a)$$

If $\mathbf{z}(\mathbf{w})$ is lower than 1, it means that there is unregistered ordinary waste that has to be calculated as done in Equation 39.

Equation 39 $$W_{unreg}(w, a) = V'(w, a) * (1 - z(w)) \ \ if \ \ z(w) < 1$$

Notice that ordinary unregistered supply of waste $\mathbf{W_{unreg}}(\mathbf{w}, \boldsymbol{a})$ is a subset of the ordinary supply of waste.
Now, we can finally determine the use of waste treatment services. Of course, the use of waste treatments will be performed only for the registered waste.

Equation 40 $$U(i_w, a) = \sum_{i_w} [(W_{sup}(w, a) - W_{unreg}(w, a)) * t(w, i_w)]$$

Where $\mathbf{W_{sup}}(\mathbf{w}, \mathbf{a})$ is the ordinary supply of waste and $\mathbf{W_{unreg}}(\mathbf{w}, \boldsymbol{a})$ the ordinary unregistered supply of waste**.** With last calculations in Equation 40, the use matrix is finally completed.
Last thing to calculate is the amount of material accumulated in the previous periods (*t*-n) and become waste in the period *t*.
The total waste from accumulated materials in the accounting period t, i.e. $W_{\Delta S}(\mathbf{w}, \boldsymbol{a})_t$**,** is the sum of all the accumulated materials that become waste in the period *t*. Equation 41 shows how it is calculated.

[30] This will be clear in Equation 40.

Equation 41 $$W_{\Delta S}(w,a)_t = \sum_n \Delta S_n^w(w,a)_{t-n}$$

Where $\mathbf{\Delta S_n^w}(\mathbf{w},\mathbf{a})_{t-n}$ are the materials accumulated in the period *t-n* that become waste after *n* periods (*t=t-n+n)*.
The unregistered waste is then determined as subset of the total waste obtained in Equation 41. As done for the waste from intermediate inputs (Equation 38), the ratio between total treated waste from accumulated materials and total supplied waste from accumulated materials, i.e. $\mathbf{s}(\mathbf{w})$, is calculated. $\mathbf{s}(\mathbf{w})$ indicated how much of the waste from accumulated material is handled by waste treatment services.

Equation 42 $$s(w) = \begin{cases} \sum_a [W_{sup}(w,a) * (z(w)-1)] / \sum_a W_{\Delta S}(w,a)_t & if\ z(w) > 1 \\ 0 & if\ z(w) \leq 1 \end{cases}$$

In Equation 42, ***z(w)*** (Equation 38) plays an important role. If higher than one, the waste from accumulated material is treated. Contrarily, if it is smaller than 1, it means that that country does not succeed to treat the ordinary supply of waste, hence the waste from accumulated materials is all considered as unregistered. $s(\mathbf{w})$ is non-negative. A value smaller than 1 implies that a sort of unregistered waste occurs for accumulated materials. A value higher than one means that there are some waste flows that has not been accounted[31]. In the latter case $s(\mathbf{w})$ is set to 1.
We can finally determine the unregistered waste from accumulated materials.

Equation 43 $$W_{\Delta S-unreg}(w,a)_t = W_{\Delta S}(w,a)_t * (1 - s(w))$$

At this point the waste accounts are finally determined. To complete the extensions, so as MR-HSUTs, emissions and the resources accounts have to be calculated. This will be introduced in the next section.

Food
Manure
Textile
Wood
Paper
Plastics
Glass
Ashes
Steel
Precious metals
Aluminium
Lead
Copper

[31] Because of the combination of collected data and calculated data, which are determined by many different assumptions, it may happen that somewhere there is an overestimation or underestimation of some flows. It could also be that there is a trade of waste that are not taken into accounts in our approach. Therefore, the ratios ***z(w)*** and ***s(w)*** could appear unrealistic. However, we firmly believe that the approach we have developed could be closer and closer to reality when more detailed and exhaustive data will be available. In addition, it is important to notice that waste flows still remain undetermined accounts for many statistical offices. Indeed, there could be many forms of illegal trade or dumping that are hardly detected.

non-ferrous metals
Construction materials and mining waste (excl. unused mining material)
Oils and hazardous materials
Sewage
Unused mining material

Table 9 – List of waste fractions

4.6.4 Emissions and resources

The last pieces to complete the MR-HSUTs are the emission and resources accounts.
The resources that are used as feedstock when producing goods, such as mining ores, use of land and water use/extraction are provided by our partners (Stadler et al., 2015); Only the land for crops is taken directly FAOSTAT (FAO Statistic division, 2015).
Here, the only resources that are endogenously calculated, which complete the resource accounts, are those necessary to carry out a combustion, i.e. oxygen and nitrogen. These inputs are necessary in order to respect the mass conservation laws when the combustion processes occur. We assume the following balance:

Equation 44 *resources + combusted material = emission + ashes*

The calculation of emissions, natural resources and ashes are performed applying emission, resource and residues factors, respectively. These factors are multiplied by the amount of energy products that is combusted by each activity.
Finally, other emissions are determined other than the emissions from combustion. The complete lists of calculated emissions is the following:

- From combustion of fossil fuels;
- From combustion of biomass;
- From waste treatment;
- From supply of products (e.g. cement production);.
- From agricultural activities;
- From the use of products (e.g. use of chemicals);
- From unregistered waste.

All these emissions, excluding the agricultural emissions calculated in the agri-module (see 4.1), are calculated using emissions factors (Schmidt, 2010b; Stadler et al., 2015). Although determined as last values in the algorithm, the emissions factors have been introduced in the balancing procedure (4.5), so to assure the mass balance.

5 Multi-regional input output tables

In addition to the MR-HSUTs, multi-regional input-output tables (MR-HIOTs) have been constructed. This is aimed to researchers that want to run the Leontief model.

Usually, there are four types of input output table that are built (EUROSTAT, 2008):

- Product by product IOT with product technology assumption

- Product by product IOT with industry technology assumption
- Industry by industry IOT with fixed industry sales structure assumption
- Industry by industry IOT with fixed product sales structure assumption

These four ways of building IOT have their own well know procedure (EUROSTAT, 2008), therefore we think that it is not relevant to say more on. Instead, we firmly believe that another approach should have special interest but is often ignored and not well known. We refer to the Stone's method (1961), i.e. by-product technology assumption, where by-products are treated as negative inputs.

We have calculated MR-HIOTs adopting the Stone's method. Next sessions will describe more in detail what has been done.

5.1 Modified by-product technology assumption

The Stone's method implies that off diagonal productions are treated as negative inputs, therefore the transactions part of the IOTs, i.e. $\boldsymbol{Z}$, is determined as follows:

Equation 45 $$\boldsymbol{Z} = (\boldsymbol{U} - \breve{\boldsymbol{V}}')$$

Where $\boldsymbol{U}$ is the matrix of uses and $\breve{\boldsymbol{V}}'$ the matrix of the off-diagonal supply. Because the production functions of activities are not manipulated, the format of an IOT based on the Stone's method is the same of the SUTs, i.e. products by activity. The only difference is that IOT must be square.

