EXIOBASE 3 - Construction and analysis of the world physical IOT

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Abstract

This paper describes the main steps of the procedure for the construction of time series of Multi-regional hybrid units Supply and Use tables (MR-HSUTs) created as part of the EU funded project DESIRE.
The choice of unit in the HSUTs follow a hierarchical use of the units of measurement, i.e. all the tangible goods are accounted in dry matter mass, then the intangible energy flows in energy unit, and, finally, the remaining flows, mainly constituted by services, in monetary unit.

The tables are calculated from 1995 to 2011, for 42 main economies of the world, plus five rest of the world regions. 200 products and 164 activities are taken into account. In addition emission, resource, land, water and waste accounts are also derived. All the accounts are calculated respecting the mass balance within the activities, and between the supply and use of products.

As a starting point, the procedure uses data from the main global statistical sources (e.g. Eurostat, FAO, IEA, USGS, BGS, IPCC, etc.). In addition, monetary MR-MSUTs provided by the DESIRE partners play an important role. These data are used as base for the calculation of missing flows. A trade linking procedure is also part of the procedure.

The final result obtained is MR-HSUTs with homogeneous activities. This means that off-diagonal productions include only outputs that are technologically indivisible from the principal productions. Therefore, the calculated MR-HSUTs may be easily used as multi-regional input output table with the by-production technology (Stone's method). The only step to perform is an aggregation, or disaggregation, of some energy products to make the tables square.
In addition to the methodological aspects of the procedure, some elaborations of the calculated data set are shown. In particular, it will be shown the time series of carbon footprints for a basket of products.

1 Introduction

The paper presents the methodology developed in the EU FP7 project DESIRE to create fully mass balanced multi-regional PSUTs (Merciai and Schmidt 2016). The presented methodology, although strongly relying on the procedure provided by the FORWAST (Schmidt 2010a, 2010b; Schmidt et al. 2010) and the CREEA projects (Schmidt et al. 2013; Merciai et al., 2013), and recalling many principles introduced in the Waste Input-Output Table (Nakamura et al., 2007), shows many novelties respect to them:

1 only homogenous activities are taken into account. This means that each activity supplies the principal production and only co-productions that are technologically linked to it.
2 in processes that transform energy products, special care is put in respecting conservation laws such as the production of electricity. Energy balance are also performed;

3 combined heat and power plant are considered as one production unit;
4 better consistency of the world trade.

PSUTs also include other units of measurement for intangible goods. The scope is to account all the transaction giving the priority to mass units, then to other units. Hence, energy and monetary units also included. 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 to creating HSUTs for 42 countries plus five rest-of-world regions. The concept of physical supply and use tables (PSUTs) is defined in the Systems of Economic and Environmental Accounts (SEEA) (SEEA Central Framework 2012).

