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Practical guide to the EXIOBASE hybrid version

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Preface

This is a quick practical user-guide to understand the core principles of the EXIOBASE hybrid version and how to interpret the data included in the files updated on exiobase.eu.

When citing this report, please use the following reference:

Merciai, S. (2021). Practical guide to the EXIOBASE hybrid version. 2.-0 LCA consultants, Aalborg, Denmark.

05/2020

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1 Introduction

The hybrid version of EXIOBASE (Merciai & Schmidt, 2018), which is part of wider input-output database (Stadler et al., 2018), is the first ever published multi-regional supply and use table. Here the term *hybrid* indicates that physical flows are accounted in mass units, energy flows in TJ and services in millions of euro (current prices).
The EXIOBASE hybrid supply and use tables (MR-HSUTs) are analytical tools that go beyond the commonly used supply and use table that are accounted in monetary units (Miller & Blair, 2008). Usually, in the latter the monetary balance is the only balance that is checked. Instead, in th MR-HSUTs, mass and energy balances play a fundamental role. As consequence of this, an IO-practioner may found difficulties to grasp the logic behind the hybrid tables and their structure. At the same time, an LCA-practicioner, which is familiar to concepts of mass and energy balances, may have problems to understand the methodological approach of supply and use tables.
This document aims to describe in a concise way the logic and the structure of the MR-HSUTs and to guide the reader within the files published on the exiobase webpage.
However, for a more in-depth knowledge of the EXIOBASE hybrid version, please check the EXIOBASE report (Merciai & Schmidt, 2016) and the article on the special JIE issue on EXIOBASE (Merciai & Schmidt, 2018).

2 Fundamental principles

The EXIOBASE hybrid supply and use tables (MR-HSUTs) are a snapshot of the reality in a given year. MR-HSUTs aim to describe the exchanges between productive activities, between activities and consumers and, finally, between the environment and humans.
The fundamental principles of MR-HSUTs are the mass/energy/monetary balances. These principles are adopted in the MR-SUTs by means of two laws:

- Input balance -> for each input there must be outputs of the same magnitude. An input can be a product, a waste flow or a natural resource;
- Process balance -> if an activity carries out a product, it must have enough inputs to implement the production. In other words, the transformation efficiency times the inputs must be equal to the final product.

2.1 Input balance

Let us assume that a generic activity has several inputs. For each input there are six possible destinations:

- *Final products (p):* the inputs (or part of it) is embodied in the products carried out by the activity. For example, the oil seeds used to produce oil. A final product also includes by-product, for example the oil seed cake used as animal feed.
- *Packaging (k)*: the input is used to wrap the final good. For example the bottle used for the oil
- *Non marketable* products (m): the input (or part of it) is embedded in products that are not sold on the market. An example can be the fertilizers that is included in straw using for animal bedding.
- *Stock addition (s)*: the input (or part of it) is stored in the activity at the end of the time period. For example, a chair purchased by an activity.
- *Waste (w):* the input (or part of it) is discharged as waste
- *Emissions (e)*: the input (or part of it) is emitted directly to the environment.

Of course, the six destinations may not occur for each input simultaneously. Some inputs may have only one or two destinations, it all depends on the nature of the input in the activity. The important thing is that the partition in the several destinations must give the exact amount of the input. Only in this way the input balance will be respected. What just said for activities can be extended to final consumption.

Be $\alpha_{p,i}$ a transformation coefficients that converts the input of *i, i.e.* u_i, into final product *p.* $\alpha_{p,i}$ indicates the share of *i* that in embodied in the produced product. Then be p_i the portion of product *p* obtained from the input *i*. Generalizing what just said to all the destinations of an input, the input balance can be implemented as follows:

Equation 1

$$p_i + k_i + m_i + s_i + w_i + e_i = u_i \quad \text{where} \quad \begin{matrix} p_i = \alpha_{p,i} \cdot u_i \\ k_i = \alpha_{k,i} \cdot u_i \\ m_i = \alpha_{m,i} \cdot u_i \\ s_i = \alpha_{s,i} \cdot u_i \\ w_i = \alpha_{w,i} \cdot u_i \\ e_i = \alpha_{e,i} \cdot u_i \end{matrix} \qquad \forall i$$

i indicates any type of input, e.g products, natural resources, waste, etc. Another way of interpreting the input balance is as follows:

Equation 2

$$\alpha_{p,i} + \alpha_{k,i} + \alpha_{m,i} + \alpha_{s,i} + \alpha_{w,i} + \alpha_{e,i} = 1 \quad \forall i$$

The input balance is valid for each input and for each activity, including final consumption. The input balance is implemented for any unit of measurement used in the HSUTs.

2.2 Process balance

Let us assume than an activity produces a final product *p* using several input $u_1, \dots u_n$. The process balance can be described as follows:

Equation 3

$$\sum_{x=1}^{n} u_x \cdot \alpha_{p,u_x} = p$$

Where α_{p,u_x} is a transformation coefficient of input u_x into final product p and indicates the share of u_x embodied in the product p. The process balance is valid for each productive process and is implemented for any unit of measurement used in the HSUTs.

3 Logic of EXIOBASE hybrid supply and use tables

Figure 1 shows the underlying logic applied in the MR-HSUTs, where the input and activity balances are respected. A generic activity that transforms inputs into outputs is shown. For simplicity only two inputs are highlighted, i.e. input x and y.

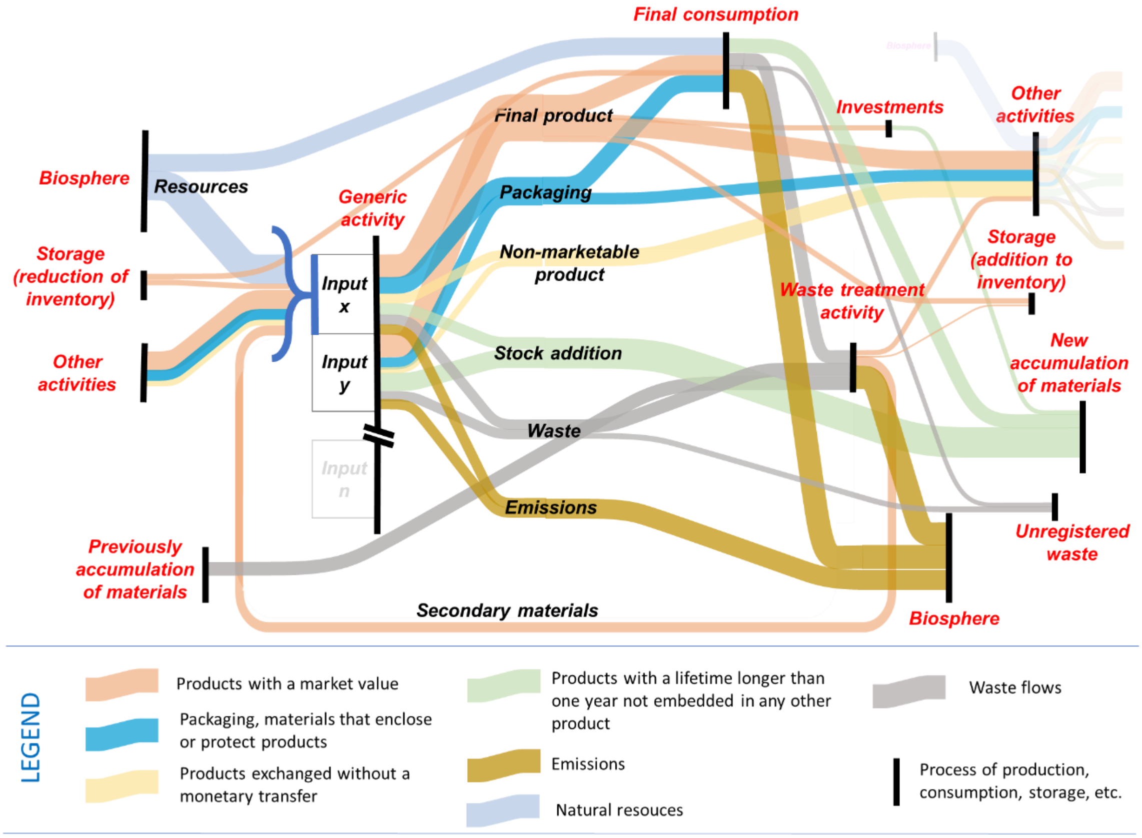


Figure 1 – A Sankey diagram showing the logic of the EXIOBASE hybrid supply and use tables. The figure shows a general case. An input (x) can be a resource, a product or a waste flow. Such input can be embodied into products, used for the packaging, embodied in non marketable goods and so on. In turn, any output of an activity can feed to other activities or be discharged into the environment.

The possible origins of an input are shown on the left side of the generic productive activity (for simplicity this generic activity has no input of waste). Moving to the right, we can see how each output of an activity is linked to other actors or nodes. An output can be consumed, treated by other activities (incl. waste treatment activities), stored or discharged into the environment.

Figure 1 shows how inputs, outputs and activities are connected in the MR-HSUTs so to generate a consistent accounting tool. MR-HSUTs are matrices and their format is shown in Figure 2.

