SIXTH FRAMEWORK PROGRAMME
PRIORITY [policy-oriented research priority SSP 5A]

SPECIFIC TARGETED RESEARCH OR INNOVATION PROJECT

FORWAST

Overall mapping of physical flows and stocks of resources to forecast waste quantities in Europe and identify life-cycle environmental stakes of waste prevention and recycling

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Title:

Documentation of the final model used for the scenario analyses

Authors:

Jannick H. Schmidt, Bo P. Weidema & Sangwon Suh, 2.-0 LCA consultants

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Contents:

1 Introduction

The overall objective of the FORWAST project is to:

1. Provide an inventory of the historically cumulated physical stock of materials in EU27 and to forecast the expected amounts of waste generated, per material category, in the next 25 years.
2. Provide an assessment of the life-cycle wide environmental impacts from different scenarios of waste prevention, recycling and waste treatment in the EU27.

These inventory and assessment results are provided as an output of a Leontief-type environmentally extended, quasi-dynamic, physical input-output model covering the EU27, including raw material extraction and processing of imported materials and waste treatment of exported wastes.

The fundamental concept behind the model is that of mass balances ("what comes in must go out"), implying that the resource input (R) minus emissions (B) and stock changes (ΔS) determines the potential waste amounts ($W=R-B-\Delta S$). To determine *where* and *when* the materials in the resource inputs come out as waste, it is also necessary to trace the materials in the resource inputs through the different activities of the economy, which is done in the input-output model, and to determine the lifetime of the material stocks.

The objective of the present Deliverable 6-4 is to document the applied model.

The practical data handling, data consolidation, balancing, and scenario parameterisation are described in deliverable D6-1 'Documentation of the data consolidation and calibration exercise, and the scenario parameterisation'. The main model outputs are described in D6-2 '25-year forecasts of the cumulated physical stocks, waste generation, and environmental impacts for each scenario for EU-27 and for the case study countries', and the result interpretation, uncertainties and policy recommendations are described in D6-3 'Documentation of the contribution analysis and uncertainty assessment. Results interpretation identifying priority material flows and wastes for waste prevention, recycling and choice of waste treatment options. Policy recommendations'.

2 Model overview

The model outputs are:

Stocks of products and residuals: Amount of material held within the technosphere in a given point of time, i.e. originally sourced from the environment, and at the beginning of a specified period not yet released as emissions. Stocks of products may either be in active use or no longer in use ("hibernating"). The model also allows the stock to be specified by material, by nature of the stock (product type), and by location of the stock (by industry, household or waste treatment activity).

Waste flow: Output flows of a human activity that remains in the technosphere and does not directly (i.e. without further processing or emissions) displace another product.

Monetarised environmental impact: Monetarised indicator of impact from human activities on the environment. The model also allows the environmental impact to be specified by emission, by midpoint impact category, and by other endpoint indicators as well as to be traced back to specific human activities.

The overall composition and mechanisms in the model are summarised in **Figure 1**.

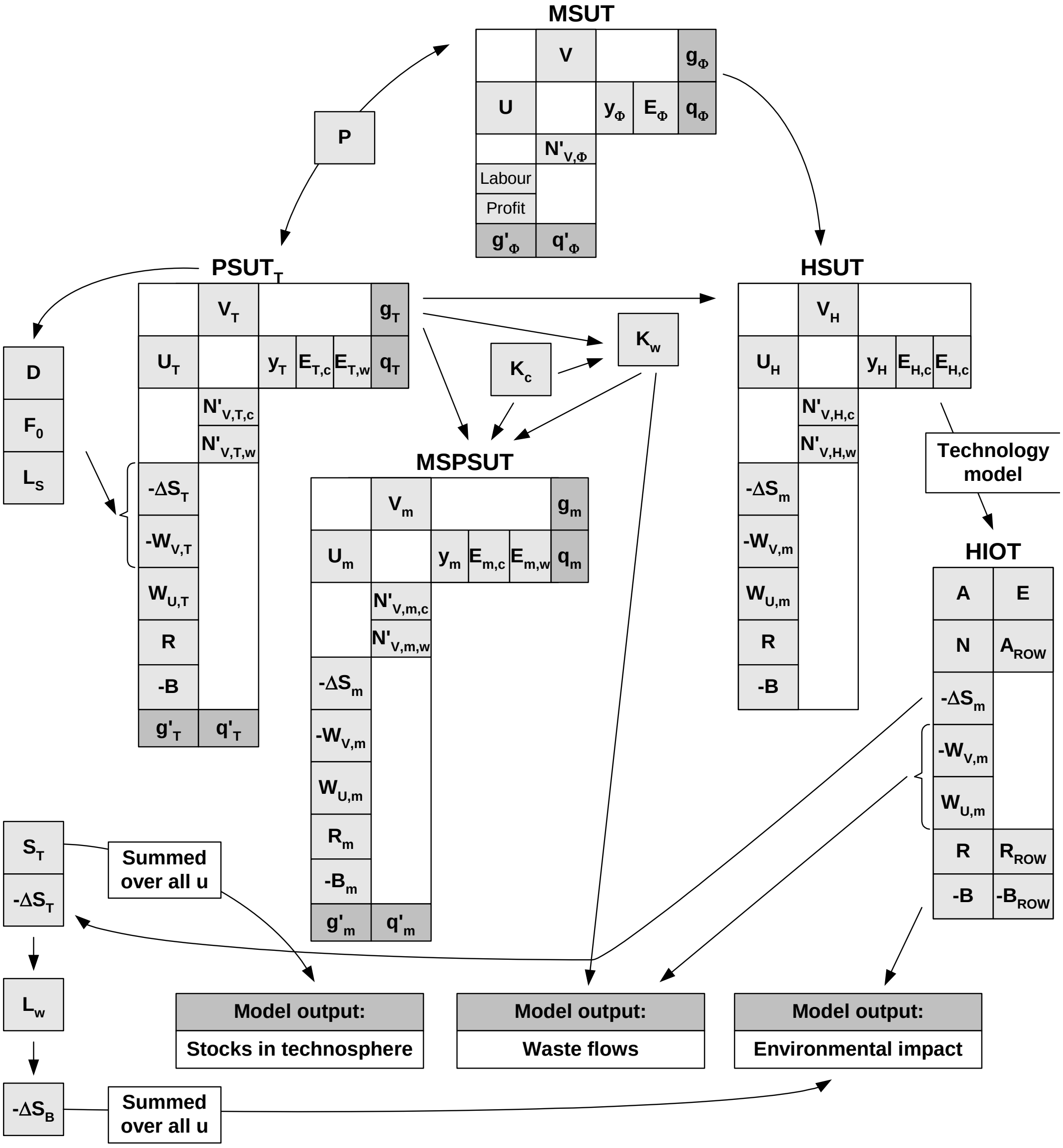


Figure 1: Model overview.

3 Definitions

3.1 Definitions of terms used

Emission:
Output flow from a human activity that directly enters the environment. NOTE: The term ‘Environmental indicators’ covers also emissions. As material outputs, emissions are also included in the physical matrices as negative inputs.

Environment:
The surroundings of the technosphere.

Human activity:
Disaggregated category of the technosphere. The sum of industry and household activities represent all human activities. Industry activities are productive activities that aim at selling the resulting products to another activity, while the remaining human activities are household activities.

Natural resources inflow:
Material inflows from the environment to the technosphere.

Physical flow:
Movement of material between different human activities or from/to the environment.

Product:
Output flow from a human activity with a positive either market or non-market value. An example of a product with a non-market value can be household childcare. Products from industry and household activities are denoted ‘industry products’ and ‘household products’ respectively. Further distinction of the products can be made in terms of determining products and by-products:

> **Determining product:**
> Product for which the production volume changes in response to changes in demand. In economic terminology, determining products may be called primary, secondary, tertiary etc.
>
> **By-product:**
> Non-determining product that directly (i.e. without further processing) is used in place of other products.

Residual:
Output flows of a human activity that remains in the technosphere and cannot directly (i.e. without further processing or emissions) displace another product. After processing in a waste treatment (recycling) activity, the recovered residuals may displace other products.

Technosphere:
Space and time where human activities take place.

Waste treatment activity:
Human activity that uses residuals. Waste treatment activities are service activities, i.e. their determining product is a service. For landfill and waste incineration, this service is to take care of the treatment and disposal of waste. For recycling activities, the service is to process residuals into by-products having a positive market value. If a waste treatment activity enriches its by-product output by adding other inputs than residuals to the by-product output (e.g. composted organic waste enriched with nutrients), then the enrichment should be modelled as a separate industrial activity, i.e. the activity should be disaggregated into a waste treatment activity and an enrichment (non-waste-treatment) activity. Similarly, in a non-waste treatment activity that uses residuals (e.g. a cement industry using waste fuels) the waste treatment activities (producing heat as a by-product) must be disaggregated from the main activity (producing cement). A further distinction is made between intermediate and final waste treatment activities:

> **Final waste treatment activity:**
> Waste treatment activity that does not have an output of residuals for further waste treatment originating from its inflow of residuals. We model only landfills and land application of waste as final waste treatment activities.
>
> **Intermediate waste treatment activity:**
> Waste treatment activity that has an output of residuals for further waste treatment originating from its inflow of residuals (while possibly converting the major part of this inflow of residuals to by-products). We model waste incineration, biogasification, composting, and recycling as intermediate waste treatment activities.

3.2 Definition of vectors and matrices

Supply matrix (V):
Product supply per human activity within a specified period and geographical area. The use of variables as subscript indicates the units of the matrix, e.g. $\mathbf{V}_{\Phi}$ (monetary supply table), $\mathbf{V}_{T}$ (total physical supply table covering all materials, m) and $\mathbf{V}_{Fe}$ (material specific supply table for iron).
The standard dimension of supply tables in literature (e.g. Hoekstra 2005, Kop Jansen and ten Raa 1990, ten Raa and Rueda-Cantuche 2003) is activities by products (a × c). This corresponds to the transpose format of the use table. Throughout this report, we use the standard dimension for **V**, but in figures and formulas, the supply table will always appear as **V'** (transpose of **V**) in order to have the same dimension as the use table (**U**).
Dimension: activities by products. (a × c)
Variables: g, t, m, Φ, x

Use matrix (U):
Products used per human activity within a specified period and geographical area. For balancing purposes, monetary use matrices are supplemented by a primary factor (net value added) matrix, with rows representing “Compensation of employees”, “Net taxes” and “Net operating surplus”.
Dimension: products by activities (c × a)
Variables: g, t, m, Φ, x

Use matrix, original ($\mathbf{U_o}$):
Products used per human activity within a specified period and geographical area, excluding gross capital formation and use of fixed capital. This is the standard format of use tables in basic prices, as supplied from statistical agencies (Note that use tables are often supplied in purchasers’ prices. Procedures for conversion are described in Chapter 4.1.3). This means that capital formation is not incorporated in the transactions of products to activities, but as one or more separate columns (capital formation) representing the total addition to capital goods per products, and a separate row (consumption of fixed capital) representing the total use of capital goods per activity.
Dimension: products by activities (c × a) + a column vector, product by capital formation (c × 1) + a row vector, consumption of fixed capital by activities (1 × a)
Variables: g, t, m, Φ, x

Import of products ($\mathbf{N_c}$) and residuals ($\mathbf{N_w}$):
Import of products and residuals for a specified period and importing geographical area. $\mathbf{N_c}$ and $\mathbf{N_w}$ represent import of products and residuals, respectively.
Dimension of each of $\mathbf{N_c}$ and $\mathbf{N_w}$: products by 2 (c × 2); the two columns representing import intra EU27 and import extra EU27
Variables: g, t, m, Φ, x

Export of products ($\mathbf{E_c}$) and residuals ($\mathbf{E_w}$):
Export of products and residuals for a specified period and exporting geographical area. $\mathbf{E_c}$ and $\mathbf{E_w}$ represent export of products and residuals, respectively.
Dimension of each of $\mathbf{E_c}$ and $\mathbf{E_w}$: products by 2 (c × 2); the two columns representing export intra EU27 and export extra EU27
Variables: g, t, m, Φ, x

Needs fulfilment vector (y) and final consumption vector ($\mathbf{y_0}$):
Demand vectors for a specified period and geographical area. $\mathbf{y_0}$ is the traditional final consumption vector, as supplied by statistical agencies. Since household and government activities are included in our Direct requirement coefficient matrix (**A**), **y** differs from $\mathbf{y_0}$ by typically containing values = 0 for industry products and positive values for household products only.
Dimension of each vector: Products by one (c × 1)
Variables: g, t, m, Φ, x

Activity output (g-vector):
Sum of the output (supplied products, residuals and emissions) or input (used resources, products, residuals, and primary factors) per human activity within a specified period and geographical area.
Dimension: activities by 1, column vector (a × 1)
Variables: g, t, m, Φ, x

Product output (q-vector):
Sum of supplied products (domestic and exported) or used products (domestic and imported) for all human activities within a specified period and geographical area (as given in **V, E** and **N**).
Dimension: products by 1, i.e. a column vector (c × 1)
Variables: g, t, m, Φ, x

Domestic product output ($\mathbf{q_d}$-vector):
Sum of the supplied products from all human activities within a specified period and geographical area (as given in **V**).
Dimension: products by 1, i.e. a column vector (c × 1)
Variables: g, t, m, Φ, x

Price-matrix (P):
Price per mass of products for each domestic product supply, domestic product use, import and export (in the **V**, **U**, $\mathbf{N_C}$, and $\mathbf{E_C}$ matrices) for a specified activity, period and geographical area. The price matrix relating to the domestic supply and import is denoted $\mathbf{P_V}$ and the price matrix relating to use and export is denoted $\mathbf{P_U}$. Additional separate rows (below $\mathbf{P_V}$ and $\mathbf{P_U}$) may indicate prices relative to other physical units (e.g. kWh). Import and export are represented by a column to the right of $\mathbf{P_V}$ and $\mathbf{P_U}$ respectively.
Dimension: products by activities [(2(c+additional rows)) × (a+1)], where ‘additional rows’ refer to separate rows (below $\mathbf{P_V}$ and $\mathbf{P_U}$) with prices relative to other physical units, and the 1 column for imports and exports.
Variables: g, t, Φ, x

Waste treatment activity identifier vectors ($\mathbf{h_i}$ and $\mathbf{h_f}$):
Vectors to identify an activity as intermediate waste treatment activity, final waste treatment activity or non-waste treatment activity. $\mathbf{h_i}$ and $\mathbf{h_f}$ are row vectors with dimensions one by activities. The vectors have entries = 1 for waste treatment activities and entries = 0 for non-waste treatment activities. $\mathbf{h_i}$ identifies intermediate waste treatment activities (for which the vector has entries = 1), and $\mathbf{h_f}$ identifies final waste treatment activities (for which the vector has entries = 1). The vector $\mathbf{h_i}+\mathbf{h_f}$ identifies activities that are either intermediate or final waste treatments, i.e. all waste treatment activities.
Dimension: One by activities (2 × a)
Variables: -

Stock changes matrix (ΔS):
Additions to stocks of products and residuals per human activity within a specified period and geographical area. Negative entries thus refers to use of stocks. In final waste treatment activities (as defined by $\mathbf{h_f}$), the

stocks are stocks of residuals. All other stock changes refer to stocks of products. Small temporary changes in inventories are not covered by the stock concept of our model, but are taken up as use in the **U** matrix.
Dimension: Products by activities (c × a)
Variables: g, t, m, x, u

Stocks matrix (S):
Stocks per activity. $\mathbf{S}_{t+1} = \mathbf{S}_t + \Delta\mathbf{S}_t$. In final waste treatment activities (as defined by $\mathbf{h}_f$), the stocks are stocks of residuals. All other stocks are stocks of products. The **S**-matrix is defined for all material categories (m); see definition of variables. $\mathbf{S}_T$ is the sum of the stocks for all materials (m).
Dimensions: Products by activities (c × a).
Variables: g, t, m, x

Residuals supply matrix ($\mathbf{W}_V$):
Residuals supplied per human activity within a specified period and geographical area.
Dimension: Residuals by activity (w × a)
Variables: g, t, m, x

Residuals use matrix ($\mathbf{W}_U$):
Residuals used per waste treatment activity within a specified period and geographical area.
Dimension: Residuals by activity (w × a)
Variables: g, t, m, x

Residuals distribution (J):
For each type of residual, the proportion of the supply of the residual used by each waste treatment activity (as defined by $\mathbf{h}_i$ and $\mathbf{h}_f$) including export. The sum of each row in **J** is = 1. Since only waste treatment activities (and export) receive residuals, the columns in **J** representing non-waste treatment activities contain only zeros.
Dimension: Residuals by activities plus 2 (w × a+2), the two additional columns representing export intra and extra EU.
Variables: g, t, x

Resources matrix (R):
Input of resources per human activity within a specified period and geographical area.
Dimension: Resources by activity (m × a)
Variables: g, t, m, x

Total resources vector ($\mathbf{r}_T$):
Total input of resources per human activity within a specified period and geographical area. $\mathbf{r}_T$ is equal to the last (sum) row in **R**.
Dimension: one by activity (1 × a)
Variables: g, t, m, x

Resource transfer coefficient matrix ($\mathbf{F_0}$):
For each product supplied by an activity, the proportion of the total resource input to the activity present in the product, i.e: (resources present in products) / (total resource input). Allowed values fall in the interval [0,1]. The sum of each column is not necessary = 1 because some of the inputs of resources may be lost as residuals.
Dimension: Products by activities (c × a)
Variables: g, t, x

Resource distribution matrix (F):
For each product supplied by an activity, the ratio between the amount of resources present in the specific product and the total amount of resources present in all the products of the activity. The sum of each column in **F** is = 1. **F** is the normalised version of $\mathbf{F_0}$ (i.e. $\mathbf{F_0}$ divided by the column sum of $\mathbf{F_0}$).
Dimension: Products by activities (c × a)
Variables: g, t, x

Emissions matrix (B):
Emissions output per human activity within a specified period and geographical area.
Dimension: Emission type by activity matrix (b × a)
Variables: g, t, m, x

Emissions distribution matrices ($\mathbf{G_c}$, $\mathbf{G_w}$, and $\mathbf{G_R}$):
For each product, residual and resource input to an activity, the emissions that originate from that specific product, residual or resource input. $\mathbf{G_c}$ refers to emissions that originate from the use of products (e.g. when an input of coal is burned), $\mathbf{G_w}$ refers to emissions that originate from the use of residuals (e.g. waste incineration), and $\mathbf{G_R}$ refers to emissions that originate from the use of resources. Thus, for each activity, the sum of all emissions (b) in **B** are distributed either on the products and residuals inputs to the activity ($\mathbf{G_c}$ and $\mathbf{G_w}$) or on the products that use the resources ($\mathbf{G_R}$). The sum of the columns of the three **G** matrices is equals the sum of the columns of the emissions matrix **B**.
Dimension: For each of the three **G** matrices: Products by activities (c × a)
Variables: g, t, x

Product transfer coefficient matrix (D):
For each product input used by an activity, the proportion of the input which is present in the products supplied by the activity, i.e: (use of a product present in the supply products) / (total use of that product). Allowed values fall in the interval [0,1]. **D** also includes those products that have a shorter lifetime than the product they enter into (e.g. windows in a building, typically exchanged several times during the life time of a building). This implies that the residuals and stock changes of these products will appear as residuals and stock changes of the composite product industry (e.g. the building industry) rather than of the activity using the composite products (e.g. the use of buildings).
Dimension: Products by activities (c × a)
Variables: g, t, x

Input data for product transfer coefficients ($\mathbf{D_1}$):
For each product input used by an activity, a specification whether the product will be present in the products supplied by the activity ($\mathbf{V'_T}$). Allowed values fall in the interval [0,1]. The value = 0 means hat the product is not present in $\mathbf{V'_T}$, the value = 1 means that the product will be present in $\mathbf{V'_T}$ but the proportion is unknown, and a value $\in$]0,1[means that the product will be present in $\mathbf{V'_T}$ in the specified proportion. $\mathbf{D_1}$ is used in the calculation of **D**.
Dimension: Products by activities (c × a)
Variables: g, t, x

Stock degradation matrix ($\mathbf{L_S}$):
For each type of stocks of products, the proportion of the initial stock that becomes residual in year u. Allowed values fall in the interval [0,1]. In the model calculations only one row of $\mathbf{L_s}$ is used at the time. We use the notation $\mathbf{L_{s,u=1}}$ to signify the *row vector* represented by the first row of $\mathbf{L_s}$.
$\mathbf{L_S}$ may be determined by the lifetime of products and/or possibly other factors.
Dimension: Age of stocks by products (u × c)
Variables: g, t, x

Residuals degradation matrix ($\mathbf{L_w}$):
For each type of residual, the proportion of the net supply of the residual that becomes emissions in year u. Net supply of a residual is the supply of the residual minus the use of the residual. Allowed values fall in the interval [0,1]. For residuals from waste treatment activities, the sum of each column = 1, and for the residuals from non-waste treatment activities the columns are empty (contain only zeros). $\mathbf{L_w}$ may be determined by the decomposition function of waste in landfills or similar.
Dimension: Age of stocks by residuals (u × w)
Variables: g, t, x

Emissions from stocks matrix ($\mathbf{S_B}$):
Emissions output from stocks, per activity.
Dimension: Emissions by activities (b × a)
Variables: g, t, m, x, u

Product material content matrix ($\mathbf{K_c}$):
Ratio between the mass of a specific material in a product and the total mass of the product. E.g., if 70% of the product “Motor vehicles and trailers” is iron, the entry in the row for the material Fe in the column for the product “Motor vehicles and trailers” should be 0.7.
Dimension: Materials by products (m × c)
Variables: g, t, x

Product material content vector ($\mathbf{k_{c,m}}$):
Ratio between the mass of material m in a product and the total mass of the product. $\mathbf{k_{c,m}}$ corresponds to one of the rows in $\mathbf{K_c}$.
Dimension: Material m by products (1 × c)
Variables: g, t, x

Residual material content matrix ($\mathbf{K_w}$):
Ratio between the mass of a specific material in a residual and the total mass of the residual. The $\mathbf{K_c}$ matrix corresponds to the $\mathbf{K_c}$ matrix, but specifies the material composition of residuals rather than products.
Dimension: Materials by residuals (m × w)Variables: g, t, x

Residual material content vector ($\mathbf{k_{w,m}}$):
Ratio between the mass of material m in a residual and the total mass of the residual. $\mathbf{k_{w,m}}$ corresponds to one of the rows in $\mathbf{K_w}$.
Dimension: Material m by residuals (1 × w)
Variables: g, t, x

Direct requirement coefficient matrix (A), normalised:
Ratio between domestic inputs and product outputs, per product, for a specified period and geographical area. This matrix is a model output produced using supply tables (**V**) and use tables (**U**).
Dimension: Products by products (c × c)
Variables: g, t, m, Φ, x

Direct requirement coefficient matrix ($\mathbf{A_{upscaled}}$), upscaled:
Domestic inputs and product outputs, per product, for a specified period and geographical area. This matrix is a model output produced using supply tables (**V**) and use tables (**U**), and by scaling the normalised direct requirement matrix **A** by the scaling factors (**scale**) obtained by using the Leontief inverse and the final demand vector (see definition of **scale** below).
$\mathbf{A_{upscaled}} = (\mathbf{scale}^T \, I) .* \mathbf{A}$ (see definition of **I** and mathematical expressions in chapter 3.4)
Dimension: Products by products (c × c)
Variables: g, t, m, Φ, x

Scaling factors (scale):
Factors to be multiplied (by column in the **A** matrix) to obtain an upscaled direct requirement coefficient matrix $\mathbf{A_{upscaled}}$.
$\mathbf{scale} = \mathbf{A}^{-1}\mathbf{y}$ (Heijungs and Suh 2002)
Dimension: Activities by 1 (a × 1)
Variables: g, t, x

Direct import requirement coefficient matrix ($\mathbf{A_N}$), normalised:
Ratio between input of imported products and product outputs, per product, for a specified period and geographical area. This matrix is a model output produced from a supply table (**V**), a use table (**U**), and an import matrix ($\mathbf{N_C}$).
Dimension: Products by products (c × c)
Variables: g, t, m, Φ, x

Direct import requirement coefficient matrix ($\mathbf{A}_{\mathbf{N,upscaled}}$), upscaled:

Input of imported products and product outputs, per product, for a specified period and geographical area.

$\mathbf{A}_{\mathbf{N,upscaled}} = (\mathbf{scale}^T \; \mathrm{I}) \,.\!*\, \mathbf{A}_{\mathbf{N}}$ (see definition of **I** and mathematical expressions in chapter 3.4)

Dimension: Products by products (c × c)

Variables: g, t, m, Φ, x

3.3 Definition of variables

Activity (a):

Industrial activities by NACE code (and further disaggregated categories) and household activities (by COICOP or other classification). The same activity can be a supplier of products and a user of products.

Allowed values: See ‘Appendix 1: Activities and products’.

Product (c):

Industrial products and household products. The same product can be supplied by activities and products can be used by activities.

Allowed values: Identical to activities (a).

Residuals (w):

Industrial residuals and household residuals.

Allowed values: Integers of values same or more than activities (a), i.e. $\geq$ a

Materials (m):

Material categories included in the FORWAST project. The mass flow analysis is carried out for these categories. Allowable values are dry weight of:

1. Al (Aluminium)
2. BI (Fibre carbon)
3. BO (Food carbon, including tobacco)
4. CC (Coal carbon)
5. CH (Crude oil and natural gas carbon)
6. CO (Carbonate carbon)
7. Cu (Copper)
8. Fe (Iron)
9. ME (Metals, n.e.c.)
10. MI (Minerals and other balancing element, n.e.c., including nitrogen and hydrogen)
11. O (Oxygen in oxidised products)
12. SO (Clay and soil)
13. ST (Sand, gravel and stone)
14. T (Total material)

Time (t):

Years with 4 digits. Multi-year periods as e.g. 2000-2004, indicating a period including fully the two years stated.

Allowed values: t or t-t; t ∈ [… 2005, 2006, 2007, 2008, …]

Age of stock (u):
Age of stock in years
Allowed values: u ∈ [1, 2, 3, 4, …]

Geographical area (g):
Country codes and regional abbreviations.
Allowed values:

- ISO 2-digitcountry codes (ftp://ftp.fao.org/FI/DOCUMENT/cwp/handbook/annex/ANNEX_DII.pdf)
- EU27
- Combinations with + or -, e.g. EU27-DK means EU27 without Denmark
- ROWg indicates the Rest-of-World for area g.