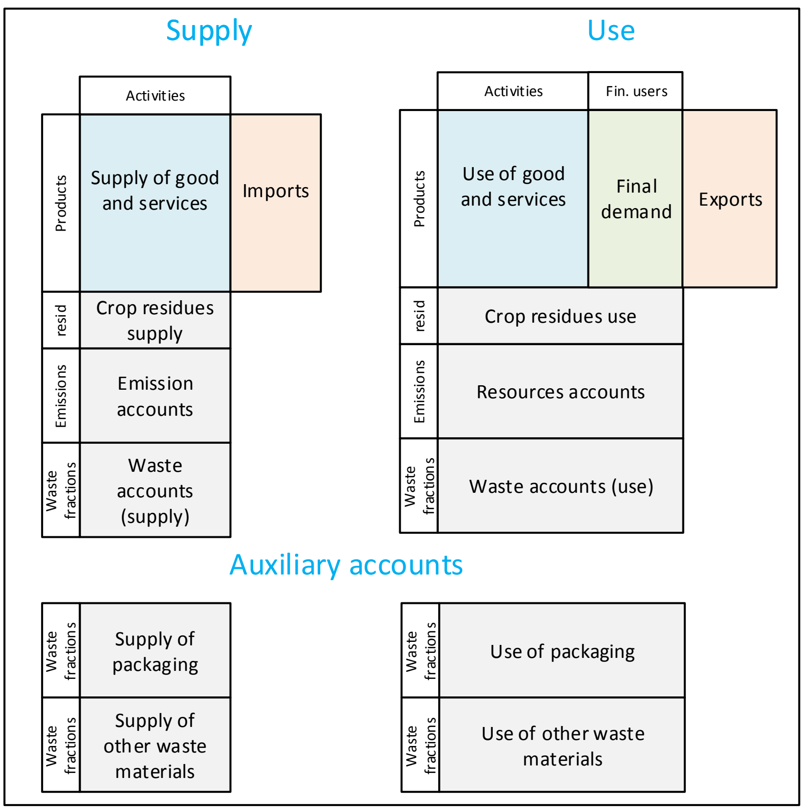

Figure 1 – Framework adopted for the construction of HSUTs. Notice that the waste treatment services are accounted in the transaction matrices (blue boxes). Waste accounts show the mass flows linked to waste treatment services.

2 The algorithm

The whole algorithm is split into *sectorial* modules and *general* modules. *A sectorial* module is a self-standing block that feeds 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.

The figure below shows the modules and the structure of the whole algorithm for creating the 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.

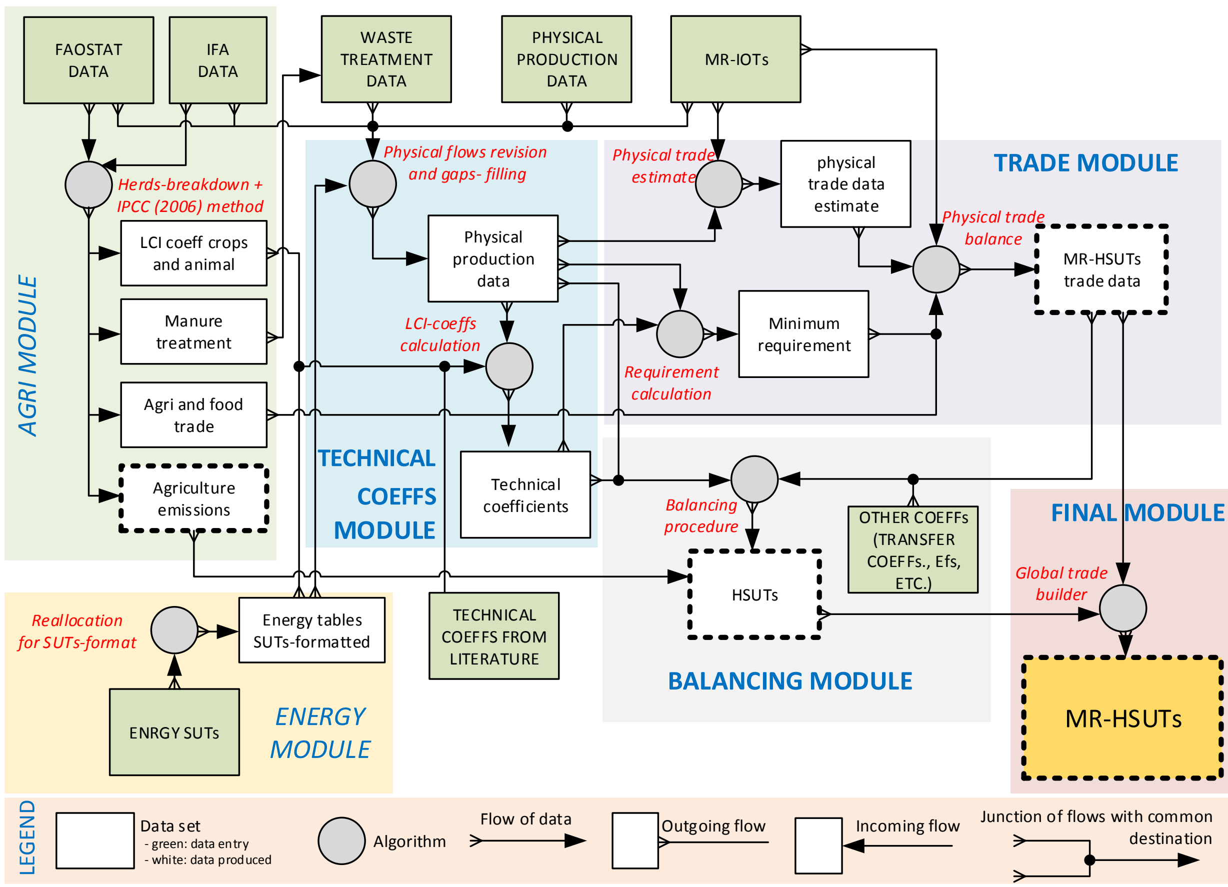

Figure 2 – MR-HSUTs algorithm. The green boxes show the data collected, while the white boxes the data calculated. The yellow box shows the final delivered results.