Currently EXIOBASE MR-HSUTs can be downloaded on the webpage exiobase.eu. The entire database is included in a few csv and excel files that are organized as shown in Figure 2.

The next chapters will illustrate the link between flows in Figure 1 and the files in Figure 2.

In the MR-HSUTs flows are accounted in dry-matter. In order to determine the wet weight, dry matter coefficients are provided on exiobase.eu. Dividing each flow by his dry matter coefficient it is possible to get flows in their real weight. Finally, mining products are accounted in metal concentrations. Therefore the value of extracted minerals does not indicate the weight of the ore but the metal included in it.

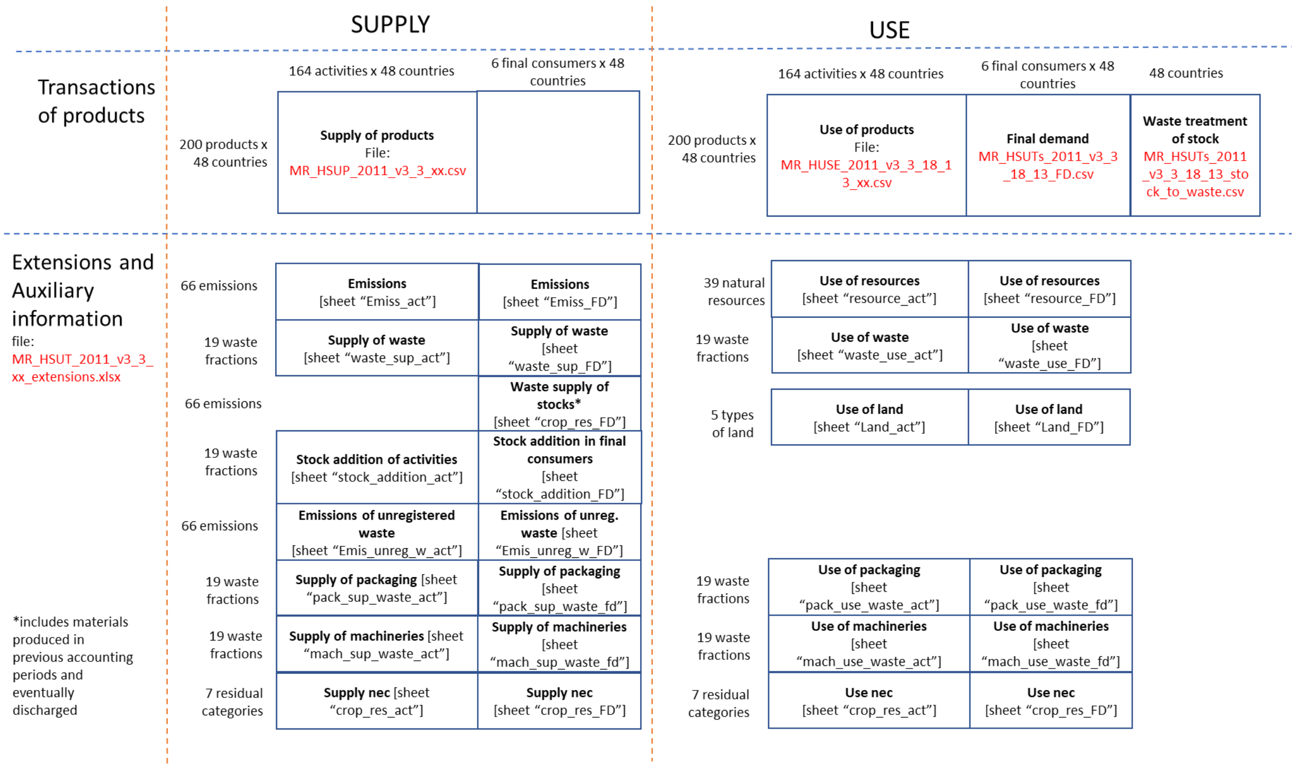


Figure 2 – EXIOBASE HSUTs framework and indication of where the accounts are included in the dataset on exiobase.eu

4 Content of the EXIOBASE hybrid database

In this Chapter it will be shown where to find what in the EXIOBASE MR-HSUTs dataset. In the Sankey diagram shown in Figure 1, the flows on the right side of the black bars are outputs (outgoing flows) for that specific activity and are included in the supply table. Contrarily, flows on left side are inputs (ingoing flows) and are included in the use table.

4.1 Supply tables

The Supply table shows everything that is supplied by productive activities, by consumers or by storages. The latter indicates finished and semi-finished products that were accumulated at the end of previous periods. These products are then sold or further processed in the accounting period.

Figure 3 shows were the outputs of productive activities are stored in the Exiobase files, while Figure 4 shows the outputs related to final consumers. In section 4.3 the difference between stock addition and waste will be further detailed.

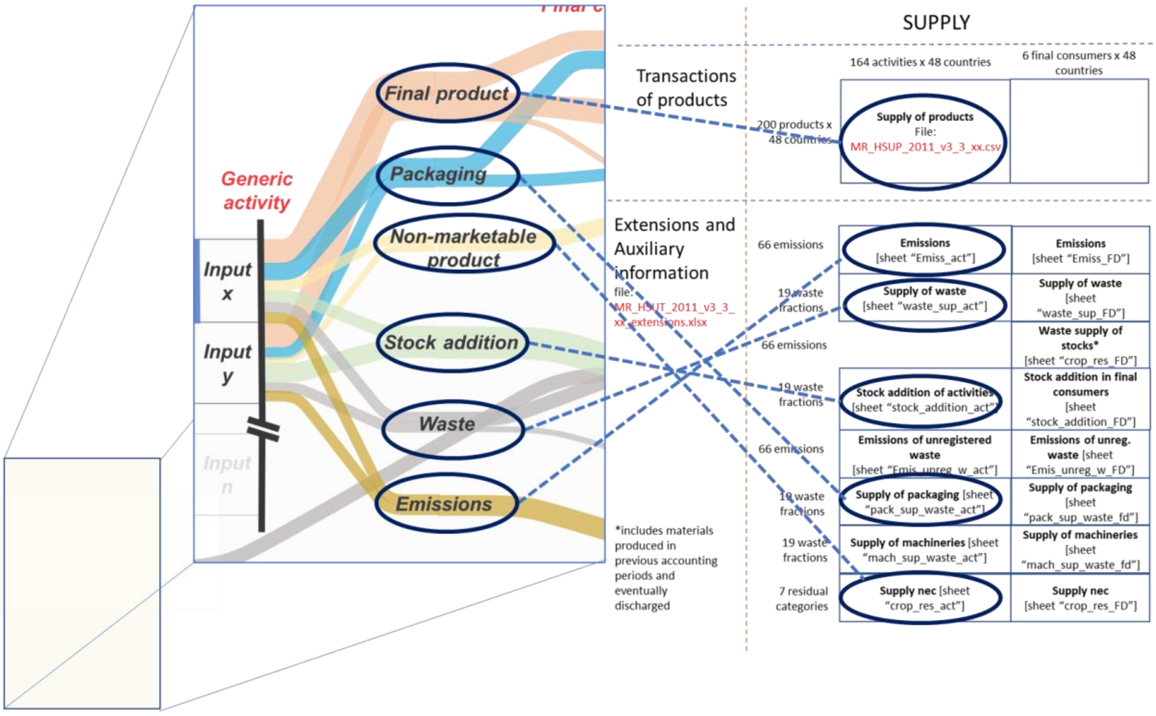


Figure 3 – Output flows of activities stored in the EXIOBASE files.