Emissions (b)
Allowed values: Listed names in 'Appendix 2: Emissions'.

Monetary units (Φ):
ISO 4217 codes with or without multipliers (k, M, G, etc.) and always with reference year, i.e. e.g. EUR2000 for Euros in year 2000. When expressed in purchasing power standards, PPS may be added, e.g. EUR2000PPS.

Scenarios (x):
9 scenarios, created as combinations of 3 macro-economic scenarios and 3 scenarios of waste prevention, recycling and waste treatment.
Allowed values: x ∈ [1, 2, 3..., 8, 9]

In **Table 1** below, an overview of the nine analysed scenarios are provided.

Macro-economic scenario / **Waste treatment scenario**	**Baseline**	**High growth**	**Low growth**
Treatment	Scenario 1	Scenario 4	Scenario 7
Recycling	Scenario 2	Scenario 5	Scenario 8
Prevention	Scenario 3	Scenario 6	Scenario 9

Table 1: Overview of the analysed scenarios.

3.4 Mathematical notation

Table 2: List of mathematical notation used.

Notation	**Description**	**Example**
m × n matrix	Matrix containing m rows and n columns.	In a matrix with dimensions “products” by “activities”, each row refer to a product and each column refer to an activity
Bold text large case letters	Matrices	Matrix **A**
Bold text small case letters	Vectors	Vector **g**
$\mathbf{A}_{ij}$ or $[\mathbf{A}+\mathbf{B}]_{ij}$	Entry of matrix **A** or [**A**+**B**]; row i and column j	$\mathbf{A}=\begin{bmatrix}1&3\\2&4\end{bmatrix}\rightarrow\mathbf{A}_{12}=3$
Hat [^] or mdiag()	Diagonal of vector	$\mathbf{g}=\begin{bmatrix}x\\y\end{bmatrix}\Rightarrow\hat{\mathbf{g}}=\mathrm{mdiag}(\mathbf{g})=\begin{bmatrix}x&0\\0&y\end{bmatrix}$
Apostrophe [´]	Transpose of vector or matrix	$\mathbf{A}=\begin{bmatrix}1&4\\2&5\\3&6\end{bmatrix}\Rightarrow\mathbf{A}'=\begin{bmatrix}1&2&3\\4&5&6\end{bmatrix}$
I	Identity matrix; a matrix with 1 for all diagonal entries and 0 for all other entries	$\mathbf{I}=\begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix}$
i	Row vector with all entries equal to one	$\mathbf{i}=\begin{bmatrix}1&1&1\end{bmatrix}$
Power -1 [$^{-1}$]	Inverted matrix or vector	$[\mathbf{A}\mid\mathbf{I}]\sim[\mathbf{I}\mid\mathbf{A}^{-1}]$ The symbol ~ denotes row-equivalent matrices
Tilde [˜]	Off-diagonal entries of a square matrix	$\mathbf{A}=\begin{bmatrix}k&l\\m&n\end{bmatrix}\Rightarrow\tilde{\mathbf{A}}=\begin{bmatrix}0&l\\m&0\end{bmatrix}$
dot star [.*]	Element-by-element multiplication of two matrices. The two input matrices as well as the output matrix all have the same dimension	$\mathbf{A}=\begin{bmatrix}a&c\\b&d\end{bmatrix}$, $\mathbf{B}=\begin{bmatrix}e&g\\f&h\end{bmatrix}$ $\mathbf{A}\ .\!*\ \mathbf{B}=\begin{bmatrix}ae&cg\\bf&dh\end{bmatrix}$

dot slash [./]	Element-by-element division of two matrices. The two input matrices as well as the output matrix all have the same dimension	$\mathbf{A} = \begin{bmatrix} \mathrm{a} & \mathrm{c} \\ \mathrm{b} & \mathrm{d} \end{bmatrix} \quad , \quad \mathbf{B} = \begin{bmatrix} \mathrm{e} & \mathrm{g} \\ \mathrm{f} & \mathrm{h} \end{bmatrix}$ $\mathbf{A} \;./\; \mathbf{B} = \begin{bmatrix} \mathrm{a/e} & \mathrm{c/g} \\ \mathrm{b/f} & \mathrm{d/h} \end{bmatrix}$
det(**A**)	Determinant of square matrix **A**	$\mathbf{A} = \begin{bmatrix} \mathrm{k} & \mathrm{l} \\ \mathrm{m} & \mathrm{n} \end{bmatrix} \Rightarrow \det(\mathbf{A}) = \mathrm{kn} - \mathrm{lm}$

4 Supply and use tables

The model outputs of the FORWAST project are:

1. Stocks in technosphere
2. Waste flows
3. Monetarised environmental impacts

The two first model outputs are calculated using mass flow analysis (MFA). Generally, flows between different activities in the technosphere are determined using information on monetary flows in the economy and by using physical statistics (e.g. resources inputs and emissions). Detailed, consistent information on monetary flows in the economy is provided in the format of supply and use tables (SUTs), e.g. see Eurostat (2007a). Supply and use tables can be established in monetary as well as physical units (Hoekstra 2005).

In the context of the FORWAST project, there are two important features of the SUT-framework. Firstly, the tables are balanced, so that use balances with supply. This ensures that the system modelling is consistent and provides the possibility for establishing equations using the balancing principle for the whole economy. Secondly, the SUTs can be converted into analytical IO-tables, which can be used for scenario analysis. The IO-tables are driven by a demand vector (which is defined for each scenario), and the model output is then calculated. Using information on emissions, i.e. contributors to environmental impacts, per activity in the SUT-framework, and converting the SUTs to IO-tables, the third model output given above is calculated.

4.1 Monetary Supply and Use Tables (MSUTs)

As the name indicates, SUTs consist of supply tables (**V**) and use tables (**U**). SUTs are always provided for a region (g) for a given period of time (typically one year, t), and in either monetary (Φ) or physical (m) units.

4.1.1 Format of MSUTs

The general format of a supply table as provided from statistical agencies is shown in **Figure 2**. The subscript, o, in **Figure 2** and **Figure 3** refer to "original", i.e. the general format of **V** and **U** as provided by statistical agencies. Before the supply and use table enters the calculations in the FORWAST model, they are modified, i.e. they are disaggregated into the product and activity categories in the FORWAST model (see the procedure in Chapter 8), the use table ($\mathbf{U}_\Phi$) is transformed from purchasers prices into basic prices (see the procedure in chapter 4.1.3), and the investments (i.e. capital formation in **Figure 3**) are included into the $\mathbf{U}_\Phi$ matrix (see the procedure in chapter 4.1.4).

Monetary supply table	Activities (a)	Import	Total
Products (c)	$\mathbf{V'_o}$	$\mathbf{N_c}$	$\mathbf{q}$
Total	$\mathbf{g'}$		

Figure 2: Format of supply table as supplied from statistical agencies, e.g. Eurostat (2007a).

In **Figure 2**, $\mathbf{V'_o}$ describes the supply of products (c) by activities (a). **g'** is the total value of the supply of products per activity and **q** is the total value of supplies per product.

Figure 3 shows the general format of a use table ($\mathbf{U_o}$) as provided from statistical agencies.

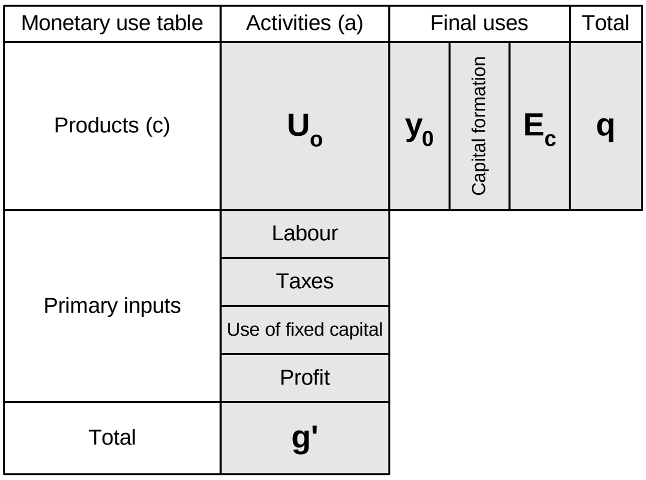


Figure 3: Format of use table as supplied from primary statistics, e.g. Eurostat (2007a).

In **Figure 3,** $\mathbf{U_o}$ describes the use of intermediate products (c) per activity (a). Primary factor inputs describe the net value added (labour, tax and profit, including the use of fixed capital) per activity. **g'** is the total factor input per activity, i.e. the sum of intermediate inputs of products and primary factor inputs. Final uses covers three elements describing final consumption ($\mathbf{y_0}$), capital formation (i.e. investments), and export (i.e. two columns; one for export intra EU27 and one for export extra EU27, **E**). **q** is the total value of the consumption (use) per product, which should match the **q** in the $\mathbf{V_o}$ matrix, i.e. the total value of the supply of the same products, when calculated in basic prices. The conversion from purchasers' prices to basic prices is described in chapter 4.1.3.

4.1.2 Modification of the original supply and use tables: Disaggregation

First, the 59 × 59 products by industries tables from the statistical agencies are disaggregated into 119 × 119 products by activities. The general purpose of disaggregation is to have a higher level of detail. As part of this, the disaggregation here has two additional special features; 1) to split production of basic materials into production of virgin material and recycled material in order to model the effect of changing the rate of recycling, and 2) to incorporate the original 'Final consumption' column ($\mathbf{y_0}$) into the use table (**U**) in order to include waste generation, stock changes and emissions of different household activities in the same way as for the industry activities. The latter implies that the final consumption column is split into several household activities and that a new **y** vector is defined for the final demand, now called "needs fulfilment vector" to distinguish it from the original final consumption vector.

The general procedure for disaggregation is described in chapter 8. Chapter 5 describes how to deal with the disaggregation in order to model waste treatment, and chapter describes how the household activities are disaggregated.

4.1.3 Modification of the original supply and use tables: Basic prices

All prices must be in basic prices before the **V** and **U** matrices can be combined for analytical purposes. Under the current ESA 95 practice, supply tables are supplied in basic prices, while use tables are in purchasers' prices, since this is the way the data are originally collected. The difference between purchasers' price and basic price can be written as follows:

Basic price = Purchasers price – Trade and transport margins – Taxes (1)

Thus, transactions expressed in purchasers' price can be, in principle, converted into basic price by subtracting trade and transport margins and taxes. However, even within the EU member countries, different practices exist in handling information on trade and transport margins and taxes for individual element of use tables.

The best practices among European countries can be found in SUT accounts of Austria, Belgium, Denmark, and Finland, where valuation matrices for trade margins and taxes are available. For these countries, derivation of use table in basic price from that in purchasers' price is straightforward.

Beyond the use of official valuation matrices, there are various techniques, none of which does the job without introducing assumptions, which can be strong ones at times. The most basic and obvious approach is to use the valuation vectors in the last columns of the original supply tables, where total trade and transport margins and net taxes on products are shown. These data are stored as vectors and are thus not transaction-specific (the valuation matrices available in Austria, Belgium, Denmark, and Finland can be understood as valuation vectors expanded to matrix form taking transaction specific variations into account). Assuming that margins and taxes on products are homogeneously allocated over the consuming sectors, proportionally to the volume of purchase in purchasers' price, one can translate the use table in purchasers' price into basic price by taking the ratio between the total supply of products in basic price vs. that in purchasers' price. This approach is used in the FORWAST model, for those countries where use tables in basic prices are not available. The exact procedure is described in the following.

The transport and trade margins as well as the taxes to subtract from the use table are shown in the supply table in **Figure 4**.

Monetary supply table	Activities (a)	Import	**Total, basic prices**	Trans. and trade margins	Taxes	**Total, purchasers prices**
Products (c)	V'_o	N_c	q_{basic}			$q_{purchaser}$
Total	g'			$\Sigma=0$	$\Sigma>0$	

Figure 4: Supply table as provided from statistical agencies, i.e. conversion to purchaser's prices is included.

The conversion of the use table into basic prices is done in two steps, where the first step concerns the transport and trade margins, and the second step concerns the taxes.

In step 1, the transport and trade margins are eliminated. The column vectors in the right side of the supply table (see **Figure 4**) are used to determine coefficients with which the entries in the use table must be reduced. These coefficients can be calculated using formula (2). The result of (2) is a column vector representing a coefficient per product.

$$\mathbf{coefficient\text{-}vector}_{\text{margin}} = (\mathbf{q}_{\text{basic}} + \mathbf{taxes}) \text{ ./ } \mathbf{q}_{\text{purchaser}} \qquad (2)$$

The elements in each row in the use table are then multiplied with the corresponding coefficient of the margin coefficient-vector.

However, three rows in the **V’** and **U** tables representing transport and trade products are not included in this operation. These are the rows in the original use table *supplying* the trade margins, i.e. representing (here as supplied by Eurostat):

- Trade, maintenance and repair services of motor vehicles and motorcycles; retail sale of automotive fuel
- Wholesale trade and commission trade services, except of motor vehicles and motorcycles
- Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods

These rows are special for two reasons:

1. because they are associated with a negative transport and trade margins in the supply table. The sum of these negative values corresponds to the sum of the transport and trade margins of all other products (see **Figure 4**: the sum of the column ‘trans. and trade margins’ is zero), and
2. because the use of these three products in the use table is too small, since it is included in the purchase price of the other products.

Thus, for each activity, the reductions of the elements in the use table determined by the margin coefficients are added to the elements of the three products mentioned above. This is illustrated with blue arrows in **Figure 5**. The transport and trade products are illustrated as yellow rows in **Figure 5**.

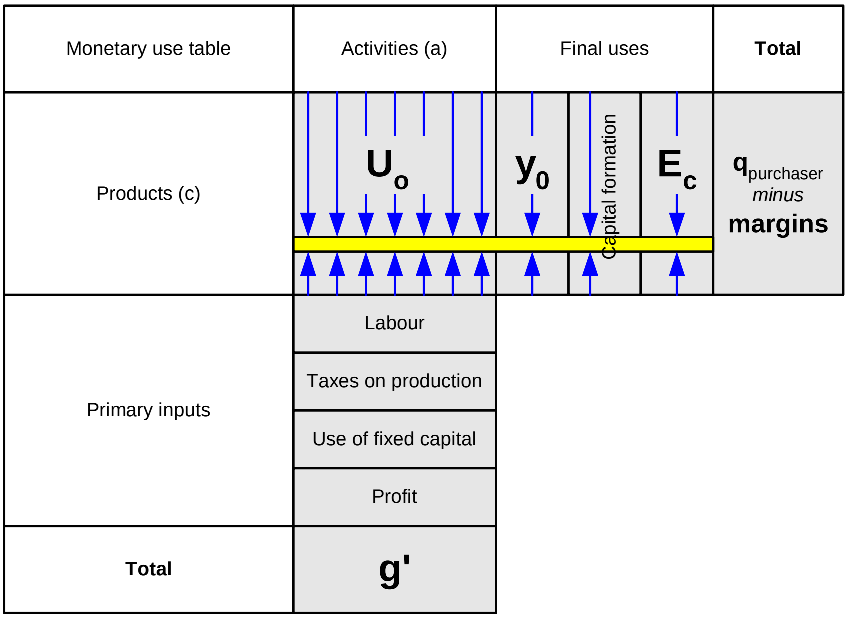


Figure 5: Use table. The blue arrows illustrate that the reduced values due to elimination of transport and trade margins are deducted in the rows representing transport and trade products. The resulting use table is a table in purchaser's prices minus transport and trade margins.

It appears that the operations in step 1 does not affect the balances for **q** in **V'** and **U** as well as for **g** in **V'** and **U**.

In step 2, the taxes on products are eliminated. The taxes on products are represented by a column vector in the right side of the supply table (see **Figure 4**). The operations in step 2 corresponds to step 1. First, a coefficient-vector representing the reduction of the entries in the use table is determined. This is done by using formula (3). The result of (3) is a column vector representing a coefficient per product. The elements in each row in the use table are multiplied with the corresponding coefficient in the taxes coefficient-vector.

$$\textbf{coefficient-vector}_{\text{taxes}} = \textbf{q}_{\text{basic}} \; ./ \; (\textbf{q}_{\text{basic}} + \textbf{taxes}) \qquad (3)$$

The sum of the reductions per activity in the **U** table is deducted in a new row next to the 'Taxes on production' row in the bottom of the use table. This is illustrated with blue arrows in **Figure 6**. The tax row is illustrated as a yellow row in **Figure 6**.

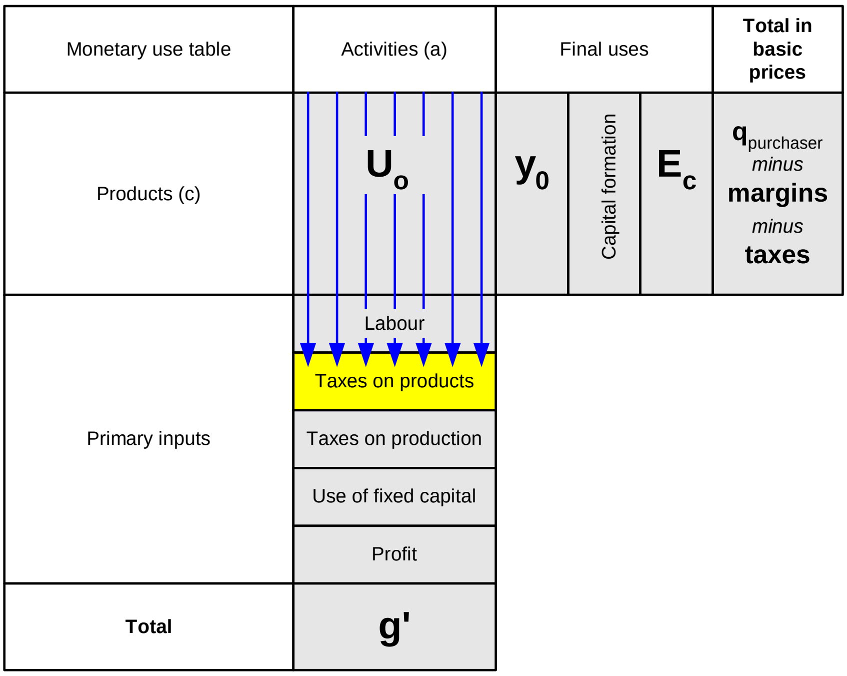


Figure 6: Use table. The blue arrows illustrate that the reduced values due to elimination of taxes are deducted in a new row representing taxes on products. The resulting use table is a table in basic prices, i.e. purchaser's prices minus transport and trade margins and minus taxes.

It appears that the operations in step 1 do not affect the balances for **q** in $\mathbf{V'}_0$ and $\mathbf{U}_0$ as well as for **g** in $\mathbf{V'}_0$ and $\mathbf{U}_0$.

The 'taxes on products' (new row) may be added to the 'taxes on production' (existing row) to form a sum row denoted 'Taxes'.

4.1.4 Modification of the original supply and use tables: Investments

The column 'Capital formation' to the right of the $\mathbf{U}_o$ table (see **Figure 3**) describes the use of products that are capitalised because they have a life time of more than one year, i.e. they are used in production for more than one period. Since these capitalised products are part of the production function of the activities, they should be incorporated in the **U** table, in the same way as use of other products.

The row 'Use of fixed capital' under the $\mathbf{U}_o$ table corresponds to the 'Capital formation' column, but it specifies the use of fixed capital per activity. The sum of this row is not necessarily equal to the sum of the 'capital formation' column because it is determined from depreciation allowances. This is provided by legal regulations, and not by the actual use of fixed capital. Therefore, the values in the 'capital formation' column are incorporated in the $\mathbf{U}_o$ table, and the discrepancies that may occur when the 'Use of fixed capital' row is eliminated are adjusted in the 'Operating surplus, net' row.

The column and row referred to above represent the degradation as it appears from companies accounts. This means, that these data only to a limited extent represents the physical formation and use of stocks. However, the depreciation allowance in company accounts generally only includes buildings, machinery, vehicles, furniture and some electronic equipment. Therefore, the information on capital formation in the original SUTs is not suitable for fulfilling the requirements on stock change information in the FORWAST model, and consequently, it is incorporated in the **U** table, and the information on stock changes is determined separately based on other data sources, i.e. the physical stock degradation (quantified in the stock degradation matrix, $\mathbf{L_S}$).

Some statistical agencies provide information on the distribution of the capital formation on activities in the form of an investment matrix, having the same format as the use table. Since such tables are not available for all countries, a Danish investment matrix for the year 1999 was used as a key for distributing the capital formation on activities. In order to use the Danish investment matrix as a distribution key for other years and other countries, it is normalised by the total product output ($\mathbf{g}_{\mathrm{DK,1999}}$) in Denmark in 1999, see (4). In (4) the Danish investment matrix for the year 1999 is denoted $\mathbf{U}_{\mathrm{investment,DK,1999}}$.

$$\text{Normalised investment matrix} = \mathbf{U}_{\mathrm{investment,DK,1999}}\ ./\ \left(\mathbf{i'}_{\mathrm{c}}\ \mathbf{g'}_{\mathrm{DK,1999}}\right) \tag{4}$$

The distribution key (i.e. the calculated investment matrix) for geographical area g and year t can then be calculated as shown in (5).

$$\mathbf{U}_{\mathrm{investment,g,t}} = \left(\mathbf{i'}_{\mathrm{c}}\ \mathbf{g'}_{\mathrm{g,t}}\right) .* \left(\mathbf{U}_{\mathrm{investment,DK,1999}}\ ./\ \left(\mathbf{i'}_{\mathrm{c}}\ \mathbf{g'}_{\mathrm{DK,1999}}\right)\right) \tag{5}$$

Having an investment matrix (actual or calculated by (5)), the ‘capital formation’ column can be distributed on activities by simply multiplying the activities relative share of the total row in the investment matrix with the value in ‘capital formation’ column. When at the same time removing the ‘use of fixed capital’ row under the $\mathbf{U}_{\Phi}$ table, discrepancies may occur in the **g’** vector. These are adjusted in the ‘Operating surplus, net’ row, so that the **g’** vector remains unaltered.

4.1.5 Balancing the monetary supply and use tables

It appears that **g** is the same in **Figure 2** and **Figure 3**, as well as **q** is the same in the two figures. **g’** = total supply of products by activities (**Figure 2**) = use of products and primary inputs by activities (**Figure 3**). Correspondingly, **q** = total supply of products (**Figure 2**) = activities’ total use of products, capital formation and export (**Figure 3**).

The MSUTs can be balanced as shown in **Figure 7**.

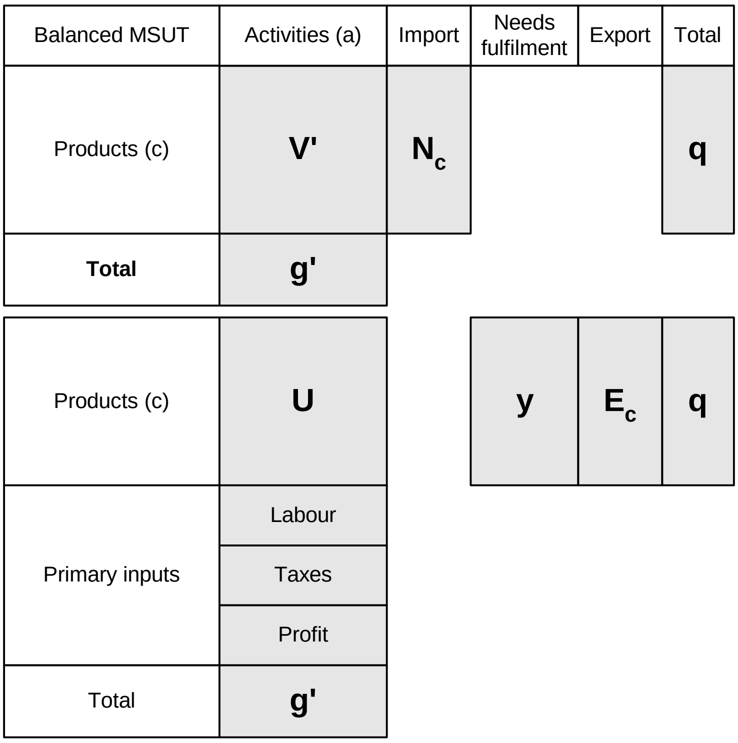


Figure 7: Balanced monetary supply and use tables (MSUTs).

4.2 Physical Supply and Use Tables (PSUTs)

In the FORWAST model, we operate with two kinds of physical SUTs, namely total physical SUTs ($PSUT_T$) and material specific physical SUTs (MSPSUTs). The sum of all MSPSUTs is equal the $PSUT_T$. This is because the included materials in the FORWAST model comprise the total amount of materials in the technosphere. Thus, the MSPSUTs can be seen as a disaggregation of the $PSUT_T$ on the level of materials. The description of physical supply and use tables in this chapter is valid for $PSUT_T$ as well as for MSPSUTs.

4.2.1 Units of measurement of mass in the physical SUTs

All physical tables are measured in dry weight, i.e. exclusive water. Data may be collected in actual weight (including water) for the supply and use tables (**V** and **U**) and then be transformed into dry weight before the data enter the model calculations.

In total 14 categories of materials are included in the model. All materials are measured in terms of mass of a single element or, if the category includes more than one element, in dry weight. The eleventh category (oxygen) is included for facilitating the balancing exercise. Thus, this material category enables balancing for content of oxygen in e.g. hydrocarbons, CO_2 and metal oxides. The content of hydrogen (H) is included in the category ‘Other minerals and balancing elements’ (MI).

The units of measurement of mass for the included material categories are given in **Table 3**.

Table 3: Unit of measurement of mass for the included material categories in the model.