In the rest of the paper we briefly describe each module of the algorithm

2.1 Agriculture module

In the Agriculture module, data from FAOSTAT (FAO Statistic division 2015) are manipulated in order to get technical coefficients, manure production, emissions and trade data in the mass units, that will be used later in the final part of the algorithm.

As first step, FAOSTAT data undergo a gap filling procedure to assure that all the data of the time series are taken into account. Then procedure consists of splitting the cattle, sheep and other herds into dairy and meat activities, as requested by the classification adopted in DESIRE. This procedure could be not relevant if more detailed national data were available on the different livestock systems.

After this step, a mass balancing procedure is performed for livestock activities, so that food intake, manure production and animal emissions are calculated.

The manure production feed the crop procedures, which together with data coming from IFA (IFA 2015), give the picture of the use of nutrients. Crop balance is performed, therefore emissions from the use of fertilizers and manure are determined.

2.2 Energy module

The energy module converts data obtained by the En-SUTs (Stadler et al. 2015) in a format that is suitable for the HSUTs. Indeed, the approach followed by En-SUTs could be hastily defined as *pure descriptive* and is strongly bound to classification of energy sectors and official guidelines (Eurostat, XXXX). Contrarily, the HSUTs aims to trace the cause-effect mechanism, hence the approach could be meant as *analytical*, suitable for analyses, exploiting the potentialities of the input-output tables, e.g. decomposition, scenarios analyses, etc..

The fulfilled changes concern:

- *Allocation of energy products from waste combustion* (in the HSUTs, the supply of energy from waste incineration is allocated directly to the waste activities; 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);
- *Treatment of biogas from waste bio-gasification* (in the En-SUTs, all the production of biogas is accounted in the gas manufacture, no matter the raw material used for. In addition to that, in some cases it is not clear which is the raw material used for the production of biogas. Because in the HSUTs what is produced in a plant that treats waste is always allocated to waste treatment activities, biogas from waste biogasification, is moved to the waste sectors)
- *Treatment of combined heat and power production* (in the En-SUTs, a plant that produces both heat and electricity, is split into two different activities with two different productive recipes. In the HSUTs procedure, the same plant is considered as one activity with two outputs, thus it is regrouped together by using IEA data (International Energy Association 2015));

2.3 Technical coefficient module

The technical coefficient module is the first general module of the HSUTs procedure. This module performs the revision of input data and fills the gaps and estimates technical coefficients.

2.3.1 Revision of collected data

The revision of data encompasses four steps:

A 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.

A reasonability check regards collected data that are considerably distant from other observations of the time series or from other cross-checked sources[1]. These values are considered as outliers, hence they are deleted.

A *linkage to specific raw material* regards products whose production usually occurs within a short distance from the raw material production plant. To apply this procedure is required that the raw material has a high score. It is assumed a one to one link between raw material availability and processed goods.
To give an example, the procedure is used for cement. Whenever the cement production is far bigger than the local availability of sand, limestone, clay, etc., the value is reduced so that it is reasonable according to the availability of raw materials.

A *data generation procedure* estimates missing data relying on the availability of raw materials. This procedure is also applied when data are not trustworthy so to be completely neglected. The underlying idea is that raw materials are assigned 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).

Initially, collected data are marked with high or low score depending on the reliability of the data source. Higher the score, higher the reliability. Only a gap-filling procedure is required for high quality data in order to complete the time series if required. For the remaining low-scored products – manufactured products mainly – all the revision procedure may be applied.

2.3.2 Additional revision of data redistribution

The necessity of introducing this part came out 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 as many issues as possible. 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 was performed for food products (including agriculture products), precious metals, stone, sand and clay, combusted products and, finally, electricity (energy inputs).
The redistribution of energy inputs is fulfilled using technical coefficients taken from Ecoinvent (www.ecoinvent.org; Merciai et al. 2010; tab. 3.1). We have collected the total request of combusted products and electricity for the all the activities included in the physical tables.