As shown in Equation 45, the calculation of the table is very simple and straightforward. Yet, the simple use of the Stone's method could cause some inconsistencies that could undermine the validity of the methodology, mainly in a multiregional framework. Therefore, we have further developed such a method, inspired by the consequential life cycle thinking (Weidema et al., 2009).

There are two substantial manipulations operated upon the data:

1. It is assured that there is homogeneity of products' properties in the input-output tables;
2. Only principal productions are treated and, at the same time, by-products only substitute principal productions.

The first bullet is aimed to solve the limits of the Stone's method raised by Majeau-Bettez et al. (2016). The authors state that the mass balance is violated anytime by-products have different properties than the principal productions.

This issue was already addressed in the construction of the MR-HSUTs. Therefore no further elaborations were needed. For example, in the case of manure treatment activity which produce manure that substitutes chemical fertilizers, the off-diagonal production was converted to fertilizers (see 4.1.5). For all the other products we have already assumed homogeneity between principal and secondary productions. By doing so, and including the avoided emissions (see 4.1.5), the limits mentioned by Majeau-Bettez et al. (2016) are solved. This means that any results that are obtained with an input-output analysis will be balanced.

The second bullet deals with a problem related to the product provision. An example may clarify the issue. In Denmark there is no production of virgin steel, however steel is recycled. Therefore there is only an off-diagonal production of steel, from secondary source. It follows that a steel produced in Denmark can be delivered only if previously an amount of steel is separated from waste flows and recycled. In other words, the supplied steel in Denmark is a function of the recycling of steel waste.

Technically speaking, in the supply table the off-diagonal production of recycled steel lies in the row of virgin steel. It follows that, when constructing the MR-HIOTs, the Stone's method will have implied that recycled steel substitutes domestic virgin steel that does not exit. The benefits of recycling steel will be completely ignored.

To solve this drawback, we have assumed that steel demanded in Denmark comes uniquely from imported virgin steel. Similarly, recycled steel substitutes imported steel and not domestic virgin steel.

In practical terms, this procedure implies that all the flows produced as by-products are assumed not to be traded. Therefore, the fraction between national and imported materials is recalculated based on this new figure. These new fractions will then shape the MR-HIOT.

In the delivered MR-HIOTs, the 200 products are aggregated to 164. Therefore, the final format is 164x164 for 49 countries/regions, i.e. 7872x7872.

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Appendix 1: Assumption on the supply of packaging

	Glass and glass products	Basic iron and steel and of ferro-alloys and first products thereof	Aluminium and aluminium products	Plastics, basic	Rubber and plastic products	Paper and paper products	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials
Vegetables, fruit, nuts				90%	50%	90%	10%
Products of meat cattle				90%	50%	90%	10%
Products of meat pigs				90%	50%	90%	10%
Products of meat poultry				90%	50%	90%	10%
Meat products nec				90%	50%	90%	10%
products of Vegetable oils and fats	90%	50%	90%	90%	50%	90%	10%
Dairy products	90%			90%	50%	90%	10%
Processed rice				90%	50%	90%	10%
Sugar				90%	50%	90%	10%
Food products nec	90%	50%	90%	90%	50%	90%	10%
Beverages	90%	50%	90%	90%	50%	90%	10%
Fish products				90%	50%	90%	10%
Wholesale trade and commission trade services, except of motor vehicles and motorcycles				90%	20%	90%	10%
Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods				90%	20%	90%	10%
Fabricated metal products, except machinery and equipment				5%	50%	20%	10%
Machinery and equipment n.e.c.				5%	50%	20%	10%
Office machinery and computers				5%	50%	20%	10%
Electrical machinery and apparatus n.e.c.				5%	50%	20%	10%
Radio, television and communication equipment and apparatus				5%	50%	20%	10%
Medical, precision and optical instruments, watches and clocks				5%	50%	20%	10%
Furniture; other manufactured goods n.e.c.				5%	50%	90%	10%

Table 10 – The percentages shows how much of the non-feedstock inputs (in the columns) to activities (in the rows) are assumed to be packaging. A feedstock input indicates a material that is embodied in the principal or secondary productions of an activity.

Appendix 2: Source data for physical flows

Product name	Total supply	Trade
Paddy rice	FAO Statistic division (2015)	FAO Statistic division (2015)
Wheat	FAO Statistic division (2015)	FAO Statistic division (2015)
Cereal grains nec	FAO Statistic division (2015)	FAO Statistic division (2015)
Vegetables, fruit, nuts	FAO Statistic division (2015)	FAO Statistic division (2015)
Oil seeds	FAO Statistic division (2015)	FAO Statistic division (2015)
Sugar cane, sugar beet	FAO Statistic division (2015)	FAO Statistic division (2015)
Plant-based fibers	FAO Statistic division (2015)	FAO Statistic division (2015)
Crops nec	FAO Statistic division (2015)	FAO Statistic division (2015)
Cattle	FAO Statistic division (2015)	FAO Statistic division (2015)
Pigs	FAO Statistic division (2015)	FAO Statistic division (2015)
Poultry	FAO Statistic division (2015)	FAO Statistic division (2015)
Meat animals nec	FAO Statistic division (2015)	FAO Statistic division (2015)
Animal products nec	FAO Statistic division (2015)	FAO Statistic division (2015)
Raw milk	FAO Statistic division (2015)	FAO Statistic division (2015)
Wool, silk-worm cocoons	FAO Statistic division (2015)	FAO Statistic division (2015)
Manure (conventional treatment)	own calculation	not considered
Manure (biogas treatment)	own calculation using default IPPC (2006) values	not considered
Products of forestry, logging and related services	FAO Statistic division (2015)	endogenous
Fish and other fishing products; services incidental of fishing	FAO Statistic division (2015)	endogenous
Anthracite	IEA	endogenous
Coking Coal	IEA	endogenous
Other Bituminous Coal	IEA	endogenous
Sub-Bituminous Coal	IEA	endogenous
Patent Fuel	IEA	endogenous
Lignite/Brown Coal	IEA	endogenous
BKB/Peat Briquettes	IEA	endogenous
Peat	IEA	endogenous

Crude petroleum and services related to crude oil extraction, excluding surveying	IEA	endogenous
Natural gas and services related to natural gas extraction, excluding surveying	IEA	endogenous
Natural Gas Liquids	IEA	endogenous
Other Hydrocarbons	IEA	endogenous
Uranium and thorium ores (12)	IEA	endogenous
Iron ores	WU, 2014	endogenous
Copper ores and concentrates	WU, 2014	endogenous
Nickel ores and concentrates	WU, 2014	endogenous
Aluminium ores and concentrates	WU, 2014	endogenous
Precious metal ores and concentrates	WU, 2014	endogenous
Lead, zinc and tin ores and concentrates	WU, 2014	endogenous
Other non-ferrous metal ores and concentrates	WU, 2014	endogenous
Stone	WU, 2014	endogenous
Sand and clay	WU, 2014	endogenous
Chemical and fertilizer minerals, salt and other mining and quarrying products n.e.c.	WU, 2014	endogenous
Products of meat cattle	FAO Statistic division (2015)	FAO Statistic division (2015)
Products of meat pigs	FAO Statistic division (2015)	FAO Statistic division (2015)
Products of meat poultry	FAO Statistic division (2015)	FAO Statistic division (2015)
Meat products nec	FAO Statistic division (2015)	FAO Statistic division (2015)
products of Vegetable oils and fats	FAO Statistic division (2015)	FAO Statistic division (2015)
Dairy products	endogenous	endogenous
Processed rice	endogenous	endogenous
Sugar	FAO Statistic division (2015) and own assumptions	FAO Statistic division (2015) and own assumptions
Food products nec	endogenous	endogenous
Beverages	endogenous	endogenous
Fish products	endogenous	endogenous
Tobacco products (16)	endogenous	endogenous
Textiles (17)	endogenous	endogenous
Wearing apparel; furs (18)	endogenous	endogenous
Leather and leather products (19)	endogenous	endogenous
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials (20)	UNIDO Indstat	endogenous