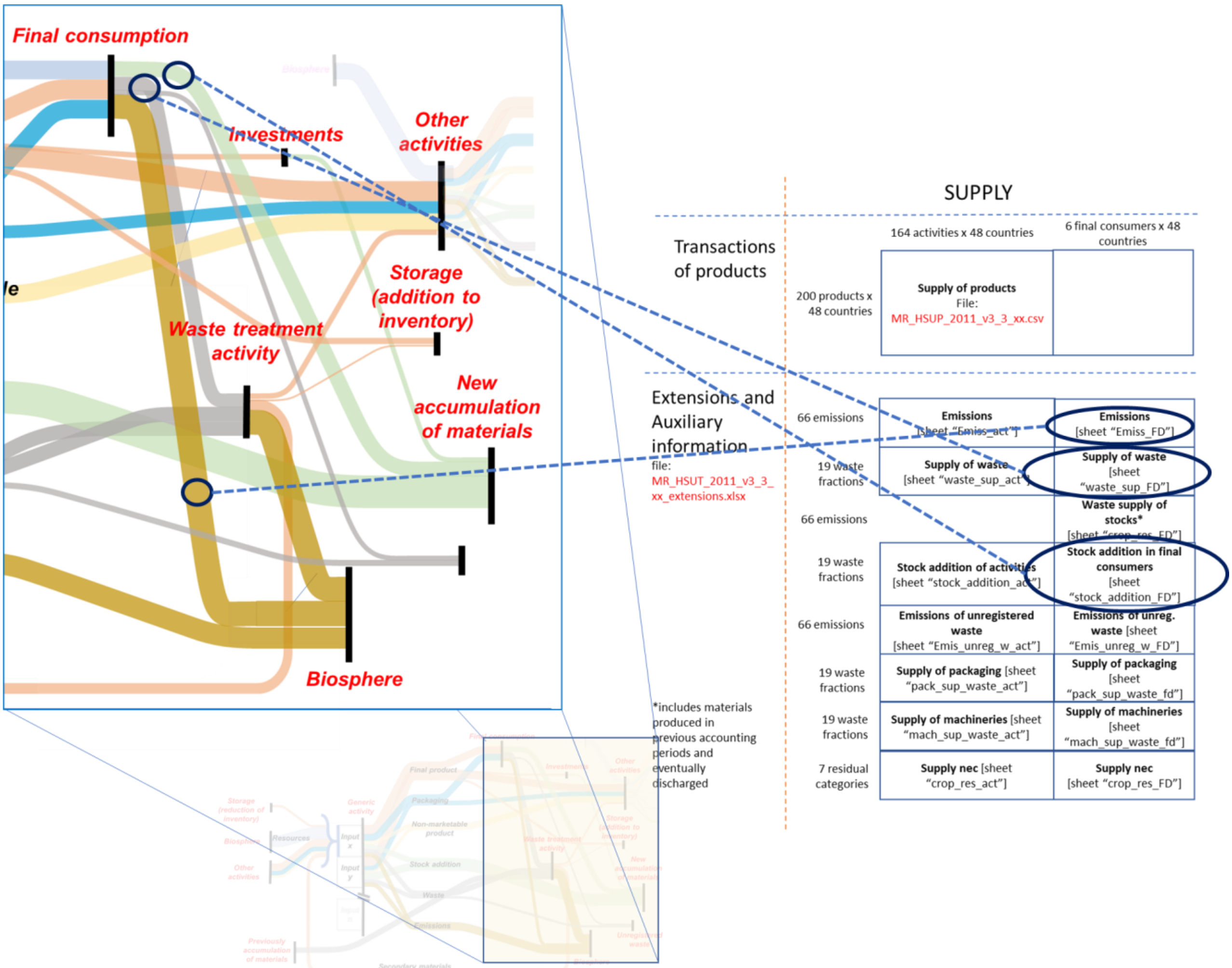


Figure 4 – Output flows of final consumers stored in the EXIOBASE files

The remaining supply aggregates shown in the EXIOBASE files and which have not been discussed in this chapter will be shown after the following chapter.

4.2 Use table

The Use tables show how the outputs (resources, products, waste flows, etc.) are used by the different actors. Figure 5 shows what flows may enter into productive activities and where in the EXIOBASE files are displayed. Figure 6 shows what flows are used by final consumers and where they are in the EXIOBASE files.

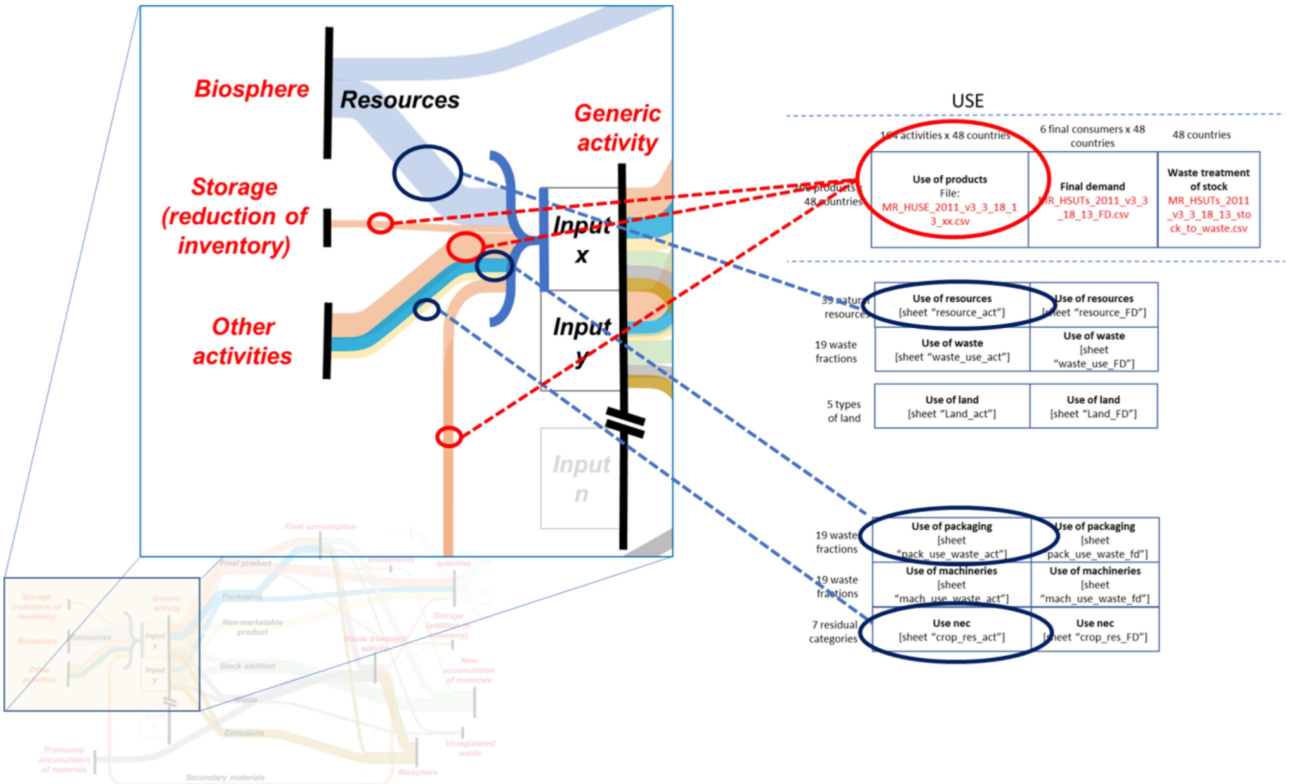


Figure 5 –Input flows of a generic productive activity in the EXIOBASE files

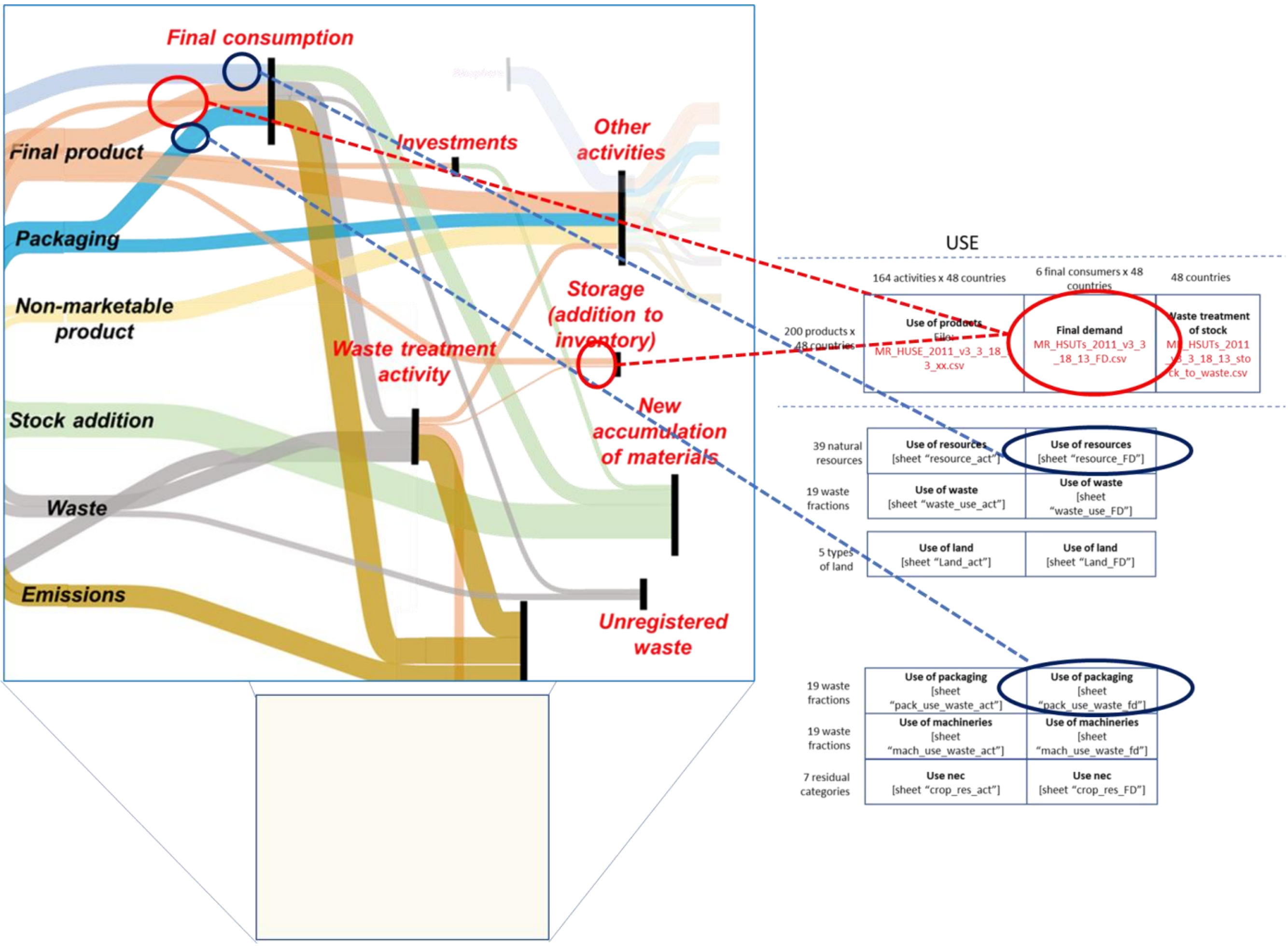


Figure 6 – Input flows to final consumption in the EXIOBASE files

4.3 Waste accounts

Waste includes end-of-life (EoL) products, used packaging and scraps that are treated in waste management activities or in other activities producing secondary materials. In order to determine if a product is discharged or accumulated, so to be used for the following periods, a lifetime function is adopted.