2.4 Technical coefficients module

This module calculates an initial estimate of technical coefficients. Some coefficients are already determined in the sectorial modules, all the others need to be calculated. The coefficients calculated refer to the use of inputs and to the supply of co-productions. The first, defined as *product input coefficients,*

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

show how much of the input *i* is necessary for the production of one unit of the principal output of *j*. The second, defined as *by-product coefficients* 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/ 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 *product input coefficients.*

The information necessary for the calculation of *by-product coefficients* comes from both *sectorial modules* and literature (www.ecoinvent.com; Merciai et al. 2010; Schmidt 2010b). The latter provides mainly coefficients on waste treatment activities co-productions. Some other *by-product coefficients*, like the production of meat in dairy cows sector, are directly derived in the agri module[2].

Once known the *by-product coefficients,* the total supply of commodity coming from data collection is split in two groups, principal productions and by-productions.

The procedure for the calculation of *input coefficients* recalls the distribution of the estimated available material (see **Error! Reference source not found.** and **Error! Reference source not found.**) along the activities. This is performed using coefficients derived from the MR-MIOTs.

Initial *product input coefficients* are simply determined by dividing the inputs to each activity by the principal output. Afterwards, some consistency checks are fulfilled, which play an important role[3]. Indeed, besides the input coefficients coming from sectorial modules, all the other coefficients are strongly dependent on the monetary distribution of inputs. Drawbacks could rise for different reasons:

1. product price inhomogeneity along the uses is a real problem for monetary tables. Therefore, the distribution of the mass 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[4].

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.

[2] 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.

[3] 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 that absolute levels.

[4] 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 is not important whether the raw material is included in a production recipe or not; one can get balanced activities anyway. Contrarily, in the mass balance the absence, or the little usage, of a raw material will pop up because of the mass conservation law. Hence, a series of checks on raw material requirements are necessarily introduced in.

Therefore, we only focus on some specific input-coefficients, leaving out the others. There are two types of possible revisions:

a. on relevant inputs to specific activities (case where there is a direct link between raw materials and processed products. For instance, paddy rice and processed rice);
b. on the distribution of a fundamental feedstock to the activities of the economy. It is mostly driven by conservation laws, technical constraints and so on (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)

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. Difference that will determine a divergence in the results of the analysis using one or the other levels[5].

2.5 Trade module

The trade module is a major improvement in the construction of the PSUTs. In the precedent version of Exiobase (Stefano Merciai et al. 2013) this procedure was exogenous. This caused that some trade flows were in conflict with other data used for the construction of the physical layers. As a consequence, inventories were manipulated to get balanced results.

After this experience, it has been decided to add the trade module in the current algorithm. Thus, trade flows are now endogenous results.

Initially the *minimum material requirement feedstock*, which is the availability of raw material/feedstock in order to justify a certain level of production, is calculated. Then a revision of the trade flows occurs. The aim is to assure that a country has access to what it needs. Indeed, initial estimates of imports and exports may already hide some drawback for the achievement of a balanced trade cube.

Two are the feasible limits hidden in the data that are addressed. For instance a country may need a quantity of a product that is higher than what the countries from whom it imports may provide with. Secondly, a country does not produce enough to satisfy its requirement and the initial estimated import is null[6].

After the initial steps, the core part of the trade module is run. It consists of a procedure that, starting from unbalanced initial estimates, determines balanced bilateral trade flows for each country (physical trade cube).

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[5] The difference will be only for those activities 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 activities.

[6] We think that the main source of these inconsistencies should lie in the different use classification categeries 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 incocnsistencies. For instance, the use of fixed prices when calculating initial estimates, errors in the data collection, and many more.

Initial estimates are determined by collected data (FAO Statistic division 2015), from monetary tables or endogenously calculated.
The physical balanced trade cube is obtained solving an optimization problem, where the objective function to minimize takes into account the variation of trade flows respect to the initial estimates.

2.6 *Balance module*

This module generates balanced tables using all the information previously calculated. With balances tables imply a balance between supply and use of products and mass balance within activities. For intangible processes accounted in energy units, e.g. production of electricity, it is assured that the supply of energy is obtained in accordance with efficiency factor derived from En-SUTs[7].
A draft version of HSUTs is already determined in the previous modules. This initial estimate is completed using other transfer coefficients that indicate the amount of natural resources that enters into the economies and the waste treated. Moreover, emissions coefficients are used, which indicate how much of input materials is discharged to the environment. So, the final balancing procedure ca be run. It is run for each country at time.
The procedure consists of an entropy optimization problem. The scope is to redistribute the available products so that for each activity there is enough feedstock to justify given levels of production while respecting conservation laws. The objective function minimizes the variation of the use accounts respect to the initial estimates.
The entropy optimization problem determines production recipes for each activities. However, before calculating the final extensions, two other steps must be done. The first consists of creating the multi-regional table of transaction, including the purchases of the final consumers. Then, in the second step, the supply of waste fractions and the stock addition is finally defined. In practice, most of the supply of waste is already determined in the balancing module. What is left out 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.