Wood material for treatment, Re-processing of secondary wood material into new wood material	Eurostat (2015); EPA (2008); Hyder consulting (2009); FAOSTAT(2013); Ecolamancha (2008) ; own elaborations;	not considered
Pulp	Faostat	endogenous
Secondary paper for treatment, Re-processing of secondary paper into new pulp	Eurostat (2015); EPA (2008); WRAP (2011); Hyder consulting (2009); OECD (2010); Perele and Solovyeva (2011); DETEC-FOEN (2008); Ecolamancha (2008) ; own elaborations;	not considered
Paper and paper products	endogenous	endogenous
Printed matter and recorded media (22)	endogenous	endogenous
Coke Oven Coke	IEA	IEA
Gas Coke	IEA	IEA
Coal Tar	IEA	IEA
Motor Gasoline	IEA	IEA
Aviation Gasoline	IEA	IEA
Gasoline Type Jet Fuel	IEA	IEA
Kerosene Type Jet Fuel	IEA	IEA
Kerosene	IEA	IEA
Gas/Diesel Oil	IEA	IEA
Heavy Fuel Oil	IEA	IEA
Refinery Gas	IEA	IEA
Liquefied Petroleum Gases (LPG)	IEA	IEA
Refinery Feedstocks	IEA	IEA
Ethane	IEA	IEA
Naphtha	IEA	IEA
White Spirit & SBP	IEA	IEA
Lubricants	IEA	IEA
Bitumen	IEA	IEA
Paraffin Waxes	IEA	IEA
Petroleum Coke	IEA	IEA
Non-specified Petroleum Products	IEA	IEA
Nuclear fuel	IEA	IEA
Plastics, basic	endogenous	endogenous

Secondary plastic for treatment, Re-processing of secondary plastic into new plastic	Eurostat (2015); EPA (2008); Hyder consulting (2009); OECD (2010); CEMPRE (2010); Statistics Canada(2008); Perele R. and Solovyeva S. (2011); DETEC-FOEN (2008); Ecolamancha (2008) ; own elaborations;	not considered
N-fertiliser	IFA	IFA
P- and other fertiliser	IFA	IFA
Chemicals nec	endogenous	endogenous
Charcoal	IEA	IEA
Additives/Blending Components	IEA	IEA
Biogasoline	IEA	IEA
Biodiesels	IEA	IEA
Other Liquid Biofuels	IEA	IEA
Rubber and plastic products (25)	endogenous	endogenous
Glass and glass products	UN Indstat	endogenous
Secondary glass for treatment, Re-processing of secondary glass into new glass	Eurostat (2015); EPA (2008); Hyder consulting (2009); CEMPRE (2010); Statistics Canada(2008); DETEC-FOEN (2008); Ecolamancha (2008) ; own elaborations;	not considered
Ceramic goods	endogenous	endogenous
Bricks, tiles and construction products, in baked clay	endogenous	endogenous
Cement, lime and plaster	endogenous	endogenous
Ash for treatment, Re-processing of ash into clinker	Smith I. (2005); own elaborations;	not considered
Other non-metallic mineral products	endogenous	endogenous
Basic iron and steel and of ferro-alloys and first products thereof	BGS World Mineral Statistics	endogenous
Secondary steel for treatment, Re-processing of secondary steel into new steel	Worldsteel Association (2010; 2012); USGS (2015);	not considered
Precious metals	BGS World Mineral Statistics; USGS Minerals Information; World Mining Data	endogenous
Secondary preciuos metals for treatment, Re-processing of secondary preciuos metals into new preciuos metals	USGS (2015) and own elaborations	not considered
Aluminium and aluminium products	BGS World Mineral Statistics	endogenous

Secondary aluminium for treatment, Re-processing of secondary aluminium into new aluminium	USGS (2015) and own elaborations	not considered
Lead, zinc and tin and products thereof	BGS World Mineral Statistics	endogenous
Secondary lead for treatment, Re-processing of secondary lead into new lead	USGS (2015) and own elaborations	not considered
Copper products	BGS World Mineral Statistics	endogenous
Secondary copper for treatment, Re-processing of secondary copper into new copper	ICSG (2010); USGS (2015); own elaborations;	not considered
Other non-ferrous metal products	endogenous	endogenous
Secondary other non-ferrous metals for treatment, Re-processing of secondary other non-ferrous metals into new other non-ferrous metals	USGS (2015) and own elaborations	not considered
Foundry work services	endogenous	endogenous
Fabricated metal products, except machinery and equipment (28)	endogenous	endogenous
Machinery and equipment n.e.c. (29)	endogenous	endogenous
Office machinery and computers (30)	endogenous	endogenous
Electrical machinery and apparatus n.e.c. (31)	endogenous	endogenous
Radio, television and communication equipment and apparatus (32)	endogenous	endogenous
Medical, precision and optical instruments, watches and clocks (33)	endogenous	endogenous
Motor vehicles, trailers and semi-trailers (34)	MSUTs	MSUTs
Other transport equipment (35)	MSUTs	MSUTs
Furniture; other manufactured goods n.e.c. (36)	endogenous	endogenous
Secondary raw materials	MSUTs	MSUTs
Bottles for treatment, Recycling of bottles by direct reuse	JCPRA(2013); Heinisch J. (2009); Brewers of Europe (2010); own elaborations;	not considered
Electricity by coal	IEA	IEA
Electricity by gas	IEA	IEA
Electricity by nuclear	IEA	IEA
Electricity by hydro	IEA	IEA
Electricity by wind	IEA	IEA
Electricity by petroleum and other oil derivatives	IEA	IEA
Electricity by biomass and waste	IEA	IEA
Electricity by solar photovoltaic	IEA	IEA
Electricity by solar thermal	IEA	IEA
Electricity by tide, wave, ocean	IEA	IEA
Electricity by Geothermal	IEA	IEA
Electricity nec	IEA	IEA
Transmission services of electricity	MSUTs	MSUTs
Distribution and trade services of electricity	MSUTs	MSUTs