In the MR-HSUTs a mass flow of waste is always accounted in the extensions, both in the supply and use sides. Waste management activities provides services which are demanded by consumuers. These services can be found in the use and supply tables and they are accounted in 'tonnes (service)'.

Waste and Stocks, lifetime functions

In Exiobase, a lifetime function is associated to each product. A lifetime function indicates how much of the total mass of demanded products will be discharged throughout periods of time. Considering the total mass of a product demanded by a generic actor in a period t, the share discharged within one year is considered to be waste in the same period. The remaining part contributes to stock addition and will be discharged in the following years. Of course, only a product that is not embodied in the final product or emitted can become waste or stock addition.

When constructing a time series, the lifetime will also determine the amount of obsolete stocks (i.e. the reduction of stocks) that are disposed as waste (see Appendix).

In Exiobase, it is assumed that the lifetime of packaging materials is one year. Hence all the packaging become waste as the product which protects is purchased.

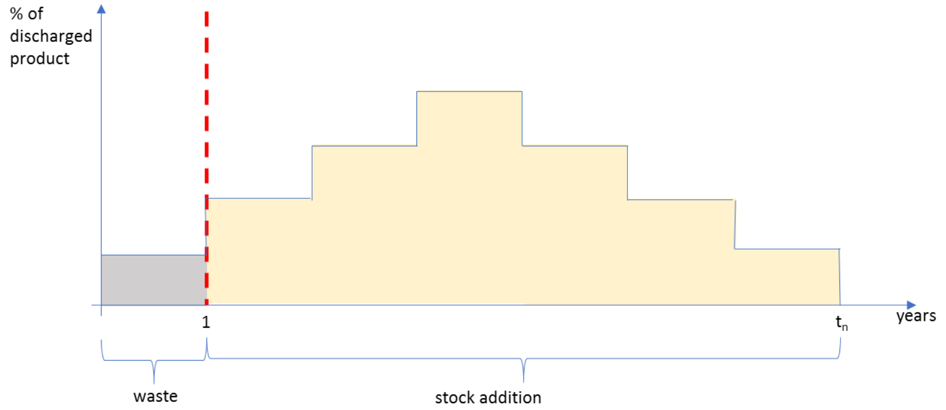
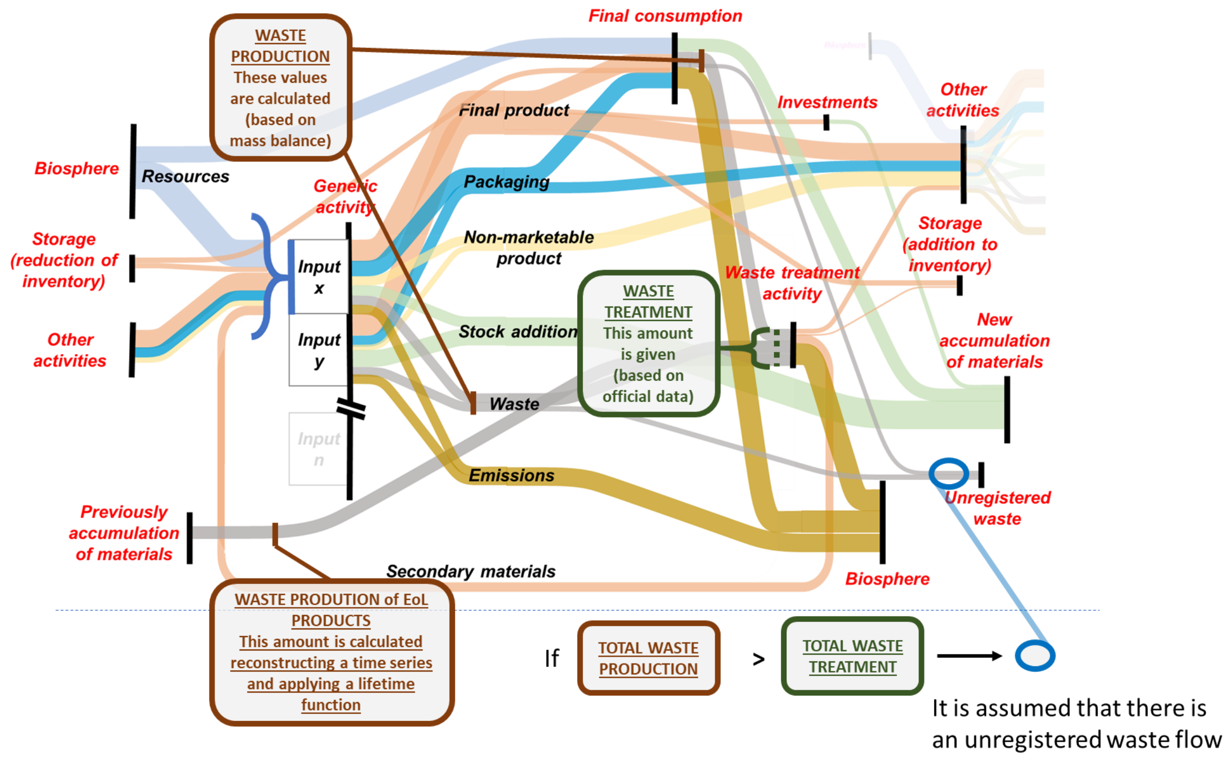


Figura 1 – Generic lifetime function associated to a product. After t_n years, the total mass of the product will be discharged as waste.

The lifetime is also applied to intermediate goods or to products purchased by final consumers.As a consequence, a stock addition row is added in the extensions of activities and of final demand, e.g. in the column households. hese rows should not be confused withproducts included in the column gross fixed capital formation, which indicates the investments of activities[1].



[1] The stock addition row in the extension may sound weird for a input-output practioners. Indeed, in the monetary input-output tables only in the column of gross capital formation it is 'accepted' to have products that can be used for more than one accounting period. All the intermediate inputs are assumed to be consumed within the accounting period. This is a pure economic construct. There are indeed products accounted as intermediate inputs, or as final consumption (e.g. durable goods) that may have a lifetime longer than one year (see for example SNA (2008) par. 1.53 or 10.34 https://unstats.un.org/unsd/nationalaccount/docs/SNA2008.pdf). When performing a mass balance of a society, it is important to go beyond the economic assumptions and to consider the lifetime of products.