2.7 *Final module*

This is the last module of the algorithm. When it is completed, the MR-HUSTs are finally ready.

2.7.1 Multi-regional transaction

In this module, the physical trade cube and the country balanced HSUTs are put together to get the multi-regional transaction tables.
For each country, the uses are split between domestic and imported products (lower part of Figure 3). The supply table is moved on the multi-regional table without any adjustments. At the end, all the diagonals of the countries together will make the diagonal of the global table.
Notice that it is assumed that there is no trade of waste.

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[7] 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. In addition to that, we impose that efficiency is not higher that a technological threhold.

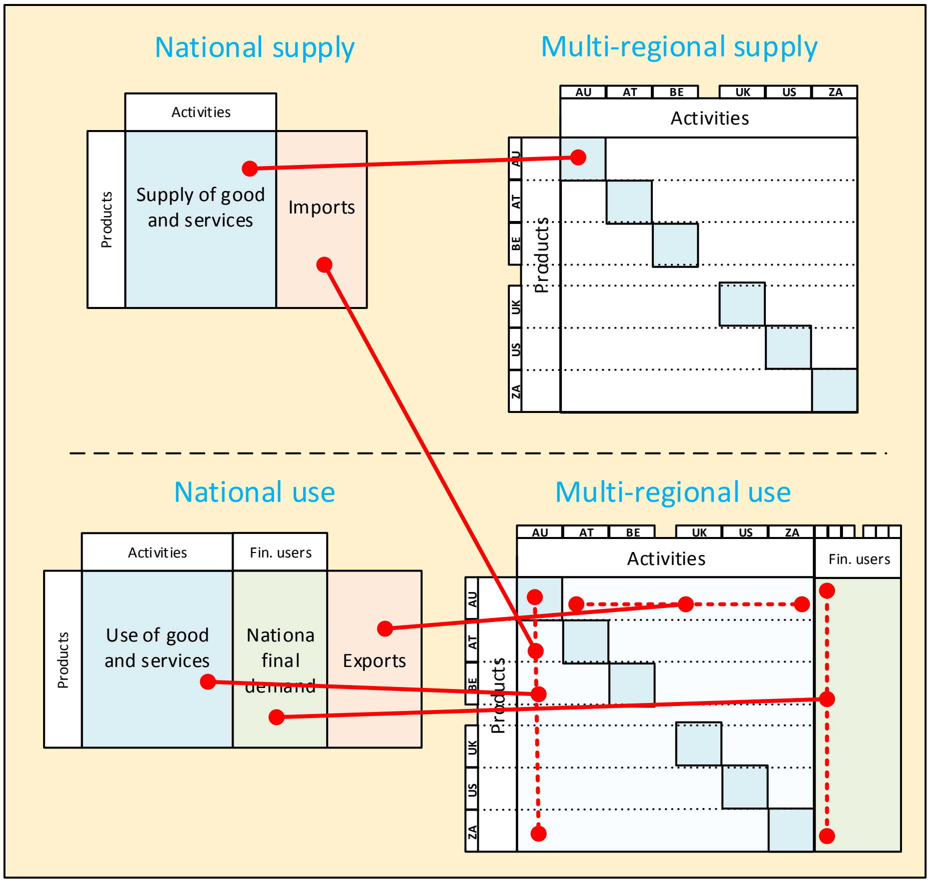

Figure 3 – From national to multi-regional transaction tables. The red lines indicate how the values obtained in the national balanced tables are redistributed in the multi-regional framework using the information of the physical trade cube.

2.7.2 Waste accounts

After the multi-regional transactions, auxiliary flows are determined because are important for the construction of waste accounts. These flows are the supply/use of waste fractions from packaging, of waste fractions as consequence of trade of heterogeneous products[8] and, finally, of waste fractions from vehicles[9]. The reason behind the calculation of these accounts only at this stage is that they are special flows that can be determined only when the multilateral trade is reconstructed. Once they are defined, everything is ready to generate waste accounts.

