SimaPro 7

Database Manual

EU & DK Input Output Database

product ecology consultants

This database manual contains 4 reports generated for the ForWast project, which was focusing on the 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. It was executed as a 6th Framework Programme project.

The following reports are included:

D6-1 Documentation of data consolidation calibration and scenario parameterization

D6-2 25 year forecast of physical stocks waste and env impact of 9 scenarios

D6-3 Contribution analysis uncertainty assessment and policy recommendation

D6-4 Documentation of the final model used for the scenario analyses

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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Deliverable n° 6-1

Title:

Documentation of the data consolidation and calibration exercise, and the scenario parameterisation.

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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 EU-27 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 EU-27.

These inventory and assessment results are provided as an output of a Leontief-type environmentally extended, quasi-dynamic, physical input-output model covering the EU-27, 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-ΔS). 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 6-1 is to document the data consolidation and calibration exercise, and the scenario parameterisation.

2 Data consolidation – country level

The data collection at the country level includes detailed data collection for some selected countries with good data availability (work package 3) and coverage data collection for other countries (work package 4). The difference between the two levels of detail is the level of aggregation. The detailed data collection include country supply and use tables (SUT) for 117 products by 117 activities, and the coverage data collection include SUTs for 59 products by 59 activities. Both types of data include the same emissions outputs and resource inputs. The data collection and processing are further described in deliverable 3-1 and 4-1 (http://forwast.brgm.fr/).

It should be noted that the total number of product and activity categories in the final model is 145. This number is higher than the above mentioned 117 because some additional 24 waste treatment activities and 4 household activities are added after the data collection. A full list of included products/activities is provided in the appendix.

2.1 Monetary supply-use tables

The starting point of the detailed data collection is the Eurostat 60x60 supply-use tables. For some countries more detailed supply-use tables are available. Firstly, the supply-use tables converted to basic prices. This is done using a standardized basic price converter tool developed as part of the project; the procedure is described in deliverable 6-4 ‘Documentation of the final model used for the scenario analyses’.

For the countries where detailed data are collected, the 60x60 tables are disaggregated into 117x117 tables. For this purpose, an Excel based macro tool is used. The tool is developed as part of the project; the procedure is described in deliverable 6-4 ‘Documentation of the final model used for the scenario analyses’. The basic inputs are monetary supply and use tables in basic prices, a specification of which activities/products to be disaggregated, and a specification of the total supply of the 117 products. By use of this, a dummy/default disaggregated supply-use table can be obtained. Using this default disaggregation, the production function of all disaggregated activities are the same. Then, manual changes are made on the supply table and on the use table to reflect differences in the production function. The disaggregation tool ensures that product and activity balances are maintained throughout the exercise.

The balanced monetary supply-use table is illustrated below.

Balanced MSUT	Activities (a)	Import	Needs fulfilment	Export	Total
Products (c)	**V'**	N_c			**q**
Total	**g'**				
Products (c)	**U**		**y**	E_c	**q**
Primary inputs	Labour				
	Taxes				
	Profit				
Total	**g'**				

Figure 2.1: Balanced monetary supply and use tables (MSUTs). **V'** (supply table), **U** (use table).

2.2 Physical supply-use tables

2.2.1 Supply-use

Data on physical product flow are collected for the 59 (low detail level countries in WP4) and 117 (high detail level countries in WP3) products, i.e. domestic production, import and export. For this purpose several data sources are used, e.g. resource statistics, agricultural statistics, energy statistics, production statistics, trade statistics etc. Service products, such as retail, marketing, education, consulting etc. have no physical weight. All flows are given in dry weight. Typically, data in statistics are provided in actual/wet weight. This is converted to dry weight using product material composition given in the $\mathbf{K_c}$ tables (available from http://forwast.brgm.fr/)

Default physical supply-use tables are constructed using the monetary tables for distributing the physical flows (total domestic supply/use and import/export) of products. Then more detailed information from statistics, e.g. data on agriculture, energy etc. are used to redistribute the default tables. Once this exercise is finished, we have supply-use tables in monetary as well as physical units.

By nature, the supply and use of products balance. But a physical balance for activities is not yet established; inputs of resources and waste and outputs of emissions and waste are not accounted for.

2.2.2 Resource table

A resource table is created specifying the resource inputs to the resource extracting activities. Distinction is made between 13 material categories:

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)

The resource table is typically constructed based on the supply table and a resource composition obtained as composition data in $\mathbf{K_c}$ for resource extracting activities (resource table and composition data are available from http://forwast.brgm.fr/).

2.2.3 Emissions tables

Two types of emission tables are created:

1) traditional format as environmental extension to IO-tables (emissions x activities); this table is called **B**
2) products x activities format specifying the origin of the emissions from an activity; this table consists of three sub tables called $\mathbf{G_c}$, $\mathbf{G_w}$, and $\mathbf{G_R}$, where the subscript specify the origin of the emission: c (products), w (waste), and R (resource input).

The second emissions table is used for the calculation of specific waste outputs from activities, e.g. input of 1 kg feed to the ‘bovine meat and milk’ activity leads to approx 0.08 kg product output and 0.71 kg emission. Now, the waste originating from feed (this is manure) can be calculated as 1 – 0.08 – 0.71 = 0.21 kg manure.

If no detailed NAMEA is available, the two emissions tables above are created from UNFCCC country submissions (UNFCCC 2009). For this purpose an ‘emissions machine’ (Excel based tool) have been developed as part of the project. The physical use table is used for distribution of emissions, when data are not at the desired level of detail in the UNFCCC data.

Conventions regarding included emissions in **B** and **G** are described in deliverable 6-4 ‘Documentation of the final model used for the scenario analyses’. An important convention for the **G** table is, that the use of 1 kg fuel (in the use table) must correspond to the emission of 1 kg fuel (in the **G** table). Thus, in order to enable the mass balance principle for fuels and associated emissions, the emission of hydrogen in H_2O is also included. This is determined based on the hydrogen content in fuels (chemical formula).

Another example of conventions is; In **B** CO_2 is included with full weight, but in **G** only the weight of the carbon in CO_2 is included. This is because simultaneous resource inputs and emissions outputs of oxygen in combustion processes is not included.

2.2.4 Waste and stock addition tables

The remaining inputs and outputs to establish balanced activities are the outputs of waste + stock additions and the inputs of waste. It is only the waste treatment and recycling activities that have inputs of waste.
The waste generation (W_v) + stock addition (ΔS) tables have the same format as the supply and use table, and *each flow* is calculated based on a mass balance:

$$W_v + \Delta S = U - D*U - G$$

The use (**U**) is obtained from the use table, the emission (G) is obtained from the second emissions table **G** (described above), and D is a feedstock efficiency transfer coefficient, which specifies how much of the current input of a product (use) is becoming part of the supply. The D coefficients are calculated in order to maintain balance: the feedstock products in the use table are specified in the $\mathbf{D_1}$ table, and then the sum of these are divided by the supply of the activity. It is possible to specify different D coefficients for different feedstock inputs to an activity (The applied $\mathbf{D_1}$ table and implied **D** tables are available from http://forwast.brgm.fr/).

In the FORWAST model, distinction is made between waste and stock additions. Time series of supply-use tables enables this. Any stock will leave the economy as waste at a given time when the product reaches the end of its life time. Thus, by use of product life times, the $\mathbf{W_V}+\mathbf{\Delta S}$ can be separated into $\mathbf{W_V}$ and $\mathbf{\Delta S}$.

The balanced physical supply-use table is illustrated below. It should be noted that waste treatment/recycling activities are not balanced here because special detailed waste modules have been constructed, see chapter 4.3.

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	$-\Delta S$						
Supply of residuals	$-W_V$						
Use of residuals	W_U						
Resources	**R**						
Emissions	**-B**						
Total	**g'**						

Figure 2.2: Balanced physical supply and use tables (PSUTs). In the table the meaning of 'residuals' is the same as waste.

2.3 Data consolidation exercise

Before the country SUTs can be used as model inputs, data consistency is checked via a consolidation exercise.

2.3.1 Balance check: Total supply and use

Firstly, the **g** and **q** vectors in **Figure 1** and q in **Figure 2** are checked for balance; it is required that the tables must balance with a maximum discrepancy of 0.5% between total supply and total use.

2.3.2 Balance check: Two emissions tables

The sum of the emissions in the two types of emissions tables described above; **B** and **G**, are compared. These totals must be the same.

2.3.3 Consistency check: Negative waste is not allowed

When constructing the physical SUTs, the data processing includes assumption of same prices of products over many activities (if no specific information is available). It is clear that ‘chemicals nec’ used by agriculture (this mainly covers pesticides) is not the same as ‘chemicals nec’ used by the food industry (this mainly covers food additives and cleaning agents) is not the same. Therefore, the assumption of same prices over activities does not hold in all cases. The effect of this is that the use of products is overestimated for some activities and underestimated for other activities. When these over/under-estimated uses are feedstocks to the supply of the activity, then in cases with underestimation of feedstocks, there will be less feedstock than supply. Since waste outputs are calculated, this leads to negative waste output. This is of course not possible in real world, and the causes of the negative waste have to be identified and corrected. The following three parameters are typically adjusted when negative waste occurs:

- the use of feedstock products is increased so that the sum of all feedstoks exceeds supply, and so that an appropriate feedstock efficiency is achieved. When a specific use is increased, the other uses of the same product by other activities are reduced accordingly in order to maintain balance between total supply and use of products
- the resource input is increased (this option is only used for resource extracting activities)
- the emissions of the specific product, that leads to negative waste, are adjusted; e.g. if the plastics industry supplies 10 kg plastic, it uses 15 kg oil and gas, and it emits 6 kg emissions originating from oil and gas; here waste = 15 – 10 – 6 = -1

The selection of an appropriate option above is based on common knowledge of the processing within the activities.

3 Data consolidation – EU-27 level

Each of the country SUT provided as data collection input to the table must fulfil some consistency and mass balance requirements. However, there are still a number balancing issues to be addressed and solved as well as some new imbalances caused by the data aggregation from country level to EU-27 level to be solved. This exercise is described in the following.

3.1 Data input to the model from data collection year 2003

The data collection includes detailed data collection for some countries with good data availability and coverage data collection for other countries. The difference between the two levels of detail is the level of aggregation. The detailed data collection include country supply and use tables (SUT) for 117 products by 117 activities, and the coverage data collection include SUTs for 59 products by 59 activities.

3.2 Aggregation of the two types of SUTs to one EU-27 117x117 SUT

Firstly, the SUTs belonging to each type of aggregation (117x117 or 59x59) are added to achieve one accumulated 117x117 table and one accumulated 59x59 table. The structure of 117x117 table is then used to disaggregate the 57x57 table. After that the two tables are added to form one 117x117 table representing EU-27’s economy.

3.3 Product balance

When using the accumulated 117x117 table to disaggregating the accumulated 59x59 table, differences in import/export shares may cause that all the disaggregated supplies does not balance with the disaggregated uses. Therefore, imbalances for the product balance occur within the disaggregated product categories. These imbalances are adjusted via import/export.

3.4 Resource alignment

In order to ensure consistency, the resource input minus emissions and waste from resources must be equal to the supply for resource extracting activities. Some example of resource activities where resources are lost as emissions and/or waste are 1) Crude petroleum and natural gas where some of the extracted resource is flared, and 2) Bovine meat and milk where some of the resource input (grass and ensilage) is lost as respiratory emissions and manure.

3.5 Elimination of investment column in use table

The column 'Capital formation' in the use table (this is not shown in Figure 2.1) 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 use table, in the same way as use of other products. The procedure for distributing the investment column into the use table is described in deliverable D6-4 'Documentation of the final model used for the scenario analyses'.

