MFA and waste accounts in physical supply-use tables

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Abstract

The paper describes a framework for MFA and waste accounts in physical supply-use tables (PSUT) making full use of all available datasets. The framework has been initially developed for the EU FP6 project FORWAST (Schmidt et al. 2010) and after a further refinement it is currently used for the construction of PSUTs incl. waste accounts within the EU FP7 project CREEA (Schmidt et al. 2012).

The MFA accounts are structured following the supply-use framework as of SEEA 2012 (United Nations Committee of Experts on Environmental-Economic Accounting 2011) with a few modifications in the terminology. Some of the major modifications include:

- the definition of products in this framework excludes secondary materials, which is included as part of the category 'materials for treatment' (see below);

- the term 'waste' is replaced by 'materials for treatment', which is not present in SEEA 2012. The new term is defined as an output flow of a human activity that remains in the technosphere and cannot directly (i.e. without further processing or emissions) displace another principal product of an activity. After processing in a waste treatment (re-processing or recycling) activity, the recovered materials for treatment may displace other products.

Furthermore, in order to accomplish a mass balance, a stock addition table is added to the Use tables in the columns of productive activities and final uses. By doing so it is possible to take into account both products and material for treatment with a lifetime longer than the accounting period, according to the destination activity.

PSUTs are created together with and in same classification as monetary supply-use tables (MSUT). The mass balance for industries is established via an iterative waste calculation procedure, which enables for the construction of detailed country specific waste accounts. The main idea behind the approach is that only a part of each type of input ends up being included in the final products. What is left out may end up either in the emissions or in stock additions or, finally, in 'materials for treatment'. The supply of 'materials for treatment' from an activity is so expressed in terms of originating flow, i.e. product, resource or 'material for treatment'. The use of the latter allows the calculation of waste with the broadest possible definition of waste, open to any desired waste definition, e.g. if it is desired to generate waste accounts according to SEEA 2012 waste definition.

In order to trace the waste pathway through the economy, the industrial production processes that involve re-processing of waste material and secondary material into new products are disaggregated into virgin and recycling production. This also involves technical disaggregation of joint production processes where secondary material is used. These activities dealing with secondary material are then considered as proper waste treatment ones. Further, a large number of different waste treatment activities are created through disaggregation of the waste industries in the original MSUT, permitting to account the pathways of different waste fractions.

The calculated ‘material for treatment’ is integrated in the PSUTs where these flows can be interpreted as waste flows. The principal product of waste treatment industries is the service to treat waste. When a ‘material for treatment’ is recycled/re-processed into new products, these are off-diagonal by-products in the supply table. On the other side the waste generating industries and households have entries in the ‘material for treatment’ rows in the physical use table. This is interpreted as these activities use the service to have waste treated. Hence the final PSUTs represent an integrated account of products and waste flows service as intermediate transactions within the economy.

The presented framework and waste calculation procedures has been tested for EU27 and Denmark in the FORWAST project, and currently it is used for the creation of MFA and waste accounts for 43 countries as part of the CREEA project. Further, since the PSUTs are classified with same products and industries as the MSUTs, the approach enables for the creation of a fully balanced (economic, mass and energy) hybrid supply-use table enabling for new and better quality hybrid life cycle assessments.

1. Introduction

Nowadays the physical accounts have a considerable role within the National Accounts published by statistical offices. The forthcoming publication of the SEEA 2012 (UN, 2011), that upgrades the version of 2003, is likely to have the effect to raise the interest on physical accounts, considering also the environmental challenges of modern societies.

The framework for physical accounts adopted by SEEA is the physical Supply and Use tables (PSUTs) that are strictly linked to the monetary Supply and Use tables (MSUTs), the basic framework for the System of National Accounts (UN, 2008). Indeed, the aims of the SEEA is to generate reliable physical accounts that are coherent in terms of definitions, classification and approach to the SNA.

Theoretically PSUTs should include all the physical flows within the economies and the exchanges with the environment. Hence, for instance, we find the extraction of natural resources, the emissions and waste accounts. We said ‘theoretically’ because the idea to have complete PSUTs is considered from the experts of UN a very ambitious target for national statistical offices and indeed a less stringent approach might be applied, which considers only some specific physical accounts and not all of them.

The awareness of such data shortage limit in the construction of complete PSUTs may explain the reason why in the SEEA great emphasis is put on the balance of rows, e.g. products or residuals, while the productive activity balance is not stressed out with the same importance.

Within the physical accounts, a central role is played by waste accounts (Delahaye 2007, United nation et al, 2003 and 2012).
Currently the waste accounts are compiled on the basis of waste registration information. As a result some waste flows in the waste accounts are not covered sufficiently: 1) some non-hazardous waste with a monetary value, and 2) illegal waste. Therefore, the current physical accounts are limited in terms of completeness, i.e. there is no direct link between the causes of waste (inputs of natural resources and transactions of physical flows) and the quantification of waste in the waste accounts. The result of this lack of integration is that the accounting system does not enable for analytic economy wide life cycle emissions calculations on the effect of different waste management interventions.