Coke oven gas	IEA	IEA
Blast Furnace Gas	IEA	IEA
Oxygen Steel Furnace Gas	IEA	IEA
Gas Works Gas	IEA	IEA
Biogas	IEA	IEA
Distribution services of gaseous fuels through mains	MSUTs	MSUTs
Steam and hot water supply services	IEA	IEA
Collected and purified water, distribution services of water (41)	MSUTs	MSUTs
Construction work (45)	MSUTs	MSUTs
Secondary construction material for treatment, Re-processing of secondary construction material into aggregates	UEPG (2008); EPA (2003); Statistics Canada(2008); Hyder consulting (2009); BGS (2012); own elaborations;	not considered
Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessoiries	MSUTs	MSUTs
Retail trade services of motor fuel	MSUTs	MSUTs
Wholesale trade and commission trade services, except of motor vehicles and motorcycles (51)	MSUTs	MSUTs
Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods (52)	MSUTs	MSUTs
Hotel and restaurant services (55)	MSUTs	MSUTs
Railway transportation services	MSUTs	MSUTs
Other land transportation services	MSUTs	MSUTs
Transportation services via pipelines	MSUTs	MSUTs
Sea and coastal water transportation services	MSUTs	MSUTs
Inland water transportation services	MSUTs	MSUTs
Air transport services (62)	MSUTs	MSUTs
Supporting and auxiliary transport services; travel agency services (63)	MSUTs	MSUTs
Post and telecommunication services (64)	MSUTs	MSUTs
Financial intermediation services, except insurance and pension funding services (65)	MSUTs	MSUTs
Insurance and pension funding services, except compulsory social security services (66)	MSUTs	MSUTs
Services auxiliary to financial intermediation (67)	MSUTs	MSUTs
Real estate services (70)	MSUTs	MSUTs
Renting services of machinery and equipment without operator and of personal and household goods (71)	MSUTs	MSUTs
Computer and related services (72)	MSUTs	MSUTs

Research and development services (73)	MSUTs	MSUTs
Other business services (74)	MSUTs	MSUTs
Public administration and defence services; compulsory social security services (75)	MSUTs	MSUTs
Education services (80)	MSUTs	MSUTs
Health and social work services (85)	MSUTs	MSUTs
Food waste for treatment: incineration	Eurostat (2015); EPA (2008);Hyder consulting (2009); Statistics Canada(2008); National Bureau of Statistics China (2008); Chen X. et al. (2010); Huang, Wang, Dong, Xi, & Zhou) 2006; Perele R. and Solovyeva S. (2011); IEA (2010); Christensen T. H. (1998); own elaborations;	not considered
Paper waste for treatment: incineration	Eurostat (2015); EPA (2008); DETEC-FOEN (2008); Statistics Canada(2008); National Bureau of Statistics China (2008); Chen X. et al. (2010); Huang, Wang, Dong, Xi, & Zhou) 2006;Perele R. and Solovyeva S. (2011); IEA (2010); Christensen T. H. (1998); own elaborations;	not considered
Plastic waste for treatment: incineration	Eurostat (2015); EPA (2008); DETEC-FOEN (2008); Statistics Canada(2008); National Bureau of Statistics China (2008); Chen X. et al. (2010); Huang, Wang, Dong, Xi, & Zhou) 2006;Perele R. and Solovyeva S. (2011); IEA (2010); Christensen T. H. (1998); own elaborations;	not considered

Intert/metal waste for treatment: incineration	Eurostat (2015); EPA (2008); DETEC-FOEN (2008); Statistics Canada(2008); National Bureau of Statistics China (2008); Chen X. et al. (2010); Huang, Wang, Dong, Xi, & Zhou) 2006;Perele R. and Solovyeva S. (2011); IEA (2010); Christensen T. H. (1998); own elaborations;	not considered
Textiles waste for treatment: incineration	Eurostat (2015); EPA (2008); DETEC-FOEN (2008); Statistics Canada(2008); National Bureau of Statistics China (2008); Chen X. et al. (2010); Huang, Wang, Dong, Xi, & Zhou) 2006;Perele R. and Solovyeva S. (2011); IEA (2010); Christensen T. H. (1998); own elaborations;	not considered
Wood waste for treatment: incineration	Eurostat (2015); EPA (2008);DETEC-FOEN (2008); Statistics Canada(2008); National Bureau of Statistics China (2008); Huang, Wang, Dong, Xi, & Zhou) 2006;Chen X. et al. (2010); Perele R. and Solovyeva S. (2011); IEA (2010); Christensen T. H. (1998); own elaborations;	not considered
Oil/hazardous waste for treatment: incineration	Eurostat (2015); EPA (2008); DETEC-FOEN (2008); Statistics Canada(2008); National Bureau of Statistics China (2008); Chen X. et al. (2010); Huang, Wang, Dong, Xi, & Zhou) 2006;Perele R. and Solovyeva S. (2011); IEA (2010); Christensen T. H. (1998); own elaborations;	not considered

Food waste for treatment: biogasification and land application	Levis J.W. et al., (2010); AEBIOM (2009); EUROSTAT (2015); EPA (2010; 2011); own elaborations;	not considered
Paper waste for treatment: biogasification and land application	Levis J.W. et al., (2010); AEBIOM (2009); EUROSTAT (2015); EPA (2010; 2011); own elaborations;	not considered
Sewage sludge for treatment: biogasification and land application	Levis J.W. et al., (2010); AEBIOM (2009); EUROSTAT (2015); EPA (2010; 2011); own elaborations;	not considered
Food waste for treatment: composting and land application	EUROSTAT (2015); EPA (2008); OECD(2010); IBGE (2002); Statistics Canada(2008); Chen X. et al. (2010); Huang, Wang, Dong, Xi, & Zhou) 2006; own elaborations;	not considered
Paper and wood waste for treatment: composting and land application	Eurostat (2015); EPA (2008); IBGE (2002); Statistics Canada(2008); Huang, Wang, Dong, Xi, & Zhou) 2006;Chen X. et al. (2010); own elaborations;	not considered
Food waste for treatment: waste water treatment	Eurostat (2015); EPA (2008); FAOSTAT(2013); DETEC-FOEN (2008); Statistics Canada(2008); own elaborations;	not considered
Other waste for treatment: waste water treatment	Eurostat (2015); EPA (2008); DETEC-FOEN (2008); Statistics Canada(2008); own elaborations;	not considered

Food waste for treatment: landfill	Eurostat (2015); EPA (2008); Hyder consulting (2009); Statistics Canada(2008); National Bureau of Statistics China (2008); Zhang D. Q et al. (2010); Huang, Wang, Dong, Xi, & Zhou) 2006; Jelenska E. (2010); CEMPRE (2010); Ecolamancha (2008) ; Christensen T. H. (1998); own elaborations;	not considered
Paper for treatment: landfill	Eurostat (2015); EPA (2008); Hyder consulting (2009); Statistics Canada(2008); National Bureau of Statistics China (2008); Zhang D. Q et al. (2010); Huang, Wang, Dong, Xi, & Zhou) 2006; Jelenska E. (2010); CEMPRE (2010); Ecolamancha (2008) ; Christensen T. H. (1998); own elaborations;	not considered
Plastic waste for treatment: landfill	Eurostat (2015); EPA (2008); Hyder consulting (2009); Statistics Canada(2008); National Bureau of Statistics China (2008); Zhang D. Q et al. (2010); Huang, Wang, Dong, Xi, & Zhou) 2006;Jelenska E. (2010); CEMPRE (2010); Ecolamancha (2008) ; Christensen T. H. (1998); own elaborations;	not considered