Figure 7 – Waste balance in the EXIOBASE MR-HSUTs

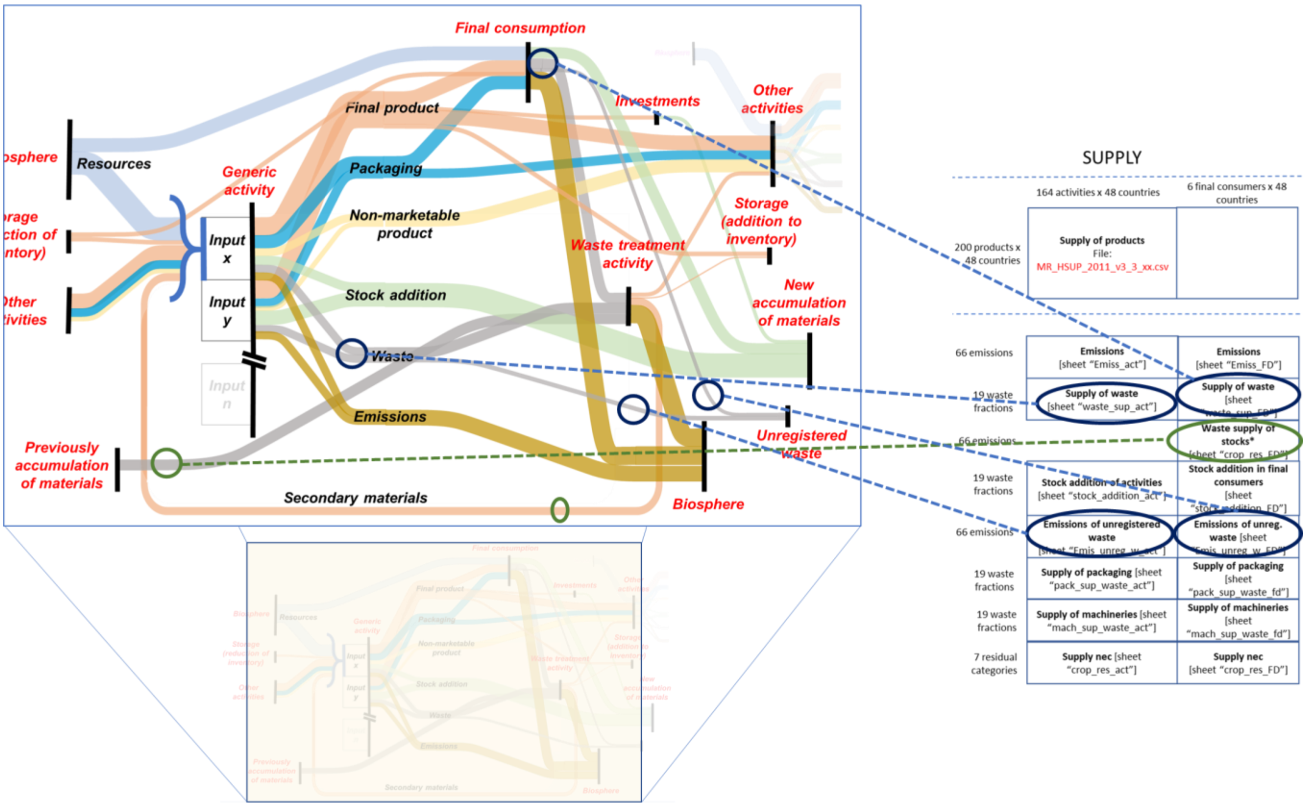


Figure 8 – Supply of waste and their location in the EXIOBASE MR-HSUTs files. The mass of produced waste is included in the extensions.

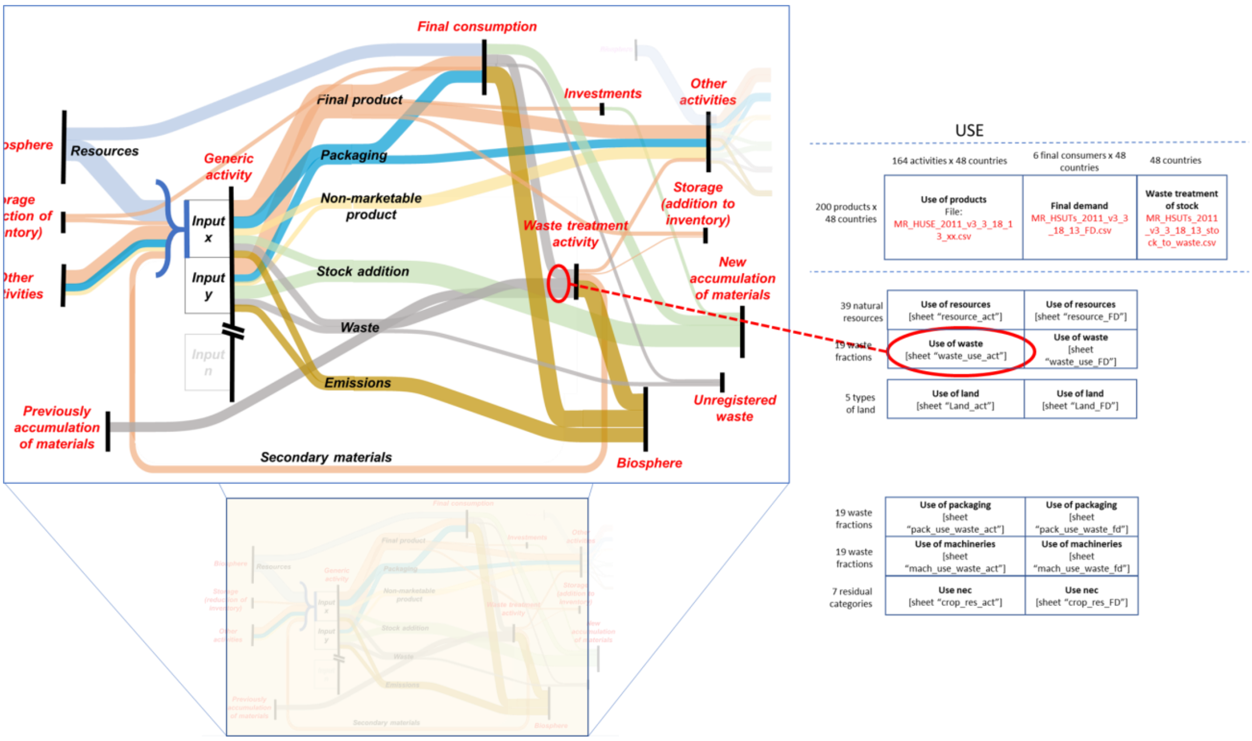


Figure 9 - Waste flows in the use table and their location in the EXIOBASE MR-HSUTs files

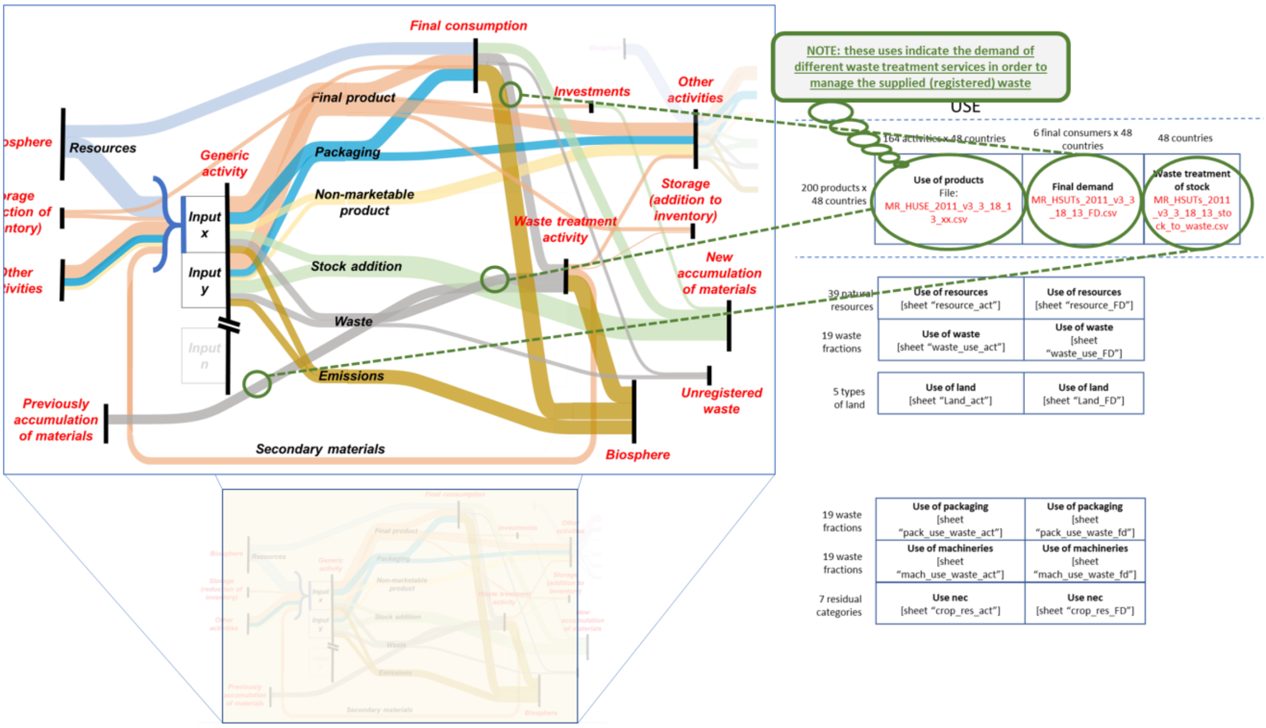


Figure 10 – Use of waste treatment services. The latter is meant to be a collection service of waste going to different waste treatment.