3.6 Human metabolism balance

In order to ensure consistency in all inputs and outputs relating to human and animal metabolism, the EU-27 supply use table is aligned using the mass balances given below. The flows which are corrected as part of the alignment exercise, are also specified below.

The human metabolism is included in the model in order to ensure that materials contained in food is coming out of the model as the correct flows: emissions, urine and faeces in waste water and food waste. The balance is based on Ortiz et al. (2007). Below, the balance is shown for one average person for one year. To have the total metabolism for the Swedish population in 2003, the figures in the table are multiplied with 10,355,844 persons.

Human metabolism (per person year)	DM (kg)
Inputs	
Food	202.2
Body growth	0.55
Total	**202.7**
Outputs	
Urine (CH_4ON_2)	27.4
Faeces (C_2H_4O)	13.7
Respiration: C in CO_2	71.2
Respiration: CH_4	0.083
Respiration: H_2O	89.9
Total	**202.2**
Balance (input - output)	**0.5**

Table 3.1: Carbon and dry mass balance for human metabolism for one person in one year.

When aligning the supply-use tables with the human metabolism given in Table 3.1, the sum of the respiratory emissions are first calculated using the mass balance in the table, and then next distributed in the $\mathbf{G_c}$ emissions table using the food products in the use table (dry weight) as distribution key. However, some activities use food as a feedstock and not for direct human consumption; these are:

- Bovine meat and milk
- Pigs
- Poultry and animals n.e.c.
- Fish
- Meat and fish products
- Dairy products
- Fruits and vegetables, processed
- Vegetable and animal oils and fats
- Flour
- Sugar
- Animal feeds
- Food preparations n.e.c.
- Beverages

The use of food in these activities are not related to the human metabolism.

3.7 *Animal metabolism balance*

Correspondingly to the human metabolism, it is ensured that materials contained in animal feed is coming out of the model as the correct flows: animal products at farm gate, emissions, and manure. Also, the balance is used to align the uses of feed inputs when knowing the output of animal products. In the tables below, the animal balances are shown normalised by the dry weight of animal products at farm gate (live weight + milk + egg + fur). The balance is based on physical information in the detailed Danish supply-use tables and figures in the National Environmental Research Institute's (NERI) reporting to the UNFCCC (Illerup et al. 2005). Swedish data are used for representing the number of animals and meat and milk outputs in EU-27 (Jordbruksverket 2007).

Bovine metabolism (per kg dry product output: milk and meat live weight)	DM (kg)
Inputs	
Grass+silage+Cereals/conc.	12.3
Total	**12.3**
Outputs	
Milk+ Meat live weight	1.00
Manure	2.61
Respiration: C in CO_2	3.74
Respiration: CH_4	0.25
Respiration: O in H_2O	4.21
Respiration: H in H_2O	0.53
Total	**12.3**
Balance (input - output)	**-0.01**

Table 3.2: Carbon and dry mass balance for bovine metabolism. The balance is given per 1 kg dry meat (live weight) and milk.

Pig metabolism (per kg dry product output: meat live weight)	DM (kg)
Inputs	
Silage+Cereals/conc.	3.42
Total	**3.42**
Outputs	
Milk+ Meat live weight	1.00
Manure	1.26
Respiration: C in CO_2	0.58
Respiration: CH_4	0.015
Respiration: O in H_2O	0.50
Respiration: H in H_2O	0.063
Total	**3.42**

Table 3.3: Carbon and dry mass balance for pig metabolism. The balance is given per 1 kg dry meat live weight.

Other animals metabolism (per kg dry product output: live weight)	DM (kg)
Inputs	
Grass+silage+Cereals/conc.	6.71
Total	**6.71**
Outputs	
Meat live weight+eggs+furs+milk	1.00
Manure	1.55
Respiration: C in CO_2	1.81
Respiration: CH_4	0.033
Respiration: O in H_2O	2.06
Respiration: H in H_2O	0.258
Total	**6.71**

Table 3.4: Carbon and dry mass balance for 'other animals' metabolism. The balance is given per 1 kg dry meat live weight. 'Other animals' mainly include poultry. The category also include fur animals, horses, goats etc.

When aligning the animal producing activities in the supply-use tables with the animal metabolism given in Table 3.2 - Table 3.4, the determining flow is the supply of animal products. Then the use of feed and respiratory emissions follow the ratio given in the tables.

To align/correct the use of feed in the animal producing activities, the uses of the following product categories + resource input (grass and silage) are scaled proportionally to balance with the feed input in the tables above:

- Resource table (**R**):
  - Resource input (grass and silage)
- Use table (**U**):
  - Grain crops
  - Crops nec.
  - Fish
  - Meat and fish products
  - Dairy products
  - Fruits and vegetables, processed
  - Vegetable and animal oils and fats
  - Flour
  - Sugar
  - Animal feeds
  - Food preparations n.e.c.
  - Beverages

To align/correct the respiratory emissions in the animal producing activities, the following emissions are corrected to balance with the emissions in the tables above. In the **B** table C in CO_2 is entered with a factor

44/12 to account for the oxygen in CO_2. In the $\mathbf{G_c}$ and $\mathbf{G_R}$ tables it is the sum of C in CO_2, CH_4, O in H_2O, and H in H_2O that is distributed using the use of feed+resource (dry mass) listed above as distribution key

- Emissions table (**B**):
  - Carbon dioxide, food carbon
  - Methane
  - Oxygen (O in H_2O)
  - Minerals, n.e.c. (H in H_2O)
- Emission distribution table ($\mathbf{G_c}$):
  - Grain crops
  - Crops nec.
  - Fish
  - Meat and fish products
  - Dairy products
  - Fruits and vegetables, processed
  - Vegetable and animal oils and fats
  - Flour
  - Sugar
  - Animal feeds
  - Food preparations n.e.c.
  - Beverages
- Emission distribution table ($\mathbf{G_R}$):
  - Bovine meat and milk (this represents grass and silage)

3.8 Fuel emissions balance

In the country level data collection, it is not ensured that the use of fuels (use table **U**) is aligned with the emissions tables (**B** and $\mathbf{G_c}$). Therefore, consistency between the use table and emissions tables is not ensured, i.e. it is not ensured that use of fuel = emission of fuel (+possible minor slag/ash/oil waste waste).

Since the emissions data used in the country level SUTs generally are based on official emissions data (UNFCCC submissions), these data are regarded as being of higher quality than the collected data on the physical use of fuels. Therefore, the uses of fuels in the use table (**U**) are aligned/corrected so that they follow the figures in the **G** and **B** tables.

For coal and biomass, the corrected use of fuel for each activities is calculated as follows:

If the supply of waste of the fuel is negative
then
    If the use of fuel is a feedstock
    then
        $U_{corrected} = G_c/(1-D)$ = emissions / (1 – feedstock efficiency)
        (the corrected use of fuel is calculated using the relationship $W_v + \Delta S = U - D*U - G$)
    else
        $U_{corrected} = -W_v + G_c$ = -waste generation + emissions
        (here the negative waste is added in order to ensure that the new waste generation is >0)
else
    $U_{corrected} = U_{old}$

The waste of coal has been cross checked with the EU-27 average content of ash in coal at 11% (based on survey by GIG).

For oil fuels, the corrected use has been calculated assuming an average waste generation at 1% of the use (oil waste), and for gas, 0% of the used gas is assumed to become waste.

3.9 Household uses

The final demand vector in the use table is integrated in ten household activities:

- Household use: Clothing
- Household use: Communication
- Household use: Education
- Household use: Health care
- Household use: Housing
- Household use: Hygiene
- Household use: Leisure
- Household use: Meals
- Household use: Security
- Household use: Social care

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 the tables below.

Product		Household activity									
		Clothing	Commu-nication	Education	Health care	Housing	Hygiene	Leisure	Meals	Security	Social care
1	Bovine meat and milk	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
2	Pigs	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
3	Poultry and animals n.e.c.	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
4	Grain crops	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
5	Crops n.e.c.	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
6	Agricultural services n.e.c.	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
7	Forest products	0%	0%	0%	0%	72%	25%	0%	3%	0%	0%
8	Recycling of waste wood	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
9	Fish	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
10	Coal, lignite, peat	0%	0%	0%	0%	72%	25%	0%	3%	0%	0%
11	Crude petroleum and natural gas	0%	0%	0%	0%	72%	25%	0%	3%	0%	0%
12	Iron ores from mine	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
13	Bauxite from mine	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
14	Copper from mine	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
15	Metals from mine n.e.c.	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
16	Sand, gravel and stone from quarry	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
17	Clay and soil from quarry	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
18	Minerals from mine n.e.c.	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
19	Meat and fish products	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
20	Dairy products	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
21	Fruits and vegetables, processed	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
22	Vegetable and animal oils and fats	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
23	Flour	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
24	Sugar	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
25	Animal feeds	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
26	Food preparations n.e.c.	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
27	Beverages	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
28	Tobacco products	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
29	Textiles	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
30	Wearing apparel and furs	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
31	Leather products, footwear	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
32	Wood products, except furniture	0%	0%	0%	0%	72%	25%	0%	3%	0%	0%
33	Pulp, virgin	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
34	Recycling of waste paper	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
35	Paper and paper products	0%	0%	0%	0%	22%	9%	62%	7%	0%	0%
36	Printed matter and recorded media	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
37	Refined petroleum products and fuels	0%	21%	0%	0%	11%	4%	50%	14%	0%	0%
38	Recycling of waste oil	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
39	Fertiliser, N	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
40	Fertiliser, other than N	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
41	Plastics basic, virgin	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
42	Recycling of plastics basic	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
43	Chemicals n.e.c.	6%	7%	0%	12%	24%	4%	23%	23%	0%	0%
44	Rubber and plastic products	0%	12%	0%	0%	67%	17%	4%	0%	0%	0%
45	Glass, mineral wool and ceramic goods, virgin	0%	0%	0%	0%	52%	0%	0%	48%	0%	0%
46	Recycling of glass, mineral wool and ceramic goods	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
47	Cement, virgin	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
48	Recycling of slags and ashes	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
49	Concrete, asphalt and other mineral products	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
50	Recycling of concrete, asphalt and other mineral products	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
51	Bricks	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
52	Recycling of bricks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
53	Iron basic, virgin	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
54	Recycling of iron basic	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
55	Aluminium basic, virgin	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
56	Recycling of aluminium basic	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
57	Copper basic, virgin	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
58	Recycling of copper basic	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 3.5: Distribution of final demand vector in use table into ten household activities. The table is continued on the next page...