Inert/metal/hazardous waste for treatment: landfill	Eurostat (2015); EPA (2008); Hyder consulting (2009); Statistics Canada(2008); National Bureau of Statistics China (2008);Zhang D. Q et al. (2010); Huang, Wang, Dong, Xi, & Zhou) 2006;Jelenska E. (2010); CEMPRE (2010); Ecolamancha (2008) ; Christensen T. H. (1998); own elaborations;	not considered
Textiles waste for treatment: landfill	Eurostat (2015); EPA (2008); Hyder consulting (2009); Statistics Canada(2008); National Bureau of Statistics China (2008); Zhang D. Q et al. (2010); Huang, Wang, Dong, Xi, & Zhou) 2006;Jelenska E. (2010); CEMPRE (2010); Ecolamancha (2008) ; Christensen T. H. (1998); own elaborations;	not considered
Wood waste for treatment: landfill	Eurostat (2015); EPA (2008); Hyder consulting (2009); Statistics Canada(2008); National Bureau of Statistics China (2008); Zhang D. Q et al. (2010); Huang, Wang, Dong, Xi, & Zhou) 2006; Jelenska E. (2010); CEMPRE (2010); Ecolamancha (2008) ; Christensen T. H. (1998); own elaborations;	not considered
Membership organisation services n.e.c. (91)	MSUTs	MSUTs
Recreational, cultural and sporting services (92)	MSUTs	MSUTs
Other services (93)	MSUTs	MSUTs
Private households with employed persons (95)	MSUTs	MSUTs
Extra-territorial organizations and bodies	MSUTs	MSUTs

Table 11 – Source of data for the physical production flows

Appendix 3: Classifications

Products

Product name	Code 1	Code 2
Paddy rice	p01.a	C_PARI
Wheat	p01.b	C_WHEA
Cereal grains nec	p01.c	C_OCER
Vegetables; fruit; nuts	p01.d	C_FVEG
Oil seeds	p01.e	C_OILS
Sugar cane; sugar beet	p01.f	C_SUGB
Plant-based fibers	p01.g	C_FIBR
Crops nec	p01.h	C_OTCR
Cattle	p01.i	C_CATL
Pigs	p01.j	C_PIGS
Poultry	p01.k	C_PLTR
Meat animals nec	p01.l	C_OMEA
Animal products nec	p01.m	C_OANP
Raw milk	p01.n	C_MILK
Wool; silk-worm cocoons	p01.o	C_WOOL
Manure (conventional treatment)	p01.w.1	C_MANC
Manure (biogas treatment)	p01.w.2	C_MANB
Products of forestry; logging and related services (02)	p02	C_FORE
Fish and other fishing products; services incidental of fishing (05)	p05	C_FISH
Anthracite	p10.a	C_ANTH
Coking Coal	p10.b	C_COKC
Other Bituminous Coal	p10.c	C_OTBC
Sub-Bituminous Coal	p10.d	C_SUBC
Patent Fuel	p10.e	C_PATF
Lignite/Brown Coal	p10.f	C_LIBC
BKB/Peat Briquettes	p10.g	C_BKBP
Peat	p10.h	C_PEAT
Crude petroleum and services related to crude oil extraction; excluding surveying	p11.a	C_COIL
Natural gas and services related to natural gas extraction; excluding surveying	p11.b	C_GASE
Natural Gas Liquids	p11.b.1	C_GASL
Other Hydrocarbons	p11.c	C_OGPL
Uranium and thorium ores (12)	p12	C_ORAN
Iron ores	p13.1	C_IRON
Copper ores and concentrates	p13.20.11	C_COPO
Nickel ores and concentrates	p13.20.12	C_NIKO

Aluminium ores and concentrates	p13.20.13	C_ALUO
Precious metal ores and concentrates	p13.20.14	C_PREO
Lead; zinc and tin ores and concentrates	p13.20.15	C_LZTO
Other non-ferrous metal ores and concentrates	p13.20.16	C_ONFO
Stone	p14.1	C_STON
Sand and clay	p14.2	C_SDCL
Chemical and fertilizer minerals; salt and other mining and quarrying products n.e.c.	p14.3	C_CHMF
Products of meat cattle	p15.a	C_PCAT
Products of meat pigs	p15.b	C_PPIG
Products of meat poultry	p15.c	C_PPLT
Meat products nec	p15.d	C_POME
products of Vegetable oils and fats	p15.e	C_VOIL
Dairy products	p15.f	C_DAIR
Processed rice	p15.g	C_RICE
Sugar	p15.h	C_SUGR
Food products nec	p15.i	C_OFOD
Beverages	p15.j	C_BEVR
Fish products	p15.k	C_FSHP
Tobacco products (16)	p16	C_TOBC
Textiles (17)	p17	C_TEXT
Wearing apparel; furs (18)	p18	C_GARM
Leather and leather products (19)	p19	C_LETH
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials (20)	p20	C_WOOD
Wood material for treatment; Re-processing of secondary wood material into new wood material	p20.w	C_WOOW
Pulp	p21.1	C_PULP
Secondary paper for treatment; Re-processing of secondary paper into new pulp	p21.w.1	C_PAPR
Paper and paper products	p21.2	C_PAPE
Printed matter and recorded media (22)	p22	C_MDIA
Coke Oven Coke	p23.1.a	C_COKE
Gas Coke	p23.1.b	C_GCOK
Coal Tar	p23.1.c	C_COTA
Motor Gasoline	p23.20.a	C_MGSL
Aviation Gasoline	p23.20.b	C_AGSL
Gasoline Type Jet Fuel	p23.20.c	C_GJET
Kerosene Type Jet Fuel	p23.20.d	C_KJET
Kerosene	p23.20.e	C_KERO
Gas/Diesel Oil	p23.20.f	C_DOIL