No	Material category (m)	Unit of measurement (Mg)	Comments
1	Aluminium (Al)	Al	Not including Al in clay, soil, sand, gravel and stone, except when used for Al production.
2	Fibre carbon (BI)	C	The remaining part of fibre biomass (i.e. not carbon) is included in the other material categories, mainly O and MI
3	Food carbon (including tobacco) (BO)	C	The remaining part of food biomass (i.e. not carbon) is included in the other material categories, mainly O and MI
4	Coal carbon (CC)	C	The remaining part of coal (i.e. not carbon) is included in the other material categories, mainly O and MI
5	Crude oil and natural gas carbon (CH)	C	The remaining part of crude oil and natural gas (i.e. not carbon) is included in the other material categories, mainly O and MI
6	Carbonate carbon (CO)	C	The remaining part of carbonate, $CaCO_3$ (i.e. not carbon) is included in the other material categories, mainly O and MI
7	Copper (Cu)	Cu	Not including Cu in clay, soil, sand, gravel and stone, except when used for Cu production.
8	Iron (Fe)	Fe	Not including Fe in clay, soil, sand, gravel and stone, except when used for Fe production.
9	Other metals (ME)	Dry mass	Not including metals in clay, soil, sand, gravel and stone, except when used for metal production.
10	Other minerals and balancing elements (MI)	Dry mass	All elements not elsewhere classified, such as H, N and P are included in this material category
11	Oxygen (O)	O_2	Including oxygen in hydrocarbons, biomass, carbonate and metal oxides, but *not* oxygen chemically bound in clay, soil, sand, gravel and stone.
12	Clay and soil (SO)	Dry mass	Including chemically bound oxygen and metals
13	Sand, gravel and stone (ST)	Dry mass	Including chemically bound oxygen and metals, e.g. oxygen in SiO
14	**Total (T)**	**Dry mass**	**Total (T) corresponds to the sum of all 13 materials**

The units of measurements given above are used for intermediate flows between industries and households (**U** and **V** matrices) as well as for resource inputs (**R**), emissions (**B**) and stocks (**S**).

Oxygen in the model: For clay, soil, sand, gravel and stone, the oxygen and metals bound in the minerals is not separated out because these elements generally remain as a part of the minerals throughout the activities in the economy. Oxygen in emissions from an activity are only included when the oxygen formed part of the product, residual or resource inputs to the activity. This means that oxygen in emissions of SO_2 from combustion is not included in the overall mass balance, while the S is included (here as an input of MI resources to the activity, since the S from combustion is assumed to originate in the product, residual or resource inputs).

Emissions containing oxygen: These emissions require special attention because oxygen in emissions are only included when the oxygen formed part of the product, residual or resource inputs to the activity. This means that oxygen in emissions of CO_2, CO, NO_x, N_2O and SO_2 from combustion is not included in the overall mass balance. However, for CO2 from carbonate, the oxygen is included. This is because the oxygen originates from the carbonate: $CaCO_3 \rightarrow CaO + CO_2$.

Thus, the abovementioned oxygen neither enters the resource matrix (**R**) nor the emissions matrices (**G**).

However, all emissions data from NAMEAs etc. are provided in mass including oxygen. These data are also the data which must be entered in the **B** matrix. The total row below the **B** matrix is calculated as the mass of the emissions excluding oxygen in CO_2, CO, NO_x, N_2O and SO_2.

The **G** matrices (distribution of emissions) are used for mass balance purposes in the model calculations. Therefore, the emissions in these matrices must correspond to the calculated total row of the **B** matrix (i.e. oxygen in CO_2, CO, NO_x, N_2O and SO_2 is excluded).

Emissions containing nitrogen: These emissions require special attention because the nitrogen may originate from nitrogen bound in the material which causes the emissions as well as from atmospheric nitrogen. An example of the first case is emissions of N_2O from denitrification of fertiliser in agricultural soils. An example of the latter is combustion processes where the nitrogen contained in the fuel only partly determines the emissions of NO_x.

If the N contained in the emissions originates from atmospheric nitrogen, it should neither be included in the resource matrix (**R**) nor in the emissions matrices.

However, as in the case of oxygen, all emissions data from NAMEAs etc. are provided in mass including nitrogen. These data are also the data which must be entered in the **B** matrix. The total row below the **B** matrix is calculated as the mass of the emissions excluding nitrogen in NO_x and N_2O. In order to include the amount of nitrogen in NO_x and N_2O in the mass balance, this amount of nitrogen is entered as emissions of 'Minerals, n.e.c.' (MI).

The abovementioned modification regarding NO_x and N_2O is introduced in order to avoid different rules for these two emissions for different activities; e.g. from agricultural soils, close to 100% of the N_2O emissions originates from the contained in fertiliser, while a smaller fraction of the same emissions from combustion processes originate from N contained in the fuel.

Water in the model: The model does not include any inputs, outputs or contents of water. As a consequence of this way of treating the mass flows of water in model, the activity which represents collection and distribution of water is regarded as a service activity. This means that the activity's determining product is not a physical product.

The information on resources and emissions from resource statistics and NAMEAs is transformed into the categories shown in **Table 3**. This transformation is carried out using molar masses for the emissions, and mass balances for combustion processes in order to back trace from which material category the CO_2 emissions originate. This is specified for each emission in 'Appendix 2: Emissions'.

4.2.2 Format of PSUTs

The general format of the physical supply table ($\mathbf{V_m}$) is equal to the format of a monetary supply table ($\mathbf{V_\Phi}$); see **Figure 2**. The only differences are that the physical supply table is given in physical units (e.g. kg, Mg or Gg) instead of monetary units (e.g. EUR, kEUR or MEUR). **Figure 8** shows the resulting format of the physical use table (**U**).

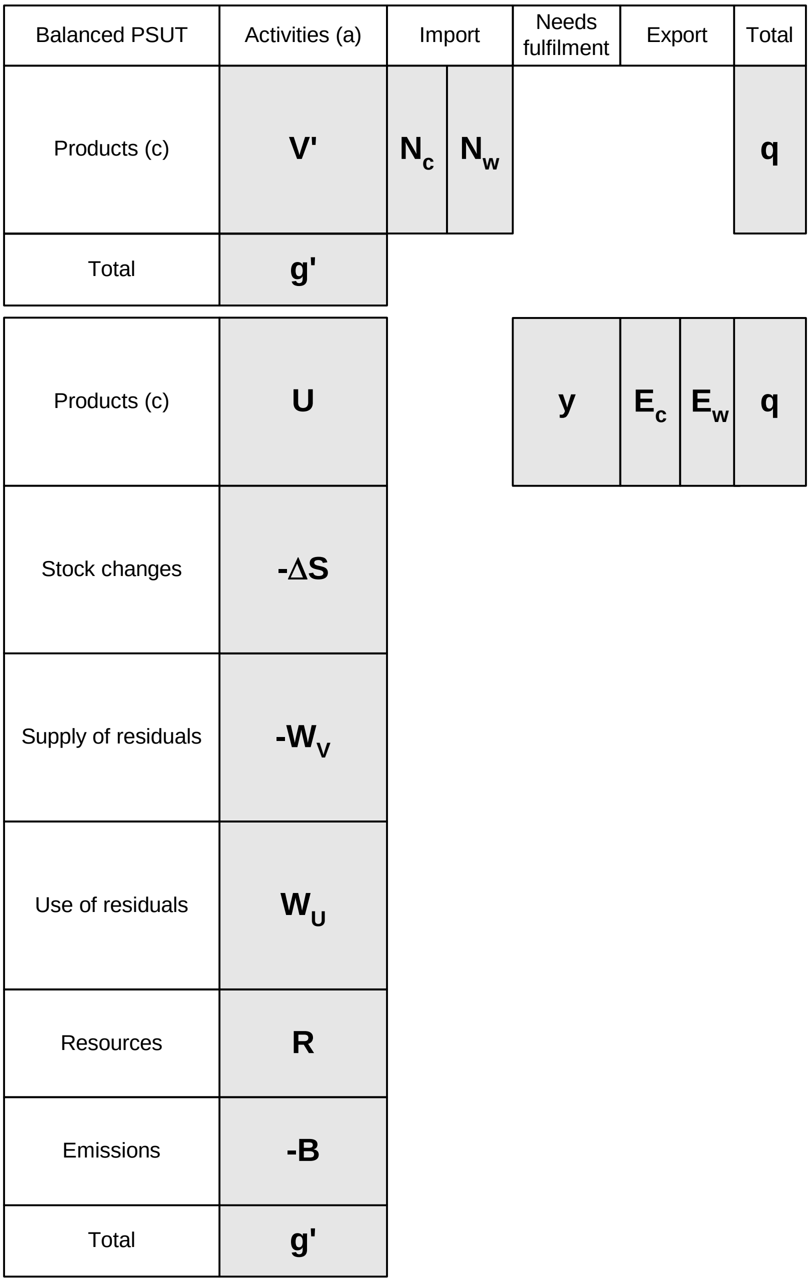
Physical use table	Activities (a)	Final uses			Total
Products (c)	**U**	**y**	$\mathbf{E_c}$	$\mathbf{E_w}$	**q**
Stock changes	**-ΔS**				
Supply of residuals	$\mathbf{-W_V}$				
Use of residuals	$\mathbf{W_U}$				
Resources	**R**				
Emissions	**-B**				
Total	**g'**				

Figure 8: Format of physical use table.

In **Figure 8, U** describes the use of products (c) per activity (a). **g'** is the total input per activity, i.e. the sum of intermediate inputs of products, supply and use of residuals, resource inputs and emissions. **q** is the total use of products, i.e. the use by activities, final consumption and export. The export includes export of products (**E_c**) and export of residuals (**E_w**). The elements **-ΔS**, **$-W_V$, W_U**, **R**, and **–B** are described later in chapter 4.2.4 to 4.2.9.

4.2.3 Balancing the physical supply and use tables

As in the case of MSUTs, the PSUTs can be balanced for **g** and **q**.



Balanced PSUT	Activities (a)	Import		Needs fulfilment	Export		Total
Products (c)	**V'**	**N_c**	**N_w**				**q**
Total	**g'**						
Products (c)	**U**			**y**	**E_c**	**E_w**	**q**
Stock changes	**-ΔS**						
Supply of residuals	**$-W_V$**						
Use of residuals	**W_U**						
Resources	**R**						
Emissions	**-B**						
Total	**g'**						

Figure 9: Balanced physical supply and use tables (PSUTs).

4.2.4 Emissions matrix (B): Application of NAMEA

NAMEAs (National Accounting Matrix including Environmental Accounts) are tables including information on emissions by industry activities (following the NACE classification) and household activities (aggregated to one category).

The NAMEAs obtained from statistical offices have to be disaggregated accordingly to the included activities in the FORWAST model. Information used for this exercise can be life cycle inventories, e.g. Ecoinvent (2004) or reference documents on best available techniques from European Integrated Pollution Prevention and Control Bureau (EIPPCB 2007).

The emissions matrix (**B**) has dimensions emissions by activities. The **B** matrix which enters the PSUT (see **Figure 9**) is either $\mathbf{B}_T$ or $\mathbf{B}_m$, where m $\in$ the materials listed in chapter 3.3, and where T represents the sum of all materials.

In **Figure 8** and **Figure 9**, **B** appears with a negative sign. Thus, most emissions appear as positive entries in the **B** matrix. Only emissions such as CO_2-sinks (when CO_2 is stored) will appear as negative entries.

4.2.5 Total emissions distribution matrices ($\mathbf{G}_C$, $\mathbf{G}_W$ and $\mathbf{G}_R$)

$\mathbf{G}_c$, $\mathbf{G}_w$ and $\mathbf{G}_R$ specify from which of the product, residual and resource inputs the total emissions originate. $\mathbf{G}_c$ refers to emissions that originate from the use of products (e.g. when an input of coal is burned), $\mathbf{G}_w$ refers to emissions that originate from the use of residuals (e.g. waste incineration), and $\mathbf{G}_R$ refers to emissions that originate from the use of resources. Thus, for each activity, the sum of all emissions (b) in **B** are distributed either on the products and residuals inputs to the activity ($\mathbf{G}_c$ and $\mathbf{G}_w$) or on the products that use the resources ($\mathbf{G}_R$). The sum of the columns of the three **G** matrices is equal to the sum of the columns of **B**.

$\mathbf{G}_c$, $\mathbf{G}_w$ and $\mathbf{G}_R$ are established using information on the physical inputs (specified in **U,** $\mathbf{W}_U$, **B** and **F**) and emissions coefficients specifying the relation between the physical inputs and emissions.

4.2.6 Resources matrix (R)

According to the format of the disaggregated NAMEA, a resource matrix is constructed using information from resource statistics. The resources matrix (**R**) has dimensions materials (m) by activities, where m $\in$ the materials listed in chapter 3.3. The resources added into the **R** matrix do not include water.

4.2.7 Stock change matrix (ΔS)

The stock change matrix (ΔS) represents the additions to stocks. Thus, positive entries represent additions to stocks while negative entries represent use of stocks. Stocks include stocks in use (products within their life time) as well as stocks not in use (residuals within their life time, i.e. residuals in landfills that has not yet become emissions). **ΔS** is determined using the mass balance and stock degradation matrix, see chapter 6.3.

4.2.8 Residuals supply matrix ($\mathbf{W}_V$)

This matrix represents the generation of residuals, i.e. flows from a human activity that remains in the technosphere but cannot directly (i.e. without further processing or emissions) displace another product. An example is residuals of 'Meat and fish products'. This residual is mainly generated in the catering industry and in household activities, where it is determined as those inputs of 'Meat and fish products' neither becoming part of products nor emissions (as stock changes do not apply to food products). After processing in a waste treatment (recycling) activity, the recovered residuals may displace other products.

A positive entry in the $\mathbf{W_V}$ matrix represents generation of a residual. The format of the matrix is residuals of products by activities. The names of the rows are identical to the names of the products from which the residuals originate. The columns specify where the residuals are generated, and the rows specify the type of the residual. Residuals that enter into final waste treatment activities (landfill and land application of waste) do not become residuals of these activities. They will always become stocks of residuals and later emissions.

The residual supply matrix ($\mathbf{W_V}$) is determined using the mass balance and stock degradation matrix ($\mathbf{L_S}$), see chapter 6.1.

4.2.9 Residuals use matrix ($\mathbf{W_U}$)

This matrix represents the use of residuals. Only waste treatment activities (see these activities in 'Appendix 1: Activities and products'), use residuals. Other activities may use some by-products that are normally seen as wastes (e.g. slag from power plants), but if these directly substitute other raw materials (such as clinker for cement production) these are (off-diagonal) products in the use matrix (**U**) and not in the $\mathbf{W_U}$ matrix. If residuals are used by other activities than those defined as waste treatment (e.g. the cement industry using waste as fuels), they should be disaggregated into a waste treatment activity (using the residuals and providing by-product outputs that can substitute other products) and a non-waste treatment activity (using the by-products of the waste treatment industry).

A positive entry in the $\mathbf{W_U}$ matrix represents the use of a residual by an activity, i.e. when a waste treatment facility receives waste. The format of the matrix is similar to the $\mathbf{W_V}$ matrix, see chapter 4.2.8. The columns specify where the residuals are used, and the rows specify the type of the residual.

The residuals use matrix ($\mathbf{W_U}$) is calculated using the hybrid input-output table (HIOT) as **A** and the needs fulfilment vector (**y**). Thus $\mathbf{W_U}$ is a model output. As described in chapter 5.3, the waste treatment activities are implemented in the model as normalised processes in the HIOT. The production volume of these activities are then calculated based on the total quantity of generated waste $\mathbf{W_V}$ ($\mathbf{W_V}$ is classified into a limited number of waste fractions) and to which waste treatment activities each waste fraction is send (determined by the **J**-matrix); e.g. food waste may be sent to 20% incineration and 80% landfill.

This calculation step means that only non-waste treatment activities can be fully balanced (as in **Figure 9**) in the data collection phase where PSUTs are established. The waste treatment activities are balanced as normalised processes in deliverable D5-4: 'Description of the environmental pressures from waste treatment'. However, this do not apply to recycling activities which are established by disaggregating activities which includes both virgin and recycled production. Recycling activities are balanced by operating with recycling efficiencies determining how much of the input of waste become part of supply, e.g. approximately 85% of the input of waste paper becomes recycled pulp in the activity 'Recycling of waste paper'.

4.2.10 Stock degradation matrix ($\mathbf{L_S}$)

The format of $\mathbf{L_S}$ is illustrated in **Figure 10**. $\mathbf{L_S}$ specifies for each type of stocks (i.e. products or residuals) how much of the initial stock that becomes waste or emissions in year u. Allowed values $\in [0,1]$.

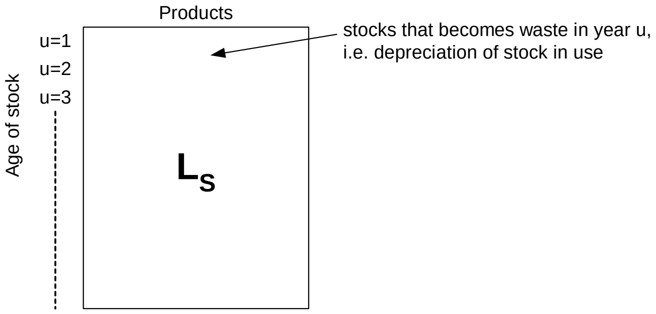


Figure 10: Format of the stock degradation matrix ($\mathbf{L_S}$).

For short-lived products and service products, the degradation is set to 1 in the first year, i.e. there is no build-up of stocks, and all materials that do not become emissions or part of the products of an activity must therefore become residuals in the first year. For service products, there is no physical product and thus no stock build-up possible. Setting the degradation to 1 is thus unnecessary, but is done anyway to maintain the sum of each column = 1 for all products. For stocks of residuals stored in final waste treatment activities such as landfills, the degradation is set to 0 in all years, i.e. landfills do not supply residuals. The used residuals will remain in the landfill as stocks of residuals until they become emissions (see residuals degradation matrix in chapter 4.2.11).

4.2.11 Residuals degradation matrix ($\mathbf{L_w}$)

The format of $\mathbf{L_w}$ corresponds to $\mathbf{L_S}$, but the entries specify when residuals become emissions, i.e. degradation of stocks of residuals. The degradation of residuals in the first year is defined to be zero. If the use of residuals in an activity becomes emissions the first year, it is included in the emissions matrix instead. If the time-frame of the model was infinite, the sum of each column = 1, i.e. the stocks used by a final waste treatment activity eventually become emissions.

5 How to handle waste treatment in the supply-use framework

A large part of the FORWAST model concerns the modelling of the effect of different waste treatment options, e.g. recycling, incineration and landfill. The modelling of these activities is not straightforward in the supply-use framework. Therefore, the issue of how to handle waste treatment is given special attention in this chapter.

5.1 Disaggregation in order to model recycling

In standard SUTs as supplied from statistical offices, production of primary materials is not distinguished from production of recycled materials. However, this distinction is important because the emissions caused by recycling vary significantly from the emissions from production of virgin materials. Therefore, these joint or combined activities are disaggregated (the procedure for disaggregation is described in chapter 8).

First, the disaggregation is done if an activity includes stages both before and after the point of substitution, where the primary material can substitute the secondary material. Since only the part of the activity before the point of substitution will be affected, the activity is disaggregated into two activities: one before and one after the point of substitution, see **Figure 11**.

Secondly, the activity before the point of substitution is disaggregated into an activity producing virgin material, and a service activity having inputs of residuals and providing as a by-product recycled materials that can substitute virgin materials. This disaggregation will, in some cases, reflect a hypothetic situation because some material producing industries use a mix of primary raw materials and waste materials as inputs in order to produce their main product, e.g. glass manufacture. The disaggregation is nevertheless necessary to allow correct modelling of recycling.

The two above-mentioned elements of disaggregation are illustrated in **Figure 11**.

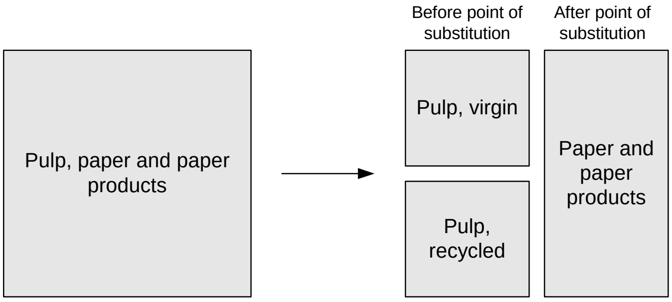


Figure 11: Disaggregation of activities by point of substitution and by recycled/virgin, using pulp, paper and paper products as example.

5.2 Modification of MSUTs and PSUTs in order to handle by-products from waste treatment

In the following it is described how waste flows (residuals) are integrated in the hybrid input-output table (HIOT), especially see chapter 5.2.3.

A problem related to the handling of waste treatment in the supply-use framework is that the processing of residuals to be recycled cannot be correctly modelled if they appear as product outputs from other activities (e.g. steel scrap which can not directly displace another product). When materials to be recycled have a positive market value, they appear in the supply matrix as an off-diagonal supply of the products they displace. In the supply tables supplied by statistical offices, these off-diagonals appear within the activities that supply the materials to be recycled. In this way, there is no activity representing the processing of the waste materials into new material (or rather, this processing is included in the industry that receives the material to be recycled). Therefore, the FORWAST model defines new recycling activities, disaggregated from the industries that receive material for recycling, and defines as residuals any product that cannot directly (i.e. without further processing or emissions) substitute another products recycled. Recycling activities are defined as waste treatment activities. Waste treatment activities are service activities, i.e. they do supply any physical products as their determining product. But the recycled materials are supplied as physical by-products on the off-diagonal in **V'**. These modifications are described more in detail in the following.

It should be noted that the theoretical descriptions in chapter 5.2.1 to 5.2.3 on how to implement the economy of recycling in the SUT framework are not implemented in the FORWAST model. Instead, it has been chosen to eliminate the monetary value and physical flows of residuals in **V'** and **U** and not to give any monetary value to the service 'to recycle'. This is described in detail in the end of chapter 5.2.1.

5.2.1 Modification of MSUT - correct placement of off-diagonals

In chapter 3.1, a product is defined as an output flow from a human activity with a positive either market or non-market value. A residual is defined as an output flow from a human activity that remains in the technosphere and that cannot directly displace another product. If a residual is to displace another product, it must first undergo processing in a waste treatment activity. It appears from the definitions that all outputs sent to recycling are defined as residuals because they cannot directly displace another product. At the same time, some of these residuals may be included in the definition of products because they have a positive value (e.g. steel scrap).

In standard MSUTs as supplied from statistical offices, the residuals having a positive market value will appear as off-diagonal products in the supply matrix, i.e. as the products they displace. Thus, no recycling activities are included. This is not a desirable modelling of recycling. Therefore, the market value of residuals should be subtracted from the off-diagonal in the $\mathbf{V}_{\Phi}$ matrix, and a corresponding value is added as an off-diagonal from the (new) recycling activity that supplies the recycled material. In order to maintain balance, the use columns of the two activities (in the $\mathbf{U}_{\Phi}$ matrix) must be modified correspondingly. The difference may be taken up in the 'Net operating surplus'. The principle is illustrated in **Figure 12**. It appears from the figure, that balance for **g** as well as **q** is maintained. The modelling of the recycling activity may additionally involve the transfer of both intermediate inputs and primary factors from the activity that originally included the recycling activities (typically the industry originally receiving the material for recycling).

In practise in the FORWAST project, this is done by eliminating off-diagonals in **V'** which represent residuals. Correspondingly, the diagonal in the use table (**U**) is reduced. This means that the monetary value of residuals are eliminated in the monetary (and also physical) supply and use tables. The determining products of the recycling activities are not Monetarised in the FORWAST project. Instead, these activities are drived by the physical amount of waste they receive from waste generating activities. This is implemented in the HSUT where the total use of residuals is placed on the diagonal in the hybrid supply table, and the supply of residuals by each activity is placed in the hybrid use table. By doing so, the described modifications in chapter 5.2.2 and 5.2.3 are not necessary (because the service 'to recycle' is given no monetary value, and because the monetary value and physical flows of residuals in **V'** and **U** are eliminated).

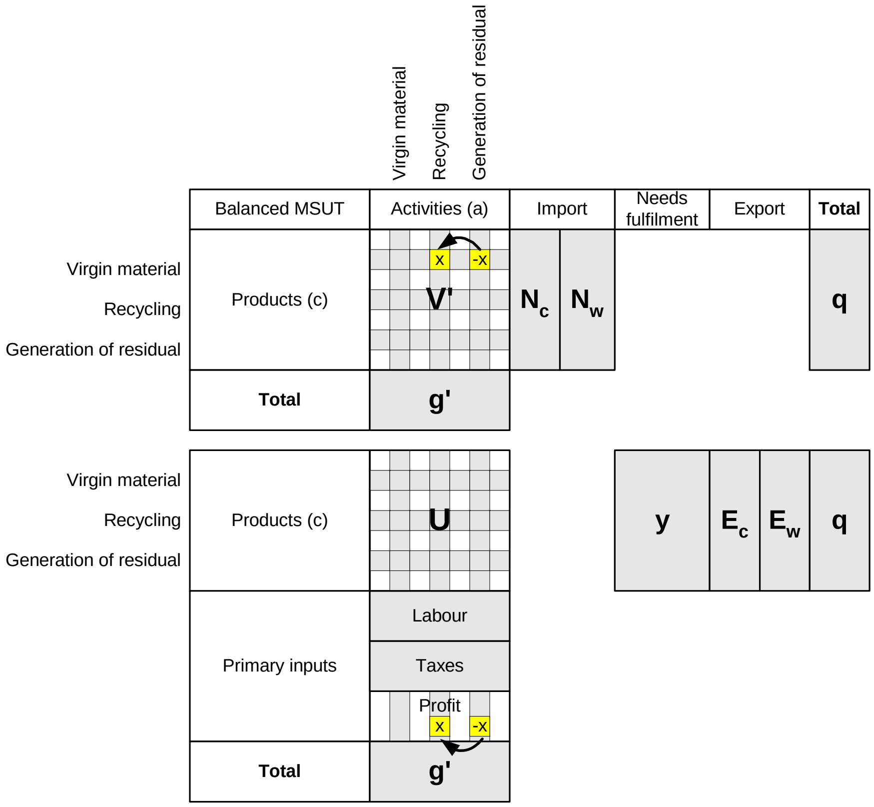


Figure 12: Modification of the MSUTs due to off-diagonal products being residuals. The off-diagonal entry 'x' is moved from a residual generating activity to a recycling activity.