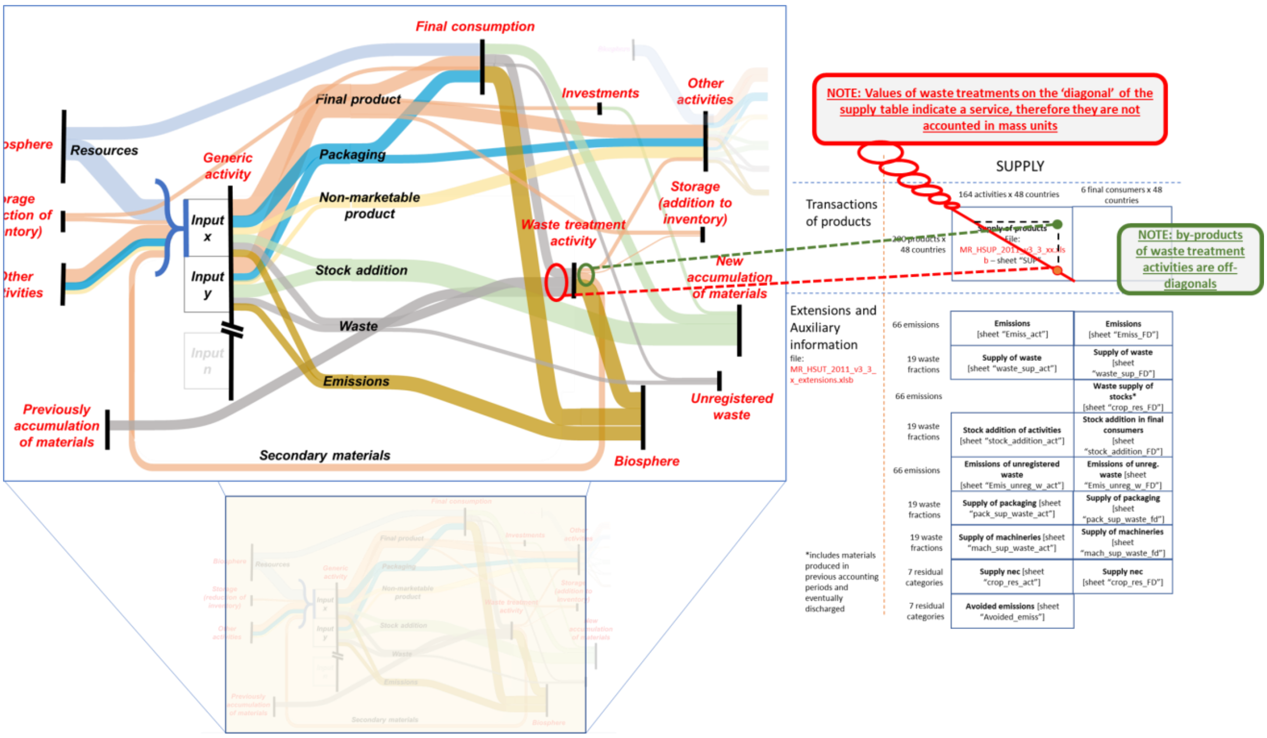


Figure 11 – Supply of waste treatment services. The latter is meant to be a collection service of waste going to different waste treatment. waste treatment service providers can also produce products, such as secondary materials or electricity.

Obsolete stocks discharged

Obsolete stocks are material produced and accumulated in previous years and discharged as waste in the current period (see Appendix). In Exiobase there are two accounts for these flows. One, in the use side, indicates how the obsolete stocks are treated. Therefore, the use of waste treatment services are shown. The other, in the supply side, shows the waste fractions that are produced. Therefore they are included in the extension of the supply table.

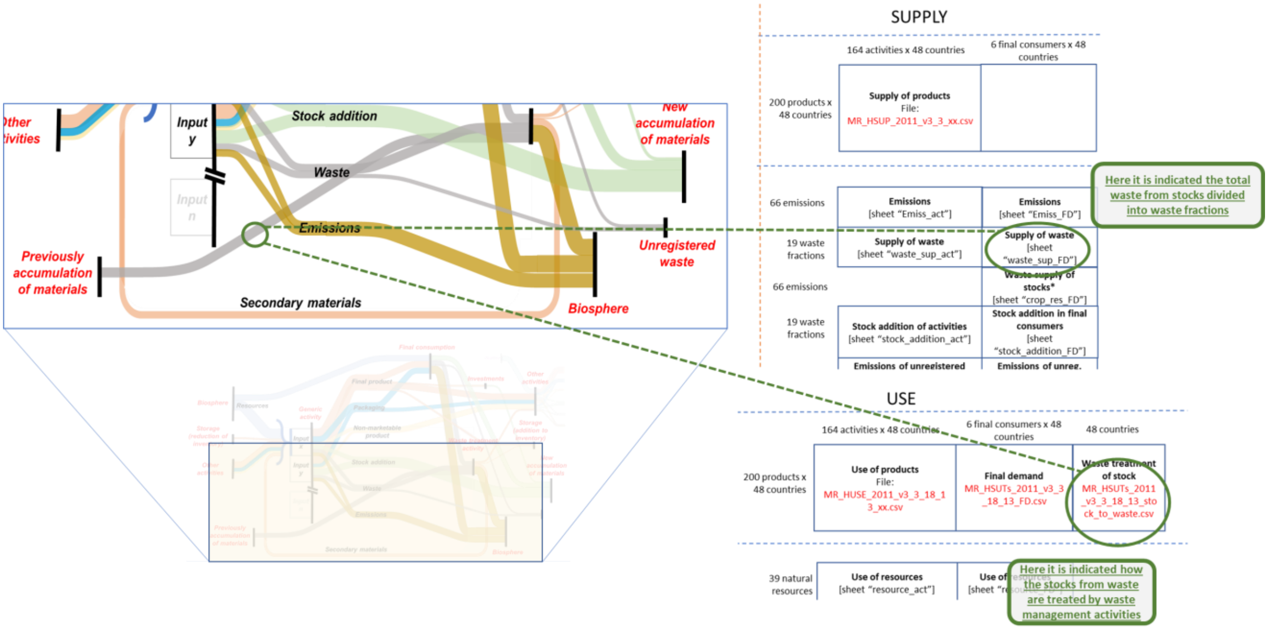


Figure 12 – How the stocks disharges as waste are accounted in Exiobase.

Trade of waste

Countries also exchange waste flows. Trade of waste consist of an exchange of waste treatment services, therefore they are indicated in the use table

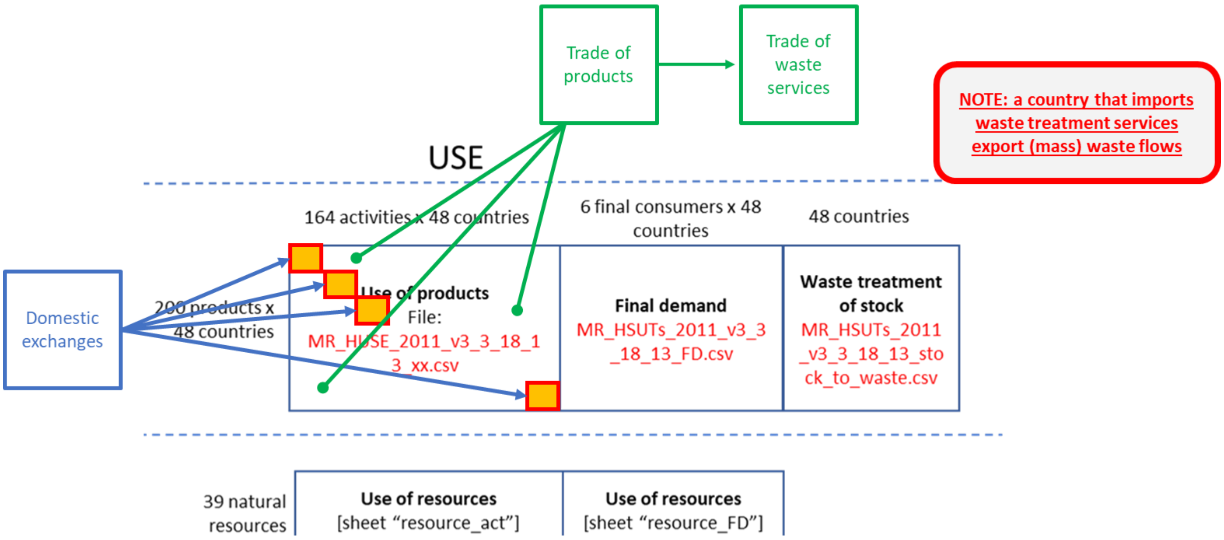


Figure 13 –The trade of waste in Exiobase

4.4 Other auxiliary accounts

In order to accomplish the mass balance it is important to account all the flows within and between economies, even if they have.

Packaging

Packaging is usually used to protect products. In most of the case the packaging has not a price, although it is a cost for the productive activities. However, packaging is an important flow to determine the amount of waste produced. In Exiobase there are specific accounts for the packaging in order to take into account the journey of the packaging from producers to consumers till waste production.

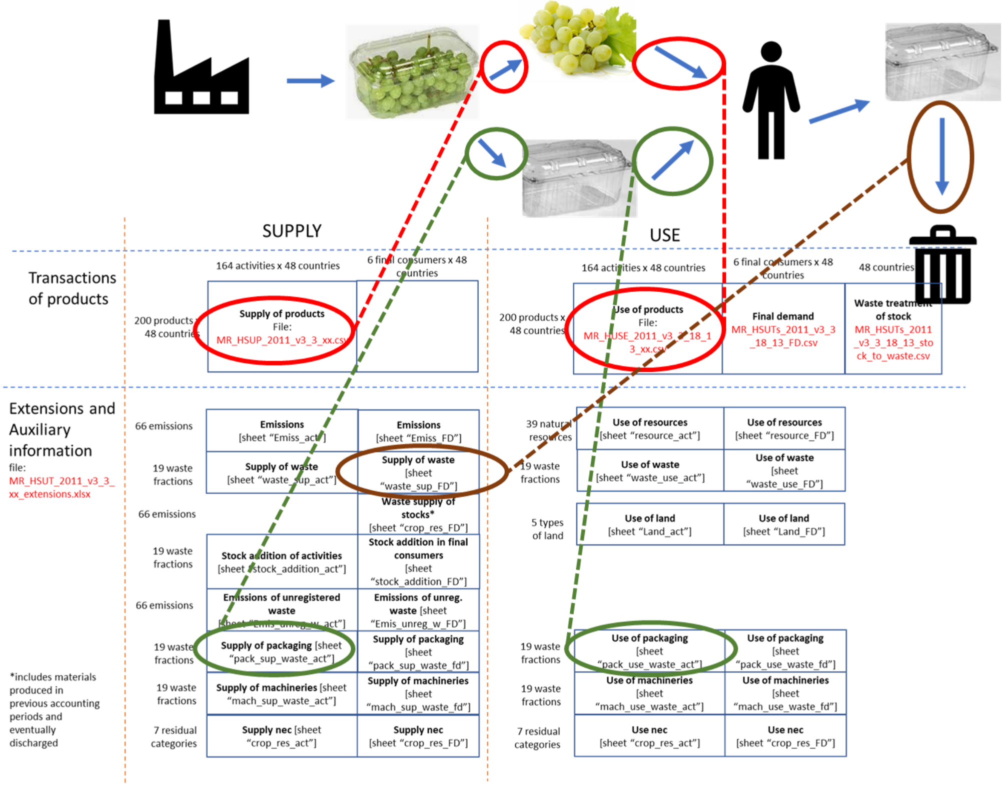


Figure 14 – Packaging accounts describe the exchange of packaging between producers and consumers. Packaging is disposed as waste by the consumer of the products packed. Consumers can also be productive activities.