Heavy Fuel Oil	p23.20.g	C_FOIL
Refinery Gas	p23.20.h	C_RGAS
Liquefied Petroleum Gases (LPG)	p23.20.i	C_LPGA
Refinery Feedstocks	p23.20.j	C_REFF
Ethane	p23.20.k	C_ETHA
Naphtha	p23.20.l	C_NAPT
White Spirit & SBP	p23.20.m	C_WHSP
Lubricants	p23.20.n	C_LUBR
Bitumen	p23.20.o	C_BITU
Paraffin Waxes	p23.20.p	C_PARW
Petroleum Coke	p23.20.q	C_PETC
Non-specified Petroleum Products	p23.20.r	C_NSPP
Nuclear fuel	p23.3	C_NUCF
Plastics; basic	p24.a	C_PLAS
Secondary plastic for treatment; Re-processing of secondary plastic into new plastic	p24.a.w	C_PLAW
N-fertiliser	p24.b	C_NFER
P- and other fertiliser	p24.c	C_PFER
Chemicals nec	p24.d	C_CHEM
Charcoal	p24.e	C_CHAR
Additives/Blending Components	p24.f	C_ADDC
Biogasoline	p24.g	C_BIOG
Biodiesels	p24.h	C_BIOD
Other Liquid Biofuels	p24.i	C_OBIO
Rubber and plastic products (25)	p25	C_RUBP
Glass and glass products	p26.a	C_GLAS
Secondary glass for treatment; Re-processing of secondary glass into new glass	p26.a.w	C_GLAW
Ceramic goods	p26.b	C_CRMC
Bricks; tiles and construction products; in baked clay	p26.c	C_BRIK
Cement; lime and plaster	p26.d	C_CMNT
Ash for treatment; Re-processing of ash into clinker	p26.d.w	C_ASHW
Other non-metallic mineral products	p26.e	C_ONMM
Basic iron and steel and of ferro-alloys and first products thereof	p27.a	C_STEL
Secondary steel for treatment; Re-processing of secondary steel into new steel	p27.a.w	C_STEW
Precious metals	p27.41	C_PREM
Secondary preciuos metals for treatment; Re-processing of secondary preciuos metals into new preciuos metals	p27.41.w	C_PREW
Aluminium and aluminium products	p27.42	C_ALUM
Secondary aluminium for treatment; Re-processing of secondary aluminium into new aluminium	p27.42.w	C_ALUW
Lead; zinc and tin and products thereof	p27.43	C_LZTP

Secondary lead for treatment; Re-processing of secondary lead into new lead	p27.43.w	C_LZTW
Copper products	p27.44	C_COPP
Secondary copper for treatment; Re-processing of secondary copper into new copper	p27.44.w	C_COPW
Other non-ferrous metal products	p27.45	C_ONFM
Secondary other non-ferrous metals for treatment; Re-processing of secondary other non-ferrous metals into new other non-ferrous metals	p27.45.w	C_ONFW
Foundry work services	p27.5	C_METC
Fabricated metal products; except machinery and equipment (28)	p28	C_FABM
Machinery and equipment n.e.c. (29)	p29	C_MACH
Office machinery and computers (30)	p30	C_OFMA
Electrical machinery and apparatus n.e.c. (31)	p31	C_ELMA
Radio; television and communication equipment and apparatus (32)	p32	C_RATV
Medical; precision and optical instruments; watches and clocks (33)	p33	C_MEIN
Motor vehicles; trailers and semi-trailers (34)	p34	C_MOTO
Other transport equipment (35)	p35	C_OTRE
Furniture; other manufactured goods n.e.c. (36)	p36	C_FURN
Secondary raw materials	*p37*	*C_RYMS*
Bottles for treatment; Recycling of bottles by direct reuse	p37.w.1	C_BOTW
Electricity by coal	p40.11.a	C_POWC
Electricity by gas	p40.11.b	C_POWG
Electricity by nuclear	p40.11.c	C_POWN
Electricity by hydro	p40.11.d	C_POWH
Electricity by wind	p40.11.e	C_POWW
Electricity by petroleum and other oil derivatives	p40.11.f	C_POWP
Electricity by biomass and waste	p40.11.g	C_POWB
Electricity by solar photovoltaic	p40.11.h	C_POWS
Electricity by solar thermal	p40.11.i	C_POWE
Electricity by tide; wave; ocean	p40.11.j	C_POWO
Electricity by Geothermal	p40.11.k	C_POWM
Electricity nec	p40.11.l	C_POWZ
Transmission services of electricity	p40.12	C_POWT
Distribution and trade services of electricity	p40.13	C_POWD
Coke oven gas	p40.2.a	C_COOG
Blast Furnace Gas	p40.2.b	C_MBFG
Oxygen Steel Furnace Gas	p40.2.c	C_MOSG
Gas Works Gas	p40.2.d	C_MGWG
Biogas	p40.2.e	C_MBIO
Distribution services of gaseous fuels through mains	p40.2.1	C_GASD
Steam and hot water supply services	p40.3	C_HWAT
Collected and purified water; distribution services of water (41)	p41	C_WATR

Construction work (45)	p45	C_CONS
Secondary construction material for treatment; Re-processing of secondary construction material into aggregates	p45.w	C_CONW
Sale; maintenance; repair of motor vehicles; motor vehicles parts; motorcycles; motor cycles parts and accessoiries	p50.a	C_TDMO
Retail trade services of motor fuel	p50.b	C_TDFU
Wholesale trade and commission trade services; except of motor vehicles and motorcycles (51)	p51	C_TDWH
Retail trade services; except of motor vehicles and motorcycles; repair services of personal and household goods (52)	p52	C_TDRT
Hotel and restaurant services (55)	p55	C_HORE
Railway transportation services	p60.1	C_TRAI
Other land transportation services	p60.2	C_TLND
Transportation services via pipelines	p60.3	C_TPIP
Sea and coastal water transportation services	p61.1	C_TWAS
Inland water transportation services	p61.2	C_TWAI
Air transport services (62)	p62	C_TAIR
Supporting and auxiliary transport services; travel agency services (63)	p63	C_TAUX
Post and telecommunication services (64)	p64	C_PTEL
Financial intermediation services; except insurance and pension funding services (65)	p65	C_FINT
Insurance and pension funding services; except compulsory social security services (66)	p66	C_FINS
Services auxiliary to financial intermediation (67)	p67	C_FAUX
Real estate services (70)	p70	C_REAL
Renting services of machinery and equipment without operator and of personal and household goods (71)	p71	C_MARE
Computer and related services (72)	p72	C_COMP
Research and development services (73)	p73	C_RESD
Other business services (74)	p74	C_OBUS
Public administration and defence services; compulsory social security services (75)	p75	C_PADF
Education services (80)	p80	C_EDUC
Health and social work services (85)	p85	C_HEAL
Food waste for treatment: incineration	*p90.1.a*	*C_INCF*
Paper waste for treatment: incineration	*p90.1.b*	*C_INCP*
Plastic waste for treatment: incineration	*p90.1.c*	*C_INCL*
Intert/metal waste for treatment: incineration	*p90.1.d*	*C_INCM*
Textiles waste for treatment: incineration	*p90.1.e*	*C_INCT*
Wood waste for treatment: incineration	*p90.1.f*	*C_INCW*
Oil/hazardous waste for treatment: incineration	*p90.1.g*	*C_INCO*
Food waste for treatment: biogasification and land application	*p90.2.a*	*C_BIOF*
Paper waste for treatment: biogasification and land application	*p90.2.b*	*C_BIOP*
Sewage sludge for treatment: biogasification and land application	*p90.2.c*	*C_BIOS*