Product		Household activity									
		Clothing	Commu-nication	Education	Health care	Housing	Hygiene	Leisure	Meals	Security	Social care
59	Metals basic, n.e.c., virgin	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
60	Recycling of metals basic, n.e.c.	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
61	Iron, after first processing	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
62	Aluminium, after first processing	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
63	Copper, after first processing	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
64	Metals n.e.c., after first processing	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
65	Fabricated metal products, except machinery	0%	0%	0%	0%	36%	3%	48%	12%	0%	0%
66	Machinery and equipment n.e.c.	20%	0%	0%	0%	8%	5%	5%	61%	0%	0%
67	Office machinery and computers	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
68	Electrical machinery n.e.c.	0%	4%	0%	0%	91%	0%	6%	0%	0%	0%
69	Radio, television and communication equipment	0%	19%	0%	0%	0%	0%	81%	0%	0%	0%
70	Instruments, medical, precision, optical, clocks	0%	0%	0%	59%	0%	0%	41%	0%	0%	0%
71	Motor vehicles and trailers	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
72	Transport equipment n.e.c.	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
73	Furniture; other manufactured goods n.e.c.	0%	0%	0%	0%	62%	0%	38%	0%	0%	0%
74	Recycling services	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
75	Electricity, steam and hot water	12%	0%	0%	0%	32%	8%	14%	34%	0%	0%
76	Gas	0%	0%	0%	0%	72%	25%	0%	3%	0%	0%
77	Water, fresh	16%	0%	0%	0%	0%	69%	0%	16%	0%	0%
78	Buildings, residential	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
79	Buildings, non-residential	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
80	Infrastructure, excluding buildings	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
81	Trade and repair of motor vehicles; service stations	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
82	Wholesale trade	4%	5%	8%	9%	17%	3%	16%	16%	9%	12%
83	Retail trade and repair services	4%	5%	8%	9%	17%	3%	16%	16%	9%	12%
84	Hotels and restaurants	0%	0%	0%	0%	0%	0%	10%	90%	0%	0%
85	Land transport; transport via pipelines	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
86	Transport by ship	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
87	Air transport	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
88	Cargo handling, harbours; travel agencies	0%	17%	0%	0%	0%	0%	83%	0%	0%	0%
89	Post and telecommunication	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
90	Financial intermediation	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%
91	Insurance and pension funding	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%
92	Services auxiliary to financial intermediation	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%
93	Real estate services	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
94	Renting of machinery and equipment etc.	0%	17%	0%	0%	52%	0%	31%	0%	0%	0%
95	Computer and related services	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
96	Research and development	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
97	Business services n.e.c.	0%	0%	0%	0%	41%	0%	33%	0%	2%	24%
98	Public service and security	0%	0%	0%	0%	0%	0%	0%	0%	99%	1%
99	Education services	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
100	Health and social work	0%	0%	0%	42%	0%	0%	0%	0%	0%	58%
109	Membership organisations	0%	0%	0%	0%	1%	0%	30%	0%	50%	20%
110	Recreational and cultural services	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
111	Services n.e.c.	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%

Table 3.6: ... Table on previous page continued. Distribution of final demand vector in use table into ten household activities.

4 Hybrid IO-table incl. waste flows for EU-27

4.1 Hybrid supply use table (HSUT)

The first step in constructing a hybrid IO-table, is to construct a hybrid supply-use table. This is done by using the rows from the physical supply and use table for all physical products, and the rows from the monetary supply and use table for all service products. The rows representing waste treatment services, are left empty in the hybrid supply-use table; these are filled in the hybrid IO-table.

4.2 Hybrid input-output table (HIOT)

The HIOT is created from the HSUT using the by-product technology model which is equivalent to the commodity technology model (Suh et al. 2010). The direct requirement coefficient matrix **A** and environmental intervention coefficient matrix **E** using the by-product-technology model are determined as follows:

$$\mathbf{A} = (\mathbf{U} - \mathbf{V}'_{\mathbf{od}})\mathbf{V}'^{-1}_{\mathbf{d}}$$

$$\mathbf{E} = \mathbf{B}\mathbf{V}'^{-1}_{\mathbf{d}}$$

respectively, where the supply table **V** is split into $\mathbf{V_d}$ (diagonal entries in **V**) and $\mathbf{V_{od}}$ (off-diagonal entries in **V**). Other matrices are: **U** (hybrid use table) and **B** (all extensions: monetary primary inputs, emissions, supply of waste, stock additions, and resources)

The calculated **A** and **E** are normalised, i.e. all columns are per one unit of supply. To have **A** and **E** in a non-normalised version, the columns in **A** and **E** are scaled with the scaling factors in **s**:

$$\mathbf{s} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$$

where **I** (identity matrix) and **y** (needs fulfilment vector).

4.3 Integration of waste module

The only waste treatment activities included in the supply-use tables are recycling activities. These are included there because activities producing basic materials are disaggregated into a) activity that supplies virgin material, and b) activity that supplies the service to treat waste and recovered material. Supply and use data on all other waste treatment activities are obtained as normalised data per kg treated waste. The waste module is obtained from deliverable D5-4 ‘Description of the environmental pressures from waste treatment’. The normalised waste treatment activities in D5-4 are balanced ensuring that inputs of waste and products equals outputs of products (recycled waste), emissions, waste, and stock additions (stocks of products and stocks of waste in landfills).

4.4 Integration of waste flows in the hybrid IO-model

Based on the physical supply and use tables the supply of waste (one type of waste per physical product) is calculated for each activity. The waste types in this supply of waste table (**W_V**), i.e. the rows in the **W_V**, is aggregated into the following waste fractions:

- Food waste
- Wood waste
- Ash and slag waste
- Oil waste
- Textile waste
- Paper waste
- Plastic waste
- Hazardous waste
- Glass waste
- Bricks waste
- Other inert waste (sand, stone, clay, cement, concrete, asphalt)
- Iron waste
- Aluminium waste
- Copper waste
- Metals nec waste

Waste of the following products are composed of more than one of the above mentioned waste fractions:

- Fabricated metal products, except machinery waste
- Machinery and equipment n.e.c. waste
- Office machinery and computers waste
- Electrical machinery n.e.c. waste
- Radio, television and communication equipment waste
- Instruments, medical, precision, optical, clocks waste
- Furniture; other manufactured goods n.e.c. waste

Waste of these composite products undergo a disassembly process which allows to allocate the wastes to the waste fractions above. The residuals distribution table (**J**) specify the fraction of the composite products sent to recycling, incineration, landfill etc. The **J** table for year 2003 for EU-27 is presented in Table 4.1 below. In the J table below, the fraction of wastes of composite products sent to recycling is specified in the 'disassembly' column. Wastes exported for recycling abroad are specified in the 'export' column (export of slag and ash is landfilled abroad).

Activity no.	8	34	38	42	46	48	50	52	54	56	58	60	101	103	104	105	106			
Activity name / **Waste fraction**	Recycling of waste wood	Recycling of waste paper	Recycling of waste oil	Recycling of plastics basic	Recycling of glass, mineral wool and ceramic goods	Recycling of slags and ashes	Recycling of concrete, asphalt and other mineral products	Recycling of bricks	Recycling of iron basic	Recycling of aluminium basic	Recycling of copper basic	Recycling of metals basic, n.e.c.	Incineration of waste	Biogasification of waste	Composting of food waste	Waste water treatment	Landfill of waste	Export	Disassembly	**Sum**
Food/organic waste													43%	0.1%	8%	2%	47%			**100%**
Wood waste	24%												34%		0.1%		36%	6%		**100%**
Ash and slag waste						9%											89%	1%		**100%**
Inert waste (sand, stone, clay, cement, concrete, asphalt)							38%						10%				51%			**99%**
Oil waste			4%										37%				60%			**100%**
Textile waste													55%				44%	1%		**100%**
Paper waste		30%											15%		1%		42%	13%		**100%**
Plastic waste				19%									39%				39%	4%		**100%**
Hazardous waste													38%				62%	0.04%		**100%**
Glass waste					38%								21%				27%	14%		**100%**
Bricks waste							28%	4%					7%				61%			**100%**
Iron waste									46%				15%				19%	20%		**100%**
Alu waste										41%			22%				20%	17%		**100%**
Copper waste											40%		23%				20%	17%		**100%**
Metals nec waste												41%	22%				20%	17%		**100%**
Fabricated metal products, except machinery													25%				24%	18%	34%	**100%**
Machinery and equipment n.e.c.													23%				28%	20%	29%	**100%**
Office machinery and computers													25%				31%	20%	24%	**100%**
Electrical machinery n.e.c.													25%				30%	20%	25%	**100%**
Radio, television and communication equipment													25%				30%	20%	25%	**100%**
Instruments, medical, precision, optical, clocks													27%				33%	20%	20%	**100%**
Furniture; other manufactured goods n.e.c.													52%				37%		11%	**100%**

Table 4.1: The **J** table for year 2003 for EU-27.

The final waste treatment of each of the fractions contained in the composite products that are sent to recycling is specified in Table 4.2 below. The figures are estimated.

Fraction contained in composite waste	Composite waste / Waste treatment	Recycling of: Fabricated metal products, except machinery waste	Recycling of: Machinery and equipment n.e.c. waste	Recycling of: Office machinery and computers waste	Recycling of: Electrical machinery n.e.c. waste	Recycling of: Radio, television and communication equipment waste	Recycling of: Instruments, medical, precision, optical, clocks waste	Recycling of: Furniture; other manufactured goods n.e.c. waste
Iron	Recycling	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Incineration	0	0	0	0	0	0	0
	Landfill	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Alu	Recycling	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Incineration	0	0	0	0	0	0	0
	Landfill	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Copper	Recycling	0.5	0.5	0.9	0.9	0.9	0.9	0.9
	Incineration	0	0	0	0	0	0	0
	Landfill	0.5	0.5	0.1	0.1	0.1	0.1	0.1
Metals nec	Recycling	0	0	0.9	0.9	0.9	0.9	0.9
	Incineration	0	0	0	0	0	0	0
	Landfill	1	1	0.1	0.1	0.1	0.1	0.1
Plastic	Recycling	0	0	0.5	0.5	0.5	0.5	0.5
	Incineration	0	0	0	0	0	0	0
	Landfill	1	1	0.5	0.5	0.5	0.5	0.5
Wood	Incineration	0	0	1	1	1	1	1
	Landfill	1	1	0	0	0	0	0
Food/organic	Incineration	0	0	0	0	0	0	0
	Landfill	1	1	1	1	1	1	1
Inert	Landfill	1	1	1	1	1	1	1

Table 4.2: Specification of the final waste treatment of each of the fractions contained in the composite products that are sent to recycling.

The supply of each of the waste fractions per activity is distributed into the rows representing different waste treatment services in the hybrid IO-table. This distribution is determined by the **J** table.

Some waste treatments are fixed in all scenarios, and are specified separate from the **J** table. These are:

- Food waste sent to waste water treatment: This is excretion and faeces and it is determined by the human metabolism balance, see section 3.6
- Animal waste to manure treatment: This is determined by the animal metabolism balances, see section 3.7
- Paper waste to waste water treatment in pulp/paper manufacturing: All waste of pulp in pulp/paper manufacturing is sent to waste water treatment
- Paper waste to waste water treatment: All paper waste in household activity: Hygiene is sent to waste water treatment

- Wood waste to landfill: All wood waste originating from forestry products in the activity ‘pulp, virgin’ is assumed to be pulp manufacturing residuals sent to landfill
- Mine waste: All residuals originating from metals mining products is assumed to be landfilled
- Recycling residues: All recycling residues, e.g. waste originating from waste paper in activity ‘recycling of waste paper’ is assumed to be sent to landfill. This includes: Residues from wood recycling, paper recycling, recycling of waste oil, recycling of plastic, recycling of slag and ash (in cement production), and recycling of inert materials and metals

5 Scenario parameterisation

Two types of scenarios are implemented in the EU-27 hybrid IO-table:

1) macro-economic scenarios, and
2) what-if-scenarios of waste treatment

5.1 Parameterisation of macro-economic scenarios

Three different future macro-economic scenarios are implemented in the model:

1) Low growth scenario
2) Baseline scenario
3) High growth scenario

The differentiation between scenarios is based on Mantzos and Capros (2006). Due to lack of information, the developments of energy efficiency are assumed to be similar in the three macro economic scenarios. A general description of the three macro-economic scenarios can be found in deliverable 5.2 ‘Description of the three chosen macro-economic scenarios for EU-27 until 2035’.