The aim of this paper is to present a generalized methodology for the construction of fully-balanced PSUTs[1] where material flow analysis (MFA) and waste accounts are harmonized with other physical and monetary accounts. Hence the purpose is to respond to the challenge issued by SEEA on complete PSUTs making full use of the available data sources both in monetary and physical terms, and relying strongly on the mass conservation law and technical information coming out life cycle surveys of products. However it is important to notice that here, for our aims, some modifications are carried out to the SEEA structure, as shown in Section 2. Yet the methodology presented in the following sections – from 3 to 7 - turns out to be a generalized approach that can be readapted to the SEEA framework or to any desired one.
Before starting with the explanation some clarifications on the mathematical notation used in the text. Matrices and vector are both indicated by bold text and by capital and in small letters, respectively. A small bold letter with the hat (^) shows a diagonal matrix where the vector is down the diagonal. Matrix **I** and vector **i** show a unit matrix and a unit vector, respectively.

2. The utilized framework and modifications of suggested frameworks

In the procedure here presented some differences are introduced respect to SEEA recommendation in terms of terminology and of positioning of specific accounts. These modifications are functional to a clearer explanation and to a generalization of the approach. Some of the major terminology modifications include:

- the definition of products in this framework excludes secondary materials, which is included as part of the category 'materials for treatment' (see below);

[1] Here for physical it is meant mass.

- the term ‘waste’ is replaced by ‘materials for treatment’, which is not present in SEEA 2012. The new term is defined as an output flow of a human activity that remains in the technosphere and cannot directly (i.e. without further processing or emissions) displace another principal product of an activity. After processing in a waste treatment (re-processing or recycling) activity, the recovered materials for treatment may displace other products.

Figure.1 shows the framework adopted in this paper. The upper part includes the flows of the supply framework and the lower part those of the use one.

Balanced PSUT	Activities	Stock formation	Final use	Export	Import	Total
Products	V'				N_c	q
Stock additions	DS					
Materials for treatment	W_V				N_w	
Emissions	B					
Total	g'					
Products	U	s^+	Y	N_c		q
Materials for treatment	W_U			N_w		
Natural resources	R					
Total	g'					

Figure.1: Format of physical supply-use tables (PSUTs).

Matrix **V’** shows the products carried out by domestic productive activities while $\mathbf{N_c}$ and $\mathbf{N_w}$ represent the import of products and materials for treatment respectively.

Matrix Δ**S** shows additions to stocks, i.e. products purchased by activities or households that have not become materials for treatment within the accounting period. In different words, Δ**S** accounts for products with a lifetime longer than one year that are accounted as intermediate inputs or final consumptions (see matrices **U** and **Y** below) by statistical offices. So Δ**S**, usually not included in PSUTs, is here introduced in order to accomplish a mass balance.
The supply of materials for treatment ($\mathbf{W_V}$) represents an output flow from a human activity that remains in the technosphere and cannot directly (i.e. without further processing or emissions) displace another principal product of an activity. Notice that the calculated supply of materials for treatment from the model is $\Delta\mathbf{S}$ + $\mathbf{W_V}$. Stock additions (Δ**S**) is included in this because it represents delayed supply of materials for treatment. The emissions matrix **B** represents the output of mass of emissions.

The use matrix **U** accounts for the use of intermediate products by domestic activities plus final consumption (**Y**), stock formation and change of inventories ($\mathbf{S^+}$) and exported products ($\mathbf{E_c}$) and materials for treatment ($\mathbf{E_w}$). Finally, the use of materials for treatment matrix ($\mathbf{W_U}$) accounts for the use of materials for treatment and the input of natural resources **R**.

The calculations of flows in the productive activities and in the accumulation and final use categories are often different. Therefore, the matrices Δ**S**, $\mathbf{W_V}$, **B** and **R** are sometimes divided into sub-sets as of Figure.2

	Activities	Stock formation / Final use
Stock additions	DS_a	DS_f
Materials for treatment	$W_{V,a}$	$W_{V,f}$
Emissions	B_a	B_f
Natural resources	R_a	R_f
Total input/output	g_a'	g_f'

Figure.2: Division of Δ**S**, $\mathbf{W_V}$, **B**, **R** and g into subsets for productive activities (subscript *a*) and for accumulation and final uses (subscript *f*).