5.2.2 Modification of MSUTs - inclusion of the use of the recycling service

In standard MSUTs, the waste treatment activities are services, typically paid (used) by the suppliers of waste. Recycling activities, however, are typically included in the industries that receive materials for recycling, and the recycling service is therefore a "hidden", internal service product within these industries, without a specified demand (use). Since the use of the recycling activities depend on the supply of residuals for recycling, the recycling activity should be used by the industries supplying the residuals, in parallel to any other waste treatment process.

Therefore, the use of the (new) recycling service must be added in the $\mathbf{U}_\Phi$ matrix for the activity that generates the residual. This is shown as a 'y' in the $\mathbf{U}_\Phi$ matrix in **Figure 13**. The activity that generates the residual may originally have been receiving this service for free, or it may even have received a payment for the residual (this payment was eliminated in chapter 5.2.1, **Figure 12**). In these cases the new payment must now be counterbalanced by a "-y" in the 'Net operating surplus' as illustrated in **Figure 13**). A prerequisite for introducing 'y' as described above is that the activity has not originally paid for the recycling service. In some cases, if the residual is of low value, the generating activity may originally have been paying "y" as a part of the payment for the waste treatment services. In these cases the recycling activity is effectively a disaggregated part of the waste treatment services and the counterbalancing "-y" should be placed there, i.e. with the recycling activity.

Secondly, the use of the recycling service in the $\mathbf{U}_\Phi$ matrix must be matched by an equivalent supply of service (i.e. 'y') in the $\mathbf{V}_\Phi$ matrix; see **Figure 13**. Finally, the resulting output of the recycling service must be balanced by the inputs to the recycling activity. These may be determined by the way the recycling service is modelled as a disaggregated part of an original industry, and any remaining balance taken up in the 'Net operating surplus' of the recycling service, as shown in **Figure 13**.

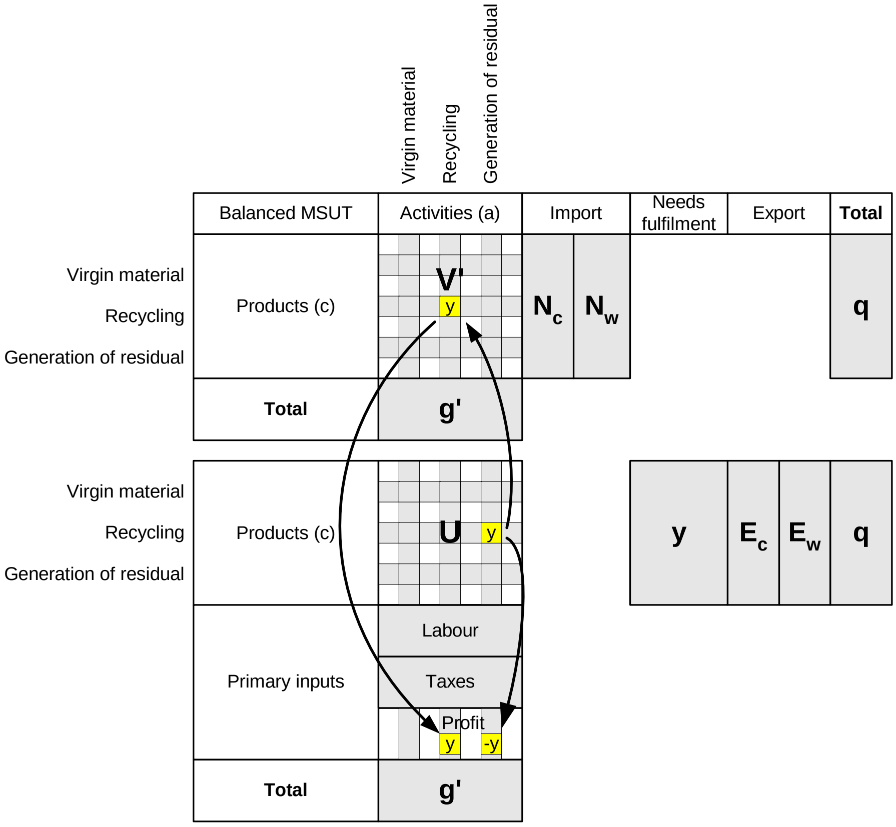


Figure 13: Modification of MSUTs in order to include the use and supply of the recycling service to process residuals into products. The increase in the use and the supply is 'y'. In order to maintain balance, the profit is adjusted correspondingly.

5.2.3 Modelling of recycling in PSUTs

The physical supply and use tables are modified correspondingly to the monetary tables (**Figure 12**). Thus, by using the price relations (**P**), the modifications in $\mathbf{V}_\Phi$ and $\mathbf{U}_\Phi$ can be implemented in the $\mathbf{V}_\mathrm{T}$ and $\mathbf{U}_\mathrm{T}$ matrices. The effect from these changes in other matrices, i.e. the supply and use of residuals matrices ($\mathbf{W_V}$ and $\mathbf{W_U}$), is calculated automatically in the model, see chapter 6.

For a residual having a positive market value, i.e. originally appearing as off-diagonal product in the supply matrix, the modifications in the physical supply and use matrices can be explained as follows (see also **Figure 14**). An amount of x kg product on the off-diagonal in the $\mathbf{V_T}$ matrix is removed from the residual generating activity. The material will instead appear as supply of residual (in the $\mathbf{W_V}$ matrix) from this activity. This increased amount of supply of residual is used (in the $\mathbf{W_U}$ matrix) by the recycling activity that supplies the increased input as an off-diagonal product in the $\mathbf{V_T}$ matrix. As can be seen from **Figure 14** the changes do not affect $\mathbf{q}$ and the balance for $\mathbf{g}$ is maintained with an increase in the output from recycling and a corresponding reduction in the output of ‘Generation of residual’.

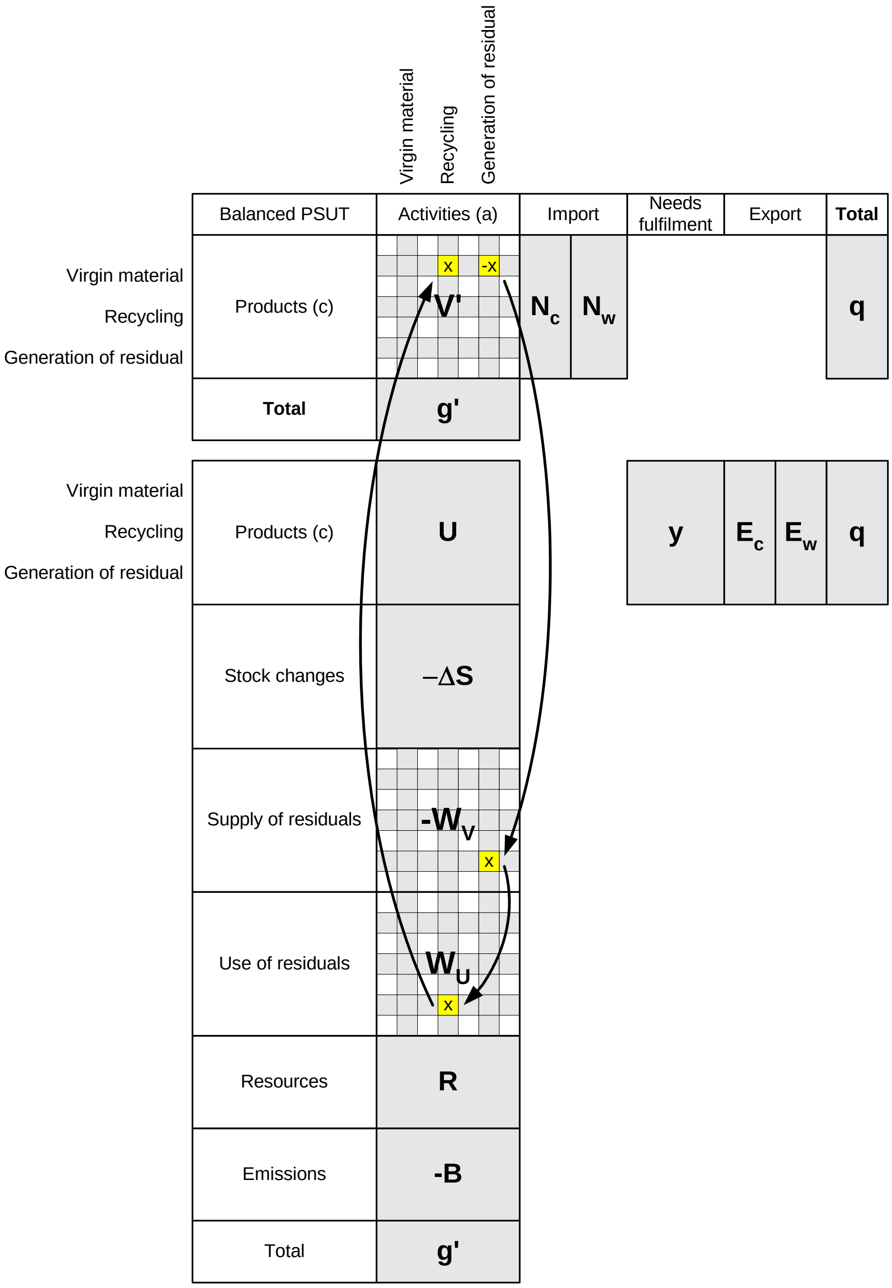


Figure 14: The figure illustrates the effects on the supply and use of residuals ($\mathbf{W_V}$ and $\mathbf{W_U}$) in the PSUT when an off-diagonal being a residual in $\mathbf{V_T}$ is moved from one activity (residual generating) to another (recycling activity).

In practise the operations described above are carried out as follows:

1. The hybrid SUT is normalised by the diagonal supply (**V**) for each activity, see chapter 9.1.3
2. The normalised $\mathbf{W_V}$ table is aggregated into a limited number of homogenous waste fractions (this is further described in deliverable D6.1 ‘Documentation of the data consolidation and calibration exercise, and the scenario parameterisation’)
3. The quantity (mass) of generated waste (per fraction) is directed to the dedicated waste treatment in the HIOT (**A**) by use of the **J**-matrix. Thus when an activity supplies say 1 kg paper waste, and the J-

matrix defines that 50% is sent to recycling and 50% is sent to incineration, then the activity uses 0.5 kg recycling of paper waste and 0.5 kg incineration of paper waste

4. The waste treatment activities then supplies the service to treat waste as their main product. This is also measured in unit of mass.

5.3 Parameterisation of incineration and landfill of waste

The waste treatment activities in the FORWAST model are created as life cycle assessment (LCA) processes directly in the HIOT, i.e. as normalised activities. This means that the total outputs of these activities are not balanced with the total output in the original MSUTs and PSUTs. The waste treatment activities in the HIOT are defined as part of deliverable D5-4: ‘Description of the environmental pressures from waste treatment’. The inputs and output of the waste treatment activities are determined by using the calculated scaling factors (**scale**) and the normalised SUT, see chapter 3.2.

6 Derivation of SUTs

The model includes three kinds of supply and use tables (SUTs):

1. Monetary supply and use tables (MSUTs)
2. Total physical supply and use tables ($PSUT_T$)
3. Material specific supply and use tables (MSPSUTs)

The MSPSUTs are defined so as to provide a full breakdown of the $PSUT_T$. The three kinds of SUTs are related through the product prices **P** (relation between MSUT and $PSUT_T$) and through the material composition $\mathbf{K_c}$ and $\mathbf{K_w}$ (relation between $PSUT_T$ and MSPSUTs). This is illustrated in **Figure 15**.

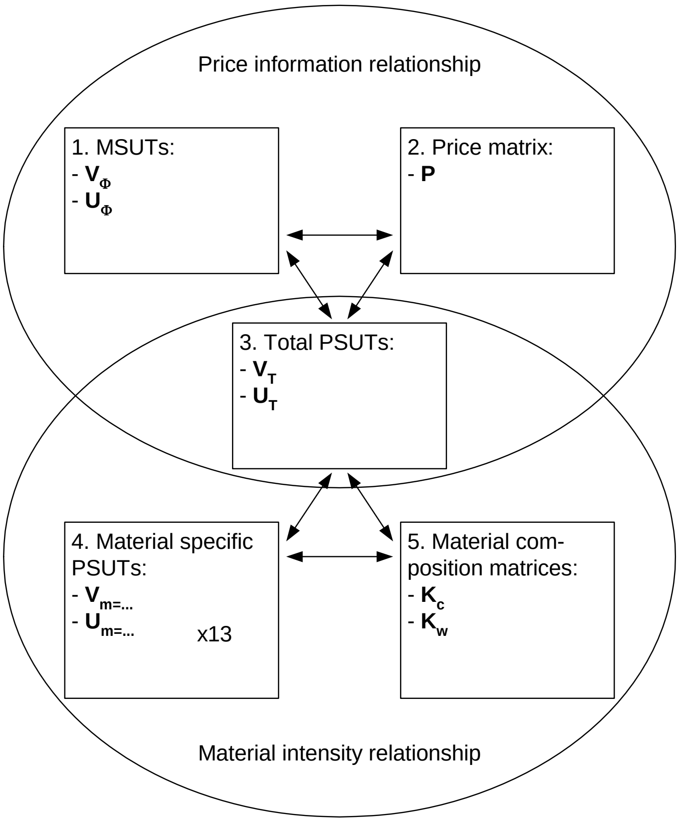


Figure 15: Five different data sources and their relationships.

Figure 15 illustrates two sets of interrelated matrices: The top three matrices which are related via a price information relationship, and the bottom three matrices which are related through a material intensity relationship. Each of these relationships consists of three data sources, where two of the data sources always determine the third. The two relationships have one matrix in common; ‘3. Total PSUTs’. Hence, the five data sources are all related. Because of the relationships between the data sources, it must be decided which two of them to be suppressed in order to avoid that the model is over-determined, since this could lead to inconsistencies.

Due to the differences in data quality, it is not all data sources are equally relevant as primary data. For the FORWAST model, MSUTs and Total PSUTs and product composition matrices ($\mathbf{K_C}$) are used as primary data sources, while waste compositions ($\mathbf{K_W}$), and MSPSUTs are generally derived. Primary data on prices may also be used, but are generally not regarded as primary input. An error check to ensure consistency between the three matrices (MSUTs, prices, and Total PSUTs) has been established, but the model does not include any automatic routine to ensure calculate the three matrices from each other. Thus, any manual change to any of the three matrices needs to be followed up by manual changes to the other matrices.

6.1 Calculation of stock changes (ΔS) and the supply of residuals (W_V) in physical units

In this chapter, the stock changes ($\mathbf{\Delta S_T}$) and the supply of residuals ($\mathbf{W_{V,T}}$) are calculated in total physical units. All calculations in this chapter are valid for a specific year $t = t_0$ and only the changes in stocks related to this year's supply and use are considered, i.e. $u = 1$. This means that the calculations given in this chapter represent a static version of the FORWAST model. Including $t \neq t_0$ and $u \neq 1$ relates to the quasi dynamic version of the model. This is described in chapter. In order to keep formulas simpler, the subscript referring to the variable 't_0' is left out for all matrices in this chapter.

The calculation of the supply of residuals in this chapter provide the total supply of residuals per product category, e.g. the sum of food waste and excretion for residuals of food. Therefore, in a later step (chapter 6.1.7) it may be required that the calculated residuals must be disaggregated into more than one fraction. This is relevant if the residual material composition of the fractions vary and if the fractions are treated by different waste treatment activities. Here in this chapter, the number of residuals is equal to the number of products, i.e. the $\mathbf{W_V}$, $\mathbf{W_U}$ and $\mathbf{J}$ matrices are square. The procedure for disaggregating residuals described in chapter 6.1.7 enables for having more than one type of residual per product.

The basic principle for calculating $\mathbf{\Delta S_T}$+$\mathbf{W_{V,T}}$ is a mass balance per activity in total physical units, see **Figure 16.** The mass balance is expressed in mathematical terms in (6). **Figure 16** illustrates some modifications to $\mathbf{V_T}$, $\mathbf{W_U}$ and $\mathbf{G_w}$. These modifications are further described in chapter 6.1.3.

We recapitulate from the definition chapter that $\mathbf{G_c}$, $\mathbf{G_w}$, **and** $\mathbf{G_R}$ are the emissions that originate from the product, residual or resource inputs, respectively, and the sum of the columns of the three **G** matrices is equals the sum of the columns of the emissions matrix **B**.

The matrix $\mathbf{F.{*}i'_c r_T}$ represents the total input of resources $\mathbf{r_T}$, distributed on the products of the activity. This is further elaborated below.

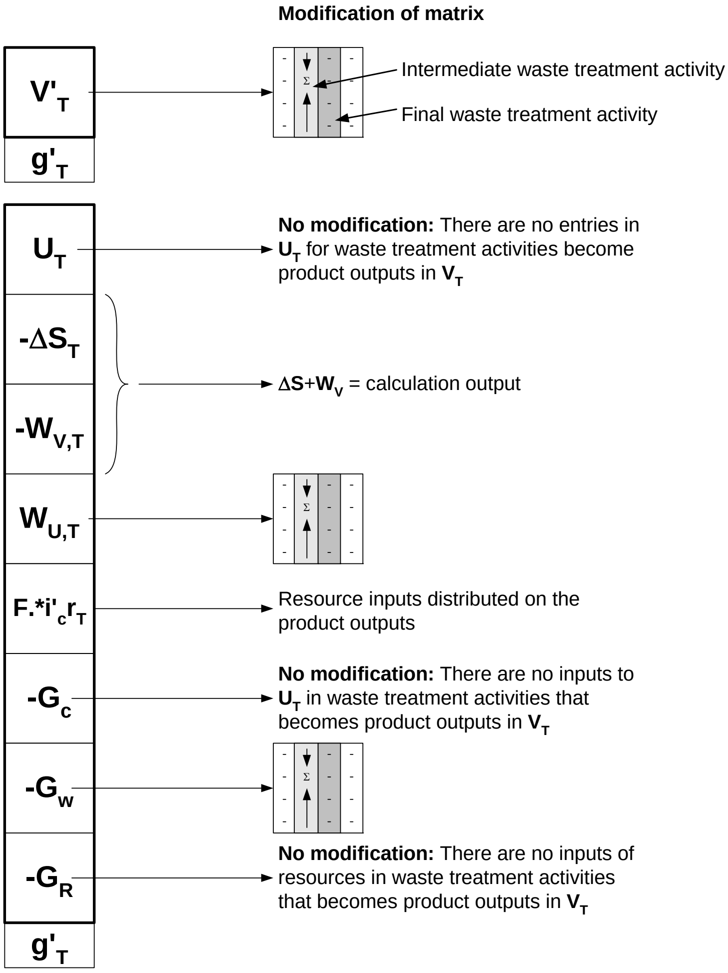


Figure 16: Mass balance used for the determination of stock changes ($\Delta \mathbf{S}_T$) and supply of residuals ($\mathbf{W}_{V,T}$).

Figure 16 enables the establishing of a mass balance:

$$\mathbf{V'}_{\mathbf{T}} = \mathbf{U}_{\mathbf{T}} - \Delta\mathbf{S}_{\mathbf{T,u=1}} - \mathbf{W}_{\mathbf{V}} + \mathbf{W}_{\mathbf{U,T}} + \left(\mathbf{F} \;.*\; \mathbf{i'}_{\mathbf{c}}\, \mathbf{r}_{\mathbf{T}}\right) - \mathbf{G}_{\mathbf{c}} - \mathbf{G}_{\mathbf{w}} - \mathbf{G}_{\mathbf{R}} \tag{6}$$

The mass balance in (6) and in **Figure 16** is the starting point for calculating $\Delta\mathbf{S}_T+\mathbf{W}_{V,T}$. However, this mass balance only enables to balance the totals per activity. Thus, (6) does not enable us to specify $\Delta\mathbf{S}_T+\mathbf{W}_{V,T}$ in terms of the products from which it originates. For the model calculations, such a specification is important in order to distinguish the degradation of different stocks and to make use of the product and residual material composition to determine material specific supply and use tables (MSPSUTs). The specification of $\Delta\mathbf{S}_T+\mathbf{W}_{V,T}$ in terms of the products from which it originates, requires a specification of how much of the inputs in $\mathbf{U}_T$, ($\mathbf{F}.*\mathbf{i'}_c\mathbf{r}_T$) and $\mathbf{W}_{U,T}$ become supply of products in $\mathbf{V'}_T$. For this purpose we introduce **D** and $\mathbf{F}_0$. The product transfer coefficient matrix (**D**) specifies for each product used by an activity, how much of this used product is present in the products supplied by the activity. In the same manner, the resource transfer coefficient matrix ($\mathbf{F}_0$) specifies for the total resource inputs used by an activity, how much of this is present in the products supplied by the activity after subtraction of direct emissions ($\mathbf{G}_R$). The proportion of $\mathbf{W}_{U,T}$ that become supply of products in $\mathbf{V'}_T$ is derived.

Thus, when accounting for abovementioned transfer coefficients, $\mathbf{\Delta S_T}+\mathbf{W_{V,T}}$ can be expressed as a function: $f(\mathbf{V'_T},\mathbf{U_T},\mathbf{W_{U,T}},\mathbf{R},\mathbf{G_c},\mathbf{G_w},\mathbf{G_R},\mathbf{D},\mathbf{F},\mathbf{F_0})$. The principle of the calculation is a balanced PSUT$_T$, where $\mathbf{\Delta S}+\mathbf{W_V}$ is the unknown to be determined, see **Figure 16**.

Before $\mathbf{\Delta S_T}+\mathbf{W_{V,T}}$ is expressed as a function $f(\mathbf{V'_T},\mathbf{U_T},\mathbf{W_{U,T}},\mathbf{r_T},\mathbf{G_c},\mathbf{G_w},\mathbf{G_R},\mathbf{D},\mathbf{F},\mathbf{F_0})$ in chapter 6.1.5, the resource distribution matrix is described and in chapter 6.1.3, and in 6.1.4 it is specified which and how much of the inputs of $\mathbf{U_T}$, $\mathbf{r_T}$ and $\mathbf{W_{U,T}}$ that become products in $\mathbf{V'_T}$.

6.1.1 Calculation of $\mathbf{W_{V,T}}$ and $\mathbf{\Delta S_T}$ for waste treatment activities is done in a satellite

The principle for calculating stock changes ($\mathbf{\Delta S_T}$) and supply of residuals in ($\mathbf{W_{V,T}}$) presented in this chapter does only apply to non-waste treatment activities. Waste treatment activities are characterised by the fact that they use residuals, i.e. they have entries $\neq 0$ in the $\mathbf{W_{U,T}}$ matrix, and they are identified by the waste treatment activity identifier vectors ($\mathbf{h_i}$ and $\mathbf{h_f}$). The reason that $\mathbf{\Delta S_T}$ and $\mathbf{W_{V,T}}$ are not calculated here is, that they are related to an additional variable in the mass balance compared to the non-waste treatment activities, i.e. entries in the $\mathbf{W_{U,T}}$ matrix. Since the entries in the $\mathbf{W_{U,T}}$ matrix are dependant on the calculated supply of residuals ($\mathbf{W_{V,T}}$), the inclusion of waste treatment activities in the calculations would lead to some very demanding iterations in terms of data handling and calculations.

Therefore, the calculation of stock changes ($\mathbf{\Delta S_T}$) and supply of residuals in ($\mathbf{W_{V,T}}$) for waste treatment activities is done separately in a satellite at the HIOT level, i.e. not in the supply-use framework but as production functions in the direct requirement matrix. The production functions in this satellite model correspond to the calculated production functions of the industry activities in the HIOT based on the PSUTs and the by-product-technology model. Use of residuals in waste treatment activities will always become supply of products, supply of residuals or emissions - they will never become stock changes. Therefore, the determination of supply of residuals can be based on engineering knowledge, e.g. the amount of slag and ash from waste incineration when incinerating 1 kg of residuals of ‘Paper and paper products’.

Taking out the waste treatment activities in a separate satellite has the consequence, that the mass balance requirement in the physical supply and use tables (as illustrated in **Figure 16**) does not apply to these activities. Also the production volumes of these activities are a model output based on the calculated $\mathbf{W_V}$ and $\mathbf{J}$ which together determines how much waste treatment service per waste fraction is required (also see description in section 5.2.3)

6.1.2 The resource distribution matrix (F)

$\mathbf{r_T}$ is a row vector representing the total resource input by activities, and $\mathbf{F}.*\mathbf{i'_c}\mathbf{r_T}$ is the total input of resources distributed on the products of the activity. **F** is defined so that the resource inputs distributed on the products in each column follow the same proportions as in the $\mathbf{F_0}$ matrix. **F** is a normalised version of $\mathbf{F_0}$ meaning that the sum of each column in **F** is 1. Thus, **F** can be directly derived from $\mathbf{F_0}$. This is shown in (7).

$$\mathbf{F} = \mathbf{F_0}\ .*\ \mathbf{i'_a}\left(\mathbf{i_a}\ ./\ \mathbf{i_a}\mathbf{F_0}\right) \tag{7}$$

In order to avoid dividing by zero, the following condition in (7) is introduced, see (8):

$$\text{if } \left(\mathbf{i_a F_0}\right)_{ij} = 0\text{, then } \left(\mathbf{i_a} \;./\; \mathbf{i_a F_0}\right)_{ij} = 0 \qquad (8)$$

6.1.3 Entries in $\mathbf{V'_T}$ originating from $\mathbf{W_{U,T}}$ (waste treatment activities)

In chapter 6.1.1 it is stated that $\mathbf{W_{V,T}}$ and $\mathbf{\Delta S_T}$ are calculated in a satellite for waste treatment activities. Nevertheless, the calculations in the following take into account, that the supply of residuals and stock additions could be included in the in the calculations here. Thus, this sub-chapter merely provide conceptual information rather than information which is actually used in the calculations.

The amount of by-product outputs from waste treatment activities becoming supplies in $\mathbf{V'_T}$, i.e. originating from the residual inputs in $\mathbf{W_{U,T}}$) is calculated applying the assumption that no other inputs than residuals become product outputs of waste treatment activities in $\mathbf{V'_T}$, i.e. all entries in the $\mathbf{U_T}$ matrix for waste treatment activities becomes either stocks or emissions. This implies that enrichment of residuals by adding other raw materials cannot be part of activities defined as waste treatment. If such enrichment occurs, it has to be described in a separate non-waste treatment activity. An example of this is composted organic waste enriched with nutrients.