Waste supply, in the general procedure, is determined as a fraction of the total potential waste. The potential waste is all the materials that enter into an activity, or a final demand category, and are not

[8] 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 **Error! Reference source not found.**.

[9] 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 assumedd to have different lifetime. For example, tyres of a car are usually changed more times during its lifetime.

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 food waste of a restaurants, bricks of a new building, a new mobile phone, manure excreted, etc. The potential waste has a format inputXactivity, where with input is meant the products, natural resources and waste fractions, while with activity both productive activities and final consumers.

However, only part of the potential waste will become waste in the accounting period of the purchase, the rest must be considered as stock addition that will become waste in future periods.

We have assumed a *lifetime function* that takes into accounts these aspects (Schmidt 2010b; Schmidt et al. 2010). The matrix of potential waste is then converted into waste fractions by activity format.

The last matrix that composes the waste accounts is the use of waste. This matrix can be directly determined converting the supply of waste treatments services into waste fraction.

2.7.3 Use of waste services

Next step consists of deriving how it is treated the waste of activities and final consumption category. First of all, it can be said that there is no difference between activities in sending the waste to waste treatments. This means that if 20% of glass is recycled in a country, it will be so for any activity or consumers[10].

The logic is that the supply of waste treatment services shapes the use of waste treatment services. For any waste fraction, it is calculated the percentage of the different treatments. For example, with regard to glass, it is calculated how much is recycled, incinerated or landfilled.

The percentages of waste treatments are then used to move from the supply of waste to the demand of waste treatment services. However, it may happens that, in a country, the total treated waste is lower or higher than the supplied waste in the accounting period. If lower, it is assumed that there are unregistered waste flows. Contrarily, if higher, it means that materials accumulated in previous years are treated in the current period

Finally, unregistered waste from material accumulated in the previous years, and become waste in the current periods, is calculated. The unregistered waste is then determined as subset of the total waste, which is the sum of all the accumulated materials that become waste.

3 Results

We show here some of the feasible results that can be obtained with MR-HSUTs Exiobase v3.

[10] This will be clear in **Error! Reference source not found.**.

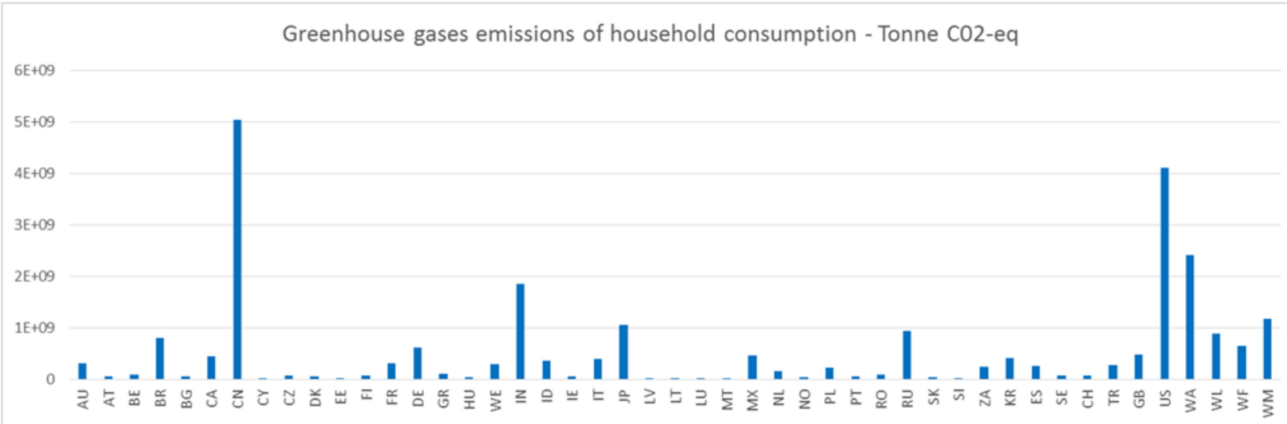

Figure 4 – Greenhouse gases emission of the household demand vector for all the country/regions accounted in Exiobase v3.

Figure 5 – Comparison of the 20 most GHGs-emitting products purchased by households.

In addition, the carbon footprint of some products is show.