The supply and use side are here perfectly balanced, from both the products and activities perspectives. This means that the mass of supplied products is equal to the mass of used products and the inputs to the activities are equal to the outputs. Translated in formula the *product balance* can be traced as follows:

$$\mathbf{V}' \cdot \mathbf{i} + \mathbf{N_c} \cdot \mathbf{i} = \mathbf{U} \cdot \mathbf{i} + \mathbf{S}^{+} \cdot \mathbf{i} + \mathbf{Y} \cdot \mathbf{i} + \mathbf{E_c} \cdot \mathbf{i} = \mathbf{q} \tag{1}$$

where **i** are proper summation vectors.

The *activity balance* for productive activities can be expressed as follows:

$$\mathbf{V} \cdot \mathbf{i} + \Delta\mathbf{S'_a} \cdot \mathbf{i} + \mathbf{W'_{W,a}} \cdot \mathrm{i} + \mathbf{B'_a} \cdot \mathbf{i} = \mathbf{U}' \cdot \mathbf{i} + \mathbf{W_U}' \cdot \mathbf{i} + \mathbf{R'_a} \cdot \mathbf{i} = \mathbf{g_a} \tag{2}$$

The *activity balance* for accumulation and final uses can be expressed as follows:

$$\Delta\mathbf{S'_f} \cdot \mathbf{i} + \mathbf{W'_{W,f}} \cdot \mathrm{i} + \mathbf{B'_f} \cdot \mathbf{i} = [\mathbf{S}^{+} \cup \mathbf{Y}]' \cdot \mathbf{i} + \mathbf{R'_f} \cdot \mathbf{i} = \mathbf{g_f} \tag{3}$$

3. Disaggregation in order to trace recycling activities

Usually classification systems used for the construction of SUTs aggregate the production from virgin materials and the production from secondary materials (Eurostat, 2008). In order to model recycling separately, these industries need to be disaggregated. The limit of classification systems is most of the times a consequence of the economic criteria used to allocate an enterprise in the due activity category. Indeed it is the principal production, identified as that one with the highest value added (Eurostat, 1996), which determines where to allocate an enterprise. In this way, since most of the times the sale of products from secondary materials is more profitable than the recycling service, the production from secondary materials will be classified together with production from virgin materials. However there are also cases where virgin production and recycling take place within the same process, e.g. glass manufacturing, where it is common practise to use a mix of virgin feedstock (silicate sand) and secondary feedstock (glass cullet), and steel production in electric arc furnace, where iron ore is added to the main feedstock (scrap) to control temperature.

Technically, the distinction between virgin production and recycling is very important because the two activities perform differently, for instance the emissions caused by the production from secondary materials are significantly different from the emissions from that using virgin materials. Furthermore, the production from secondary materials implies also a service of recycling (waste treatment) that the production from virgin materials does not carry out.

Therefore, in order to highlight these relevant aspects, joint or combined virgin/recycling activities are disaggregated. It is important to notice that the following approach goes beyond the economic criteria; highest value added. Further, it should be noted that the applied approach deviates from the recommended one based on SEEA 2012 (UN, 2011). Below, in Figure.3, it is illustrated how the applied approach deviates from the one suggested in SEEA 2012.

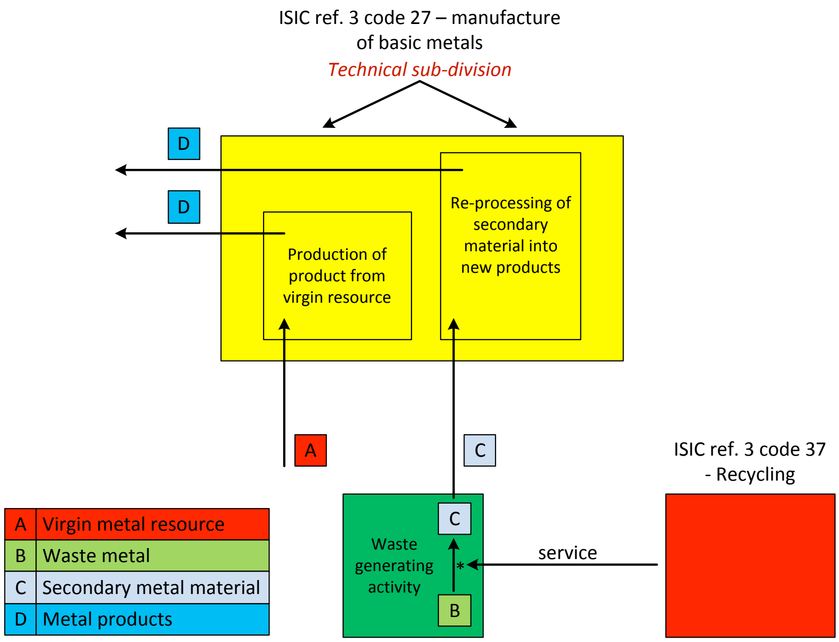

Figure.3: Applied approach for sub-dividing and modelling virgin production vs. production from secondary material.