We distinguish between intermediate and final waste treatment activities. An intermediate waste treatment activity is defined as a waste treatment activity that supplies residuals generated from the use of residuals, and a final waste treatment activity is defined as a waste treatment activity that does not supply any residuals originating from the use of residuals. There are two reasons for this distinction:

1. Intermediate waste treatment activities actively modify the used residuals and then supply these modified residuals to other activities, while final waste treatment activities do not. Therefore, the supply of residuals from an intermediate waste treatment activity cannot be represented in terms of the types of residual inputs. An example is waste incineration, which uses e.g. household waste and supplies ash.
2. In intermediate waste treatment activities, there is no accumulation of residuals originating from residual inputs, while for final waste treatment activities, there is no supplies of residuals originating from residual inputs, i.e. because the residuals supplied to a final waste treatment activity remains within the activity, i.e. it becomes stocks of residuals (landfilled waste).

In the calculations, the distinction between intermediate and final waste treatment activities is done by the introduction of two row vectors; intermediate waste treatment activity identifier ($\mathbf{h_i}$) and final waste treatment activity identifier ($\mathbf{h_f}$). These vectors have dimensions one by activities and contain values $\in \{0,1\}$. An entry = 1 means that the activity is a waste treatment activity (intermediate in $\mathbf{h_i}$ and final in $\mathbf{h_f}$).

The consequence of the two bullets presented above is that for intermediate waste treatment activities (identified by $\mathbf{h_i}$), residuals in the $\mathbf{W_{U,T}}$ matrix are summed and moved to the diagonal. The reason for this is that a residual generated from residuals has another material composition than the original residual, i.e. it is modified during the waste treatment activity. For final waste treatment activities (identified by $\mathbf{h_f}$), the use of residuals is kept at its original place in the $\mathbf{\Delta S}+\mathbf{W_V}$ matrix. The argument for this is that a stock being generated directly from residuals has the same material composition as the residual (which has the same material composition as the products from which it originates). For consistency, the same modification as in $\mathbf{W_{U,T}}$ is done for product outputs of intermediate waste treatment activities in the $\mathbf{V'_T}$ matrix and emissions of residuals from intermediate waste treatment activities in the $\mathbf{G_w}$ matrix. If this modification was not done, the inputs of residuals in $\mathbf{W}_U$ would (incorrectly) appear in the same column as the product output in $\mathbf{V'_T}$. The modifications of the matrices are illustrated in **Figure 16**.

The modifications of $\mathbf{W_{U,T}}$ and $\mathbf{G_w}$ described above can be expressed in mathematical terms as in (9):

$$\mathbf{W_{U,T}} - \mathbf{G_w} \rightarrow (\mathbf{i'_a}\,\mathbf{h_i})\,.\!*\ \mathrm{mdiag}(\mathbf{i_c}(\mathbf{W_{U,T}} - \mathbf{G_w})) + (\mathbf{i'_a}\,\mathbf{h_f})\,.\!*\,(\mathbf{W_{U,T}} - \mathbf{G_w}) \tag{9}$$

The first part of the expression in (9) moves the residuals of *intermediate* waste treatments to the diagonal; the second part ensures that the residuals of the *final* waste treatments are carried unaltered over into the new $\mathbf{W_{U,T}} - \mathbf{G_W}$. It should be noted that when an expression is multiplied by $\mathbf{i'_a h_i}$ and $\mathbf{i'_a h_f}$ all other columns than those for waste treatment activities contain only zero entries.

Accounting for the modifications described above, the supply of products in $\mathbf{V'_T}$ originating from residuals entries in $\mathbf{W_{U,T}}$ can be calculated using formula (10).

$$\mathbf{V'_T}\ .\!*\ \mathbf{i'_a}(\mathbf{h_i} + \mathbf{h_f}) = (\mathbf{i'_a}\,\mathbf{h_i})\,.\!*\ \mathrm{mdiag}(\mathbf{i_c}\mathbf{V'_T}) + (\mathbf{i'_a}\,\mathbf{h_f})\,.\!*\ \mathbf{W_{U,T}}\ .\!*\,(\mathbf{i'_c}(\mathbf{i_a}\mathbf{V'_T}\ ./\ \mathbf{i_a}\mathbf{W_{U,T}})) \tag{10}$$

The calculation in (10) requires that each entry in $\mathbf{i_a W_{U,T}}>0$. Therefore the condition shown in (11) is introduced for formula (10).

$$\text{if } \lfloor \mathbf{i_a}\mathbf{W_{U,T}} \rfloor_{ij} = 0 \text{ then } \lfloor \mathbf{i_a}\mathbf{V'_T}\ ./\ \mathbf{i_a}\mathbf{W_{U,T}} \rfloor_{ij} = 0 \tag{11}$$

6.1.4 Entries in $\mathbf{V'_T}$ originating from $\mathbf{U_T}$ and $\mathbf{r_T}$ (non-waste treatment activities)

The **D** matrix is used to include information on which inputs from $\mathbf{U_T}$ are becoming product outputs in $\mathbf{V'_T}$. Correspondingly, $\mathbf{F_0}$ provides the information on which distributed resource inputs from ($\mathbf{F}.*\mathbf{i'_c r_T}$) becoming product outputs in $\mathbf{V'_T}$. Summarising, $\mathbf{V'_T}$ for non-waste treatment activities can be expressed as shown in (12):

$$\mathbf{V'_T} = \mathbf{D}\ .\!*\ \mathbf{U_T} + \mathbf{F_0}\ .\!*\,(\mathbf{F}\ .\!*\ \mathbf{i'_c}\,\mathbf{r_T}) \tag{12}$$

Since non-waste treatment activities are defined as activities not using residuals (i.e. columns in $\mathbf{W_{U,T}} = \mathbf{0}$), the use of residuals matrix ($\mathbf{W_{U,T}}$) is not present in (12). It should also be noted that the columns in **D** for waste treatment activities only contains entries = 0. If there are inputs of products or resources in the **U** and **R** matrices becoming a product in the $\mathbf{V'_T}$ matrix for a waste treatment activity, then the input should be regarded as enrichment of a co-product from waste treatment, and the waste treatment activity should be disaggregated into a waste treatment activity and an enrichment activity as described in chapter 6.1.3. In the previous chapter on ‘waste treatment activities’, the affected parts of the matrices were identified by multiplying with $\mathbf{i'_a}(\mathbf{h_i}+\mathbf{h_f})$ in the formulas. This is not necessary here for ‘non-waste treatment activities’ because no inputs of residuals ($\mathbf{W_{U,T}}$) become supply of products in ($\mathbf{V_T}$).

To calculate $\mathbf{D}$ from (12), a specification is required of which entries in $\mathbf{U_T}$ will be present in $\mathbf{V'_T}$. This is done in the $\mathbf{D_1}$ matrix where the default value = 1 is entered for all uses of products by activities which will be present in the supply of products from that activity, and 0 is entered for all uses of products in $\mathbf{U_T}$ *not* becoming supply of products in $\mathbf{V'_T}$. When specific information is available, the actual value can be entered directly in $\mathbf{D_1}$.

Thus, $\mathbf{D}$ can be calculated using (13).

$$\mathbf{D_{ij}} = \begin{cases} \mathbf{D_{1,ij}} = 0 & \rightarrow \quad \mathbf{D_{ij}} = 0 \\ \mathbf{D_{1,ij}} =]0{,}1[& \rightarrow \quad \mathbf{D_{ij}} = \mathbf{D_{1ij}} \\ \mathbf{D_{1,ij}} = 1 & \rightarrow \quad \mathbf{D_{ij}} = \mathbf{i'_c} \left\{ \left[\mathbf{i_a V'_T} - \mathbf{i_a} \left(\mathbf{F_0} \;.*\; \left(\mathbf{F} \;.*\; \mathbf{i'_c\, r_T} \right) \right) - \mathbf{i_a} \left(\mathbf{D_{1,ij=]0,1[}} \;.*\; \mathbf{U_T} \right) \right] ./ \right. \\ & \qquad\qquad \left. \left[\mathbf{i_a} \left(\mathbf{D_{1,ij=1}} \;.*\; \mathbf{U_T} \right) \right] \right\} \end{cases} \tag{13}$$

For $\mathbf{D}_{1,ij} = 1$ in (13), the calculation of $\mathbf{D}$ requires that $[\mathbf{i_a}(\mathbf{D}_{1,ij=1}.*\mathbf{U_T})]_{ij} \neq 0$ for all i and j. Therefore the condition shown in (14) is introduced for formula (13).

$$\begin{aligned} &\textbf{if } \left[\mathbf{i_a} \left(\mathbf{D_1} \;.*\; \mathbf{U_T} \right) \right]_{\mathbf{ij}} = 0 \textbf{ then} \\ &\left\{ \left[\mathbf{i_a V'_T} - \mathbf{i_a} \left(\mathbf{F_0} \;.*\; \left(\mathbf{F} \;.*\; \mathbf{i'_c\, r_T} \right) \right) - \mathbf{i_a} \left(\mathbf{D_{1,ij=]0,1[}} \;.*\; \mathbf{U_T} \right) \right] ./ \left[\mathbf{i_a} \left(\mathbf{D_{1,ij=1}} \;.*\; \mathbf{U_T} \right) \right] \right\}_{\mathbf{ij}} = 0 \end{aligned} \tag{14}$$

6.1.5 Calculation of $\Delta\mathbf{S_T}+\mathbf{W_V}$

Substituting the expression for $\mathbf{V'_T}$ shown in (10) and (12) into the mass balance expressed in formula (6), and applying the modifications of $\mathbf{W_{U,T}}$ and $\mathbf{G_w}$ described in (9), $\Delta\mathbf{S_T}+\mathbf{W_V}$ can be calculated as shown in (15).

$$\begin{aligned} \Delta\mathbf{S_{T,u=1}} + \mathbf{W_V} = {} & \mathbf{U_T} - \left(\mathbf{D} \;.*\; \mathbf{U_T} \right) + \left(\mathbf{F} \;.*\; \mathbf{i'_c\, r_T} \right) - \left[\mathbf{F_0} \;.*\; \left(\mathbf{F} \;.*\; \mathbf{i'_c\, r_T} \right) \right] - \mathbf{G_c} - \mathbf{G_R} \\ & + \left(\mathbf{i'_a\, h_i} \right) .* \left[\mathbf{mdiag} \left(\mathbf{i_c} \left(\mathbf{W_{U,T}} - \mathbf{G_w} - \mathbf{V'_T} \right) \right) \right] \\ & + \left(\mathbf{i'_a\, h_f} \right) .* \left[\mathbf{W_{U,T}} - \mathbf{G_w} - \mathbf{W_{U,T}} \;.*\; \left(\mathbf{i'_c} \left(\mathbf{i_a V'_T} \;./\; \mathbf{i_a W_U} \right) \right) \right] \end{aligned} \tag{15}$$

$\Delta\mathbf{S_T}$ in (15) refers to u=1, i.e. only the stock changes related to the supply of products in year t_0 (stocks with age = 1 year) are considered here.

The expression $\left(\mathbf{F} \;.*\; \mathbf{i'_c\, r_T} \right) - \left[\mathbf{F_0} \;.*\; \left(\mathbf{F} \;.*\; \mathbf{i'_c\, r_T} \right) \right]$ in (15) describes the amount of resources used that are not present in the supply of products. Inputs of resources that do not become products or emissions will always become residuals, i.e. not stocks (since we do not consider temporary changes in inventories). Since resource statistics most often report only the resources sold, the amount of resources that become residuals is usually zero, i.e. $\mathbf{F} = \mathbf{F_0}$, and most entries in $\mathbf{F_0}$ will be = 1 on the diagonal. However, there are cases where entries in $\mathbf{F_0} \in [0;1[$. Examples are resources including mine dust sent to treatment, and the food carbon from grazing cattle, where the cattle manure is sent to treatment.

6.1.6 Calculation of square $\mathbf{W}_{\mathbf{V,T}}$

As described in the beginning of chapter 6.1, the result of the calculation of the supply of residuals is the sum of all waste fractions of a product, e.g. the supply of residuals of the product food is the sum of food waste and excretion, and the supply of residual of the product cars is the sum of the fractions which it is disassembled into. Thus, the number of residuals in the calculated $\mathbf{W}_{\mathbf{V,T}}$ here is equal to the number of products and activities in $\mathbf{V}$ and $\mathbf{U}$, i.e. $\mathbf{W}_{\mathbf{V,T}}$ is a square matrix. In chapter 6.1.7 it is described how to deal with disaggregation of the calculated residuals in this chapter.

The relationship between stocks and waste, $\mathbf{\Delta S}_{\mathbf{T}}$ and $\mathbf{W}_{\mathbf{V,T}}$, is determined solely by the stock degradation matrix $\mathbf{L}_{\mathbf{S}}$. The residuals degradation matrix $\mathbf{L}_{\mathbf{w}}$ does not affect the relationship between $\mathbf{\Delta S}_{\mathbf{T}}$ and $\mathbf{W}_{\mathbf{V,T}}$ because $\mathbf{L}_{\mathbf{w}}$ only concerns degradation of stocks of residuals after year u = 1.

$\mathbf{W}_{\mathbf{V,T}}$ can be determined as a function of $\mathbf{W}_{\mathbf{V,T}} + \mathbf{\Delta S}_{\mathbf{T},u=1}$, as given in (15), and $\mathbf{L}_{\mathbf{S,u=1}}$. The vector $\mathbf{L}_{\mathbf{S,u=1}}$ is the first row of $\mathbf{L}_{\mathbf{S}}$. The formula for $\mathbf{W}_{\mathbf{V,T}}$ is shown in (16). The premises for formula (16) are that:

- The inputs of products in $\mathbf{U}_{\mathbf{T}}$ can become either residuals or stocks. Therefore, in (16) the terms of (15) that concern $\mathbf{U}_{\mathbf{T}}$ are multiplied with the $\mathbf{L}_{\mathbf{S,u=1}}$ vector, which specifies the proportion of residuals to stocks in year 1.
- Resources will always become products, emissions or residuals, but never stocks. Therefore, the terms in (15) concerning $\mathbf{r}_{\mathbf{T}}$, are not multiplied with any stock degradation in (16)
- The inputs of residuals to intermediate waste treatment activities, will always become products, emissions or residuals, but never stocks. Therefore, the terms in (15) concerning $\mathbf{W}_{\mathbf{U,T}}$ for intermediate waste treatment activities (specified by $\mathbf{h}_{\mathbf{i}}$), are not multiplied with any stock degradation in (16)
- The inputs of residuals to final waste treatment activities will always become stocks (in landfills or land application of wastes). Therefore, the terms in (15) concerning $\mathbf{W}_{\mathbf{U,T}}$ for final waste treatment activities (specified by $\mathbf{h}_{\mathbf{f}}$) are not entering the formula for $\mathbf{W}_{\mathbf{V,T}}$ in (16)

$$\begin{aligned}\mathbf{W}_{\mathbf{V,T}} &= f\left(\mathbf{W}_{\mathbf{V}} + \mathbf{\Delta S}_{\mathbf{u=1}}, \mathbf{L}_{\mathbf{S}}\right) \Rightarrow \\ \mathbf{W}_{\mathbf{V,T}} &= \left[\mathbf{U}_{\mathbf{T}} - \left(\mathbf{D} \,.\!*\, \mathbf{U}_{\mathbf{T}}\right) - \mathbf{G}_{\mathbf{c}}\right] .\!*\, \mathbf{L'}_{\mathbf{S,u=1}}\, \mathbf{i}_{\mathbf{c}} + \left(\mathbf{F} \,.\!*\, \mathbf{i'}_{\mathbf{c}}\, \mathbf{R}_{\mathbf{T}}\right) - \left[\mathbf{F}_{\mathbf{0}} \,.\!*\, \left(\mathbf{F} \,.\!*\, \mathbf{i'}_{\mathbf{c}}\, \mathbf{R}_{\mathbf{T}}\right)\right] - \mathbf{G}_{\mathbf{R}} \\ &\quad + \left(\mathbf{i'}_{\mathbf{a}}\, \mathbf{h}_{\mathbf{i}}\right) .\!*\, \left[\mathbf{mdiag}\left(\mathbf{i}_{\mathbf{c}}\left(\mathbf{W}_{\mathbf{U,T}} - \mathbf{G}_{\mathbf{w}} - \mathbf{V'}_{\mathbf{T}}\right)\right)\right]\end{aligned} \tag{16}$$

6.1.7 Calculation of non-square $\mathbf{W}_{\mathbf{V,T}}$

The $\mathbf{W}_{\mathbf{V,T}}$ in (16) is square, i.e. the number of residuals is equal to the number of products and activities in $\mathbf{V}$ and $\mathbf{U}$. Here in this chapter, the procedure for disaggregating a residual into two or more fractions is described. When a residual is disaggregated, additional rows in the $\mathbf{W}_{\mathbf{V,T}}$ matrix are added. The number of activities (columns) is unchanged. Thus, the disaggregation of residuals has the consequence that the $\mathbf{W}_{\mathbf{V,T}}$ matrix becomes non-square.

Disaggregation of a residual is required when the residuals of a product appears with different material composition and when these different fractions are treated in different waste treatment activities. This is the case for food products and residuals which undergo a disassembly process. Food products can become the following waste fractions; food waste, human excretion and manure (animal excretion). The material composition of these fractions is different and the fractions are treated in different waste treatment activities, i.e. municipal waste (incineration, landfill etc.), waste water treatment and land application of manure. Residuals which undergo a disassembly process are separated into different fractions having different material composition, e.g. a metal fraction and a waste fraction. The metal fraction is treated in a recycling activity and the waste fraction is treated in another treatment activity, e.g. landfill.

The reason that the disaggregation is required in the abovementioned cases is that when calculating the MSPSUT it is important to have the correct material composition. If disaggregation is not carried of in the case of the disassembly example above, the input of metal to the recycling activity would be too small and the input of metal to the landfill activity would be too high. Hence, if the required disaggregations are not carried out, the MSPSUTs will become inconsistent. Another feature of the disaggregation is that the model outputs provide more usefull information. E.g. knowing the total sum of residuals of the product ‘food’ (the sum of food waste, human excretion and manure) does not provide much useful information.

When a residual is disaggregated row i in the $\mathbf{W}_{\mathbf{V,T}}$ matrix is split into two or more rows. The $\mathbf{W}_{\mathbf{U,T}}$ and $\mathbf{J}$ matrices are modified (split of rows) accordingly, and additional columns are added in the $\mathbf{K}_{\mathbf{w}}$ matrix.

The procedure presented in the following is valid for disaggregating row (i) into two rows (i_1 and i_2). If more disaggregation is required, the procedure is just repeated. The disaggregation required the introduction of new unknowns in the equations. Thus, in order to be able to make the required calculations the following information must be specified for one of the waste fractions of which the total residual is disaggregated into: Supply of residuals (row in $\mathbf{W}_{\mathbf{V,T}}$) and residual material composition (column in $\mathbf{K}_{\mathbf{w}}$). In the standard model without disaggregating residuals $\mathbf{W}_{\mathbf{V,T}}$ and $\mathbf{K}_{\mathbf{w}}$ are calculated and not specified as required here. The procedure is described as a two step procedure in the following:

- Step 1: Decide for which of the disaggregated fractions (i_1 and i_2) where the best data on the supply of residuals (i_1 and i_2 in $\mathbf{W}_{\mathbf{V,T}}$) and residual material composition (column i_1 and i_2 in $\mathbf{K}_{\mathbf{w}}$) are available, and specify this. In the following this fraction is referred to as the residual in row i_2 in $\mathbf{W}_{\mathbf{V,T}}$
- Step 2: The entries in row i_1 in $\mathbf{W}_{\mathbf{V,T}}$ is calculated as: $\mathbf{W}_{\mathbf{V,T,i1}} = \mathbf{W}_{\mathbf{V,T,i}} - \mathbf{W}_{\mathbf{V,T,i2}}$

No further modifications than described in this chapter are required related to the disaggregation of residuals. The matrix formulas in chapter 6.2.4 relating to the determination of MSPSUTs are not affected by the fact that the $\mathbf{W}_{\mathbf{V,T}}$, $\mathbf{W}_{\mathbf{U,T}}$ and $\mathbf{K}_{\mathbf{w}}$ has changed dimensions as described above.

6.1.8 Calculation of ΔS_T

Since $\Delta\mathbf{S}_{\mathbf{T},u=1}$ is the amount of $\left(\mathbf{W}_{\mathbf{V},u=1} + \mathbf{\Delta S}_{\mathbf{T},u=1}\right)$ not being residuals, $\Delta\mathbf{S}_{\mathbf{T},u=1}$ can be determined by substituting formula (16) in (15):

$$\begin{aligned}\mathbf{\Delta S}_{\mathbf{T,u=1}} &= \left[\mathbf{U}_{\mathbf{T}} - \left(\mathbf{D} .* \mathbf{U}_{\mathbf{T}}\right) - \mathbf{G}_{\mathbf{c}}\right] .* \left(\mathbf{i'}_{\mathbf{c}}\, \mathbf{i}_{\mathbf{c}} - \mathbf{L'}_{\mathbf{S,u=1}}\, \mathbf{i}_{\mathbf{c}}\right) \\ &\quad + \left(\mathbf{i'}_{\mathbf{a}}\, \mathbf{h}_{\mathbf{f}}\right) .* \left[\mathbf{W}_{\mathbf{U,T}} - \mathbf{G}_{\mathbf{w}} - \mathbf{W}_{\mathbf{U,T}} .* \left(\mathbf{i'}_{\mathbf{c}} \left(\mathbf{i}_{\mathbf{a}} \mathbf{V'}_{\mathbf{T}} ./\, \mathbf{i}_{\mathbf{a}} \mathbf{W}_{\mathbf{U}}\right)\right)\right]\end{aligned} \tag{17}$$

6.2 Default derivation of SUTs

This chapter describes the procedures for the default derivation of the SUTs (MSUT, PSUT$_T$ and MSPSUTs).

6.2.1 Construction of default MSUT

The MSUTs available from statistics do not include all the products and activities required by the FORWAST model (see Appendix 1: Activities and products). Therefore, the original MSUT has to be disaggregated. The procedure for this is described in chapter 8.

6.2.2 Construction of default price matrix (P)

Generic price information that fits the classification in the FORWAST project does not exist. Therefore, prices are estimated. The approach for estimating prices is to look up in price databases such as Prodcom (Eurostat 2007b). Such a database is however at a very detailed level, and it is almost always the case that a product definition in an input-output definition contains multiple products with various prices in such databases. Without knowing the exact composition of each and every product of the input-output classification, any combination of such price data would be arbitrary. However, by selecting the most representative products within a category, such a database helps estimate the possible range of prices. When both detailed monetary and corresponding physical SUTs exist, prices can be derived from these.

6.2.3 Default calculation of PSUT$_T$

Total physical supply ($\mathbf{V_T}$) and use tables ($\mathbf{U_T}$) can be established either directly from physical information or by combining the monetary supply ($\mathbf{V_\Phi}$) and use tables ($\mathbf{U_\Phi}$) and the price matrix (**P**). Prices of products are described in a product by activity matrix having monetary units per mass unit. Thus, the physical use and supply tables, $\mathbf{U_T}$ and $\mathbf{V_T}$, can be calculated as:

$$\mathbf{U_T} = \mathbf{U_\Phi} \ ./\ \mathbf{P}_\mathrm{U} \tag{18}$$

and

$$\mathbf{V_T} = \mathbf{V_\Phi} \ ./\ \mathbf{P_V} \tag{19}$$

6.2.4 Construction of default MSPSUTs

This chapter described how to calculate material specific physical SUTs. However, this is not carried out in practise due to a too high level of aggregation of waste flows; e.g. the waste flow ‘Residuals of chemicals nec.’ has significant different material composition depending on which activity that supplies the waste. Therefore, it is not possible to make the MSPSUTs consistent when operating with the same material composition of each waste type for all activities, i.e. negative waste will occur. The balancing exercise would become enormous, and since the material categories in the FORWAST model only include non-toxic substances, this would not provide useful information on toxic wastes. . Therefore, this sub-chapter merely provide conceptual information rather than information which is actually used in the calculations.

The construction of the default MSPSUTs is carried out using the following input information:

- Total PSUTs ($\mathbf{V_T}$ and $\mathbf{U_T}$)

- Resource statistics are used to determine the gross input of materials (**R**)
- Total stock changes ($\Delta\mathbf{S_T}$)
- Total residuals ($\mathbf{W_{V,T}}$ and $\mathbf{W_{U,T}}$)
- Emissions (**B**)
- Product material composition ($\mathbf{K_c}$)

The first step in this approach of establishing the MSPSUTs is to calculate the material content per material category relative to the total PSUT. The PSUT is calculated in chapter 6. The material content is calculated by establishing a material specific mass balance for each row and column based on the balanced total physical supply and use table (PSUT_T). In **Figure 17**, the balancing is established for $\mathbf{g_m}$ and $\mathbf{g'_m}$. Since the balance is carried out for **g** and not **q** (see chapter 4.1.2), import and export do not have to be considered.

The material content is specified by the two composition matrices; product material composition matrix ($\mathbf{K_c}$) and residual material composition matrix ($\mathbf{K_w}$). $\mathbf{k_{c,m}}$ and $\mathbf{k_{w,m}}$ in **Figure 17** are row vectors specifying the material content of material m for each product and residual respectively.