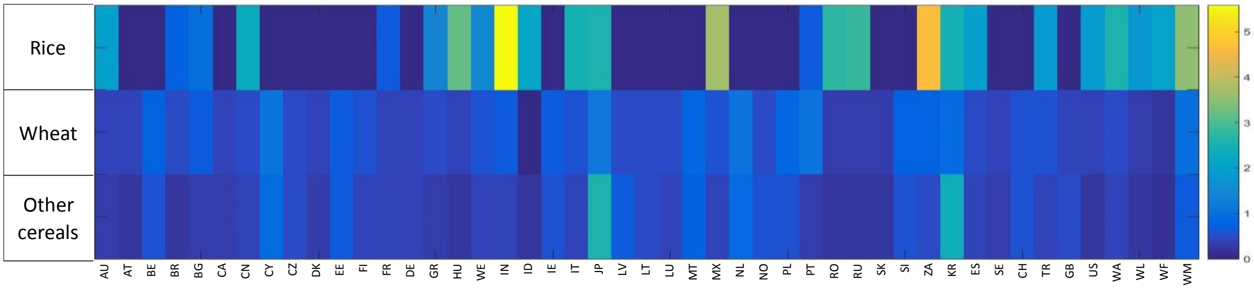

Figure 6 – Total GHGs emissions for cereals (1kg/1kg)

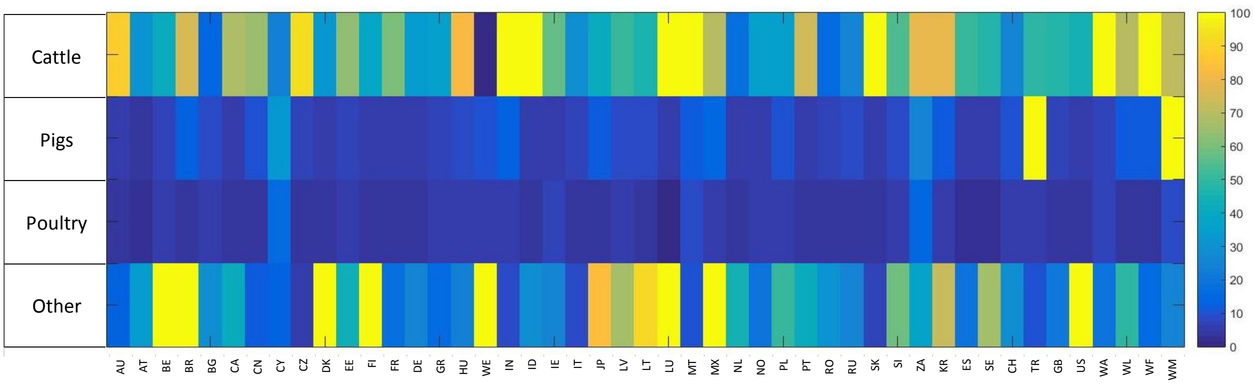

Figure 7 – Total GHGs emissions for animal farming (1kg/1kg)

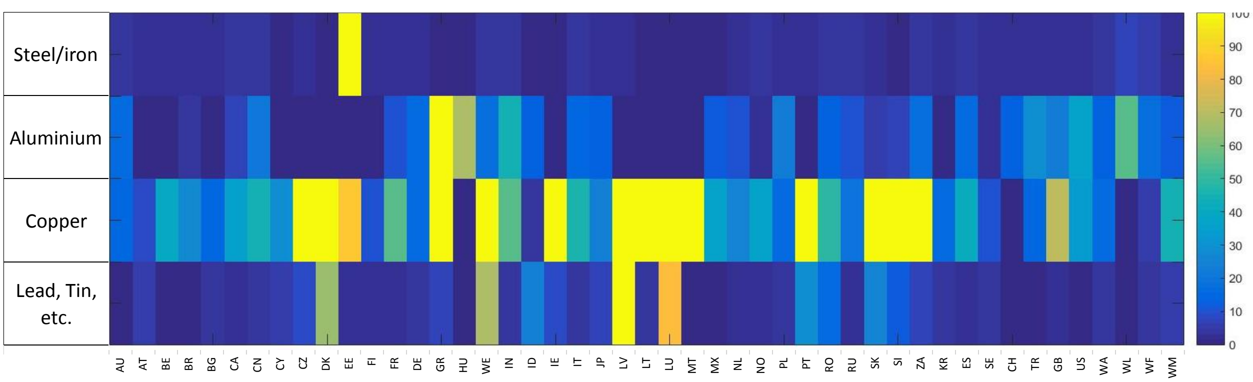

Figure 8 - Total GHGs emissions for metal productions (1kg/1kg)

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