In Figure.3 it is illustrated that the distinction between virgin production and re-processing of secondary materials is modelled via a technical sub-division of the producing activity (in the figure this is basic metals, ISIC ref. 3 code 27). The input to the re-processing activity is secondary materials. Secondary materials are generated by the waste generating activity. In some cases the generated material is of such a quality that sorting/cleaning is required before re-processing. This is modelled via service inputs to the waste generating activity from the recycling activity (ISIC ref. 3 code 37).

All the resulting recycling or re-processing activities have a service of recycling (as kg 'material for treatment') as principal production (diagonal product in the supply table **V'**) and the product from secondary materials as by-product (Nakamura and Kondo, 2009). Because of products from virgin and secondary materials are considered homogenous in the PSUT, they are structured in the same row.

4. Calculating the material for treatment

In this section, the approach for the calculation of materials for treatment flows in order to determine the waste accounts and to integrate waste flows in the MFA accounts is described. It is noteworthy that we refer to materials for treatment rather than waste. The purpose of this is to operate with the broadest possible definition of waste in the model to enable the application of any waste definition when extracting data for the waste accounts (model outputs). See Section 2 for the definition of the material for treatment.

The approach is based on a coherent mass balance for every activity. Figure.4 shows the mass balance for a general activity, which summarizes what is accounted in the

PSUTs.

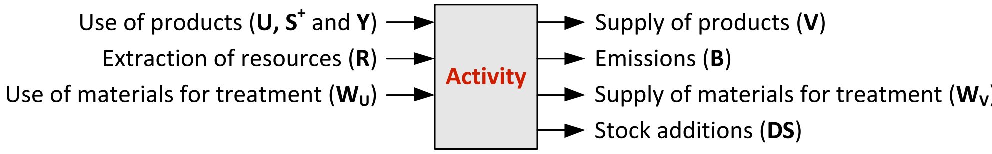

Figure.4: Input- and output flows for a generic activity. Inputs and outputs are always balanced. The matrices referred to in the figure contain the input and output flows.

Generally speaking, for any human activity the inputs in terms of products in **U**-table, materials for treatment in $\mathbf{W_U}$-table and natural resources in **R**-table are balanced by the outputs in terms products in **V**-table, emissions in **B**-table, materials for treatment in $\mathbf{W_V}$-table and stock additions in $\Delta\mathbf{S}$-table.

Supply of materials for treatment in a productive activity or a household can originate from three different sources: use of products (**U**, $\mathbf{S^+}$ and **Y**), extraction of natural resources (**R**) and from input of waste ($\mathbf{W_U}$). This inspires the strategy behind the approach here presented, i.e. only a part of each type of input ends up being included in the final products. What is left out may end up in the emissions (**B**), materials for treatment ($\mathbf{W_V}$) or stock additions ($\Delta\mathbf{S}$).

When calculating the supply of materials for treatment from an activity, this is expressed in terms of the products from which it originates and also if the materials for treatment originates from resource or materials for treatment inputs. The following three sub-sections concern the supply of materials for treatment originating from natural resources, products and materials for treatment respectively. Figure.5 illustrates the possible fate of each of the three types of inputs which may end up as materials for treatment plus stock additions. The proportions of the inputs that end up in the supply of products are specified in transfer coefficients ($\mathbf{D_0}$, $\mathbf{f_0}$, and $\mathbf{e_0}$ in Figure.5).

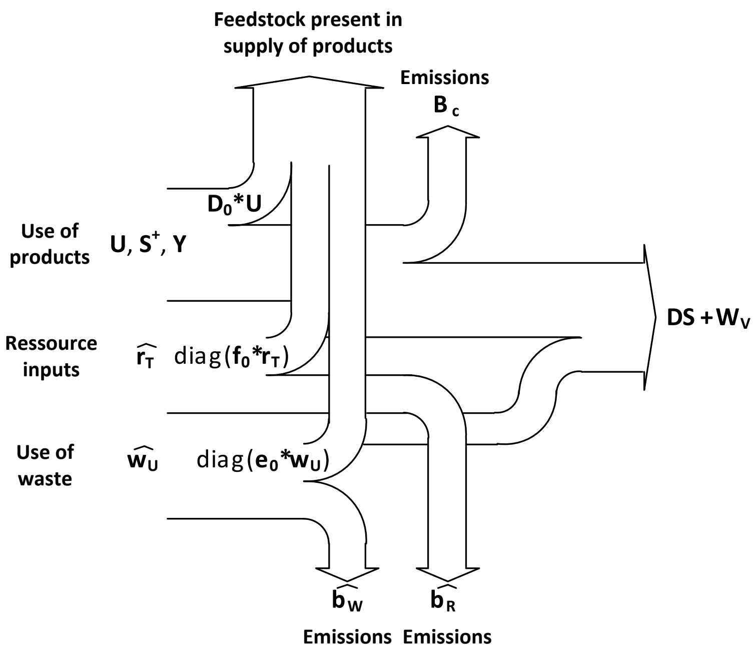

Figure.5: Principal fate of any input to an activity. Based on physical supply-use tables inclusive emissions and natural resources as well as some transfer-coefficients, the stock additions plus materials for treatment can be calculated.