5.1.1 Scaling of the economy representing different scenarios

The macro-economic scenarios are implemented in the hybrid supply-use tables. First, developments in GDP and TMR are established (index 100 = year 2003). Historical figures on GDP are obtained from Eurostat (2009), and future figures are from Mantzos and Capros (2006). The latter provides differentiated information for a range of different activities/sectors. Historical TMR data are represented by EU-27 direct resource extraction of:

- Energy resources: IEA (2004) and IEA (2008)
- Agricultural products and fish: FAOSTAT (2009a)
- Forest products: FAOSTAT (2009b)
- Metals and mineral mining: USGS (2009)
- Aggregates: Koziol et al. (2008)

Projections of future TMR developments are based on the historical relationship between GDP and TMR, see **Figure 5.1**. Differentiation between activities is not taken into account for historical developments, i.e. for years before 2003. Differentiation between activities for projection of future TMR is based on future differentiated projections on future GDP.

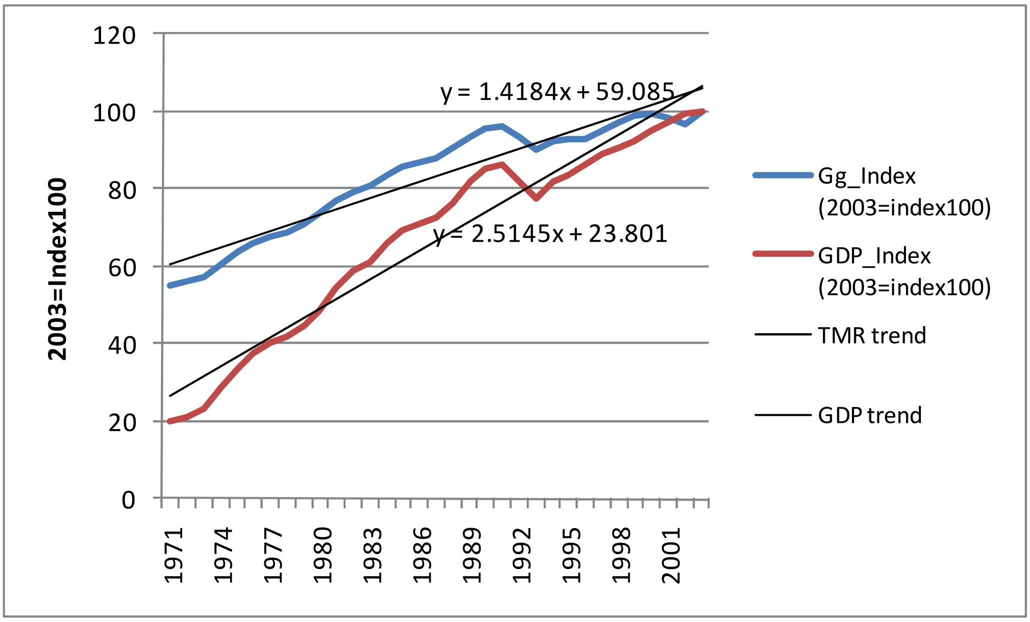

Figure 5.1: Relationship between development in GDP and TMR from 1971 to 2003. Index 100 = Year 2003.

The developments in GDP and TMR are used to scale the columns in the supply-use tables. In addition all exports of products are multiplied with the same scaling factor as for the corresponding activity. This scaling of activities and export represents the developments in the economy at the activity/sector level. Discrepancies in total supply of products and total use of products are adjusted in prioritised order 1) import 2) if adjustment causes negative import, then import is set to zero, and the remaining correction is added to export.

5.1.2 Correcting for developments in energy efficiency in the electricity activity

The scaling of activities described above does not take into account that energy efficiency may change over time. Therefore, the use of fuels and associated emissions are also adjusted to representing the changes in energy efficiencies. This is implemented in the hybrid input-output table, i.e. the use of different fuels per unit of supply as well as associated emissions in the HIOT are multiplied with a factor. This factor is calculated for each fuel (*i*) and associated emissions for activity (*j*) as:

efficiency factor for fuel (*i*) = index of supply of activity (*j*) / index for use of fuel (*i*) by activity (*j*)

The index of supply of activity (*j*) is obtained as the projected supply in a given year compared to the supply in year 2003. For activities supplying a physical product as the main product, the projected development in TMR is used, and for activities supplying a service product as the main product, the projected development in GDP is used. These data are obtained from; see section 5.1.1.

The index for use of fuel (*i*) is obtained from energy scenarios in Mantzos et al. (2003), which provides information on the projected use of different fuels for a range of different activities:

- Industry
- Services and agriculture
- Households
- Transport
- Electricity and steam

It should be noted that the projections of supply and of use of fuels are based on slightly different datasets; For projections of GDP, Mantzos and Capros (2006) have been used. This is combined with calculated ratio between development in GDP and TMR. For projections of the use of fuels, Mantzos et al. (2003) have been used. It has been possible to cross-check this with emissions from the electricity activity with data from IEA (2008), where the fuel mix in the electricity sector is specified for different years and ecoinvent (2007), where the emission per kWh electricity per fuel type is specified. See comparison in Table 5.1. Note that the emissions given in Table 5.1 are per total kWh generated (all electricity technologies), thus the emissions in Table 5.1 are a result of the fuel mix and the emission factor for each fuel (kg CO_2/kWh). The total CO_2 emission per kWh cannot be seen in the table. To have this, also emissions of CO_2-fibre should be added. There are no direct CO_2 emissions from nuclear and hydro power.

	CO_2 emission from **coal** power plants (kg CO_2/kWh)		CO_2 from **gas** power plants (kg CO_2/kWh)	
Year	Projection of fuel efficiency according to method above	Figures calculated from IEA (2008) and ecoinvent (2007)	Projection of fuel efficiency according to method above	Figures calculated from IEA (2008) and ecoinvent (2007)
2010	0.275	0.285	0.095	0.134
2015	0.301	0.260	0.101	0.124
2035	0.496	0.215	0.123	0.134

Table 5.1: Comparison of emissions of CO_2-coal and CO_2-gas in scenarios by using the method for fuel efficiency described in this section and by using projections of fuel consumption mix and efficiency in IEA (2008) and CO_2 emissions factors from ecoinvent (2007). Note that the emissions given in the table are per total kWh generated (all electricity technologies), thus the emissions in the table are a result of the fuel mix and the emission factor (kg CO_2/kWh).

The comparison in Table 5.1 shows that there is relatively good coherence between emissions calculated using the two approaches, except for emissions from coal power plants in 2035, where the projection in the method above significantly overestimates the emission. It has been chosen to apply the emissions calculated by using data from IEA (2008) and ecoinvent (2007).

5.2 Parameterisation of 'what-if-scenarios of waste treatment'

Three 'what-if-scenarios of waste treatment' have been implemented in the hybrid input-output table:

1) Waste prevention scenario
2) Waste recycling scenario
3) Waste treatment scenario

The waste treatment scenarios are comprehensively described in deliverable 5.3 'Report chapter with description of three what-if scenarios of waste treatment policies and their interplay with the macro-economic scenarios'. The following three tables (Table 5.2, Table 5.3, and Table 5.4) provide information of which parameters in the HIOT that are changed in the scenarios. Parameter values for years within the intervals given in the tables are calculated using linear interpolation.

When implementing the scenario parameterisation, it is ensured in all cases, that mass balance per column in the HIOT is maintained. Hence, the scenario parameterisation does not imply monetary or physical inconsistencies. This is also indicated in the tables below: e.g. in table Table 5.2; it is indicated that both use and waste generation are changed, i.e. reduced use of a product within an activity leads to corresponding reduced waste generation within this activity. Also, in some cases, reduced use leads to reduced emissions; this is the case for the use of fuels. When the scenarios imply a change of the amount of waste sent to recycling or incineration, a corresponding change is assumed for landfill.

Activity	Changed parameter		2003	2015	2035
Household	Use	Meat use	100	85	81
	Use	Flour use	increased correspondingly by dry mass		
Food industry	Use, waste	Fruit and veg. Use & waste	100	85	81
	Use, waste	Grain crops & waste	100	97.6	97
	Use, waste	Crops nec & waste	100	85	81
Beverages	Use, waste	Use of plastic & waste	100	90	88
	Use, waste	Use of glass & waste	100	90	88
Household	Use, waste	Textiles, wearing and apperal, leather & waste	100	94	93
All, except household	Use, waste	Printed matter	100	92	90
All, except refinery industry	Use, waste, emissions	Use of refined petroleum, waste, and emissions	100	94	93
All, except machinery product activities	Use, waste	Machinery and equipment n.e.c.	100	94	93
	Use, waste	Office machinery and computers	100	94	93
	Use, waste	Electrical machinery n.e.c.	100	94	93
	Use, waste	Radio, television and communication equipment	100	94	93
	Use, waste	Instruments, medical, precision, optical, clocks	100	94	93

Table 5.2: Specification of changed parameters and parameter values in the **waste prevention scenario**. Note that detailed scenario descriptions can be found in deliverable 5.3 'Report chapter with description of three what-if scenarios of waste treatment policies and their interplay with the macro-economic scenarios'.

Activity	Changed parameter		2003	2015	2035
Beveages industry	Waste to recycling	paper and paper products	20%	30%	50%
		Plastic and rubber products	25%	70%	85%
		Glass	60%	90%	95%
		Fabricated metal products	59%	80%	90%
Construction industry	Waste to recycling	Sand, gravel and stone	15%	40%	80%
		Forest products and wood products	15%	20%	40%
		Plastic and rubber products	3%	7%	14%
		Bricks	15%	40%	70%
		Fabricated metal products	20%	85%	95%
Agriculture	Waste to biogas	Manure	0%	70%	70%
All	Waste to biogas	Food waste	0%	40%	60%
All	Waste to recycling	Paper waste	59%	67%	77%
Motor vehicles and trailers	ELV to recycling	Iron waste	95%	95%	95%
		Alu waste	95%	95%	95%
		Copper waste	61%	61%	61%
		Metals nec waste	61%	61%	61%
		Fabricated metal products, except machinery waste	60%	95%	95%
		Machinery and equipment n.e.c. waste	60%	95%	95%
All	WEEE waste to trecycling	Office machinery and computers waste	24%	75%	90%
		Radio, television and communication equipment waste	25%	75%	90%
		Instruments, medical, precision, optical, clocks waste	20%	75%	90%

Table 5.3: Specification of changed parameters and parameter values in the **waste recycling scenario**. Note that detailed scenario descriptions can be found in deliverable 5.3 'Report chapter with description of three what-if scenarios of waste treatment policies and their interplay with the macro-economic scenarios'.

Activity	Changed parameter		2003	2015
Agriculture	Waste to biogas	Manure	0%	100%
All	Waste to incineratin	Food waste	43%	80%
		Textile waste	55%	80%
		Paper waste	15%	35%
All	Waste to recycling	Inert waste	1%	5%
All	Waste to recycling	Iron waste	46%	52%
		Alu waste	41%	50%
		Copper waste	40%	50%
		Metals nec waste	41%	50%

Table 5.4: Specification of changed parameters and parameter values in the **waste treatment scenario**. Note that detailed scenario descriptions can be found in deliverable 5.3 'Report chapter with description of three what-if scenarios of waste treatment policies and their interplay with the macro-economic scenarios'.

5.3 Implementation of scenario parameterisation

The scenario implementation of macro-economic scenarios and what-if-scenarios of waste treatment as described in the previous sections are implemented in an Excel spreadsheet so that the following input-parameters need to be specified:

- Scenario parameter 1: Year, allowed values $\in$ [1971;2035]
- Scenario parameter 2: Macro-economic scenario, allowed values $\in$ [Baseline;Low;High]
- Scenario parameter 3: Waste scenario, , allowed values $\in$ [Waste prevention;Recycling;Treatment]

Based on the implemented scenarios (previous two sections) and the input-parameters (three bullets above), the HIOTs for analytical purposes are automatically derived.