When establishing the mass balance, the supply of residuals matrix ($\mathbf{W_{V,T}}$) is modified so that all entries are moved to the diagonal. The reason for this is that the mass balance is used for calculating the residuals material composition, and if some activities have no supply of their corresponding residual, then the residual material composition can not be determined. In mathematical terms, it would lead to an inconsistent equation system. The consequence of this modification is that information is lost on the origin of the residuals in the material specific supply of residual matrix ($\mathbf{W_{V,T}}$) in terms of which used products it originates from. The modification of $\mathbf{W_{V,T}}$ is shown in (20):

$$\mathbf{W_{V,T}} \rightarrow \text{mdiag}\left(\mathbf{i_w}\,\mathbf{W_{V,T}}\right) \tag{20}$$

Balanced MSPSUT for material m	Activities (a)
Sum of products (row vector)	$\mathbf{k_{c,m}V'_T}$
Total (row vector)	$\mathbf{g'_m}$

Sum of products (row vector)	$\mathbf{k_{c,m}U_T}$
Sum of stock changes (row vector)	$\mathbf{k_{c,m}(-\Delta S_T)}$
Sum of supply of residuals (row vector)	$\mathbf{k_{w,m}(-W_{V,T})}$
Sum of use of residuals (row vector)	$\mathbf{k_{w,m}W_{U,T}}$
Resource (m) (row vector)	$\mathbf{R_m}$
Emissions (m) (row vector)	$\mathbf{-B_m}$
Total (row vector)	$\mathbf{g'_m}$

Figure 17: Balanced material specific physical supply and use table (MSPSUT) for material m. The total $\mathbf{V'_T}$, $\mathbf{U_T}$, $\mathbf{\Delta S_T}$, $\mathbf{W_V}$ and $\mathbf{W_U}$ tables are converted to material m by multiplying with the material content vectors ($\mathbf{k_{c,m}}$ and $\mathbf{k_{w,m}}$).

The balance shown in **Figure 17** can be established for all materials simultaneously, by multiplying the $\mathbf{V'_T}$, $\mathbf{U_T}$, $\mathbf{\Delta S_T}$, $\mathbf{W_V}$ and $\mathbf{W_U}$ matrices with $\mathbf{K_c}$ and $\mathbf{K_w}$ instead of $\mathbf{k_{c,m}}$ and $\mathbf{k_{w,m}}$. In this case the totals ($\mathbf{g_m}$ and $\mathbf{g'_m}$) will be matrices having dimensions materials by activities, i.e. the same dimension as the resource matrix (**R**), see (21).

$$\begin{bmatrix} \cdots & \mathbf{g'}_{m=1} & \cdots \\ \cdots & \mathbf{g'}_{m=2} & \cdots \\ & \vdots & \\ \cdots & \mathbf{g'}_{m=12} & \cdots \end{bmatrix} \tag{21}$$

Also the **B** matrix has to have the same dimension as (**R**). The **B** matrix as defined in chapter 3.2 has dimensions; emissions by activities. The rearranged emissions matrix presented here in the following is only used in an intermediate calculation in (23). It is termed $\mathbf{B_{m\times a}}$ referring to its dimensions. Each entry in $\mathbf{B_{m\times a}}$ specifies the sum of a column in one of the original material specific emissions matrices $\mathbf{B_m}$. Thus, each row in $\mathbf{B_{m\times a}}$ specifies the total emission of a material by activities, see (22).

$$\mathbf{B}_{\mathbf{m\times a}} = \begin{bmatrix} \cdots & \mathbf{i_b}\mathbf{B}_{\mathrm{m=1}} & \cdots \\ \cdots & \mathbf{i_b}\mathbf{B}_{\mathrm{m=2}} & \cdots \\ & \vdots & \\ \cdots & \mathbf{i_b}\mathbf{B}_{\mathrm{m=12}} & \cdots \end{bmatrix} \tag{22}$$

The balanced MSPSUTs are expressed in equation (23):

$$\mathbf{K_c V'_T} = \mathbf{K_c U_T} - \mathbf{K_c \Delta S_T} - \mathbf{K_w W_{V,T}} + \mathbf{K_w W_{U,T}} + \mathbf{R} - \mathbf{B_{m\times a}} \tag{23}$$

It appears that the balancing using (23) provides one equation and two unknowns, i.e. $\mathbf{K_c}$ and $\mathbf{K_w}$. Thus, different options must be considered for using (23) to calculate material specific $\mathbf{V'_m}$, $\mathbf{U_m}$, $\mathbf{\Delta S_m}$, $\mathbf{W_{V,m}}$ and $\mathbf{W_{U,m}}$ matrices:

1. Material composition of products $\mathbf{K_c}$ is established using empirical data; $\mathbf{K_w}$ is derived: Using $\mathbf{k_{c,m}}$ and formula (25) to (29), the material specific $\mathbf{V'_m}$, $\mathbf{U_m}$, $\mathbf{\Delta S_m}$, $\mathbf{W_{V.m}}$ and $\mathbf{W_{U,m}}$ matrices can be calculated.
2. Material composition of residuals $\mathbf{K_w}$ is established using empirical data; $\mathbf{K_c}$ is derived: Using $\mathbf{k_{w,m}}$ and formula (25) to (29), the material specific $\mathbf{V'_m}$, $\mathbf{U_m}$, $\mathbf{\Delta S_m}$, $\mathbf{W_{V.m}}$ and $\mathbf{W_{U,m}}$ matrices can be calculated.
3. Iterative solution: Initially assume that $\mathbf{W_{V,T}}$ and $\mathbf{W_{U,T}}$ are zero and then calculate $\mathbf{K_c}$ using (23). Then $\mathbf{k_{c,m}}$ is used for calculating an initial estimate of the material specific $\mathbf{U_m}$, $\mathbf{V'_m}$ and $\mathbf{\Delta S_m}$, and the material specific $\mathbf{W_{U,m}}$ is determined using empirical data. These material specific tables are then used for calculating an estimate of $\mathbf{W_{V,T}}$ using (16). Then by iteration using the calculated $\mathbf{W_{V,T}}$ as an input to (23) and by repeating the procedure, the material specific $\mathbf{W_{V,m}}$ can be calculated.
4. Substitute (23) into (25) to (29) and then substitute (25) to (29) into (16): This option would not reqire any additional data (as required in option 1 and 2), nor any iteration (as in option 3). However, the substitution of matrix equations leads to an equation where the material specific $\mathbf{V'_m}$, $\mathbf{U_m}$, $\mathbf{\Delta S_m}$, $\mathbf{W_{V.m}}$ and $\mathbf{W_{U,m}}$ cannot be isolated, i.e. the solution to the equation cannot be calculated.

We choose option 1. We regard option 3 as too demanding in terms of data handling and calculations, and option 4 as mathematically complex. Out of options 1 and 2, option 1 has the best data availability for the additional data to be collected, i.e. product material composition ($\mathbf{K_c}$). The material specific $\mathbf{V'_m}$, $\mathbf{U_m}$ and $\mathbf{\Delta S_m}$, can directly be calculated using (25), (26) and (27).

Using equation (23), $\mathbf{K_w}$ can then be derived, see (24):

$$\begin{gathered} \mathbf{K_c V'_T} = \mathbf{K_c U_T} - \mathbf{K_c \Delta S_T} - \mathbf{K_w W_{V,T}} + \mathbf{K_w W_{U,T}} + \mathbf{R} - \mathbf{B_{m\times a}} \Leftrightarrow \\ \mathbf{K_w} = \left[\mathbf{K_c}\left(\mathbf{V'_T} - \mathbf{U_T} + \mathbf{\Delta S_T}\right) - \mathbf{R} + \mathbf{B_{m\times a}}\right]\left(-\mathbf{W_{V,T}} + \mathbf{W_{U,T}}\right)^{-1} \end{gathered} \tag{24}$$

Having calculated $\mathbf{K_w}$, the material specific $\mathbf{W_{V,m}}$ and $\mathbf{W_{U,m}}$ matrices can be calculated using formula (28) and (29).

$$\mathbf{V'_m} = \mathbf{V'_T} \; .* \left(\mathbf{k'_{c,m}} \; \mathbf{i_c}\right) \tag{25}$$

$$\mathbf{U_m} = \mathbf{U_T} \; .* \left(\mathbf{k'_{c,m}} \; \mathbf{i_c}\right) \tag{26}$$

$$\mathbf{\Delta S_m} = \mathbf{\Delta S_T} \; .* \left(\mathbf{k'_{c,m}} \; \mathbf{i_c}\right) \tag{27}$$

$$\mathbf{W_{V,m}} = \mathbf{W_{V,T}} \; .* \left(\mathbf{k'_{w,m}} \; \mathbf{i_w}\right) \tag{28}$$

$$\mathbf{W_{U,m}} = \mathbf{W_{U,T}} \; .* \left(\mathbf{k'_{w,m}} \; \mathbf{i_w}\right) \tag{29}$$

7 Balancing of the total – from input data to model output

Chapter 6 describes how the different elements of the supply and use tables are interlinked. These links are mathematical described from input data to model outputs. In this chapter, we describe the input data and how these inputs are treated in order to have model outputs.

The data to be provided as model inputs are shown in **Figure 18**.

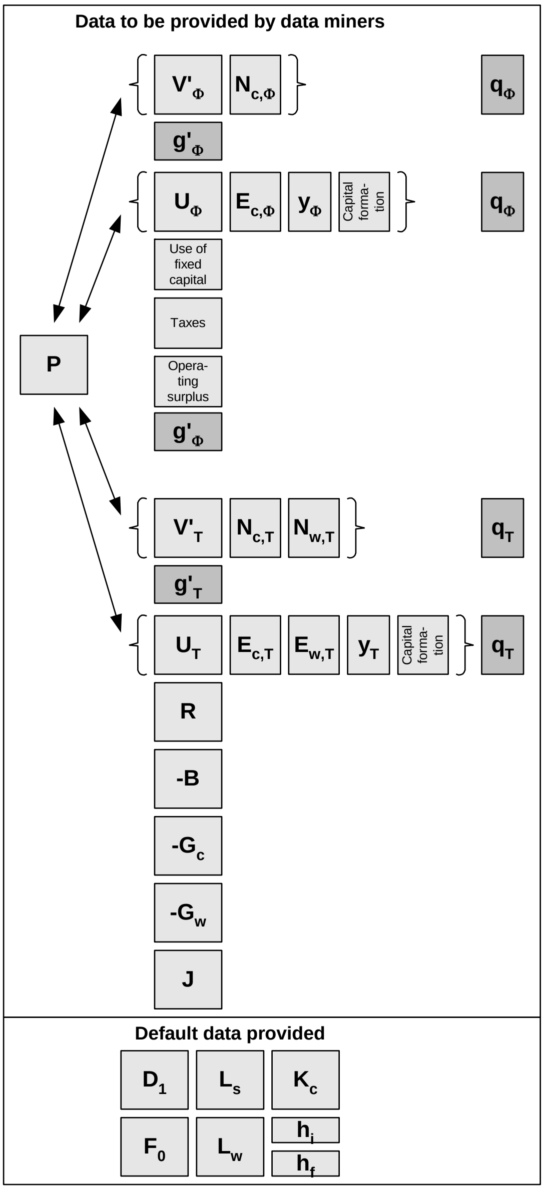


Figure 18: Overview of all input matrices required per geographical region (g) and per year (t) for the FORWAST model.

The calculation steps from the input data in **Figure 18** includes a range of data consolidation and balancing operations. These operations are described in deliverable D6.1: ‘Documentation of the data consolidation and calibration exercise, and the scenario parameterisation’.

8 Disaggregation of the SUTs obtained from Eurostat

Monetary supply and use tables are available from Eurostat for most countries for each year from 1995 and onwards. The categories of activities and products in these tables follow the NACE classification. This level of detail does not represent a desirable level of detail of the FORWAST model. FORWAST deliverable 1-1: ‘Review of available data and recommendation for the appropriate level of model detail’ suggest a level of detail where the 59 categories of industry activities and products plus final consumption in the SUTs from Eurostat are disaggregated into a number of categories, see ‘Appendix 4: Disaggregation of Eurostat 60x60 SUTs’.

The following procedure for disaggregation requires the existence of a set of aggregated matrices, at least a balanced set of supply and use tables (**V’** and **U**) with primary data and/or default calculated values. The calculation procedure is implemented in an excel macro which make the method operational for data miners in the FORWAST project.

The only other values required to perform the default disaggregation is the *total supply* of each disaggregated product, which is used in step 3 of the procedure. All other values are calculated by default, and the procedure may therefore in principle be terminated after step 3. However, without additional data input, the default disaggregation obviously cannot provide any added information relative to the aggregated matrix, which is why the default values are to be adjusted when more knowledge is available. This is the purpose of steps 4 to 17 in the following procedure.

Steps 13 to 18 deals with the treatment of more detailed disaggregation information for other matrices than the **V** and **U** when aggregated versions of such matrices are available.

8.1 Minimum procedure for disaggregation

1) Determine the source of data to be used for *total supply and use* for each disaggregated product and *total output* of each disaggregated activity, i.e. either:
    a) More detailed monetary SUTs.
    b) Physical information and corresponding prices.
    c) Same proportions as for another specified country/region, e.g. Rest of EU

In the following description, the data entry is made in the monetary SUT if 1a) is chosen, and in the physical SUT if route 1b) is chosen.

2) In the supply matrix **V’**, the total supply of each disaggregated product is entered in the column for total supply. Data source is added to the documentation sheets. The total supply of the disaggregated products shall sum to the original aggregated values.

8.2 Adding more detailed disaggregation information to the supply table

3) In the supply matrix **V’**, off-diagonal supplies of the aggregated product (i.e. supplies from activities other than the activity being disaggregated) are redistributed over the disaggregated **products**, when knowledge is available that specifies these products, and the data source is added to the documentation sheet. By default, the distribution is made in proportion to the total supply of each disaggregated product. More specific knowledge may be available from more detailed monetary SUTs, from engineering knowledge of physical relationships, or from data of similar countries or regions. If the off-diagonal supplies are redistributed, the diagonal supply (i.e. the supply from the main activity being disaggregated) will automatically be redistributed within the row in order to maintain the specified total supply of each disaggregated product.

4) In the supply matrix **V’**, the diagonal supplies of the aggregated product (i.e. the supplies from the activity being disaggregated) are redistributed over the disaggregated **activities**, when knowledge is available that specifies the supplies from these activities, and the data source is added to the documentation sheet. By default, the supplies are distributed to the new diagonal cells only, corresponding to an assumption that each disaggregated activity produce only one of the disaggregated products, and the default value is calculated from the total supply of each disaggregated product (from point 3 in the procedure) minus the off-diagonal supplies. More specific knowledge may be available from more detailed monetary SUTs, from engineering knowledge of physical relationships, or from data of similar countries or regions.

5) When internal trade between two disaggregated activities were not originally recorded in the aggregated data, i.e. when the original data that were used to construct the aggregated data were more aggregated than the new disaggregation, the total supply and use of the disaggregated products *can* be larger than the original aggregated values. *Example: For an integrated pulp and paper mill, the original monetary data will record only the supply of pulp and paper sold to the market, not the pulp supplied internally and used to produce the paper. If the aggregated activity is split into pulp production and paper production, the supply of pulp for internal use is “exposed” and now has to be recorded.* In this situation, route 1a) is not an option, and the following procedure should be followed:

6a) If you wish to maintain the default distributions of off-diagonal supplies of the aggregated product in the **V’** matrix as they have been determined in steps 4 and 5, these should be changed to manual inputs, thus disabling the default calculation, since this calculation will change when the supply of specific disaggregated products changes. Reference to the original data and the default procedure is added to the documentation sheet.

6b) The previously unrecorded supply and use of internal flows is determined from engineering knowledge of the physical relationships between the internal flow and the final products, and a monetary value established through the use of shadow prices, typically determined from the market prices of equivalent products.

6c) The previously unrecorded supply and use of internal flows are added to the diagonal cells of the *aggregated* physical **V** and **U** matrices, thereby changing the amount to be disaggregated according to step 3 of the procedure. Correspondingly, the monetary value of the previously unrecorded internal flow is added to the diagonal cells of the *aggregated monetary* **V’** and **U** matrices (alternatively the corresponding cell in the aggregated price matrix may be changed). The aggregated triangulation matrix is changed for the diagonal cell, as appropriate to reflect the new primary data in the calculated aggregated matrices. The data sources are added to the documentation sheets for those aggregated matrices where data have been changed by manual entry.

6d) Step 3 of the procedure is repeated with the new aggregated data, adding the previously unrecorded supply to the totals for the relevant disaggregated products. The previously unrecorded supply is automatically added to the diagonal value of these disaggregated products and to the totals in the **V** matrix.

6e) The previously unrecorded supply is added manually to the relevant disaggregated activity in the **U** matrix (and subtracted from the diagonal entry of the same row to maintain the same total use). In the monetary **U** matrix, the same amount is subtracted from the ‘value added’ of this activity and added to the ‘value added’ of the activity supplying the previously unrecorded flow. The change in ‘value added’ is by default distributed proportionally over the individual elements of the ‘value added’. The data source is added to the documentation sheet for changed cells in the **U** matrix. When relevant, the corresponding cell in the **D** matrix is adjusted.

6) In the supply matrix **V’**, off-diagonal supplies from the aggregated activity (i.e. supplies of products other than the main product of the aggregated activity) are redistributed over the disaggregated activities, when knowledge is available that specifies these activities, and the data source is added to the documentation sheet. By default, the distribution is made in proportion to the distribution of the main product (i.e. the distribution in the disaggregated diagonal cells). More specific knowledge may be available from more detailed monetary SUTs, from engineering knowledge of physical relationships, or from data of similar countries or regions.

7) At this stage in the procedure, all cells in the **V’** matrix have been reviewed and revised as needed, and the total output from the disaggregated activities have been calculated as a result. This total output is automatically transferred to the disaggregated U matrix, and provides the starting point for the disaggregation of the **U** matrix.

8.3 Adding more detailed disaggregation information to the use table

8) In the use matrix **U**, the internal trade within the aggregated activity (the value on the diagonal in the aggregated matrix)[1] is redistributed over the corresponding disaggregated cells, when knowledge is available that specifies the use of the disaggregated products by these activities, and the data source is added to the documentation sheet. By default, the aggregated value is distributed to the diagonal cells of the disaggregated **U** matrix in proportion to the share in total output. This corresponds to an assumption that the aggregated activity is composed of separate, parallel activities that trade only

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[1] Possibly altered relative to the original data source, if the procedure described in step 6 has been applied.

like products between like activities. *Example: The aggregated activity 'Mining of metal ores' may be disaggregated into 'Mining of iron ores', 'Mining of bauxite' etc., each of which supply a completely separate and parallel product, i.e. there will be no iron ores used directly by 'Mining of bauxite' and vice versa.* Off-diagonal inputs, i.e. when the product of one disaggregated activity is a raw material for another disaggregated activity within the same aggregated activity, must be entered manually, and the source of data or assumption added to the documentation sheet. This is obviously already done when the procedure in step 6 is applied, as in the pulp and paper example above, but can also be relevant in situations when the total output remains unaltered. *Example: The food industry may be disaggregated into several activities, with products such as 'Flour' and 'Sugar' that are both used as raw materials for 'Food preparations n.e.c.'. Thus, rather than the internal trade of 'Flour' being used only by other 'Flour' producers, some of the 'Flour' is placed off-diagonal as an input to 'Food preparations n.e.c.'.* The actual distribution may be determined from more detailed monetary SUTs, from engineering knowledge of the physical relationships, or from data of similar countries or regions.

9) In the use matrix **U**, the non-diagonal inputs to the aggregated activity, as well as the 'Value added' (wages, taxes and operating surplus) in the monetary **U** matrix, are redistributed over the disaggregated **activities**, when knowledge is available that specifies these items, and the data source is added to the documentation sheet. By default, the inputs and value added are distributed proportionally to the total output of each disaggregated activity minus the values that are distributed manually. Data for the disaggregation may be available from either:
   - More detailed monetary SUTs.
   - Engineering knowledge of the destiny of specific inputs. *Example: An input of grain to the aggregated food industry is likely to go to mainly to the disaggregated activity 'Flour' and that this can be validated by knowledge of the output of flour and residuals from this activity.*
   - Engineering knowledge of the main parameters determining the use of the input. *Example: The input of nitrogen fertiliser to the aggregated agriculture can be distributed to the disaggregated agricultural activities in proportion to the typical nitrogen requirement of the crops.*
   - Process data (e.g. from LCA databases), specifying the amount of inputs relative to outputs for specific disaggregated activities. Typically, process data are not available for all the disaggregated activities, which implies that there will be a residual input to be disaggregated over these remaining activities, using the default procedure.

10) In the use matrix **U**, the non-diagonal inputs of the aggregated product to each activity are redistributed over the disaggregated **products**, when knowledge is available that specifies the destiny of these inputs, and the data source is added to the documentation sheet. By default, the products are distributed proportionally to the total use of each disaggregated product minus the values that have already been distributed manually. This default distribution should be corrected when better information is available, from either:
   - More detailed monetary SUTs.
   - Engineering knowledge of the destiny of specific supplies. *Example: A supply of an agricultural product to the activity 'Meat and fish industry' is likely to be mainly meat animals and not any of the other disaggregated agricultural outputs.* Having applied such data for some receiving activities, the distribution of the remaining supplies over the remaining activities is recalculated,

using the default procedure (i.e. proportionally to the total output of each disaggregated activity minus the values that have already been distributed manually).

8.4 Disaggregating other matrices than the V and U

If other matrices than the **V** and **U** matrices are available in aggregated format, the following steps of the procedure describe how the disaggregation of these matrices should be performed and how this is done by default. If aggregated matrices are not available, the disaggregated matrices will be empty and will therefore have to be filled directly with primary data.

11) In the price matrix **P**, the prices of the disaggregated products are adjusted, when knowledge is available of price differences between the disaggregated products, and the data source is added to the documentation sheet. By default, the disaggregated cells in the price matrix are filled with the same prices as for the corresponding aggregated product. This implies that the physical and monetary SUTs will by default obtain the same proportional distribution. If the price matrix is altered, the total output of the disaggregated activities/products will not necessarily add up to the total output for the aggregated activity. When route 1a) is chosen, this is allowed, since the price information at the disaggregated level may be of a higher quality than at the aggregated level. When route 1b) is chosen, the prices must be adjusted in such a way that the total monetary output of the disaggregated activities/products adds up to the total for the aggregated activity. This can either be done by letting one of the disaggregated products/activities take up the residual difference, or by distributing the difference proportionally over all disaggregated prices.

12) In the matrix for use of residuals $\mathbf{W}_U$, the data on use of disaggregated residuals by activities and use of residuals by disaggregated activities are adjusted, when knowledge is available of differences between the use of disaggregated residuals by activities or between the use of residuals by disaggregated activities, and the data source is added to the documentation sheet. By default, the disaggregated residuals are distributed proportionally to the total use (= total supply) of each disaggregated residual minus the values that have already been distributed manually (parallel to step 11 for products), and the disaggregated activities are assumed to use the residuals in proportion to their total outputs (for disaggregated waste treatment activities) or to their use of the product that the residual use is expected to displace (for all other disaggregated activities).

13) In the product transfer coefficient matrix **D**, the coefficients for the disaggregated activities and products are adjusted when knowledge is available of differences between the disaggregated activities or products, and the data source is added to the documentation sheet. By default, the disaggregated values are the same as for the aggregated activity or product, with the exception of internal trade within the aggregated activity (the value on the diagonal in the aggregated matrix) where the off-diagonal coefficients in the disaggregated **D** matrix are by default given the value 1.

14) In the stock degradation matrix $\mathbf{L}_S$, the degradation data are adjusted when knowledge is available of differences between the disaggregated products, and the data source is added to the documentation sheet. By default, the disaggregated values are the same as for the aggregated product.

15) In the resource matrix **R**, the resource inputs to the disaggregated activities are adjusted, when knowledge is available of differences between the disaggregated activities, and the data source is

added to the documentation sheet. By default, the disaggregated activities are given the same resource input *per kg output* as for the aggregated activity in the physical use table, whereby possible price differences are taken into account.

16) In the emissions matrix **B**, the emissions from the disaggregated activities are adjusted, when knowledge is available of differences in emission coefficients between the disaggregated activities, and the data source is added to the documentation sheet. By default, the emissions are disaggregated in proportion to the total physical output of each disaggregated activity. However, for the emissions mainly related to fuel combustion, these are distributed over the disaggregated activities in the same proportions as the inputs of fuels for combustion (inputs from NACE codes 10, 11 and 40.2 multiplied by 1-d, where d is the value of the corresponding cells in the **D** matrix) to the disaggregated activities in the physical use table. The latter default procedure, i.e. on fuel-related emissions, does not apply to disaggregation of waste treatment activities.

17) In the material composition matrices $\mathbf{K_c}$ and $\mathbf{K_w}$, the material composition of the disaggregated products are adjusted, when data are available on the differences between the disaggregated products, and the data source is added to the documentation sheet. By default, the material composition of the disaggregated products is identical to that of the aggregated product. If the manually entered data are to have effect on the calculation of the SUTs, the appropriate route has to be chosen in the triangulation matrix.

8.5 Disaggregation of household uses

The final demand vector in the use table is integrated in ten household activities, see Appendix 1: Activities and products. The distribution of the final demand vector into the household uses is based on Weidema et al. (2005) and the detailed Danish SUT (described in the chapter on Denmark in deliverable D3.1 ‘Report describing data processing and validation’). The distribution is specified in deliverable D6-1: ‘Documentation of the data consolidation and calibration exercise, and the scenario parameterisation’.

In the supply table each household activity supplies the sum of all its uses (there are no primary inputs) in the use table on the diagonal. To maintain balance, also a new final demand vector is created; needs fulfilment vector (**y**) containing the same values as the diagonal supplies of the household activities..

9 Constructing IO-tables (direct requirement coefficient matrices)

One of the analytical applications of SUTs is the modelling of product inputs required to satisfy a specified product output. This is done by constructing the IO-tables. Thus, **Figure 7** and **Figure 9** are used to determine the inputs of products (in **U**) per each output of products (in **V'**). If all activities supplied only one product, i.e. if there were only entries on the diagonal of **V'**, this would be straight forward. However, since some activities supply multiple product outputs (non-diagonal entries in **V'**), it requires some assumptions in order to trace the product inputs to each industry (in **U**) by applying the data available in **Figure 7**.

Therefore, the balanced SUTs are converted into analytical tables (product requirement coefficient matrices) by using so-called technology models (Hoekstra 2002, p 29; Kop Jansen and ten Raa 1990). In general, two technology models are widely used for conversion of SUTs into product-by-product symmetric IO-tables, namely the industry-technology model and the commodity-technology model. The industry-technology model is equivalent to economic allocation of co-products in LCA, and the commodity-technology model is equivalent to system expansion in LCA.

9.1 Technology model

The following four sub-chapters describe different technology models.