Materials for treatment from input of natural resources

A transfer coefficient vector $\mathbf{f_0}$ is defined to specify the proportion of the total mass of resource input to an activity that is present in the supply of products of the same activity. $\mathbf{f_0}$ is a vector with as many components as the activities. All the values of $\mathbf{f_0}$ fall in the interval [0;1]. A value equal to 0 can indicates:

1) that the extracted natural resources are not present in the product output
2) that no natural resources are extracted in the given activity

Values of $\mathbf{f_0}$ in the interval]0;1] indicate the feedstock efficiency.

The supply of products originating from inputs of natural resources ($\mathbf{v_R}$) can be expressed as **()**. The vector $\mathbf{v_R}$ has format one by activities.

$$\mathbf{v_R} = \widehat{\mathbf{r_T}} \cdot \mathbf{f}_0 \qquad \textbf{(4)}$$

where $\mathbf{r_T} = \mathbf{R}' \cdot \mathbf{i}$ is the vector of total mass. The vector of emissions originating from inputs of natural resources is denoted $\mathbf{b_R}$, and it has format one by activities. In the following, notice that $\mathbf{b_R}$ is subdivided accordingly to **Figure.2** using subscript a for productive activities and subscript f for accumulation and final uses.

The supply vector of materials for treatment plus stock additions ($\mathbf{w_{V,R}}+\Delta\mathbf{s_R}$) originating from the input of natural resources to productive activities and to household and stock categories can be calculated as shown in **()**.

$$\mathbf{w_{V,a,R}} + \Delta\mathbf{s_{a,R}} = \widehat{\mathbf{r_{T,a}}} \cdot (\mathbf{i} - \mathbf{f_0}) - \mathbf{b_{a,R}}$$

$$\mathbf{w_{V,f,R}} + \Delta\mathbf{s_{f,R}} = \mathbf{r_{f,T}} - \mathbf{b_{f,R}} \quad \textbf{(5)}$$

where the only difference lays in the fact that no of the inputs ends up as supply of products in the households.

In order to operate with only one matrix with supply of materials for treatment information, it has been decided that the vector in **()** is diagonalised and merged into the $\mathbf{W_V}$+$\Delta\mathbf{S}$ square matrix. This implies that materials for treatment originating from resource inputs are present on the diagonal in the $\mathbf{W_V}$ table.

Materials for treatment from input of materials for treatment

The materials for treatment, entering into waste treatment activities, may entirely, partially or not at all end up as part of the supply of products. The part of materials for treatment not becoming part of the supply of products will be an output of the activity in the form of emissions, materials for treatment and/or stock additions. The latter is the case for landfills where inputs of material accumulate in the activity.

Similarly to the case of previous section, a transfer coefficient vector $\mathbf{e_0}$ is defined to specify the proportion of the total mass of materials for treatment input to an activity that is present in the supply of products of the same activity.

The supply of products originating from inputs of materials for treatment ($\mathbf{v_W}$) can be expressed as **()**. The vector $\mathbf{v_W}$ has format one by activities.

$$\mathbf{w_w} = \widehat{\mathbf{w}}_{\mathbf{U,T}} \cdot \mathbf{e_0} \quad \textbf{(6)}$$

where $\mathbf{w_{U,T}} = \mathbf{W_U}' \cdot \mathbf{i}$ is the vector of total mass of materials for treatment. The vector of emissions originating from inputs of materials for treatment is denoted $\mathbf{b_W}$, and it has as many components as the productive activities.

The supply of materials for treatment plus stock additions ($\mathbf{w_{V,W}}$+$\Delta\mathbf{s_W}$) originating from the input of materials for treatment can be calculated as shown in **()** for productive activities. The format of $\mathbf{w_{V,W}}$+$\Delta\mathbf{s_W}$ is one by activities.

$$\mathbf{w_{V,W}} + \Delta\mathbf{s_W} = \widehat{\mathbf{w}}_{\mathbf{U,T}} \cdot (\mathbf{i} - \mathbf{e_0}) - \mathbf{b_W} \quad \textbf{(7)}$$

In order to operate with only one matrix with supply of materials for treatment information, it has been decided that the vector in **(7)** is diagonalised and merged into the $\mathbf{W_V}$+$\Delta\mathbf{S}$ square matrix. This implies that materials for treatment originating from inputs of materials for treatment are present on the diagonal in the $\mathbf{W_V}$ table. Notice that there is not any overlapping problem down the diagonal of $\mathbf{W_V}$ between natural resources and materials for treatment because of in general activities using natural resources in the supplied products do not use materials for treatment and vice versa.