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Appendix: Included product groups in the model

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.

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

Contract number: 044409

Deliverable n° 6-2

Title:

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.

Authors:

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Due date of deliverable: 31th August 2009
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Revision: final
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Project home page: http://forwast.brgm.fr/

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 EU-27 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 EU-27.

These inventory and assessment results are provided as an output of a Leontief-type environmentally extended, quasi-dynamic, physical input-output model covering the EU-27, 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-ΔS). 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 D6-2 is to document 25-year forecasts of the cumulated physical stocks, waste generation, and environmental impacts for each scenario for EU-27.

1.1 Methodology and data used for calculating model results

The methodology used for model calculations to obtain the results presented in this report is described in deliverable D6-4 'Documentation of the final model used for the scenario analyses'. The data collection is described in deliverable D3-1 and D4-1 which are reports describing data processing and validation for each of the EU-27 countries. The data from D3-1 and D4-1 are aggregated to an EU-27 model, a waste treatment module is implemented and the data are consolidated. This is described in deliverable D6-1 'Documentation of the data consolidation and calibration exercise, and the scenario parameterisation'. Nine future scenarios are applied to the aggregated EU-27 model. The scenarios are described in deliverables D5-2 'Description of the three chosen macroeconomic scenarios for EU-27 until 2035' and D5-3 'Report with description of three what-if scenarios of waste treatment policies and their interplay with the macro-economic scenarios'. The implementation of the scenarios in the model (scenario parameterisation) is described in deliverable D6-1 'Documentation of the data consolidation and calibration exercise, and the scenario parameterisation'. In order to calculate the current stocks and waste generation in reference year 2003 (originating from products that exceed their life time expectancy) historical time series of the EU-27 model are carried out. The method and data used for this purpose are also described in D6-1 'Documentation of the data consolidation and calibration exercise, and the scenario parameterisation'.

The reports referred to above as well as the data used for model calculations are available at: http://forwast.brgm.fr/.

It should be noted that the model results presented in this report represents data for EU-27. The data used for this are based on data collection for 20 countries, see Table 1.1. The supply-use table created from the 20 country data sets are scaled up to represent EU-27 by using the 20 countries' GDP share of EU-27 GDP.

Country code	Country	Included (x)	Data level	GDP share
AT	Austria		117x117	2%
BE	Belgium	x	57x57	3%
BG	Bulgaria	x	57x57	0.2%
CY	Cyprus	x	57x57	0.1%
CZ	Czech Republic	x	57x57	1%
DE	Germany		117x117	21%
DK	Denmark	x	117x117	2%
EE	Estonia	x	57x57	0%
ES	Spain		117x117	8%
FI	Finland	x	57x57	1%
FR	France	x	117x117	16%
GR	Greece	x	117x117	2%
HU	Hungary	x	57x57	1%
IE	Ireland		57x57	1%
IT	Italy		57x57	13%
LT	Lithuania	x	57x57	0.2%
LU	Luxembourg	x	57x57	0.3%
LV	Latvia	x	57x57	0.1%
MT	Malta	x	57x57	0.04%
NL	Netherlands	x	117x117	5%
PL	Poland	x	117x117	2%
PT	Portugal	x	57x57	1%
RO	Romania	x	57x57	1%
SE	Sweden	x	117x117	3%
SI	Slovenia		117x117	0.3%
SK	Slovakia	x	57x57	0.3%
UK	United Kingdom		117x117	16%
38% of EU27 GDP is included				100%

Table 1.1: Overview of the data used for the creation of the EU-27 supply-use table used in the model calculations.

1.2 *Overview of scenarios*

In Table 1.2 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 1.2: Overview of the analysed scenarios.

When interpreting the results, it is important to note, that the recycling ratio of metals is higher in the treatment scenario than in the recycling scenario. The recycling scenario only affects the recycling rate of the following two metal containing waste streams: 1) end-of-life-vehicles and 2) WEEE waste to recycling. The treatment scenario affects the recycling rate of all metal containing waste streams. This is described in deliverable D5.3 ‘Report with description of three what-if scenarios of waste treatment policies and their interplay with the macro-economic scenarios’.

2 Forecasts of the cumulated physical stocks in EU-27 the next 25 years

This chapter presents results on the accumulated stocks in the EU-27 for the reference year (2003) and for future scenarios. The stock tables present the total quantity of a number of different stock, and it is specified where in the economy each of the stock categories are stored (given as percentage of the total quantity). All stocks are given in metric tonnes, dry weight.

Distinction is made between stocks in economy and stocks of waste. Stocks in economy are products, which has entered the economy (use of products) by a given activity at a given time, which have not yet exceeded their life time expectancy. Stocks of waste are materials in landfills that are not yet degraded, i.e. has not yet become emissions.

It should be noted that the applied definition of stocks implies that intermediate storage of products and wastes throughout the product chain are not included. The definition also implies that only products with life time expectancy and wastes with degradation times more than one year are included as stocks.

Most of the stocks of construction materials in residential housing and industry will appear in the construction sector. This is because the physical material input (use) of construction materials takes place in the construction sector. The physical flow of materials contained in houses and structures from the construction sector to other activities using construction products is only included as a service flow (monetary value). The same applies to transport vehicles. The reason for not including the physical flow of these ‘composite’ products is that this allows to operate with different life time expectancies for the different components in the ‘composite’ products, e.g. windows has a shorter life time than concrete and bricks. The same applies to stocks of motor vehicles which appears as stocks of the feedstock materials and components in the motor vehicles activity.

2.1 Cumulated stocks in EU-27 in year 2003

In Table 2.1, the accumulated stocks in the EU-27 are presented. It appears that the total quantity of stocks in economy is 167,700 million tonne in 2003 in EU-27. The most significant part of the stocks belongs to construction materials (sand, gravel, concrete, asphalt, bricks) and wood products (also contained in construction). These stocks account for approximately 97% of the total stocks. Most of these stocks are present in the industry and construction sectors.

Other significant stocks in economy are:

- Iron products: 948 million tonnes
- Machinery and equipment nec.: 723 million tonnes
- Fabricated metal products, except machinery: 624 million tonnes
- Glass products 558 million tonnes
- Furniture, and other manufactured products: 408 million tonnes
- Electrical machinery: 335 million tonnes

Stocks of waste in landfills are mainly inert wastes (landfilled construction materials etc.). Also landfilled slag/ash is significant. All stocks of waste are stored in the waste treatment sector. In this context, diffuse littering is included as part of the waste treatment sector.

Accumulated stocks in:
Region: EU27
Year: 2003

Stock category		Quantity, dry weight (Million t)	Sector: Agriculture and fishery	Forestry	Resource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Stocks in the economy														
Construction materials	Sand, stone, clay	116,345	1.0%	0.0%	6.3%	1.3%	19.4%	52.4%	0.1%	0.1%	11.3%	6.6%	1.5%	100%
	Concrete, asphalt	30,647	0.4%	0.0%	0.1%	1.7%	5.5%	80.4%	0.0%	0.0%	4.9%	2.2%	4.6%	100%
	Bricks	3,086	0.3%	0.0%	0.3%	0.3%	8.4%	72.6%	0.0%	0.1%	8.1%	1.7%	8.0%	100%
Textile	Textile, wearing apperel, footwear	105	0.8%	0.0%	0.1%	1.2%	23.7%	2.6%	0.0%	0.1%	13.1%	1.6%	56.7%	100%
Wood	Wood products	3,280	2.2%	0.4%	0.5%	2.3%	28.7%	40.5%	0.1%	0.6%	12.4%	2.2%	10.2%	100%
Paper products	Paper and printed/recorded media	210	0.4%	0.0%	0.1%	4.2%	15.1%	0.8%	0.2%	0.1%	45.5%	4.1%	29.5%	100%
Plastic	Plastic and rubber products	139	2.1%	0.1%	0.5%	6.6%	24.7%	19.4%	1.3%	0.1%	18.4%	2.3%	24.5%	100%
Glass	Glass products	558	2.3%	0.0%	2.1%	27.5%	22.0%	23.0%	0.4%	0.2%	11.7%	6.2%	4.9%	100%
Metal products	Iron products	948	0.2%	0.0%	0.9%	0.8%	64.3%	26.1%	0.2%	0.1%	5.5%	1.0%	0.8%	100%
	Aluminium products	39	0.1%	0.0%	0.2%	3.3%	73.8%	16.3%	0.3%	0.2%	4.1%	1.3%	0.5%	100%
	Copper products	21	0.1%	0.0%	0.0%	1.6%	86.5%	9.1%	0.2%	0.1%	1.7%	0.3%	0.5%	100%
	Metals nec products	11	0.1%	0.0%	0.2%	1.6%	69.7%	15.1%	0.3%	0.2%	10.4%	1.8%	0.8%	100%
	Fabricated metal products, except machinery	624	1.5%	0.1%	0.7%	3.9%	28.8%	27.3%	0.8%	0.3%	17.9%	12.0%	6.8%	100%
	Machinery and equipment n.e.c.	723	6.0%	0.2%	1.8%	3.8%	31.9%	8.6%	0.7%	0.3%	27.4%	5.2%	14.2%	100%
	Office machinery and computers	5	0.3%	0.0%	0.2%	0.9%	12.6%	0.8%	0.3%	0.1%	62.6%	7.3%	15.0%	100%
	Electrical machinery n.e.c.	335	0.5%	0.0%	0.4%	0.8%	26.1%	19.1%	1.2%	1.3%	29.4%	3.5%	17.7%	100%
	Radio, television and communication equipment	69	0.0%	0.0%	0.1%	0.2%	31.0%	2.4%	0.3%	0.5%	37.3%	2.0%	26.2%	100%
	Instruments, medical, precision, optical, clocks	30	0.1%	0.0%	0.0%	0.3%	16.3%	2.9%	0.2%	0.7%	48.4%	1.0%	30.2%	100%
	Furniture and other manufactured goods n.e.c.	408	0.1%	0.0%	0.0%	0.5%	9.7%	2.2%	0.1%	0.2%	24.3%	2.6%	60.3%	100%
Total		**157,583**												
Stocks of waste														
Stocks in landfill	Landfill of waste: Food	5,922	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Paper	1,317	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Plastic	1,247	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Metals	2,249	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Glass/inert	186,695	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Mine waste	3,954	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Textiles	223	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Wood	2,568	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Oil/Hazardous waste	8,665	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Slag/ash	32,550	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
Total		**245,388**												

Table 2.1: Cumulated stocks in the EU-27 in 2003.

2.2 Cumulated stocks in EU-27 year 2035

In Table 2.3 to Table 2.11 the cumulated stocks for scenario 1-9 are given.

In Table 2.1 below, the cumulated stocks in 2035 are compared with the cumulated stocks in 2003 for scenario 1. It appears from Table 2.1 that most stocks in the economy increases with the same rate. Only the growth of stocks of plastic are forecasted to be significant higher than for the other stocks. For stocks of waste, it appears that some categories are decreasing from 2003 to 2035, namely food waste and textiles waste. The underlying reason for this is that more waste is sent to incineration in the treatment scenario, and consequently less is sent to landfill. At the same time the stock of food waste degrades in the landfill. A consequence of the increased incineration is that more slag/ash is landfilled.