9.1.1 Industry-technology model

The direct requirement coefficient matrix (**A**) using the industry-technology model is determined by (30) (Hoekstra 2005, p 29).

$$\mathbf{A} = \left(\mathbf{U}\hat{\mathbf{g}}^{-1}\right)\left(\mathbf{V}\hat{\mathbf{q}}^{-1}\right) \tag{30}$$

The first term in (30), $\left(\mathbf{U}\hat{\mathbf{g}}^{-1}\right)$ expresses the industrial activities by product inputs, normalised by the total inputs (product inputs and primary inputs). Thus, the sum of each column (product inputs and primary inputs to an industrial activity) is one. $\left(\mathbf{V}\hat{\mathbf{q}}_{\mathbf{d}}^{-1}\right)$ expresses the products by industrial inputs, normalised by industrial inputs. Thus, the sum of each column (industrial inputs to a product) is one.

In the industry-technology model, it is assumed that each industry has a homogeneous product output, irrespective of its product mix (Hoekstra 2005, p 29). The normalised use table $\left(\mathbf{U}\hat{\mathbf{g}}^{-1}\right)$ expresses the use of products for each industry activity (per industry output). If there were no co-producing industries (i.e. no off-diagonal non-zero entries in the supply table (**V**), **A** would be equal to $\left(\mathbf{U}\hat{\mathbf{g}}^{-1}\right)$ (because $\left(\mathbf{V}\hat{\mathbf{q}}_{\mathbf{d}}^{-1}\right) = \mathbf{I}$).

When there are non-zero off-diagonal entries in the normalised supply matrix $\left(\mathbf{V}\hat{\mathbf{q}}_{\mathbf{d}}^{-1}\right)$, each column specifies the contribution of industrial inputs to a product output in terms of share per industry output. Since the industry-technology model assumes that each industry has a homogeneous product output, the industry inputs to products $\left(\mathbf{V}\hat{\mathbf{q}}_{\mathbf{d}}^{-1}\right)$ can be used as a key for determining the product-by-product direct requirement matrix (**A**). Each entry in **A** is then determined as the scalar product of the corresponding row in $\left(\mathbf{U}\hat{\mathbf{g}}^{-1}\right)$ and the column in $\left(\mathbf{V}\hat{\mathbf{q}}_{\mathbf{d}}^{-1}\right)$, where $\left(\mathbf{V}\hat{\mathbf{q}}_{\mathbf{d}}^{-1}\right)$ determine the share of the supplying products. E.g. if the total supply of animal feed is produced by 80% feed industry and 20% vegetable oil industry, the entries in the animal feed column in **A** is calculated as 0.8 multiplied with the 'animal feed' column in $\left(\mathbf{U}\hat{\mathbf{g}}^{-1}\right)$ plus 0.2 multiplied with the 'vegetable oil' column in $\left(\mathbf{U}\hat{\mathbf{g}}^{-1}\right)$.

According to Suh et al. (2010), the industry-technology model is equivalent to allocation which is used in attributional modelling in life cycle assessment (LCA).

9.1.2 Commodity-technology model

The direct requirement coefficient matrix (**A**) using the commodity-technology model is determined by (31) (Kop Jansen and Ten Raa 1990).

$$\mathbf{A} = \mathbf{U}\mathbf{V}'^{-1} \qquad (31)$$

The right side of formula (32) is equivalent to (31) , but easier to explain:

$$\mathbf{A} = \mathbf{U}\mathbf{V}'^{-1} \Leftrightarrow \mathbf{U} = \mathbf{A}\mathbf{V}' \qquad (32)$$

The commodity-technology model assumes that each commodity is produced in its own specific way, irrespective of the industries producing it (Hoekstra 2005, p 29). Thus, the expression $\mathbf{U} = \mathbf{A}\mathbf{V}'$ provides a recipe for each product (i.e. the columns in **A**: the input of products per product output). An industry's use of a certain product (an entry in the **U**-matrix) is determined as the scalar product of the input of the product per product type (a row in **A**), and the supply of the industry's products (a column in **V'**). E.g., if we want to determine an entry in the use table (**U**), namely the use of 'agricultural crops' by the industry 'vegetable oil', we know the use of products per total supply of the products 'vegetable oil' and 'animal feed' (the **A** matrix), and we know the supply of these two products from the 'vegetable oil' industry and from the 'animal feed' industry (the **V'**-matrix). **A**: the production of 1 kg 'vegetable oil' uses 1.2 kg 'agricultural crop', and the production of 1 kg 'animal feed' uses 1 kg 'agricultural crop'. **V'**: the supply from the 'vegetable oil' industry is 160 kg 'vegetable oil' and 50 kg 'animal feed', and the supply from the 'animal feed' industry is 300 kg 'animal feed'. Assuming that each product is produced in its own specific way, represented by the columns in **A,** the use of ‘agricultural crop’ by the ‘vegetable oil’ industry can be calculated as: 160 kg ‘vegetable oil’ multiplied with 1.2 kg ‘agricultural crop’ plus 50 kg ‘animal feed’ multiplied with 1 kg ‘agricultural crop’. This calculation corresponds to $\mathbf{U} = \mathbf{A}\mathbf{V}'$.

When applying the commodity-technology model, there may be negative entries in the **A**-matrix. This is because the product inputs per product output are reduced, corresponding to the alternative supply of the co-products.

According to Suh et al. (2010), the commodity-technology model leads to the same results (emissions and other externalities) as when using the byproduct-technology model. The byproduct-technology model is equivalent to system expansion which is used in consequential modelling in life cycle assessment (LCA).

9.1.3 By-product-technology model

The direct requirement coefficient matrix (**A**) using the by-product-technology model is determined by (33) (Kop Jansen and Ten Raa 1990).

$$\mathbf{A} = \left(\mathbf{U} - \tilde{\mathbf{V}}'\right)\hat{\mathbf{V}}^{-1} \tag{33}$$

where **V** is split into $\hat{\mathbf{V}}$ (diagonal entries in **V**) and $\tilde{\mathbf{V}}$ (off-diagonal entries in **V**).

According to Suh et al. (2010), the byproduct-technology model is equivalent to system expansion which is used in consequential modelling in life cycle assessment (LCA).

9.1.4 Applied technology model: Byproduct-technology model

The applied technology-model is the byproduct-technology model. This model is used because it is the only one:

- which is able to handle supply-use tables in hybrid units
- which do not alter mass balance of allocated processes (this is the case when using the industry-technology model), see Weidema and Schmidt (2010)
- solving multiple-output problems by system expansion is in line with the ISO standards on LCA as well as state of art methodology of consequential modelling (ISO14040; ISO14044; Weidema and Ekvall 2009)

9.2 The monetary IO-table (MIOT)

Based on the descriptions in this chapter is possible to construct a MIOT. The constructed MIOT is arranged as shown in **Figure 19**.

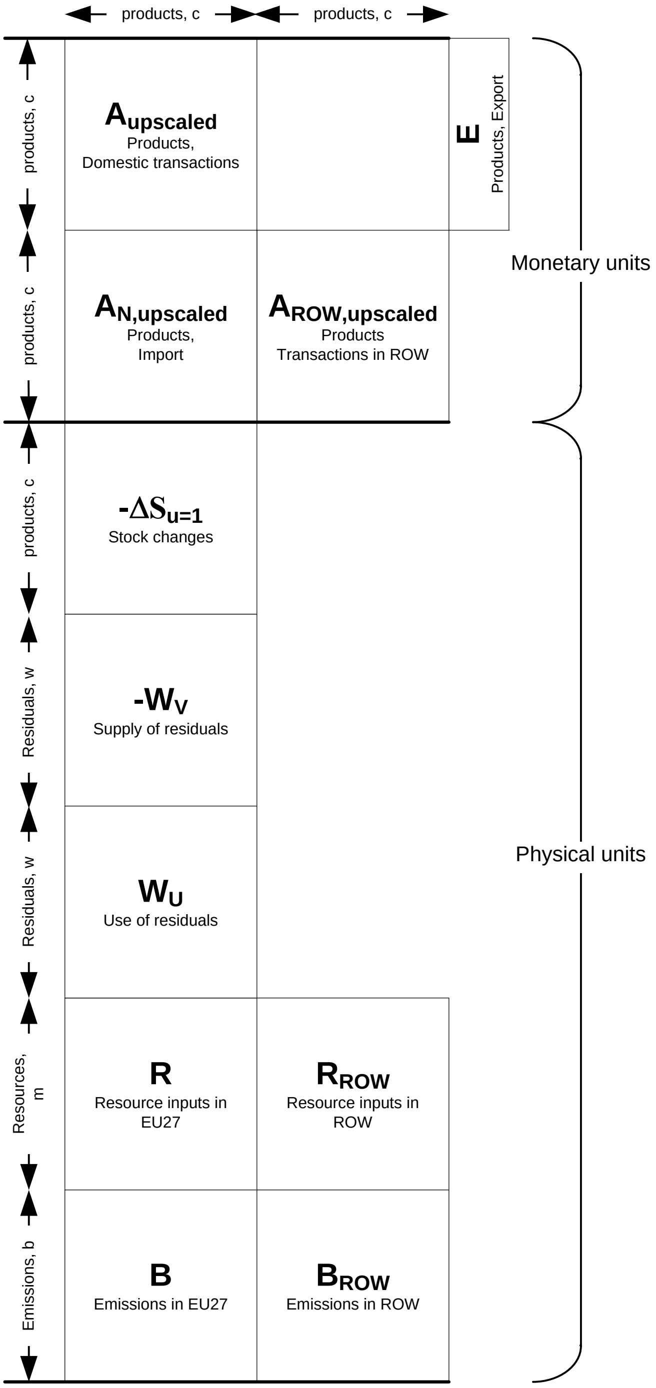

Figure 19: Illustration of the dimensions and composition of the MIOT.

The MIOT shown in **Figure 19** takes into account import and exports. $\mathbf{A}_{\mathbf{ROW}}$ and $\mathbf{A}_{\mathbf{N}}$ are described in chapter 9.5.

The sign of the stock change matrix (**ΔS**) is negative because stocks are recorded as product outputs or supplied stocks (in the use table **U**). In the MIOT stocks are placed vertically in relation to **A**, and hence as an input. Therefore, the sign is negative.

9.3 The physical IO-table (PIOT)

The PIOT is composed as and has the same dimensions as the MIOT, see **Figure 19**. The only difference is that all units in the PIOT are physical. This means that the matrix is fully balanced for all physical transactions: products, residuals, stock additions, resources and emissions.

9.4 Hybrid IO-table (HIOT)

A hybrid input-output table (HIOT) is a combination of the MIOT and the PIOT, to be used for life cycle assessment of the future scenarios. The purpose of combining the MIOT and the PIOT is to obtain the most appropriate units of each activity in the IO tables. E.g., when using the model for assessing scenarios, it is more appropriate to enter amounts of waste into the model in terms of mass than in Euro. Likewise, to ensure that also the indirect material requirement of service industries are included in the scenario analyses, it is more appropriate to represent service products in terms of monetary units, since they are not associated with a physical product output.

The basic exercise is to choose whether the rows in the HIOT should be obtained from the balanced PIOT or MIOT. The HIOT is established for the total PIOT only, i.e. the single material PIOTs are not used as direct entries in the HIOT.

9.5 HIOT for imported products to the EU-27

Due to lack of HIOTs representing the technosphere outside the EU-27, the normalised direct requirement coefficient matrix ($\mathbf{A}$) for EU-27 is used for representing the direct requirement coefficient matrix for rest of world ($\mathbf{A}_{\mathbf{ROW}}$) including the normalised externality matrices. The direct import requirement coefficient matrix ($\mathbf{A}_{\mathbf{N}}$) is determined by using the import share = import / (domestic supply + import) for each product.

9.6 Calculating model outputs from HIOT and needs fulfilment vector

The normalised $\mathbf{A}$, and the normalised externalities matrices ($\Delta\mathbf{S}$, $\mathbf{W}_{\mathrm{V}}$, $\mathbf{B}$, $\mathbf{R}$) are scaled up to actual values by using the formula (the formula applies to externalities matrices when substituting normalised **A** with thenormalised externalities matrices in the formala):

$$\mathbf{A}_{\mathbf{upscaled}} = (\mathbf{scale}^{T}\ I)\ .*\ \mathbf{A} \qquad (34)$$

Where:

$$\mathbf{scale} = \mathbf{A}^{-1}(\mathbf{y}+\mathbf{E}) \qquad \text{(Heijungs and Suh 2002)} \qquad (35)$$

In formula (35), the driving vector is needs fulfilment + export. This corresponds to analysing total production and consumption, also see **Figure 20**.

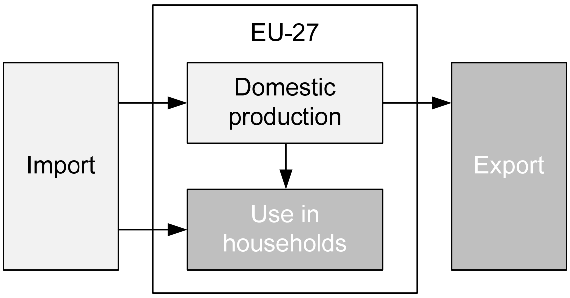

Figure 20: Illustration of major commodity flows. Total supply (output of import and domestic production) is equal to total use (input to use in households and export). The latter is used as functional unit (driving vector) in the model.

10 Making the model quasi-dynamic, i.e. adding the time dimension

In this analytical step, the time dimension is added by establishing the previously described model for each year over an appropriate period. The time dimension is implemented in the HSUT and model calculations as described in previous chapters are carried out for each year. The scenario implementation is also carried out in the HIOT.

Adding the time dimension to the model has two main purposes: 1) to provide an inventory of the historically cumulated physical stock of materials in EU27, and 2) to forecast the expected amounts of waste generated and its environmental impacts. Correspondingly, the temporal modelling includes two phases. These are illustrated in **Figure 21**.

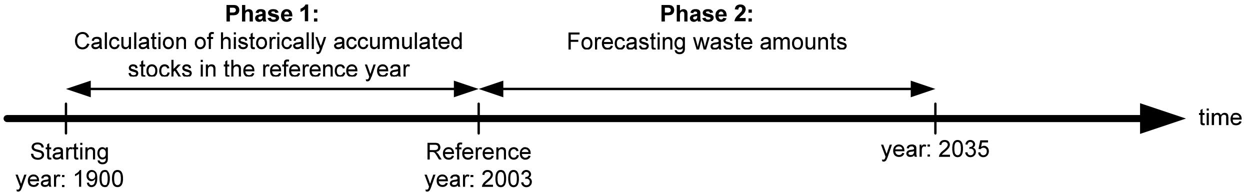

Figure 21: Two phases of the dynamic modelling.

10.1 Historically accumulated stocks

The purpose of the first, historical phase of the dynamic modelling is to calculate the stocks per material category in the reference year. At present, the best data availability for MIOTs and PIOTs for the EU27 is for the year 2003. Therefore, this year is chosen as reference year. The establishment of IO tables from the starting year until the reference year is based on time series of supply and use tables. The data used for this are described in deliverable D6-1: ‘Documentation of data consolidation, calibration and scenario parameterisation’.

In general, the data availability of annual production of products is good. Combining these data with the *lifetime* of the products and initial stocks in a reference year, the stocks and waste generation over time can be determined. A stock degradation matrix **($\mathbf{L}_S$)** (or product lifetime tables) is established for the product outputs of the industry activities in the **A** matrix of the IO table. It could be taken into account that the product lifetime for a product category may change over time. Examples are changing quality of buildings, and new products such as mobile phones and other electronic equipment emerging on the market. Therefore, product lifetime tables should be established for periods of e.g. five years. However, due to data availability, the same product life times has been used throughout the model. The entries in the product lifetime table consist of average lifetimes of the products, and one or more variables representing the distribution. As a default, we will use a symmetric, triangular distribution around the average. The entries for each product category in the table are: 1) average lifetime, and 2) the distributions of these (range of period of release).

In order to have appropriate data on production to estimate current stocks, a desirable timeframe of e.g. 100 year back in time is chosen. By choosing a starting year 100 years back in time, the period exceeds the product lifetime for most product categories and the stocks in the starting year will have negligible influence on the current stocks.

The principle of using time series of supply of residuals tables ($\mathbf{W_V}$), stock addition tables (**ΔS**) and lifetime table ($\mathbf{L_S}$) for estimating the historically accumulated stocks are illustrated in **Figure 22** and **Figure 23**. The principle of calculating the supply of residuals originating from the depreciation of the accumulated stocks are shown in **Figure 24** and **Figure 25.**

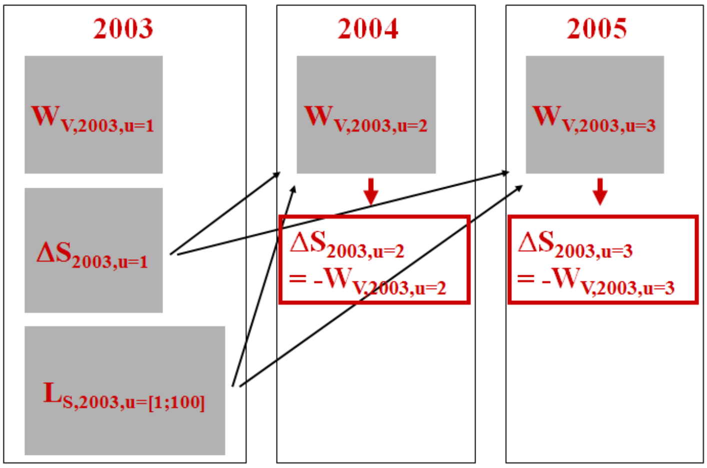

Figure 22: Principle of using stock addition table (**ΔS**) for a given year (2003) and lifetime table ($\mathbf{L_S}$) for estimating the future stock changes and supply of residuals. Here the stock changes originating from stock addition in year 2003 are shown for year 2004 and 2005.

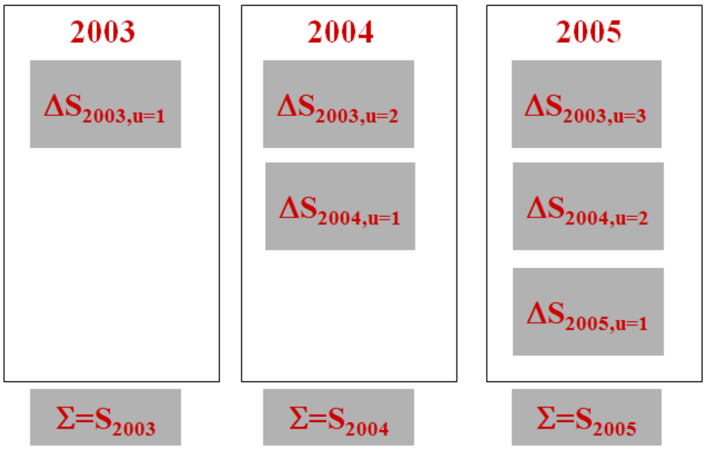

Figure 23: Principle of using time series of stock change tables (ΔS) for estimating the historically accumulated stocks. Here is the accumulated stock in year 2005 shown for year 2003 to 2005.

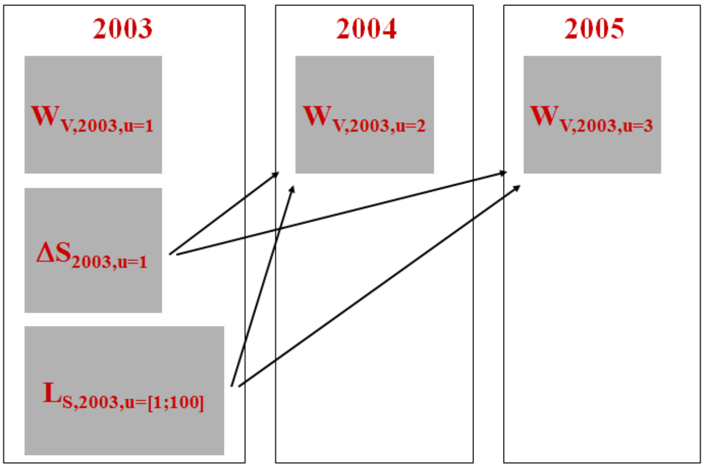

Figure 24: Principle of calculating supply of residuals originating from activities in year 2003. Here the supply of residuals originating from 2003 are shown for year 2003 to 2005.

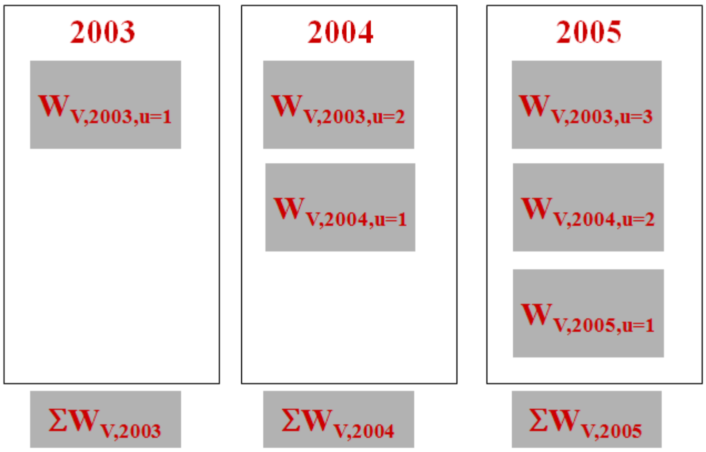

Figure 25: Principle of calculating accumulated supply of residuals originating from activities in several years. Here the supply of residuals in year 2005 originating from activities in year 2003 to 2005 are shown.

10.2 Forecasting stocks, waste amounts and environmental impacts

The purpose of the second phase is to forecast the waste amounts generated the next 25 years, i.e. until 2035, as well as the corresponding environmental impacts. For the forecasting, the intermediate flows are required in order to facilitate the modelling of the scenarios from the FORWAST project WP5 and WP6, which may in principle affect all activities in the IO table.

Future HSUTs are established based on the scenarios described in deliverable D5-2: 'Description of the three chosen macro-economic scenarios for EU-27 until 2035', and D5-3: 'Report chapter with description of three what-if-scenarios of waste treatment policies and their interplay with the macro-economic scenarios'. The scenario implementation is described in deliverable D6-1: 'Documentation of data consolidation, calibration and scenario parameterisation'.

The calculation principles presented in **Figure 22**, **Figure 23**, **Figure 24**, and **Figure 25** are implemented in a Matlab procedure which enable running the model from year 1900 to 2035. The outputs of this Matlab procedure are: Accumulated stocks each year from 1900 to 2035, and accumulated waste generation each year from 2003 to 2035 (including supply of residuals originating of depreciation of stocks from previous years).

Life cycle emissions are calculated by:

$$\text{emissions} = \begin{bmatrix} \text{Carbon dioxide (CO2), fossil as well as biogenic} \\ \text{Resource extraction of biogenic carbon} \\ \text{Nitrogen oxides (NOx)} \\ \text{Methane (CH4)} \\ \text{Sulphur dioxide (SO2)} \\ \text{Dinitrogen monoxide (N2O)} \\ \text{Carbon monoxide (CO)} \\ \text{Non - methane volatile organics (NMVOC)} \end{bmatrix} = \mathbf{B} * \mathbf{scale} = \mathbf{B}\left(\mathbf{A}^{-1}\left(\mathbf{y}+\mathbf{E}\right)\right) \tag{36}$$

where **B** here is the normalised emissions table; normalised by the diagonal supply in the hybrid supply table **V**. The driving vector is (**y**+**E**), i.e. the needs fulfilment plus the export (also see chapter 9.6).

When calculating environmental impacts for a given year, this is done by including the total waste generation originating from this specific year, i.e. by operating with product life times = 1 year for all products (then there are no stock additions), and also disregarding waste originating from activities previous years. This way of calculating emissions corresponds to the usual way of treating waste treatment in life cycle assessment (waste flows of actual product system are included), and it introduces the assumption that the economy in balance (stock additions are equal to stock depreciations).

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Appendix 1: Activities and products

The table below specifies the 145 included product groups in the FORWAST model. The model contains four different types of products:

- Physical products, i.e. products that have a physical weight (mass unit, dry weight) or products being electricity/heat (energy unit)
- Service products, i.e. products that are measured in monetary units
- Waste treatment services, i.e. services to treat or recycle waste. These may be intermediate treatments (e.g. incineration that supplies ash and slag as waste) or final (e.g. landfill)
- Household uses, i.e. groups of final uses

The unit of measurement for each product group in the hybrid model is specified in the table below. The table also specifies the main by-product of each waste treatment activity (the main product/determining product is the service to treat waste). The table also specifies the NACE classification numbers relating to each product group.