Materials for treatment from input of products

The matrices **U, Y** and $\mathbf{S^+}$**,** described in, show the total mass of products entering human activities. Also for these products an analogous approach to the previous sections on natural resources can be applied although a matrix is introduced rather than a vector. So a transfer coefficient matrix $\mathbf{D_0}$ is defined to specify the proportion of inputs of products to an activity that is present in the supply of products of the same activity. The format of $\mathbf{D_0}$ is products by productive activities. All the values of $\mathbf{D_0}$ fall in the interval [0;1].

The transfer coefficient matrix $\mathbf{D_0}$ is created as a combination of manual specified and calculated coefficients. This ensured consistency between inputs (natural resources, products, materials for treatment), outputs of products, and the transfer coefficients. This is further described in equations **(6)** and **(7)**.

The total supply of products originating from inputs of products ($\mathbf{V_C'}$) can be expressed as:

$$\mathbf{V}_{\mathrm{C}} \cdot \mathbf{i} = (\mathbf{D_0} * \mathbf{U})' \cdot \mathbf{i} \tag{4}$$

The matrix of emissions originating from inputs of products is denoted $\mathbf{B_C}$, and it has format products by activities.

The supply of materials for treatment plus stock additions ($\mathbf{W_{V,C}}+\Delta\mathbf{S_C}$) originating from the input of products can be calculated as shown in **(5)** for productive activities and for household and stock categories. The format of $\mathbf{W_{V,C}}+\Delta\mathbf{S_C}$ is products by activities.

$$\begin{gathered}\mathbf{W_{V,a,C}} + \Delta\mathbf{S_{a,C}} = \mathbf{U} - \mathbf{D_0} * \mathbf{U} - \mathbf{B_{a,C}} \\ \mathbf{W_{V,f,C}} + \Delta\mathbf{S_{f,C}} = (\mathbf{Y} \cup \mathbf{S^+}) - \mathbf{B_{f,C}}\end{gathered} \tag{5}$$

The transfer coefficient matrix $\mathbf{D_0}$ is based on specified information and calculated mass balances. This enables to specify the coefficients for which good information is available, while the remaining coefficients are calculated to ensure consistency between inputs (natural resources, products, materials for treatment), outputs of products, and the transfer coefficients. For this purpose a feedstock specification matrix $\mathbf{D_1}$ is defined for data inputs regarding product feedstocks. This matrix has same format as the $\mathbf{D_0}$ matrix. In $\mathbf{D_1}$ feedstocks can be specified if the value of a cell is within the interval]0;1]. If the value 1 is entered, the feedstock will be calculated based on mass balance, and if a value]0;1[is entered, then this specific feedstock efficiency is carried on to the corresponding cell in $\mathbf{D_0}$. This is specified in **(6)**.

$$\mathbf{D_0}_{i,j} = \begin{cases} \mathbf{D_1}_{i,j} = 0 \rightarrow \ \mathbf{D_0}_{i,j} = 0 \\ \mathbf{D_1}_{i,j} =]0,1[\ \rightarrow \ \mathbf{D_0}_{i,j} = \mathbf{D}_{i,j} \\ \mathbf{D_1}_{i,j} = 1 \rightarrow \ \mathbf{D_0}_{i,j} = \hat{\mathbf{d}}_{\boldsymbol{j}} \text{ [see (7)]} \end{cases} \quad \textbf{(6)}$$

The last term in **(6)** is calculated as:

$$\hat{\mathbf{d}} = \mathbf{mdiag}\left[\mathbf{V} \cdot \mathbf{i} - \widehat{\mathbf{r_{T,a}}} \cdot \mathbf{f_0} - (\mathbf{W_U}' \cdot \mathbf{i}) \cdot \mathbf{e_0} - \left(\mathbf{D_{1ij<1}} * \mathbf{U}\right)' \cdot \mathbf{i}\right] \cdot \mathbf{mdiag}\left[\left(\mathbf{D_{1ij=1}} * \mathbf{U}\right)' \cdot \mathbf{i}\right] \quad \textbf{(7)}$$

Also in the case, if the vector in the denominator has some null components, by default the value 0 is assigned to all values in that column of the $\mathbf{D_0}$ matrix.

Equation (7) says that components of $\mathbf{D_0}$ for $\mathbf{D_{1ij}=1}$ are the ratio between the total mass of the supplied products less the natural resources, materials for treatment and products already transferred, and the total mass of products still to be transferred.

5. Stock formation

This Section concerns the formation of fixed assets, i.e. machinery, construction works, etc., and the change in inventories, i.e. the products accumulated at the end of the accounting periods.

By definition fixed assets contribute to the formation of stock while the change in inventories can generate both materials for treatment and stocks, depending on the nature of the accumulated products.