Supply and use of transportation vehicles

Transportation vehicles are accounted in the EXIOBASE MR-HSUTs in monetary units. Yet, when vehicles are sold, there is a mass flow exchange from the seller to the buyer. When the vehicles is obsolete, it will be discharged by the buyer. Therefore, if a waste management has to be modelled for the obsolete vehicles, it is important to know the material composition of them.

In order to quantify these exchanges in mass units, in the EXIOBASE MR-HSUTs the supply and use accounts of vehicles are built. The supply of vehicles indicates the supply of materials embedded in the produced vehicles. Then the use tables indicate the total sum of materials the buyers get when purchasing vehicles.

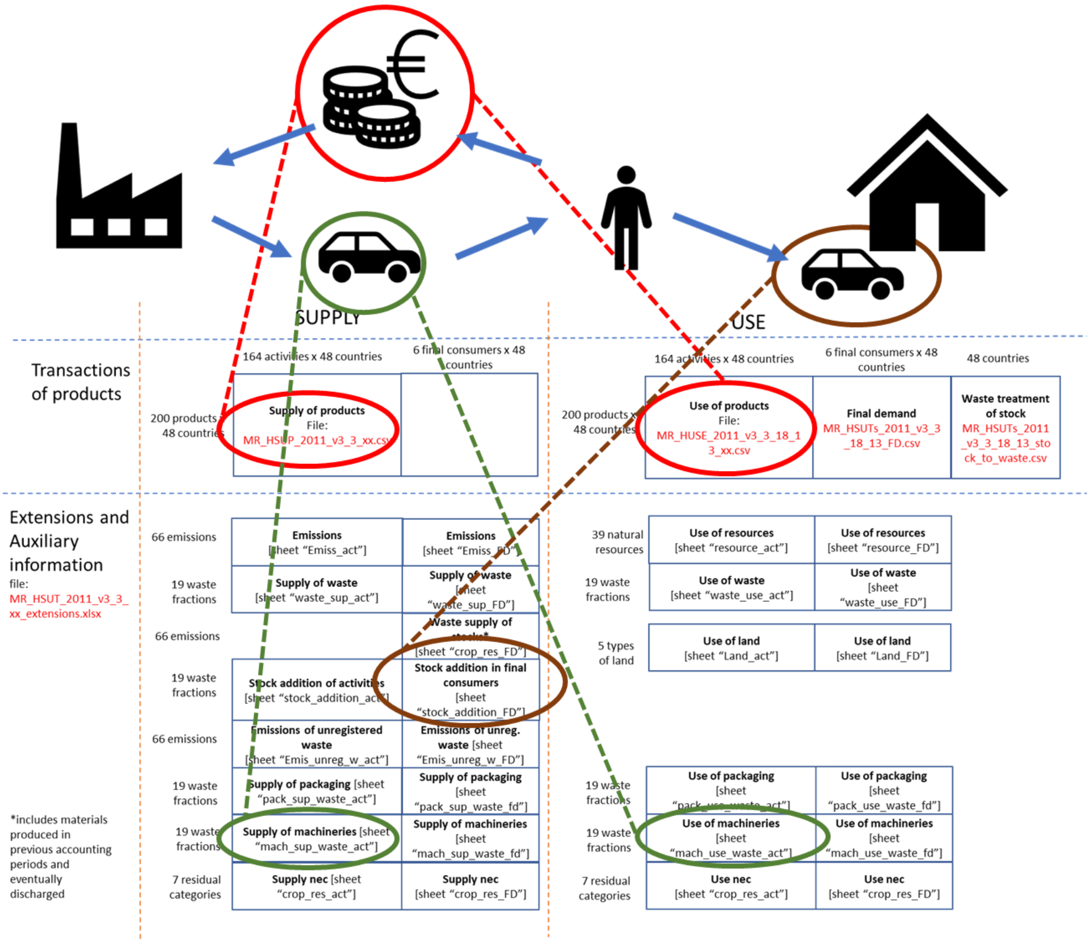


Figure 15 – Modeling of the transportation vehicles in Exiobase hybrid.

Land use

The land use accounts indicated the land used by each activity process and final consumers

Supply and use nec

This account includes the supply and use of non-marketable products, such as crop residues used as animal feed or as bedding, grazing grass eaten by animal. The inputs used for these not ma Then there are some values that could be useful for specific mass flow analyses, i.e. the supply and use of energy crops and the fertilisers absorbed by crops.

Value added

Value added is reported for the productive activities. Values are derived from the monetary version of Exiobase (Stadler et al., 2018).

5 Additional files:

There are files that could be useful to the database users.

- MR_HSUTs_2011_v3_3_xx_dry_matter_coeff.xlsx indicates the dry matter coefficients of the 115 mass products included in the MR-HSUTs (format: products by country). These coefficients can be used to convert value from dry matter to wet weight.

- MR_HSUTs_2011_v3_3_18_waste_coefficients.xlsx includes the destination of products once it will be discharged as waste (format: country/product by waste fraction). Food may have two routes. It can be eaten by humans or by animals, therefore it may end up in the sewage (i.e. when excreted by humans) or in the manure. As a consequence, the sum of waste fraction of food does not give 1 but 2 because both routes are taken into account. These coefficients can be also useful for determing the material layers of supply table
- Classifications_v_3_3_18.xlsx includes all the classification used in the Exiobase hybrid version

6 Multi-regional hybrid input output table

On exiobase.eu it is also published an input-output table, i.e a multi-regional hybrid input-output table (MR-HIOT).

The input-output table published on the exiobase.eu is calculated adopting the logic of by-product technology assumption (the Stone method) (Stone, 1961). However, a practioner can always use the MR-HSUTs and apply any technology model of her interest in order to calculate input-output tables (Eurostat, 2008).

In the literature, the matrix of technical coefficients derived with the Stone method is indicated in the following way (Miller & Blair, 2008; Suh et al., 2010):

Equation 4 $\quad \boldsymbol{A} = (\boldsymbol{V}' - \boldsymbol{U}) \cdot \widehat{\boldsymbol{V}}'$

Where V' is the supply matrix, U is the use table and $\widehat{\boldsymbol{V}}$ is the matrix of principal productions. The advantage of the Stone method is that of preserving the mass balance (Weidema & Schmidt, 2010; Merciai, 2019). Yet, before implementing this method in the MR-HIOT, hybrid supply and use tables are manipulated. The aim of the manipulation is to assure that each activity uses only virgin materials. The logic is shown in Figure 16.

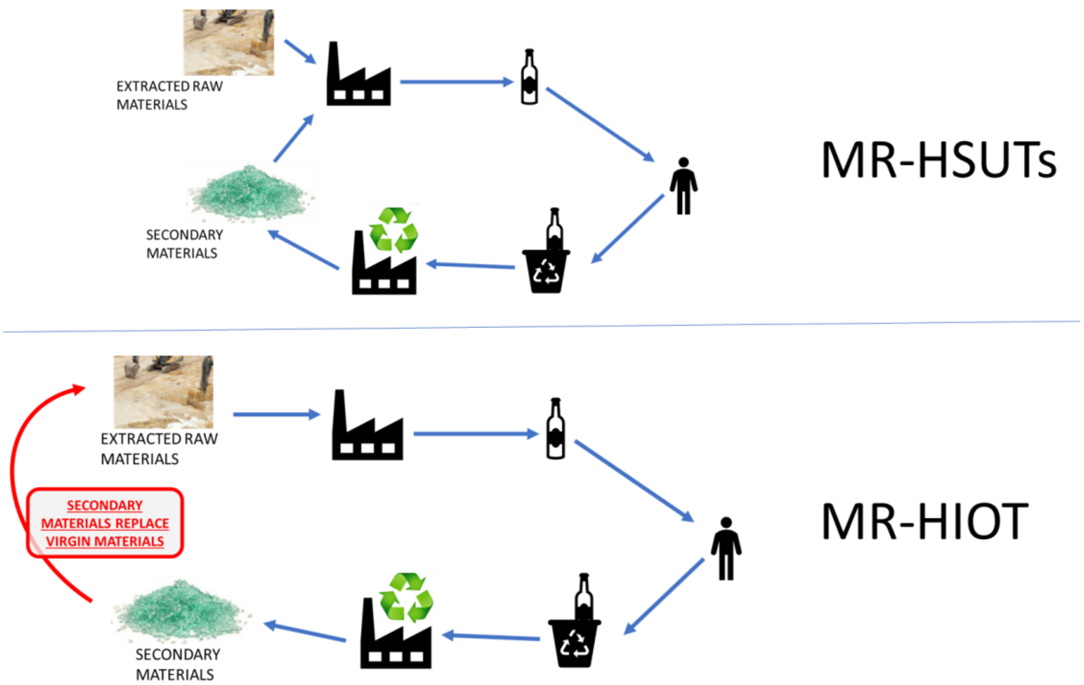


Figure 16 – Logic behind the construction of the MR-HIOTs. In the MH-SUTs, which is a snapshot of the reality, secondary materials are used by activities to produce goods. In the MR-HIOT, which is instead a model of the reality, secodary materials are assumed not to be directly requested by productive activities. The latter can only directly use virgin materials. Yet, whenever there would be availability of secondary materials, these can replace virgin materials.