Food waste for treatment: composting and land application	*p90.3.a*	*C_COMF*
Paper and wood waste for treatment: composting and land application	*p90.3.b*	*C_COMW*
Food waste for treatment: waste water treatment	*p90.4.a*	*C_WASF*
Other waste for treatment: waste water treatment	*p90.4.b*	*C_WASO*
Food waste for treatment: landfill	p90.5.a	C_LANF
Paper for treatment: landfill	p90.5.b	C_LANP
Plastic waste for treatment: landfill	p90.5.c	C_LANL
Inert/metal/hazardous waste for treatment: landfill	p90.5.d	C_LANI
Textiles waste for treatment: landfill	p90.5.e	C_LANT
Wood waste for treatment: landfill	p90.5.f	C_LANW
Membership organisation services n.e.c. (91)	p91	C_ORGA
Recreational; cultural and sporting services (92)	p92	C_RECR
Other services (93)	p93	C_OSER
Private households with employed persons (95)	p95	C_PRHH
Extra-territorial organizations and bodies	p99	C_EXTO

Activities

Activity name	Code 1	Code 2
Cultivation of paddy rice	i01.a	A_PARI
Cultivation of wheat	i01.b	A_WHEA
Cultivation of cereal grains nec	i01.c	A_OCER
Cultivation of vegetables; fruit; nuts	i01.d	A_FVEG
Cultivation of oil seeds	i01.e	A_OILS
Cultivation of sugar cane; sugar beet	i01.f	A_SUGB
Cultivation of plant-based fibers	i01.g	A_FIBR
Cultivation of crops nec	i01.h	A_OTCR
Cattle farming	i01.i	A_CATL
Pigs farming	i01.j	A_PIGS
Poultry farming	i01.k	A_PLTR
Meat animals nec	i01.l	A_OMEA
Animal products nec	i01.m	A_OANP
Raw milk	i01.n	A_MILK
Wool; silk-worm cocoons	i01.o	A_WOOL
Manure treatment (conventional); storage and land application	i01.w.1	A_MANC
Manure treatment (biogas); storage and land application	i01.w.2	A_MANB
Forestry; logging and related service activities (02)	i02	A_FORE
Fishing; operating of fish hatcheries and fish farms; service activities incidental to fishing (05)	i05	A_FISH
Mining of coal and lignite; extraction of peat (10)	i10	A_COAL
Extraction of crude petroleum and services related to crude oil extraction; excluding surveying	i11.a	A_COIL
Extraction of natural gas and services related to natural gas extraction; excluding surveying	i11.b	A_GASE
Extraction; liquefaction; and regasification of other petroleum and gaseous materials	i11.c	A_OGPL
Mining of uranium and thorium ores (12)	i12	A_ORAN
Mining of iron ores	i13.1	A_IRON
Mining of copper ores and concentrates	i13.20.11	A_COPO
Mining of nickel ores and concentrates	i13.20.12	A_NIKO
Mining of aluminium ores and concentrates	i13.20.13	A_ALUO
Mining of precious metal ores and concentrates	i13.20.14	A_PREO
Mining of lead; zinc and tin ores and concentrates	i13.20.15	A_LZTO
Mining of other non-ferrous metal ores and concentrates	i13.20.16	A_ONFO
Quarrying of stone	i14.1	A_STON
Quarrying of sand and clay	i14.2	A_SDCL
Mining of chemical and fertilizer minerals; production of salt; other mining and quarrying n.e.c.	i14.3	A_CHMF
Processing of meat cattle	i15.a	A_PCAT
Processing of meat pigs	i15.b	A_PPIG
Processing of meat poultry	i15.c	A_PPLT

Production of meat products nec	i15.d	A_POME
Processing vegetable oils and fats	i15.e	A_VOIL
Processing of dairy products	i15.f	A_DAIR
Processed rice	i15.g	A_RICE
Sugar refining	i15.h	A_SUGR
Processing of Food products nec	i15.i	A_OFOD
Manufacture of beverages	i15.j	A_BEVR
Manufacture of fish products	i15.k	A_FSHP
Manufacture of tobacco products (16)	i16	A_TOBC
Manufacture of textiles (17)	i17	A_TEXT
Manufacture of wearing apparel; dressing and dyeing of fur (18)	i18	A_GARM
Tanning and dressing of leather; manufacture of luggage; handbags; saddlery; harness and footwear (19)	i19	A_LETH
Manufacture of wood and of products of wood and cork; except furniture; manufacture of articles of straw and plaiting materials (20)	i20	A_WOOD
Re-processing of secondary wood material into new wood material	i20.w	A_WOOW
Pulp	i21.1	A_PULP
Re-processing of secondary paper into new pulp	i21.w.1	A_PAPR
Paper	i21.2	A_PAPE
Publishing; printing and reproduction of recorded media (22)	i22	A_MDIA
Manufacture of coke oven products	i23.1	A_COKE
Petroleum Refinery	i23.2	A_REFN
Processing of nuclear fuel	i23.3	A_NUCF
Plastics; basic	i24.a	A_PLAS
Re-processing of secondary plastic into new plastic	i24.a.w	A_PLAW
N-fertiliser	i24.b	A_NFER
P- and other fertiliser	i24.c	A_PFER
Chemicals nec	i24.d	A_CHEM
Manufacture of rubber and plastic products (25)	i25	A_RUBP
Manufacture of glass and glass products	i26.a	A_GLAS
Re-processing of secondary glass into new glass	i26.a.w	A_GLAW
Manufacture of ceramic goods	i26.b	A_CRMC
Manufacture of bricks; tiles and construction products; in baked clay	i26.c	A_BRIK
Manufacture of cement; lime and plaster	i26.d	A_CMNT
Re-processing of ash into clinker	i26.d.w	A_ASHW
Manufacture of other non-metallic mineral products n.e.c.	i26.e	A_ONMM
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	i27.a	A_STEL
Re-processing of secondary steel into new steel	i27.a.w	A_STEW
Precious metals production	i27.41	A_PREM
Re-processing of secondary preciuos metals into new preciuos metals	i27.41.w	A_PREW
Aluminium production	i27.42	A_ALUM
Re-processing of secondary aluminium into new aluminium	i27.42.w	A_ALUW
Lead; zinc and tin production	i27.43	A_LZTP
Re-processing of secondary lead into new lead	i27.43.w	A_LZTW