In general the fixed assets generate materials for treatment when they are dismissed entirely or partially while the intermediate and non-durable products included in the formation of new inventories, create materials for treatment in a subsequent accounting periods when products are purchased. These aspects become of fundamental relevant when the analysis of waste scenarios requires the time dynamic as was pursued in the FORWAST project (Schmidt et al. 2010).

The stock formation is not a productive activity in the sense that the incoming products are delivered in the same shape, without any processing; only degradation may take place. Hence the incoming flows are included in the supply side straightforward in the stock change accounts, of course excluding the degraded part that generates materials for treatment and emissions. As a consequence, the product transfer coefficients related to stock formation are null.

One of the advantages of the introduction of transfer coefficient matrices, as seen in the previous section is that the stock formation accounts can be detailed according to the inputs present in the product. The information embodied in the transfer coefficients combined with the matrices of the inputs of materials (natural resources, materials for treatment and products) can trace the material composition of equipment.

6. Waste treatment activities; allocation of materials for treatment and by-products

Input of materials for treatment, accounted in $\mathbf{W_U}$, concerns the waste treatment activities. All supply of materials for treatment is accounted for (used in) the use of materials for treatment matrix. Also import and export of materials for treatment should be taken into account. However, as a default/starting point trade with materials for treatment is not included in the CREEA project due to limited data availability and challenging balancing exercises regarding a balanced trade-linking for materials for treatment (which also has to be consistent with the supply and use of products). Hence we have:

$$(\mathbf{W_V} \cdot \mathbf{i})' \cdot \mathbf{i} = (\mathbf{W_U}' \cdot \mathbf{i})' \cdot \mathbf{i} \quad \textbf{(8)}$$

The format of the $\mathbf{W_U}$ matrix is different from the supply of materials for treatment matrix $\mathbf{W_V}$. The columns in $\mathbf{W_V}$ and $\mathbf{W_U}$ are the same; they represent activities. The rows in the $\mathbf{W_V}$ matrix have same classification as the products in the supply (**V'**) and use (**U**) tables (due to the calculation in **(5)**). This classification is not used in the $\mathbf{W_U}$ matrix. This is because some of the materials for treatment in the $\mathbf{W_V}$ table are composed of different materials, e.g. machinery waste may be composed by iron, aluminium, copper and plastics while the waste treatment activities are defined for homogeneous waste fractions. In order to achieve correspondence between the defined waste treatment activities (which treat homogenous waste fractions), the composite wastes (e.g. machinery) are disaggregated and same wastes appearing in different product classifications (e.g. meat waste and other food wastes will both be treated as just food waste) are aggregated. *This procedure is possible due to the information kept in the efficiency coefficients presented in the previous sections.*

For the purpose of the reclassification of the supply of materials for treatment, the correspondence matrix **Q** is defined. The **Q** matrix has format materials for treatment (same as products in use table) by re-classified homogeneous materials for treatment. The sums of the rows in **Q** are 1. The reclassification of materials for treatment in $\mathbf{W_V}$ and $\mathbf{W_U}$ is illustrated in **Figure.6** and in **(9)**.

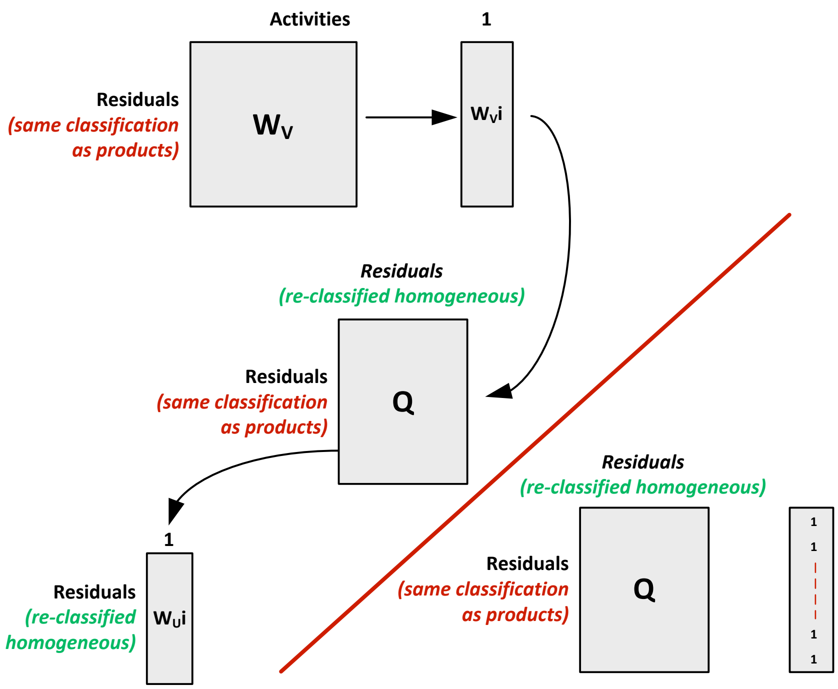

Figure.6: Re-classification of the materials for treatment in W_V to homogeneous materials for treatment in W_U by use of Q. In the lower right corner it is illustrated that the row sums of Q are 1.