No	Product type	Unit	Name	Main by-product of waste treatment services	NACE classification
1	Physical	Mass product	Bovine meat and milk		1.21
2	Physical	Mass product	Pigs		1.23
3	Physical	Mass product	Poultry and animals n.e.c.		01.24+01.25
4	Physical	Mass product	Grain crops		01.1(disaggr.)
5	Physical	Mass product	Crops n.e.c.		01.1(disaggr.)
6	Service	Monetary value	Agricultural services n.e.c.		01(disaggr.)+01.4+01.5
7	Physical	Mass product	Forest products		2 (disaggr.)
8	Waste treatment	Mass waste	Recycling of waste wood	Forest products	2 (disaggr.)
9	Physical	Mass product	Fish		5
10	Physical	Mass product	Coal, lignite, peat		10
11	Physical	Mass product	Crude petroleum and natural gas		11
12	Physical	Mass product	Iron ores from mine		13.1
13	Physical	Mass product	Bauxite from mine		13.2(disaggr.)
14	Physical	Mass product	Copper from mine		13.2(disaggr.)
15	Physical	Mass product	Metals from mine n.e.c.		13.2(disaggr.)
16	Physical	Mass product	Sand, gravel and stone from quarry		14.1+14.21
17	Physical	Mass product	Clay and soil from quarry		14.22
18	Physical	Mass product	Minerals from mine n.e.c.		14.3+14.4+14.5
19	Physical	Mass product	Meat and fish products		15.1+15.2
20	Physical	Mass product	Dairy products		15.5
21	Physical	Mass product	Fruits and vegetables, processed		15.3
22	Physical	Mass product	Vegetable and animal oils and fats		15.4
23	Physical	Mass product	Flour		15.6
24	Physical	Mass product	Sugar		15.83
25	Physical	Mass product	Animal feeds		15.7
26	Physical	Mass product	Food preparations n.e.c.		15.8(ext.)
27	Physical	Mass product	Beverages		15.9
28	Physical	Mass product	Tobacco products		16
29	Physical	Mass product	Textiles		17
30	Physical	Mass product	Wearing apparel and furs		18
31	Physical	Mass product	Leather products, footwear		19
32	Physical	Mass product	Wood products, except furniture		20
33	Physical	Mass product	Pulp, virgin		21.11(disaggr.)
34	Waste treatment	Mass waste	Recycling of waste paper	Pulp, virgin	21.11(disaggr.)
35	Physical	Mass product	Paper and paper products		21.12+21.2
36	Physical	Mass product	Printed matter and recorded media		22
37	Physical	Mass product	Refined petroleum products and fuels		23 (disaggr.)
38	Waste treatment	Mass waste	Recycling of waste oil	Refined petroleum products and fuels	23 (disaggr.)
39	Physical	Mass product	Fertiliser, N		24.15(disaggr.)
40	Physical	Mass product	Fertiliser, other than N		24.15(disaggr.)
41	Physical	Mass product	Plastics basic, virgin		24.16(disaggr.)+24.17(disaggr.)
42	Waste treatment	Mass waste	Recycling of plastics basic	Plastics basic, virgin	24.16(disaggr.)+24.17(disaggr.)
43	Physical	Mass product	Chemicals n.e.c.		24(disaggr.)
44	Physical	Mass product	Rubber and plastic products		25
45	Physical	Mass product	Glass, mineral wool and ceramic goods,		26.1(disaggr.)+26.2(disaggr.)
46	Waste treatment	Mass waste	Recycling of glass, mineral wool and ceramic goods	Glass, mineral wool and ceramic goods, virgin	26.1(disaggr.)+26.2(disaggr.)+26.3(disaggr.)
47	Physical	Mass product	Cement, virgin		26.5(disaggr.)
48	Waste treatment	Mass waste	Recycling of slags and ashes	Cement, virgin	26.5(disaggr.)
49	Physical	Mass product	Concrete, asphalt and other mineral products		26.6(disaggr.)+26.7(disaggr.)+26.8(disaggr.)
50	Waste treatment	Mass waste	Recycling of concrete, asphalt and other mineral products	Sand, gravel and stone from quarry	26.6(disaggr.)+26.7(disaggr.)+26.8(disaggr.)

No	Product type	Unit	Name	Main by-product of waste treatment services	NACE classification
51	Physical	Mass product	Bricks		26.3(disaggr.)+26.4
52	Waste treatment	Mass waste	Recycling of bricks	Bricks	26.3(disaggr.)+26.4
53	Physical	Mass product	Iron basic, virgin		27.1(disaggr.)
54	Waste treatment	Mass waste	Recycling of iron basic	Iron basic, virgin	27.1(disaggr.)
55	Physical	Mass product	Aluminium basic, virgin		27.42(disaggr.)
56	Waste treatment	Mass waste	Recycling of aluminium basic	Aluminium basic, virgin	27.42(disaggr.)
57	Physical	Mass product	Copper basic, virgin		27.44(disaggr.)
58	Waste treatment	Mass waste	Recycling of copper basic	Copper basic, virgin	27.44(disaggr.)
59	Physical	Mass product	Metals basic, n.e.c., virgin		27.4(disaggr.)
60	Waste treatment	Mass waste	Recycling of metals basic, n.e.c.	Metals basic, n.e.c., virgin	27.4(disaggr.)
61	Physical	Mass product	Iron, after first processing		27.2(disaggr.)+27.3(disaggr.)+27.5(disaggr.)
62	Physical	Mass product	Aluminium, after first processing		27.2(disaggr.)+27.3(disaggr.)+27.5(disaggr.)
63	Physical	Mass product	Copper, after first processing		27.2(disaggr.)+27.3(disaggr.)+27.5(disaggr.)
64	Physical	Mass product	Metals n.e.c., after first processing		27.2(disaggr.)+27.3(disaggr.)+27.5(disaggr.)
65	Physical	Mass product	Fabricated metal products, except		28
66	Physical	Mass product	Machinery and equipment n.e.c.		29
67	Physical	Mass product	Office machinery and computers		30
68	Physical	Mass product	Electrical machinery n.e.c.		31
69	Physical	Mass product	Radio, television and communication		32
70	Physical	Mass product	Instruments, medical, precision, optical,		33
71	Service	Monetary value	Motor vehicles and trailers		34
72	Service	Monetary value	Transport equipment n.e.c.		35
73	Physical	Mass product	Furniture and other manufactured goods		36
74	Service	Monetary value	Recycling services		37
75	Physical	Energy unit	Electricity, steam and hot water		40(disaggr.)
76	Physical	Mass product	Gas		40(disaggr.)
77	Service	Monetary value	Water, fresh		41
78	Service	Monetary value	Buildings, residential		45.1(disaggr.)+45.21(disaggr.)+45.22+45.3+45.4+45.5(disaggr.)
79	Service	Monetary value	Buildings, non-residential		45.1(disaggr.)+45.21(disaggr.)+45.22+45.3+45.4+45.5(disaggr.)
80	Service	Monetary value	Infrastructure, excluding buildings		45.1(disaggr.)+45.21(disaggr.)+45.22+45.3+45.4+45.5(disaggr.)
81	Service	Monetary value	Trade and repair of motor vehicles and		50
82	Service	Monetary value	Wholesale trade		51
83	Service	Monetary value	Retail trade and repair services		52
84	Service	Monetary value	Hotels and restaurants		55
85	Service	Monetary value	Land transport and transport via pipelines		60
86	Service	Monetary value	Transport by ship		61
87	Service	Monetary value	Air transport		62
88	Service	Monetary value	Cargo handling, harbours and travel		63
89	Service	Monetary value	Post and telecommunication		64
90	Service	Monetary value	Financial intermediation		65
91	Service	Monetary value	Insurance and pension funding		66
92	Service	Monetary value	Services auxiliary to financial		67
93	Service	Monetary value	Real estate services		70
94	Service	Monetary value	Renting of machinery and equipment etc.		71
95	Service	Monetary value	Computer and related services		72
96	Service	Monetary value	Research and development		73
97	Service	Monetary value	Business services n.e.c.		74
98	Service	Monetary value	Public service and security		75
99	Service	Monetary value	Education services		80
100	Service	Monetary value	Health and social work		85

No	Product type	Unit	Name	Main by-product of waste treatment services	NACE classification
101	Waste treatment	Mass waste	Incineration of waste: Food	Electricity, steam and hot water	90(disaggr.)
102	Waste treatment	Mass waste	Incineration of waste: Paper	Electricity, steam and hot water	90(disaggr.)
103	Waste treatment	Mass waste	Incineration of waste: Plastic	Electricity, steam and hot water	90(disaggr.)
104	Waste treatment	Mass waste	Incineration of waste: Metals	none	90(disaggr.)
105	Waste treatment	Mass waste	Incineration of waste: Glass/inert	none	90(disaggr.)
106	Waste treatment	Mass waste	Incineration of waste: Textiles	Electricity, steam and hot water	90(disaggr.)
107	Waste treatment	Mass waste	Incineration of waste: Wood	Electricity, steam and hot water	90(disaggr.)
108	Waste treatment	Mass waste	Incineration of waste: Oil/Hazardous waste	none	90(disaggr.)
109	Waste treatment	Mass waste	Manure treatment, conventional storage	none	1.2(disaggr.)
110	Waste treatment	Mass waste	Manure treatment, biogas	Electricity, steam and hot water	1.2(disaggr.)
111	Waste treatment	Mass waste	Biogasification of food waste	Electricity, steam and hot water	90(disaggr.)
112	Waste treatment	Mass waste	Biogasification of paper	Electricity, steam and hot water	90(disaggr.)
113	Waste treatment	Mass waste	Biogasification of sewage slugde	Electricity, steam and hot water	90(disaggr.)
114	Waste treatment	Mass waste	Composting of food waste	none	90(disaggr.)
115	Waste treatment	Mass waste	Composting of paper and wood	none	90(disaggr.)
116	Waste treatment	Mass waste	Waste water treatment, food	none	90(disaggr.)
117	Waste treatment	Mass waste	Waste water treatment, other	none	90(disaggr.)
118	Waste treatment	Mass waste	Landfill of waste: Food	Electricity, steam and hot water	90(disaggr.)
119	Waste treatment	Mass waste	Landfill of waste: Paper	Electricity, steam and hot water	90(disaggr.)
120	Waste treatment	Mass waste	Landfill of waste: Plastic	none	90(disaggr.)
121	Waste treatment	Mass waste	Landfill of waste: Iron	none	90(disaggr.)
122	Waste treatment	Mass waste	Landfill of waste: Alu	none	90(disaggr.)
123	Waste treatment	Mass waste	Landfill of waste: Copper	none	90(disaggr.)
124	Waste treatment	Mass waste	Landfill of waste: Metals nec	none	90(disaggr.)
125	Waste treatment	Mass waste	Landfill of waste: Glass/inert	none	90(disaggr.)
126	Waste treatment	Mass waste	Landfill of waste: Mine waste	none	90(disaggr.)
127	Waste treatment	Mass waste	Landfill of waste: Textiles	Electricity, steam and hot water	90(disaggr.)
128	Waste treatment	Mass waste	Landfill of waste: Wood	Electricity, steam and hot water	90(disaggr.)
129	Waste treatment	Mass waste	Landfill of waste: Oil/Hazardous waste	none	90(disaggr.)
130	Waste treatment	Mass waste	Landfill of waste: Slag/ash	none	90(disaggr.)
131	Waste treatment	Mass waste	Land application of manure	Fertiliser, N and Fertiliser, other than N	1.2(disaggr.)
132	Waste treatment	Mass waste	Land application of compost	Fertiliser, N and Fertiliser, other than N	90(disaggr.)
133	Service	Monetary value	Membership organisations		91
134	Service	Monetary value	Recreational and cultural services		92
135	Service	Monetary value	Services n.e.c.		93
136	Household	Monetary value	Household use: Clothing		n.a.
137	Household	Monetary value	Household use: Communication		n.a.
138	Household	Monetary value	Household use: Education		n.a.
139	Household	Monetary value	Household use: Health care		n.a.
140	Household	Monetary value	Household use: Housing		n.a.
141	Household	Monetary value	Household use: Hygiene		n.a.
142	Household	Monetary value	Household use: Leisure		n.a.
143	Household	Monetary value	Household use: Meals		n.a.
144	Household	Monetary value	Household use: Security		n.a.
145	Household	Monetary value	Household use: Social care		n.a.

Appendix 2: Emissions

This appendix lists the allowed values of the variable ‘emissions’ (b).

Compartment	Name used in FORWST	Formula/description	Relative mass of emissions that enters the mass balances in the model
Air	Ammonia	NH_3	1
Air	Arsenic	*As	1
Air	Cadmium	*Cd	1
Air	Carbon dioxide, fibre carbon	*CO_2	12/44 (oxygen in combustion/respiration processes is not included)
Air	Carbon dioxide, food carbon	*CO_2	12/44 (oxygen in combustion/respiration processes is not included)
Air	Carbon dioxide, coal carbon	*CO_2	12/44 (oxygen in combustion processes is not included)
Air	Carbon dioxide, crude oil and natural gas carbon	*CO_2	12/44 (oxygen in combustion processes is not included)
Air	Carbon dioxide, carbonate	CO_2	1 (this originates from the material: $CaCO_3 \rightarrow CaO + CO_2$)
Air	Carbon monoxide	*CO	12/28 (oxygen in combustion processes is not included)
Air	Chromium	*Cr	1
Air	Copper	*Cu	1
Air	Dinitrogen monoxide	N_2O	0 (oxygen and nitrogen from atmosphere in combustion processes are not included)
Air	Hydrogen chloride	HCl	1
Air	Hydrogen fluoride	HF	1
Air	Lead	*Pb	1
Air	Mercury	*Hg	1
Air	Methane	CH_4	1
Air	Nickel	*Ni	1
Air	Nitric acid	HNO_3	1
Air	Nitrogen dioxide	*NO_2	0 (oxygen and nitrogen from atmosphere in combustion processes are not included)
Air	NMVOC	*Non-methane volatile organic compounds	1
Air	ODP	Ozone depletion potential (measured as CFC11-eq.)	1
Air	PAH, measured as Benzo(a)pyrene	*PAH	1
Air	Particulates, < 10 um	*PM10	1
Air	Phosphorus	P	1
Air	Selenium	*Se	1
Air	Sulfur dioxide	*SO_2	32/64 (oxygen in combustion processes is not included)
Air	Vanadium	*V	1
Air	Zinc	*Zn	1
Water	Copper	Cu	1
Water	Nitrogen, total	N	1

Water	Phosphorus	P	1
Soil	Antimony	Sb	1
Soil	Arsenic	As	1
Soil	Barium	Ba	1
Soil	Cadmium	Cd	1
Soil	Chromium	Cr	1
Soil	Cobalt	Co	1
Soil	Copper	Cu	1
Soil	Lead	Pb	1
Soil	Mercury	Hg	1
Soil	Nickel	Ni	1
Soil	Phosphorus	P	1
Soil	Selenium	Se	1
Soil	Zinc	Zn	1
	Aluminium**	Al	1
	Carbon, biomass, unspecified***	C	1
	Carbon, fossil, unspecified***	C	1
	Clay and soil**	SO	1
	Iron **	Fe	1
	Minerals, n.e.c.**	MI	1
	Oxygen**	O	1
	Sand, gravel and stone**	ST	1

* Mainly fuel related emissions. ** In addition to the environmentally important emissions, some unimportant emissions have also been added to the added in order to take into account in the physical supply and use tables that materials are emitted. *** This covers unspecified emissions of carbon from food and fibre biomass, coal, oil and natural gas. The compartment is not specified because these emissions do not have any impact factor.

Appendix 3: Special cases in the model)modelling and data)

Dry matter vs. wet matter mass balances

If the data collection for VT and UT is done in wet mass, this may cause problems if the product is an aggregate of products with different water content. Therefore, the mass balances for supply and use tables should be carried out on dry matter basis.

Example 1: ‘Bovine meat and milk’
The use of ‘Bovine meat and milk’ (cows) by the activity ‘Meat products’ will not receive enough dry matter to produce its supply (and consequently the supply of residuals will become negative). The other way around the use of ‘Bovine meat and milk’ (milk) by the activity ‘Dairy’ will receive too much dry matter to produce its supply (and consequently the supply of residuals will become too high).

Example 2: ‘Crops n.e.c.’
The use of ‘Crops n.e.c.’ (rapeseed) by the activity ‘Vegetable oils’ will not receive enough dry matter to produce its supply (and consequently the supply of residuals will become negative). The other way around the use of ‘Crops n.e.c.’ (sugar beets) by the activity ‘Sugar’ will receive too much dry matter to produce its supply (and consequently the supply of residuals will become too high).

Fertiliser efficiency in the model (D matrix)

The activities supplying plant material products (grain crops, crops n.e.c., and horticulture) only have three different raw materials in the use table:

1. Internal use
2. N-fertiliser
3. Other fertilisers

The remaining products in the use table are ancillaries, i.e. they are associated with the value zero in the $\mathbf{D_1}$ matrix.

In the $\mathbf{D_1}$ matrix, the internal use is associated with the value 0.99999 in order to force the value 1 in the **D** matrix. There are two ways of entering the fertiliser efficiency in the model:

1. To enter the efficiency directly in the $\mathbf{D_1}$ matrix
2. To enter the value 1 in the $\mathbf{D_1}$ matrix, and then let the model calculate the fertiliser efficiency

It is obvious, that 1) should be preferred. However, then there would be no ones in the $\mathbf{D_1}$ matrix for the activities supplying plant material. The consequence of this is that there is inconsistency between $\mathbf{V_T}$, $\mathbf{U_T}$, **R** and ($\mathbf{W_{V,T}}+\Delta\mathbf{S_T}$). This is because the calculated part of **D** ensures this consistency (inconsistencies are placed as residuals in via the **D** matrix where the values 1 have been entered in the $\mathbf{D_1}$ matrix). Therefore, the option 2) should be used.

The resource use for the activities supplying plant material products is obtained from resource statistics. The figures obtained from statistics include the amount of fertiliser that becomes supply of products from the activity supplying plant material. Therefore, this amount should be subtracted from the resource use as provided from the statistics.

The amount to be subtracted from **R** is determined via the actual fertiliser efficiency which can be identified in various agronomic literatures.

If the fertiliser efficiency is D, then the amount to be subtracted from the figures from the resource statistics (x) is calculated as:

$D = (V'_T - F_0.*R) / (D_1.*U_T)$
$D = (V'_T - F_0.*R) / U_{T,fertiliser}$
$D = ((R+x) - F_0.*R) / U_{T,fertiliser}$

Since $F_0 = 1$ for plant production then,

$D = ((R+x) - R) / U_{T,fertiliser}$
$x = D*U_{T,fertiliser}$
(which is exactly the amount of fertiliser that becomes part of the supply)

Appendix 4: Disaggregation of Eurostat 60x60 SUTs

Split No.	Default Values i.e TOTALS	Default Values (Proportional)	New Product No.	New Code	ORIGINAL Product Categories from Original_V i.e.Row Headings	New Product Categories for Result_V i.e. ROW Headings
6	14,390,422	0.279544	1	1.21	Products of agriculture, hunting an	Bovine meat and milk
	3,222,000	0.0625896	2	1.23		Pigs
	3,839,065	0.0745765	3	01.24+01.25		Poultry and animals n.e.c.
	8,003,200	0.1554677	4	01.1(disaggr.)		Grain crops
	20,148,520	0.391399	5	01.1(disaggr.)		Crops n.e.c.
	1,875,000	0.0364232	6	01(disaggr.)+01.4+01.5		Agricultural services n.e.c.
2	35,326,614	1	7	2 (disaggr.)	Products of forestry, logging and re	Forest products
	0	0	8	2 (disaggr.)		Recycling of waste wood
1		1	9	05	Fish and other fishing products; se	Fish and other fishing products; servi
1		1	10	10	Coal and lignite; peat	Coal and lignite; peat
1		1	11	11	Crude petroleum and natural gas; s	Crude petroleum and natural gas; ser
7	6,521,808	0.3212054	12	13.1	Metal ores	Iron ores from mine
	6,103	0.0003006	13	13.2(disaggr.)		Bauxite from mine
	3,007,717	0.148133	14	13.2(disaggr.)		Copper from mine
	2,061,539	0.1015328	15	13.2(disaggr.)		Metals from mine n.e.c.
	7,138,660	0.3515859	16	14.1+14.21		Sand, gravel and stone from quarry
	744,684	0.0366764	17	14.22		Clay and soil from quarry
	823,656	0.0405659	18	14.3+14.4+14.5		Minerals from mine n.e.c.
10	43,195,740	0.2675913	19	15.1+15.2	Food products and beverages	Meat and fish products
	22,973,020	0.1423145	20	15.5		Dairy products
	14,758,580	0.0914272	21	15.3		Fruits and vegetables, processed
	4,611,080	0.028565	22	15.4		Vegetable and animal oils and fats
	2,273,520	0.0140841	23	15.6		Flour
	6,196,050	0.0383836	24	15.83		Sugar
	7,785,580	0.0482305	25	15.7		Animal feeds
	35,970,300	0.2228307	26	15.8(ext.)		Food preparations n.e.c.
	19,586,340	0.1213345	27	15.9		Beverages
	4,074,101	0.0252385	28	16		Tobacco products
1		1	29	17	Textiles	Textiles
1		1	30	18	Wearing apparel; furs	Wearing apparel; furs
1		1	31	19	Leather and leather products	Leather and leather products
1		1	32	20	Wood and products of wood and co	Wood and products of wood and cork
3	45,701,313	0.3206103	33	21.11(disaggr.)	Pulp, paper and paper products	Pulp, virgin
	0	0	34	21.11(disaggr.)		Pulp, recycled
	96,843,431	0.6793897	35	21.12+21.2		Paper and paper products
1		1	36	22	Printed matter and recorded media	Printed matter and recorded media
2	1	1	37	23 (disaggr.)	Coke, refined petroleum products a	Refined petroleum products and fuels
	0	0	38	23 (disaggr.)		Recycling of waste oil
5	1,309,700	0.0076162	39	24.15(disaggr.)	Chemicals, chemical products and	Fertiliser, N
	280,815	0.001633	40	24.15(disaggr.)		Fertiliser, other than N
	35,563,740	0.2068118	41	24.16(disaggr.)+24.17(di		Plastics basic, virgin
	0	0	42	24.16(disaggr.)+24.17(di		Plastics basic, recycled
	134,807,619	0.783939	43	24(disaggr.)		Chemicals n.e.c.
1		1	44	25	Rubber and plastic products	Rubber and plastic products
8	8,708,241	0.5210384	45	26.1(disaggr.)+26.2(disa	Other non-metallic mineral product	Glass, mineral wool and ceramic goo
	0	0	46	26.1(disaggr.)+26.2(disa		Glass, mineral wool and ceramic goo
	1,260,088	0.0753946	47	26.5(disaggr.)		Cement, virgin
	0	0	48	26.5(disaggr.)		Recycling of slags and ashes
	6,526,420	0.390494	49	26.6(disaggr.)+26.7(disa		Concrete, asphalt and other mineral p
	0	0	50	26.6(disaggr.)+26.7(disa		Recycling of concrete, asphalt and ot
	218,492	0.013073	51	26.3(disaggr.)+26.4		Bricks
	0	0	52	26.3(disaggr.)+26.4		Recycling of bricks
12	66,406,060	0.5818543	53	27.1(disaggr.)	Basic metals	Iron basic, virgin
	0	0	54	27.1(disaggr.)		Recycling of iron basic
	8,538,471	0.0748146	55	27.42(disaggr.)		Aluminium basic, virgin
	0	0	56	27.42(disaggr.)		Recycling of aluminium basic
	4,262,383	0.0373473	57	27.44(disaggr.)		Copper basic, virgin

Split No.	Default Values i.e TOTALS	Default Values (Proportional)	New Product No.	New Code	ORIGINAL Product Categories from Original_V i.e.Row Headings	New Product Categories for Result_V i.e. ROW Headings
	0	0	58	27.44(disaggr.)		Recycling of copper basic
	5,228,127	0.0458092	59	27.4(disaggr.)		Metals basic, n.e.c., virgin
	0	0	60	27.4(disaggr.)		Recycling of metals basic, n.e.c.
	20,373,407	0.1785131	61	27.2(disaggr.)+27.3(disa		Iron, after first processing
	5,228,957	0.0458165	62	27.2(disaggr.)+27.3(disa		Aluminium, after first processing
	2,697,462	0.0236353	63	27.2(disaggr.)+27.3(disa		Copper, after first processing
	1,393,461	0.0122096	64	27.2(disaggr.)+27.3(disa		Metals n.e.c., after first processing
1		1	65	28	Fabricated metal products, except	Fabricated metal products, except m
1		1	66	29	Machinery and equipment n.e.c.	Machinery and equipment n.e.c.
1		1	67	30	Office machinery and computers	Office machinery and computers
2	0.58	0.5829049	68	31	Electrical machinery and apparatu	Electrical machinery n.e.c.
	0.42	0.4170951	69	32		Radio, television and communication
0					Radio, television and communicati	Radio, television and communication
1		1	70	33	Medical, precision and optical inst	Medical, precision and optical instru
1		1	71	34	Motor vehicles, trailers and semi-tr	Motor vehicles, trailers and semi-trail
1		1	72	35	Other transport equipment	Other transport equipment
1		1	73	36	Furniture; other manufactured goo	Furniture; other manufactured goods
1		1	74	37	Secondary raw materials	Secondary raw materials
2	139,802,200	0.9505431	75	40 (disaggregated)	Electrical energy, gas, steam and	Electricity, steam and hot water
	7,273,935	0.0494569	76	40 (disaggregated)		Gas
1		1	77	41	Collected and purified water, distri	Collected and purified water, distribut
3	0.31	0.3144896	78	45 (disaggregated)	Construction work	Buildings, residential
	0.38	0.3796825	79	45 (disaggregated)		Buildings, non-residential
	0.31	0.3058278	80	45 (disaggregated)		Infrastructure, excluding buildings
3	0.16	0.1614668	81	50	Trade, maintenance and repair ser	Trade and repair of motor vehicles; se
	0.43	0.4299727	82	51		Wholesale trade
	0.41	0.4085605	83	52		Retail trade and repair services
0					Wholesale trade and commission	Wholesale trade and commission tra
0					Retail trade services, except of m	Retail trade services, except of moto
1		1	84	55	Hotel and restaurant services	Hotel and restaurant services
1		1	85	60	Land transport; transport via pipeli	Land transport; transport via pipeline
1		1	86	61	Water transport services	Water transport services
1		1	87	62	Air transport services	Air transport services
1		1	88	63	Supporting and auxiliary transport	Supporting and auxiliary transport se
1		1	89	64	Post and telecommunication servic	Post and telecommunication services
1		1	90	65	Financial intermediation services,	Financial intermediation services, ex
1		1	91	66	Insurance and pension funding ser	Insurance and pension funding servic
1		1	92	67	Services auxiliary to financial inter	Services auxiliary to financial interme
1		1	93	70	Real estate services	Real estate services
1		1	94	71	Renting services of machinery and	Renting services of machinery and e
1		1	95	72	Computer and related services	Computer and related services
2	0.08	0.0799209	96	73	Research and development service	Research and development
	0.92	0.9200791	97	74		Business services n.e.c.
1		1	98	75	Public administration and defence	Public administration and defence se
1		1	99	80	Education services	Education services
1		1	100	85	Health and social work services	Health and social work services
8	1	1	101	90 (disaggregated)	Sewage and refuse disposal servic	Incineration of waste
	0	0	102	90 (disaggregated)		Manure treatment
	0	0	103	90 (disaggregated)		Biogasification of waste
	0	0	104	90 (disaggregated)		Composting of food waste
	0	0	105	90 (disaggregated)		Waste water treatment
	0	0	106	90 (disaggregated)		Landfill of waste
	0	0	107	90 (disaggregated)		Land application of waste
	0	0	108	90 (disaggregated)		Unexpected waste
1		1	109	91	Membership organisation services	Membership organisation services n.
1		1	110	92	Recreational, cultural and sporting	Recreational, cultural and sporting se
1		1	111	93	Other services	Other services