Stock category		Quantity 2003, dry weight (Million t)	Quantity 2035, dry weight (Million t)	2035 relative to 2003
Stocks in the economy				
Construction materials	Sand, stone, clay	116,345	184,849	159%
	Concrete, asphalt	30,647	47,338	154%
	Bricks	3,086	4,793	155%
Textile	Textile, wearing apperel, footwear	105	150	143%
Wood	Wood products	3,280	5,185	158%
Paper products	Paper and printed/recorded media	210	314	149%
Plastic	Plastic and rubber products	139	363	260%
Glass	Glass products	558	786	141%
Metal products	Iron products	948	1,350	142%
	Aluminium products	39	56	141%
	Copper products	21	29	138%
	Metals nec products	11	16	142%
	Fabricated metal products, except machinery	624	875	140%
	Machinery and equipment n.e.c.	723	1,043	144%
	Office machinery and computers	5	8	151%
	Electrical machinery n.e.c.	335	489	146%
	Radio, television and communication equipment	69	103	148%
	Instruments, medical, precision, optical, clocks	30	45	148%
	Furniture and other manufactured goods n.e.c.	408	586	144%
Total		**157,583**	**248,378**	**158%**
Stocks of waste				
Stocks in landfill	Landfill of waste: Food	5,922	4,115	69%
	Landfill of waste: Paper	1,317	1,655	126%
	Landfill of waste: Plastic	1,247	1,645	132%
	Landfill of waste: Metals	2,249	3,434	153%
	Landfill of waste: Glass/inert	186,695	346,948	186%
	Landfill of waste: Mine waste	3,954	7,246	183%
	Landfill of waste: Textiles	223	196	88%
	Landfill of waste: Wood	2,568	3,918	153%
	Landfill of waste: Oil/Hazardous waste	8,665	17,460	202%
	Landfill of waste: Slag/ash	32,550	65,120	200%
Total		**245,388**	**451,738**	**184%**

Table 2.2: Development in cumulated stocks in the EU-27 from 2003 to 2035 in scenario 1.

2.2.1 Scenario 1: Baseline scenario, treatment waste scenario, year 2035

Accumulated stocks in:
Region: EU27
Year: 2035
Macro-economic scenario: baseline
Waste treatment scenario: Treatment

Stock category		Quantity, dry weight (Million t)	Sector: Agriculture and fishery	Forestry	Resource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Stocks in the economy														
Construction materials	Sand, stone, clay	184,849	1%	0%	6%	1%	22%	51%	0%	0%	12%	5%	2%	100%
	Concrete, asphalt	47,338	0%	0%	0%	2%	6%	80%	0%	0%	5%	2%	5%	100%
	Bricks	4,793	0%	0%	0%	0%	9%	72%	0%	0%	9%	1%	8%	100%
Textile	Textile, wearing apperel, footwear	150	1%	0%	0%	1%	22%	2%	0%	0%	14%	1%	58%	100%
Wood	Wood products	5,185	2%	0%	1%	2%	29%	39%	0%	1%	13%	2%	11%	100%
Paper products	Paper and printed/recorded media	314	0%	0%	0%	4%	15%	1%	0%	0%	47%	3%	29%	100%
Plastic	Plastic and rubber products	363	1%	0%	1%	8%	25%	21%	2%	0%	20%	2%	21%	100%
Glass	Glass products	786	2%	0%	2%	28%	22%	22%	1%	0%	12%	5%	5%	100%
Metal products	Iron products	1,350	0%	0%	1%	1%	65%	25%	0%	0%	6%	1%	1%	100%
	Aluminium products	56	0%	0%	0%	3%	73%	16%	1%	0%	4%	1%	0%	100%
	Copper products	29	0%	0%	0%	2%	86%	9%	0%	0%	2%	0%	1%	100%
	Metals nec products	16	0%	0%	0%	2%	70%	14%	1%	0%	11%	1%	1%	100%
	Fabricated metal products, except machinery	875	1%	0%	1%	4%	30%	26%	1%	1%	19%	9%	7%	100%
	Machinery and equipment n.e.c.	1,043	5%	0%	2%	4%	33%	8%	1%	0%	28%	4%	14%	100%
	Office machinery and computers	8	0%	0%	0%	1%	13%	1%	1%	0%	64%	6%	15%	100%
	Electrical machinery n.e.c.	489	0%	0%	1%	1%	26%	18%	3%	2%	30%	3%	18%	100%
	Radio, television and communication equipment	103	0%	0%	0%	0%	31%	2%	1%	1%	38%	1%	26%	100%
	Instruments, medical, precision, optical, clocks	45	0%	0%	0%	0%	17%	3%	0%	1%	48%	1%	29%	100%
	Furniture and other manufactured goods n.e.c.	586	0%	0%	0%	0%	10%	2%	0%	0%	25%	2%	60%	100%
Total		**248,378**												
Stocks of waste														
Stocks in landfill	Landfill of waste: Food	4,115	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Paper	1,655	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Plastic	1,645	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Metals	3,434	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Glass/inert	346,948	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Mine waste	7,246	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Textiles	196	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Wood	3,918	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Oil/Hazardous waste	17,460	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Slag/ash	65,120	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
Total		**451,738**												

Table 2.3: Cumulated stocks in the EU-27 in 2035; Scenario 1.

2.2.2 Scenario 2: Baseline scenario, recycling waste scenario

Accumulated stocks in:
Region: EU27
Year: 2035
Macro-economic scenario: baseline
Waste treatment scenario: Recycling

Stock category		**Quantity, dry weight (Million t)**	**Sector** Agriculture and fishery	Forestry	Resource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Stocks in the economy														
Construction materials	Sand, stone, clay	238,072	1%	0%	4%	1%	41%	39%	0%	0%	9%	4%	1%	100%
	Concrete, asphalt	47,140	0%	0%	0%	2%	6%	80%	0%	0%	5%	2%	5%	100%
	Bricks	4,758	0%	0%	0%	0%	9%	72%	0%	0%	9%	1%	9%	100%
Textile	Textile, wearing apperel, footwear	150	1%	0%	0%	1%	22%	2%	0%	0%	14%	1%	58%	100%
Wood	Wood products	5,177	2%	0%	0%	2%	29%	39%	0%	1%	13%	2%	11%	100%
Paper products	Paper and printed/recorded media	317	0%	0%	0%	4%	16%	1%	0%	0%	46%	3%	29%	100%
Plastic	Plastic and rubber products	364	1%	0%	0%	8%	25%	21%	2%	0%	20%	2%	21%	100%
Glass	Glass products	773	2%	0%	1%	29%	22%	22%	1%	0%	13%	5%	5%	100%
Metal products	Iron products	1,404	0%	0%	1%	1%	67%	23%	0%	0%	6%	1%	1%	100%
	Aluminium products	56	0%	0%	0%	3%	74%	15%	1%	0%	4%	1%	0%	100%
	Copper products	29	0%	0%	0%	2%	86%	9%	0%	0%	2%	0%	1%	100%
	Metals nec products	16	0%	0%	0%	2%	70%	14%	1%	0%	11%	1%	1%	100%
	Fabricated metal products, except machinery	906	1%	0%	1%	4%	33%	25%	1%	0%	18%	9%	7%	100%
	Machinery and equipment n.e.c.	1,046	5%	0%	2%	4%	34%	8%	1%	0%	28%	4%	14%	100%
	Office machinery and computers	8	0%	0%	0%	1%	13%	1%	1%	0%	64%	6%	15%	100%
	Electrical machinery n.e.c.	489	0%	0%	0%	1%	26%	18%	3%	2%	30%	3%	18%	100%
	Radio, television and communication equipment	103	0%	0%	0%	0%	31%	2%	1%	1%	38%	1%	26%	100%
	Instruments, medical, precision, optical, clocks	45	0%	0%	0%	0%	17%	3%	0%	1%	49%	1%	29%	100%
	Furniture and other manufactured goods n.e.c.	587	0%	0%	0%	0%	10%	2%	0%	0%	25%	2%	60%	100%
Total		**301,440**												
Stocks of waste														
Stocks in landfill	Landfill of waste: Food	3,539	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Paper	1,720	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Plastic	1,599	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Metals	3,256	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Glass/inert	336,512	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Mine waste	7,226	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Textiles	343	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Wood	3,785	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Oil/Hazardous waste	17,421	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Slag/ash	68,225	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
Total		**443,627**												

Table 2.4: Cumulated stocks in the EU-27 in 2035; Scenario 2.

2.2.3 Scenario 3: Baseline scenario, prevention waste scenario

Accumulated stocks in:
Region: EU27
Year: 2035
Macro-economic scenario: baseline
Waste treatment scenario: Waste prevention

Stock category		Quantity, dry weight (Million t)	Sector: Agriculture and fishery	Forestry	Resource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Stocks in the economy														
Construction materials	Sand, stone, clay	163,724	1%	0%	6%	2%	21%	50%	0%	0%	13%	5%	2%	100%
	Concrete, asphalt	42,392	0%	0%	0%	2%	6%	78%	0%	0%	6%	2%	5%	100%
	Bricks	4,329	0%	0%	0%	0%	9%	69%	0%	0%	9%	1%	9%	100%
Textile	Textile, wearing apperel, footwear	146	1%	0%	0%	1%	21%	2%	0%	0%	14%	1%	59%	100%
Wood	Wood products	4,832	2%	0%	1%	3%	29%	37%	0%	1%	14%	2%	11%	100%
Paper products	Paper and printed/recorded media	301	0%	0%	0%	4%	14%	1%	0%	0%	47%	3%	30%	100%
Plastic	Plastic and rubber products	341	1%	0%	1%	8%	25%	19%	2%	0%	20%	2%	22%	100%
Glass	Glass products	727	2%	0%	2%	30%	22%	19%	1%	0%	13%	5%	5%	100%
Metal products	Iron products	1,183	0%	0%	1%	1%	67%	22%	0%	0%	6%	1%	1%	100%
	Aluminium products	52	0%	0%	0%	4%	75%	13%	1%	0%	5%	1%	1%	100%
	Copper products	28	0%	0%	0%	2%	88%	7%	0%	0%	2%	0%	1%	100%
	Metals nec products	15	0%	0%	0%	2%	71%	12%	1%	0%	11%	1%	1%	100%
	Fabricated metal products, except machinery	790	1%	0%	1%	4%	31%	23%	1%	1%	21%	9%	8%	100%
	Machinery and equipment n.e.c.	984	5%	0%	2%	4%	32%	7%	1%	1%	29%	4%	15%	100%
	Office machinery and computers	7	0%	0%	0%	1%	12%	1%	1%	0%	65%	5%	15%	100%
	Electrical machinery n.e.c.	458	0%	0%	1%	1%	26%	15%	3%	2%	31%	2%	19%	100%
	Radio, television and communication equipment	98	0%	0%	0%	0%	30%	2%	1%	1%	38%	1%	27%	100%
	Instruments, medical, precision, optical, clocks	44	0%	0%	0%	0%	16%	2%	0%	1%	49%	1%	30%	100%
	Furniture and other manufactured goods n.e.c.	577	0%	0%	0%	0%	9%	2%	0%	0%	25%	2%	61%	100%
Total		**221,029**												
Stocks of waste														
Stocks in landfill	Landfill of waste: Food	9,189	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Paper	1,814	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Plastic	1,560	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Metals	3,423	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Glass/inert	326,616	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Mine waste	7,138	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Textiles	327	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Wood	3,643	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Oil/Hazardous waste	17,157	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Slag/ash	60,447	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
Total		**431,313**												

Table 2.5: Cumulated stocks in the EU-27 in 2035; Scenario 3.