$$\mathbf{W_U} \cdot \mathbf{i} = \ [\mathbf{Q}' \cdot \mathrm{mdiag}(\mathbf{W_V} \cdot \mathbf{i})] \cdot \mathbf{i} \qquad \textbf{(9)}$$

The next step in creating $\mathbf{W_U}$ is to distribute the re-classified materials for treatment ($\mathbf{W_U} \cdot \mathbf{i}$) into the use of materials for treatment matrix ($\mathbf{W_U}$). This distribution is carried out in a two-step procedure. First, some of the total supply of materials for treatment is estimated based on information in the framework combined with ancillary information (e.g. human metabolism can be used to estimate urine and excretion in sewage water). The second step is to allocate the remaining materials for treatment, which are not specified in the first step, to a default waste treatment activity, e.g. landfill.

This can also be explained by an example: Imagine that we have calculated the total supply of paper waste as 1000 tonne. Then from the data collection for the supply table (**V'**) we know that the 'Re-processing of secondary paper into new pulp' activity supplies 500 tonne pulp. We also know that the proportion of ingoing waste paper ending up in the final product ($\mathbf{e_0}$) for this activity is 0.85. Hence, we can calculate that the 'Re-processing of secondary paper into new pulp' activity treats 500 tonne pulp divided by 0.85 tonne pulp per tonne paper waste. This equals 588 tonne paper waste used by the 'Re-processing of secondary paper into new pulp' activity. For some other waste treatment activities we may use other information to estimate the quantity of materials for treatment used by these activities. And then the remaining paper waste is allocated to landfill of paper waste.

7. Mass balance check and consolidated calculation of DS+WV

The scope of this section is to present the iterative procedure that is be applied to the default PSUTs based on the approach explained above to ensure mass balance and consistency within the framework.

The first step in determining the waste accounts is to calculate the supply of materials for treatment ($\mathbf{W_V}$) plus stock additions ($\Delta\mathbf{S}$), by using **formulas ()**, **()** and **(5)**.

In this way a first construction of matrix $\mathbf{\Delta S}+\mathbf{W_V}$ is carried out. However, experiences from the FORWAST project (Schmidt et al. 2010) show that this first calculation implies several inconsistencies depending on the quality of the input data. If the physical supply and use tables are created based on a default assumption of constant prices, the calculated inputs of feedstock may be less than the sum of the output of the associated supply of products and emissions. This leads to negative values in matrix $\mathbf{\Delta S}+\mathbf{W_V}$ which is inconsistent; activities do not generate negative quantities of waste. Another aspect of the inconsistency appears when some of the calculated product transfer coefficients in $\mathbf{D_0}$ show values outside the interval [0;1]. Again, this is inconsistent; if entries in $\mathbf{D_0}>1$ it means that activities produce more product output than input of feedstock. Correspondingly, if entries in $\mathbf{D_0}<1$ it means that some feedstock cause negative supply of products.

The inconsistent values of $\mathbf{D_0}$ and of $\mathbf{\Delta S}+\mathbf{W_V}$ will be eliminated by:

1. Redistribute the entries in the rows with the relevant feedstocks in the use table (**U**)
2. Scale the production volume and associated inputs and outputs of products, natural resources, emissions and materials for treatment. This option will only be used if the production volume of an activity appears to be too big compared with the available feedstocks.

Option 1) above can be implemented in an automated optimization procedure which is defined to ensure consistency and to maximise the agreement with some defined criteria on expected production functions. An example of the latter could be that approximately 1.1 kg DM wood is used to produce 1 kg DM pulp in the pulp manufacturing activity.

Redistribution of the entries in the rows in the use table is equivalent to differentiate the prices over activities.

Option 2) will be used when the automated procedure explained above fails to produce satisfactory agreement with the defined criteria expected production functions.

8. Conclusion

A procedure to construct PSUTs making use of all the information available from different data sources and technological knowledge of industrial processes has been outlined in this paper. The procedure has been initially developed in the FORWAST project and is now further enriched in the on-going CREEA project.

The final objective is to build coherent PSUTs that can be used to carry out a MFA of economies and to generate waste accounts that are organically introduced in the physical accounts. Furthermore the procedure here presented aims to directly link the causes of waste and the quantification of waste in the waste accounts. This enables analytic economy wide life cycle emissions calculations on the effect of different waste management interventions. *Further, since the PSUTs are classified with same products and industries as the MSUTs, the approach enables for the creation of a fully balanced (economic, mass and energy) hybrid supply-use table enabling for new and better quality hybrid life cycle assessments.*

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