Copper production	i27.44	A_COPP
Re-processing of secondary copper into new copper	i27.44.w	A_COPW
Other non-ferrous metal production	i27.45	A_ONFM
Re-processing of secondary other non-ferrous metals into new other non-ferrous metals	i27.45.w	A_ONFW
Casting of metals	i27.5	A_METC
Manufacture of fabricated metal products; except machinery and equipment (28)	i28	A_FABM
Manufacture of machinery and equipment n.e.c. (29)	i29	A_MACH
Manufacture of office machinery and computers (30)	i30	A_OFMA
Manufacture of electrical machinery and apparatus n.e.c. (31)	i31	A_ELMA
Manufacture of radio; television and communication equipment and apparatus (32)	i32	A_RATV
Manufacture of medical; precision and optical instruments; watches and clocks (33)	i33	A_MEIN
Manufacture of motor vehicles; trailers and semi-trailers (34)	i34	A_MOTO
Manufacture of other transport equipment (35)	i35	A_OTRE
Manufacture of furniture; manufacturing n.e.c. (36)	i36	A_FURN
Recycling of waste and scrap	*i37*	A_RYMS
Recycling of bottles by direct reuse	i37.w.1	A_BOTW
Production of electricity by coal	i40.11.a	A_POWC
Production of electricity by gas	i40.11.b	A_POWG
Production of electricity by nuclear	i40.11.c	A_POWN
Production of electricity by hydro	i40.11.d	A_POWH
Production of electricity by wind	i40.11.e	A_POWW
Production of electricity by petroleum and other oil derivatives	i40.11.f	A_POWP
Production of electricity by biomass and waste	i40.11.g	A_POWB
Production of electricity by solar photovoltaic	i40.11.h	A_POWS
Production of electricity by solar thermal	i40.11.i	A_POWE
Production of electricity by tide; wave; ocean	i40.11.j	A_POWO
Production of electricity by Geothermal	i40.11.k	A_POWM
Production of electricity nec	i40.11.l	A_POWZ
Transmission of electricity	i40.12	A_POWT
Distribution and trade of electricity	i40.13	A_POWD
Manufacture of gas	i40.2.a	A_MGWG
Distribution of gaseous fuels through mains	i40.2.b	A_GASD
Steam and hot water supply	i40.3	A_HWAT
Collection; purification and distribution of water (41)	i41	A_WATR
Construction (45)	i45	A_CONS
Re-processing of secondary construction material into aggregates	i45.w	A_CONW
Sale; maintenance; repair of motor vehicles; motor vehicles parts; motorcycles; motor cycles parts and accessoiries	i50.a	A_TDMO
Retail sale of automotive fuel	i50.b	A_TDFU
Wholesale trade and commission trade; except of motor vehicles and motorcycles (51)	i51	A_TDWH

Retail trade; except of motor vehicles and motorcycles; repair of personal and household goods (52)	i52	A_TDRT
Hotels and restaurants (55)	i55	A_HORE
Transport via railways	i60.1	A_TRAI
Other land transport	i60.2	A_TLND
Transport via pipelines	i60.3	A_TPIP
Sea and coastal water transport	i61.1	A_TWAS
Inland water transport	i61.2	A_TWAI
Air transport (62)	i62	A_TAIR
Supporting and auxiliary transport activities; activities of travel agencies (63)	i63	A_TAUX
Post and telecommunications (64)	i64	A_PTEL
Financial intermediation; except insurance and pension funding (65)	i65	A_FINT
Insurance and pension funding; except compulsory social security (66)	i66	A_FINS
Activities auxiliary to financial intermediation (67)	i67	A_FAUX
Real estate activities (70)	i70	A_REAL
Renting of machinery and equipment without operator and of personal and household goods (71)	i71	A_MARE
Computer and related activities (72)	i72	A_COMP
Research and development (73)	i73	A_RESD
Other business activities (74)	i74	A_OBUS
Public administration and defence; compulsory social security (75)	i75	A_PADF
Education (80)	i80	A_EDUC
Health and social work (85)	i85	A_HEAL
Incineration of waste: Food	*i90.1.a*	A_INCF
Incineration of waste: Paper	*i90.1.b*	A_INCP
Incineration of waste: Plastic	*i90.1.c*	A_INCL
Incineration of waste: Metals and Inert materials	*i90.1.d*	A_INCM
Incineration of waste: Textiles	*i90.1.e*	A_INCT
Incineration of waste: Wood	*i90.1.f*	A_INCW
Incineration of waste: Oil/Hazardous waste	*i90.1.g*	A_INCO
Biogasification of food waste; incl. land application	*i90.2.a*	A_BIOF
Biogasification of paper; incl. land application	*i90.2.b*	A_BIOP
Biogasification of sewage slugde; incl. land application	*i90.2.c*	A_BIOS
Composting of food waste; incl. land application	*i90.3.a*	A_COMF
Composting of paper and wood; incl. land application	*i90.3.b*	A_COMW
Waste water treatment; food	*i90.4.a*	A_WASF
Waste water treatment; other	*i90.4.b*	A_WASO
Landfill of waste: Food	i90.5.a	A_LANF
Landfill of waste: Paper	i90.5.b	A_LANP
Landfill of waste: Plastic	i90.5.c	A_LANL
Landfill of waste: Inert/metal/hazardous	i90.5.d	A_LANI
Landfill of waste: Textiles	i90.5.e	A_LANT
Landfill of waste: Wood	i90.5.f	A_LANW
Activities of membership organisation n.e.c. (91)	i91	A_ORGA

Recreational; cultural and sporting activities (92)	i92	A_RECR
Other service activities (93)	i93	A_OSER
Private households with employed persons (95)	i95	A_PRHH
Extra-territorial organizations and bodies	i99	A_EXTO

Final demand

Final demand category name	Code 1	Code 2
Final consumption expenditure by households	y01	F_HOUS
Final consumption expenditure by non-profit organizations serving households (NPISH)	y02.a	F_NPSH
Final consumption expenditure by government	y02.b	F_GOVE
Gross fixed capital formation	y04	I_GFCF
Changes in inventories	y05.a	I_CHIN
Changes in valuables	y05.b	I_CHVA

Waste fractions

Food
Manure
Textile
Wood
Paper
Plastics
Glass
Ashes
Steel
Precious metals
Aluminium
Lead
Copper
non-ferrous metals
Construction materials and mining waste (excl. unused mining material)
Oils and hazardous materials
Sewage
Unused mining material

Resources

Chemical and fertilizer minerals
Other non-ferrous metal ores
Slate
Peat
Fish, unspecified, in sea
Carbon dioxide, in air
Uranium
Iron ore
Copper ore
Nickel ore
Bauxite
Precious metal ores
Lead, zinc and tin ores
Oxygen
Sand and clay
Gravel
Minerals nec. (incl nitrogen and hydrogen)
Unspecified input
Animal matter
Oil, crude
Gas, natural
Other metal ore
Kaolin
Limestone
Other industrial minerals
Coal, hard
Coal, brown
Gold
Lead ore
Platinum
Silver
Tin ore
Zinc ore
Water, unspecified natural origin

Land use

Arable
Forest
grassland
Other
infrastructure

Emissions

Carbon dioxide, fossil
N2O
CH4
HFCs
PFCs
SF6
NOX
Sox
NH3
NMVOC
CO
CFCs
HCFCs
Pb
Cd
Hg
As
Cr
Cu
Ni
Se
Zn
Aldrin
Chlordane
Chlordecone
Dieldrin
Endrin
Heptachlor
Hexabr.-biph.
Mirex
Toxaphene
HCH
DDT
PCB
dioxin
PM10
PAH (total of 4 components, sum of EM_AIR.43, 45, 46, 47)
Benzene
1,3 Butadiene
Formaldehyd

PM2.5
Furans
Benzo-[a]-pyrene
PBDEs
Benzo-[b]-fluoranthene
Benzo-[k]-fluoranthene
Indeno-[1,2,3-cd]-pyrene
HCB
PCDD/F (dioxins and furans)
TSP (total suspended particulate)
N
P
BOD
N
P
Cd
Cu
Zn
Pb
Hg
Cr
Ni
C
other emissions
Carbon dioxide, biogenic
Carbon dioxide, from unregistered waste