2.2.4 Scenario 4: High growth scenario, treatment waste scenario

Accumulated stocks in:
Region: EU27
Year: 2035
Macro-economic scenario: high
Waste treatment scenario: Treatment

Stock category		Quantity, dry weight (Million t)	Sector											
			Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Stocks in the economy														
Construction materials	Sand, stone, clay	193,035	1%	0%	6%	1%	23%	50%	0%	0%	12%	5%	2%	100%
	Concrete, asphalt	49,043	0%	0%	0%	2%	6%	79%	0%	0%	5%	2%	5%	100%
	Bricks	4,982	0%	0%	0%	0%	9%	71%	0%	0%	9%	1%	9%	100%
Textile	Textile, wearing apperel, footwear	174	1%	0%	0%	1%	22%	2%	0%	0%	14%	1%	58%	100%
Wood	Wood products	5,461	2%	0%	1%	2%	29%	38%	0%	1%	13%	2%	11%	100%
Paper products	Paper and printed/recorded media	369	0%	0%	0%	4%	15%	1%	0%	0%	47%	3%	29%	100%
Plastic	Plastic and rubber products	402	1%	0%	1%	8%	25%	20%	2%	0%	20%	2%	21%	100%
Glass	Glass products	893	2%	0%	2%	30%	22%	21%	1%	0%	13%	5%	5%	100%
Metal products	Iron products	1,497	0%	0%	1%	1%	66%	23%	0%	0%	6%	1%	1%	100%
	Aluminium products	64	0%	0%	0%	4%	74%	15%	1%	0%	4%	1%	0%	100%
	Copper products	33	0%	0%	0%	2%	87%	8%	0%	0%	2%	0%	1%	100%
	Metals nec products	18	0%	0%	0%	2%	71%	14%	1%	0%	11%	1%	1%	100%
	Fabricated metal products, except machinery	975	1%	0%	1%	4%	31%	25%	1%	1%	20%	9%	7%	100%
	Machinery and equipment n.e.c.	1,182	5%	0%	2%	4%	33%	8%	1%	1%	29%	4%	14%	100%
	Office machinery and computers	9	0%	0%	0%	1%	13%	1%	1%	0%	65%	5%	15%	100%
	Electrical machinery n.e.c.	550	0%	0%	1%	1%	26%	17%	2%	2%	31%	2%	18%	100%
	Radio, television and communication equipment	119	0%	0%	0%	0%	31%	2%	0%	1%	38%	1%	26%	100%
	Instruments, medical, precision, optical, clocks	51	0%	0%	0%	0%	17%	2%	0%	1%	49%	1%	29%	100%
	Furniture and other manufactured goods n.e.c.	668	0%	0%	0%	0%	10%	2%	0%	0%	25%	2%	60%	100%
Total		**259,523**												
Stocks of waste														
Stocks in landfill	Landfill of waste: Food	4,398	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Paper	1,841	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Plastic	1,783	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Metals	3,634	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Glass/inert	356,612	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Mine waste	7,553	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Textiles	210	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Wood	4,243	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Oil/Hazardous waste	17,941	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Slag/ash	67,432	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
Total		**465,647**												

Table 2.6: Cumulated stocks in the EU-27 in 2035; Scenario 4.

2.2.5 Scenario 5: High growth scenario, recycling waste scenario

Accumulated stocks in:
Region: EU27
Year: 2035
Macro-economic scenario: high
Waste treatment scenario: Recycling

Stock category		Quantity, dry weight (Million t)	Sector: Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Stocks in the economy														
Construction materials	Sand, stone, clay	250,921	1%	0%	3%	1%	42%	38%	0%	0%	9%	4%	1%	100%
	Concrete, asphalt	48,836	0%	0%	0%	2%	6%	79%	0%	0%	5%	2%	5%	100%
	Bricks	4,944	0%	0%	0%	0%	9%	71%	0%	0%	9%	1%	9%	100%
Textile	Textile, wearing apperel, footwear	174	1%	0%	0%	1%	22%	2%	0%	0%	14%	1%	58%	100%
Wood	Wood products	5,451	2%	0%	0%	2%	30%	38%	0%	1%	13%	2%	11%	100%
Paper products	Paper and printed/recorded media	371	0%	0%	0%	4%	16%	1%	0%	0%	46%	3%	29%	100%
Plastic	Plastic and rubber products	403	1%	0%	0%	8%	26%	20%	2%	0%	20%	2%	21%	100%
Glass	Glass products	879	2%	0%	1%	30%	22%	21%	1%	0%	13%	5%	5%	100%
Metal products	Iron products	1,557	0%	0%	1%	1%	68%	22%	0%	0%	6%	1%	1%	100%
	Aluminium products	64	0%	0%	0%	4%	75%	15%	1%	0%	4%	1%	0%	100%
	Copper products	33	0%	0%	0%	2%	87%	8%	0%	0%	2%	0%	1%	100%
	Metals nec products	18	0%	0%	0%	2%	71%	13%	1%	0%	11%	1%	1%	100%
	Fabricated metal products, except machinery	1,009	1%	0%	1%	4%	34%	24%	1%	0%	19%	8%	7%	100%
	Machinery and equipment n.e.c.	1,185	5%	0%	1%	4%	34%	7%	1%	0%	28%	4%	14%	100%
	Office machinery and computers	9	0%	0%	0%	1%	13%	1%	1%	0%	64%	5%	15%	100%
	Electrical machinery n.e.c.	549	0%	0%	0%	1%	27%	17%	2%	2%	31%	2%	18%	100%
	Radio, television and communication equipment	119	0%	0%	0%	0%	31%	2%	0%	1%	38%	1%	26%	100%
	Instruments, medical, precision, optical, clocks	51	0%	0%	0%	0%	17%	2%	0%	1%	49%	1%	29%	100%
	Furniture and other manufactured goods n.e.c.	668	0%	0%	0%	0%	10%	2%	0%	0%	25%	2%	60%	100%
Total		**317,242**												
Stocks of waste														
Stocks in landfill	Landfill of waste: Food	3,781	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Paper	1,877	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Plastic	1,732	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Metals	3,439	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Glass/inert	345,429	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Mine waste	7,530	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Textiles	373	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Wood	4,090	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Oil/Hazardous waste	17,903	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Slag/ash	70,720	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
Total		**456,874**												

Table 2.7: Cumulated stocks in the EU-27 in 2035; Scenario 5.

2.2.6 Scenario 6: High growth scenario, prevention waste scenario

Accumulated stocks in:
Region: EU27
Year: 2035
Macro-economic scenario: High
Waste treatment scenario: Waste prevention

			Sector											
Stock category		**Quantity, dry weight (Million t)**	Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Stocks in the economy														
Construction materials	Sand, stone, clay	171,008	1%	0%	6%	2%	21%	49%	0%	0%	13%	5%	2%	100%
	Concrete, asphalt	43,939	0%	0%	0%	2%	6%	77%	0%	0%	6%	2%	6%	100%
	Bricks	4,503	0%	0%	0%	0%	9%	68%	0%	0%	10%	1%	10%	100%
Textile	Textile, wearing apperel, footwear	170	1%	0%	0%	1%	21%	2%	0%	0%	14%	1%	60%	100%
Wood	Wood products	5,092	2%	0%	1%	3%	30%	36%	0%	1%	14%	2%	11%	100%
Paper products	Paper and printed/recorded media	354	0%	0%	0%	4%	14%	1%	0%	0%	48%	3%	30%	100%
Plastic	Plastic and rubber products	379	1%	0%	1%	8%	25%	17%	2%	0%	21%	2%	23%	100%
Glass	Glass products	831	2%	0%	2%	32%	23%	18%	1%	0%	13%	4%	5%	100%
Metal products	Iron products	1,319	0%	0%	1%	1%	68%	21%	0%	0%	7%	1%	1%	100%
	Aluminium products	59	0%	0%	0%	4%	76%	13%	1%	0%	5%	1%	1%	100%
	Copper products	32	0%	0%	0%	2%	88%	7%	0%	0%	2%	0%	1%	100%
	Metals nec products	17	0%	0%	0%	2%	72%	12%	1%	0%	11%	1%	1%	100%
	Fabricated metal products, except machinery	887	1%	0%	1%	5%	32%	22%	1%	1%	21%	8%	8%	100%
	Machinery and equipment n.e.c.	1,118	5%	0%	2%	4%	33%	6%	1%	1%	30%	3%	15%	100%
	Office machinery and computers	9	0%	0%	0%	1%	12%	1%	0%	0%	65%	5%	15%	100%
	Electrical machinery n.e.c.	517	0%	0%	1%	1%	27%	14%	2%	2%	32%	2%	19%	100%
	Radio, television and communication equipment	114	0%	0%	0%	0%	30%	2%	0%	1%	39%	1%	27%	100%
	Instruments, medical, precision, optical, clocks	50	0%	0%	0%	0%	16%	2%	0%	1%	49%	1%	30%	100%
	Furniture and other manufactured goods n.e.c.	657	0%	0%	0%	0%	9%	2%	0%	0%	25%	2%	61%	100%
Total		**231,054**												
Stocks of waste														
Stocks in landfill	Landfill of waste: Food	10,103	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Paper	2,017	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Plastic	1,693	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Metals	3,628	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Glass/inert	335,555	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Mine waste	7,438	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Textiles	355	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Wood	3,953	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Oil/Hazardous waste	17,623	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Slag/ash	62,446	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
Total		**444,811**												

Table 2.8: Cumulated stocks in the EU-27 in 2035; Scenario 6.

2.2.7 Scenario 7: Low growth scenario, treatment waste scenario

Accumulated stocks in:
Region: EU27
Year: 2035
Macro-economic scenario: low
Waste treatment scenario: Treatment

			Sector											
Stock category		**Quantity, dry weight (Million t)**	Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Stocks in the economy														
Construction materials	Sand, stone, clay	177,075	1%	0%	6%	1%	22%	50%	0%	0%	11%	5%	2%	100%
	Concrete, asphalt	45,334	0%	0%	0%	2%	6%	80%	0%	0%	5%	2%	5%	100%
	Bricks	4,588	0%	0%	0%	0%	9%	72%	0%	0%	9%	1%	8%	100%
Textile	Textile, wearing apperel, footwear	132	1%	0%	0%	1%	23%	3%	0%	0%	14%	1%	58%	100%
Wood	Wood products	4,967	2%	0%	1%	2%	29%	39%	0%	1%	13%	2%	10%	100%
Paper products	Paper and printed/recorded media	274	0%	0%	0%	4%	16%	1%	0%	0%	46%	4%	29%	100%
Plastic	Plastic and rubber products	335	1%	0%	1%	8%	25%	22%	2%	0%	19%	2%	20%	100%
Glass	Glass products	707	2%	0%	2%	28%	22%	22%	1%	0%	12%	5%	5%	100%
Metal products	Iron products	1,230	0%	0%	1%	1%	65%	25%	0%	0%	6%	1%	1%	100%
	Aluminium products	51	0%	0%	0%	3%	74%	15%	1%	0%	4%	1%	0%	100%
	Copper products	27	0%	0%	0%	2%	87%	9%	0%	0%	2%	0%	1%	100%
	Metals nec products	15	0%	0%	0%	2%	70%	14%	1%	0%	11%	1%	1%	100%
	Fabricated metal products, except machinery	798	1%	0%	1%	4%	30%	26%	1%	1%	18%	10%	7%	100%
	Machinery and equipment n.e.c.	952	5%	0%	2%	4%	34%	8%	1%	1%	27%	4%	14%	100%
	Office machinery and computers	7	0%	0%	0%	1%	13%	1%	1%	0%	63%	6%	15%	100%
	Electrical machinery n.e.c.	441	0%	0%	1%	1%	26%	18%	3%	3%	29%	3%	17%	100%
	Radio, television and communication equipment	91	0%	0%	0%	0%	32%	2%	1%	1%	37%	2%	25%	100%
	Instruments, medical, precision, optical, clocks	40	0%	0%	0%	0%	17%	3%	0%	1%	48%	1%	29%	100%
	Furniture and other manufactured goods n.e.c.	525	0%	0%	0%	0%	10%	2%	0%	0%	25%	2%	60%	100%
Total		**237,590**												
Stocks of waste														
Stocks in landfill	Landfill of waste: Food	3,945	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Paper	1,482	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Plastic	1,505	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Metals	3,237	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Glass/inert	334,028	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Mine waste	7,025	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Textiles	182	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Wood	3,639	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Oil/Hazardous waste	16,906	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Slag/ash	62,870	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
Total		**434,819**												

Table 2.9: Cumulated stocks in the EU-27 in 2035; Scenario 7.