The reason of this approach lies once again in the importance of the mass balance. A secondary material can be requested only if it is really produced. Therefore, in order to have a secondary material, it is necessary to have somebody that produces waste and, then, an activity that converts the waste into secondary materials. In other words, the production (or availability) of secondary materials is constrained by the supply of waste and the consequent recyclying process (Weidema et al., 2009).

Input-Output tables are used for modeling the behaviour of an economy. If the agents of one economy can request as much secondary materials as they wish, there could be an imbalance between the demand of secondary materials and the production of them. This circumstance violates the Law of Physics and so it should be not acceptable. The approach used in the MR-HIOTs assures that a secondary material is available only if produced. In general, this approach is applied to any by-product of activities, for example the meat produced by the dairy cow system.

6.1 Files of the HIOT

Here a list of the files related to the Exiobase hybrid input-output table:

- MR_HIOT_2011_v3_3_18_xx_principal_production.csv indicates the principal production of the productive activities;
- MR_HIOT_2011_v3_3_18_xx_by_product_technology.csv indicates the matrix of the uses where by-products are included with a negative sign;
- MR_HIOT_2011_v3_3_18_xx_FD.csv includes the consumption of final consumers
- MR_HIOT_2011_v3_3_18_xx_stock_to_waste.csv includes the demand of waste treatment services to treat the stock reduction
- MR_HIOT_2011_v3_3_18_xx_extensions.csv includes the extensions as reported in the HSUTs. Very minor changes are applied

In the HIOT the 200 products are aggregated so to determine a squared HIOT. The products that are aggregated can be seen in the sheet 'Correspondence_products' of the file Classifications_v_3_3_18.xlsx

7 Appendix

7.1 Method for the assessment of stock reduction in Exiobase hybrid v3.3.18

This session describes the method used for the calculation of the total stock reduction in the v3.3.18 of Exiobase hybrid for the year 2011 (Merciai & Schmidt, 2018). In the previous versions the stock reduction was calculated as a residual value as described in Merciai & Schmidt (2016).

The new approach estimates the stock accumulated in previous years and then applies a lifetime distribution for each product in order to get the stock eventually discharged as waste (Müller, 2005; Pauliuk et al., 2015; Schmidt, 2010; Van der Voet et al., 2002). The time series of stock accumulation is calculate starting for the time series 1995-2011 of Exiobase monetary v3.4 at constant prices (Stadler et al., 2018).

The following method is an initial exercise and surely there is room for improvements. We are aware that further work will be needed in the future, both in the modelling and in the data collection.

7.2 Data entry

Input of data from the time series 1995-2011 of the monetary version of Exiobase v3.4 at constant prices

- $P_t(i,c)$ is the level of production of product *i* in country *c* in the period *t* at constant prices.
- $F_t(i,c)$ is the total level of consumption of product *i* in country *c* in the period *t* at constant prices.

Input of data from Exiobase hybrid v3.3.18 , year 2011 ($t_0 = 2011$)

- $S^+_{t_0}(w,i,j,c)$ is the new of stock addition divided into waste fractions *w* in consequence of the purchase of product *i* by activity *j* in the country *c*. $i \in \mathrm{I}$ which is the set of products in Exiobase. In this case *i* indicates products inserted as intermediate inputs in the supply and use table but that have a lifetime longer than one year.
- $S^+_{t_0}(w,i_v,c|f)$) is the new of stock addition divided in waste fractions *w* in consequence of the purchase of product *i* by total final demand categories in the country *c.* Final demand categories include final consumer, i.e. households and government, and gross fixed capital formation.
- $L(i,d)$ indicates the lifetime distribution of a product. $L(i,d)$ how much of a total purchase of the product *i* is discharged after *d* periods.
- V'_{t0} is the hybrid supply table. From V'_{t0} the matrix of production share is calculated: $\gamma(i,j) = V'_{t0}(i,j)/\sum_{j'}(i,j')$

7.3 Calculation of the total stock reduction

Given the limited information, it is assumed that the production function of activities is constant over the years.

Stock reduction of activities

The time series of production activities (A_t) is derived from the time series of commodities' production at constant prices as follows:

$$A_t(j,c) = P_t(i,c) \cdot \gamma(i,j) \quad \forall i,j,c \text{ and for } t \geq 1995$$

Where $\gamma(i,j)$ indicates the share of product *i* are produced by activities *j* as principal production (($\sum_j \gamma(i,j) = 1$). γ is derived from the supply table of Exiobase hybrid.

The estimated time series of stock addition in the period 1995-2011 is then calculated as follow:

$$\tilde{V}'_t(j,c) = V_{t_0}(j,c)/A_{t_0}(j,c) \cdot A_t(j,c) \quad \forall j,c \text{ and for } t \geq 1995$$

Because the lifetime of a product may be longer than the 17 years of the period 1995-2011, the times series is also estimated for the years before 1995:

$$V_t(j,c) = V_{t_0}(j,c)/A_{t_0}(j,c) \cdot \breve{A}_t(j,c) \quad \forall j,c \text{ and for } t < 1995$$

$$with\ \breve{A}_t(j,c) = A_{t+1}(j,c) \cdot \left[\sum_{d=1}^{5} A_{t+d}(j,c)\right] / \left[\sum_{d=1}^{5} A_{t+d+1}(j,c)\right]$$

$\breve{A}_t(j,c)$ uses the average of five years to build the trend.

Once obtained the time series of the production in hybrid units, it is imposed an upper limit to the production before year 2011:

$$V_t(j,c) = \begin{cases} V_t(j,c) & if\ V_t(j,c) \leq V_{t_0}(j,c) \\ V_{t_0}(j,c) & if\ V_t(j,c) \geq V_{t_0}(j,c) \end{cases}$$

This assumption implies that an activity that interrupts the production discharges its stock immediately. In this case the activity influences directly the lifetime of products. In the future further research and data collection are needed to better understand the dynamic of productive systems and eventually overcome this assumption.

The stock reduction of activities is finally calculated in this way:

$$S_{t_0}^{-}(w,i,j,c) = \sum_{d=1}^{50}\left[S_{t_0}^{+}(w,i,j,c)\cdot\frac{V_{t_0-d}(j,c)}{V_{t_0}(j,c)}\cdot L(i,d)\right]$$

A period of 50 years seemed a reasonable time span to take into account.

Stock reduction of final demand

Likewise what shown for the activities, the construction of the time series of the total final demand consumption in hybrid units is determined as follows:

$$Y_t(i,c) = Y_{t_0}(i,c)/F_{t_0}(i,c)\cdot\ F_t(i,c) \quad \forall i,c \ \text{ and for } t \geq 1995$$

For period before 1995 the time series is estimated in this way

$$Y_t(i,c) = Y_{t_0}(i,c)/F_{t_0}(i,c)\cdot\ \check{F}_t(i,c) \quad \forall i,c \ \text{ and for } t < 1995$$

$$with\ \check{F}_t(j,c) = F_{t+1}(j,c)\cdot\left[\sum_{d=1}^{5}F_{t+d}(j,c)\right]/\left[\sum_{d=1}^{5}F_{t+d+1}(j,c)\right]$$

Finally, the final stock reduction in the final demand is equal to

$$S_{t_0}^{-}(w,i,c|f) = \sum_{d=1}^{50}\left[S_{t_0}^{+}(w,i,c|f)\cdot\frac{Y_{t_0-d}(j,c)}{Y_{t_0}(j,c)}\cdot L(i,d)\right]$$

Total stock reduction of countries

Once obtained the stock reduction of activities and final consumption categories, the values are summed up in order to get the total reduction of countries divided into waste fractions.

$$S_{t_0}^{-}(w,c) = \sum_j\sum_i S_{t_0}^{-}(w,i,j,c) + \sum_i S_{t_0}^{-}(w,i,c|f)$$

It was not possible to obtain a reduction of stock per productive activity. For that aim investments must be redistributed (Södersten et al., 2018), but currently there is no information for that. This task is left to the further developments of the database in the next future.

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