2.2.8 Scenario 8: Low growth scenario, recycling waste scenario

Accumulated stocks in:
Region: EU27
Year: 2035
Macro-economic scenario: low
Waste treatment scenario: Recycling

Stock category		Quantity, dry weight (Million t)	Sector: Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Stocks in the economy														
Construction materials	Sand, stone, clay	226,672	1%	0%	4%	1%	41%	39%	0%	0%	9%	4%	1%	100%
	Concrete, asphalt	45,253	0%	0%	0%	2%	6%	80%	0%	0%	5%	2%	5%	100%
	Bricks	4,565	0%	0%	0%	0%	9%	72%	0%	0%	9%	1%	8%	100%
Textile	Textile, wearing apperel, footwear	132	1%	0%	0%	1%	23%	3%	0%	0%	14%	1%	57%	100%
Wood	Wood products	4,968	2%	0%	1%	2%	29%	39%	0%	1%	13%	2%	10%	100%
Paper products	Paper and printed/recorded media	276	0%	0%	0%	4%	17%	1%	0%	0%	46%	4%	29%	100%
Plastic	Plastic and rubber products	336	1%	0%	1%	8%	26%	21%	2%	0%	19%	2%	20%	100%
Glass	Glass products	696	2%	0%	1%	28%	22%	22%	1%	0%	12%	5%	5%	100%
Metal products	Iron products	1,283	0%	0%	1%	1%	67%	24%	0%	0%	5%	1%	1%	100%
	Aluminium products	51	0%	0%	0%	3%	74%	15%	1%	0%	4%	1%	0%	100%
	Copper products	27	0%	0%	0%	2%	87%	9%	0%	0%	2%	0%	1%	100%
	Metals nec products	15	0%	0%	0%	2%	70%	14%	1%	0%	10%	1%	1%	100%
	Fabricated metal products, except machinery	826	1%	0%	1%	4%	33%	25%	1%	0%	18%	10%	7%	100%
	Machinery and equipment n.e.c.	955	5%	0%	2%	4%	35%	8%	1%	0%	27%	4%	14%	100%
	Office machinery and computers	7	0%	0%	0%	1%	13%	1%	1%	0%	63%	6%	15%	100%
	Electrical machinery n.e.c.	440	0%	0%	1%	1%	27%	18%	3%	2%	29%	3%	17%	100%
	Radio, television and communication equipment	91	0%	0%	0%	0%	32%	2%	1%	1%	37%	2%	25%	100%
	Instruments, medical, precision, optical, clocks	40	0%	0%	0%	0%	18%	3%	0%	1%	48%	1%	29%	100%
	Furniture and other manufactured goods n.e.c.	525	0%	0%	0%	0%	10%	2%	0%	0%	25%	2%	60%	100%
Total		**287,160**												
Stocks of waste														
Stocks in landfill	Landfill of waste: Food	3,384	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Paper	1,621	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Plastic	1,502	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Metals	3,130	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Glass/inert	328,636	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Mine waste	6,997	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Textiles	322	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Wood	3,593	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Oil/Hazardous waste	16,879	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Slag/ash	66,274	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
Total		**432,339**												

Table 2.10: Cumulated stocks in the EU-27 in 2035; Scenario 8.

2.2.9 Scenario 9: Low growth scenario, prevention waste scenario

Accumulated stocks in:
Region: EU27
Year: 2035
Macro-economic scenario: low
Waste treatment scenario: Waste prevention

Stock category		Quantity, dry weight (Million t)	Sector: Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Stocks in the economy														
Construction materials	Sand, stone, clay	157,334	1%	0%	6%	1%	21%	50%	0%	0%	13%	6%	2%	100%
	Concrete, asphalt	40,685	0%	0%	0%	2%	6%	78%	0%	0%	6%	2%	5%	100%
	Bricks	4,152	0%	0%	0%	0%	9%	69%	0%	0%	9%	1%	9%	100%
Textile	Textile, wearing apperel, footwear	129	1%	0%	0%	1%	22%	2%	0%	0%	14%	1%	59%	100%
Wood	Wood products	4,635	2%	0%	1%	3%	30%	37%	0%	1%	14%	2%	11%	100%
Paper products	Paper and printed/recorded media	262	0%	0%	0%	4%	14%	1%	0%	0%	47%	3%	30%	100%
Plastic	Plastic and rubber products	314	2%	0%	1%	8%	26%	19%	2%	0%	20%	2%	22%	100%
Glass	Glass products	653	2%	0%	2%	30%	23%	19%	1%	0%	13%	5%	5%	100%
Metal products	Iron products	1,079	0%	0%	1%	1%	66%	22%	0%	0%	6%	1%	1%	100%
	Aluminium products	47	0%	0%	0%	3%	76%	13%	1%	0%	4%	1%	1%	100%
	Copper products	26	0%	0%	0%	2%	88%	7%	0%	0%	2%	0%	1%	100%
	Metals nec products	14	0%	0%	0%	2%	71%	12%	1%	0%	11%	1%	1%	100%
	Fabricated metal products, except machinery	720	1%	0%	1%	4%	32%	23%	1%	1%	20%	10%	8%	100%
	Machinery and equipment n.e.c.	897	5%	0%	2%	4%	33%	7%	1%	1%	28%	4%	15%	100%
	Office machinery and computers	6	0%	0%	0%	1%	12%	1%	1%	0%	64%	6%	15%	100%
	Electrical machinery n.e.c.	412	0%	0%	1%	1%	26%	15%	3%	3%	30%	3%	18%	100%
	Radio, television and communication equipment	87	0%	0%	0%	0%	30%	2%	1%	1%	38%	1%	27%	100%
	Instruments, medical, precision, optical, clocks	39	0%	0%	0%	0%	17%	2%	0%	1%	48%	1%	30%	100%
	Furniture and other manufactured goods n.e.c.	516	0%	0%	0%	0%	10%	2%	0%	0%	25%	2%	61%	100%
Total		**212,006**												
Stocks of waste														
Stocks in landfill	Landfill of waste: Food	8,580	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Paper	1,629	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Plastic	1,428	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Metals	3,227	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Glass/inert	315,044	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Mine waste	6,923	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Textiles	299	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Wood	3,385	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Oil/Hazardous waste	16,621	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
	Landfill of waste: Slag/ash	58,543	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
Total		**415,680**												

Table 2.11: Cumulated stocks in the EU-27 in 2035; Scenario 9.

3 Forecasts of the waste generation in EU-27 the next 25 years

This chapter presents model results on the waste generation in the EU-27 for the reference year (2003) and for future scenarios. The model output is presented as standardised waste tables. The waste tables present the total quantity of waste generation for a number of different waste fractions, and it is specified where in the economy each of the waste fractions are generated (given as percentage of the total quantity). All waste flows are given in metric tonnes, dry weight.

The applied definition of waste is: “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” (see deliverable D6.4: ‘Documentation of the final model used for the scenario analyses’). This definition implies that materials sent to recycling are included as waste. The waste flows in the model outputs originates from inputs of resources or products to activities. Some products have a long time expectancy, e.g. construction materials. The waste of these materials therefore originates from uses of the materials up to hundred years ago; time series of supply-use tables starting from year 1900 are included in the data input to the model.

The waste flows presented in the standardised waste tables are pure fractions. Thus the waste fraction ‘iron waste’ contains 100% iron and no impurities. The impurities that are present in real life iron scrap appears as quantities in other waste fractions. Typical real life waste fractions such as mixed municipal solid waste cannot be seen in the standardised waste tables.

The standardised waste tables specify where in economy waste generation occurs. However, some wastes will occur one stage upstream in the life cycle of the flows. These are:

- Packaging waste occur in the industries supplying the products contained in the packaging material that becomes waste
- Construction waste from demolition of buildings occur in industry that supplied the construction
- Motor vehicles waste (ELV) occur in the transport manufacturing industries that supplied the vehicles

The reason why the above mentioned three types of waste do not occur in the ‘right activity’ in the standardised waste tables is that the physical flow of these products (the wastes are products before they become wastes) are not included in the physical supply table. Packaging material is generally not recorded in statistical information of physical flows, e.g. the physical supply and use of beverages that can be obtained from FAOSTAT (2009) only include the weight of the beverage itself, and not the packaging. Therefore, the packaging materials will enter the beverage activity, but not leave it in the supply table. Consequently, the packaging material comes out in the beverage activity. As explained in section 3, the physical flows of constructions and motor vehicles are not included. This implies that the physical weight of these products do not appear in the activities where they are used. Instead, the feedstock materials appear as waste outputs and stock additions in the construction and motor vehicle activities.

3.1 Waste generation in EU-27 in year 2003

Waste generation in:
Region: EU27
Year: 2003

			Sector											
Waste category	**Waste fraction**	**Quantity, dry weight (Million t)**	Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Organic	Food waste	526	4%	0%	0%	32%	3%	0%	0%	0%	11%	1%	50%	100%
	Food waste to WWT	4	0%	0%	0%	1%	2%	0%	0%	0%	18%	0%	77%	100%
	Manure	157	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
	Wood waste	82	1%	12%	1%	2%	25%	21%	0%	11%	9%	2%	16%	100%
Textile	Textile waste	18	1%	0%	0%	1%	16%	2%	0%	0%	11%	2%	68%	100%
Paper	Paper waste	113	0%	0%	0%	8%	27%	1%	0%	0%	39%	3%	20%	100%
Plastic	Plastic waste	167	2%	0%	0%	8%	24%	24%	1%	0%	19%	3%	19%	100%
Glass	Glass waste	60	2%	0%	2%	27%	22%	23%	0%	0%	12%	6%	5%	100%
Construction and inert	Sand, stone, clay	1,657	1%	0%	6%	1%	23%	50%	0%	0%	10%	6%	2%	100%
	Cement, concrete, asphalt	566	0%	0%	0%	2%	10%	75%	0%	0%	5%	2%	5%	100%
	Bricks waste	38	0%	0%	0%	0%	8%	73%	0%	0%	8%	2%	8%	100%
	Ash and slag waste	762	0%	0%	1%	0%	3%	0%	1%	7%	2%	83%	2%	100%
	Metal ore waste	90	0%	0%	3%	0%	80%	2%	0%	0%	14%	1%	0%	100%
Metal	Iron waste	218	2%	0%	1%	2%	46%	19%	1%	0%	16%	5%	9%	100%
	Aluminium waste	20	2%	0%	1%	3%	44%	17%	1%	0%	17%	5%	10%	100%
	Copper waste	6	1%	0%	0%	2%	53%	12%	0%	0%	18%	3%	11%	100%
	Metals nec waste	7	2%	0%	1%	2%	38%	16%	1%	0%	21%	6%	12%	100%
	Other materials (non metal)	34	0%	0%	0%	1%	17%	7%	0%	1%	30%	3%	42%	100%
Special fractions	Special fractions	378	11%	0%	0%	1%	28%	2%	17%	0%	12%	2%	26%	100%
Total		**4,904**												

Table 3.1: Waste generation in the EU-27 in 2003.

It appears from the table, that the most significant waste flows (in terms of dry weight) are:

- Construction waste
  - Sand, stone, clay 1657 million tonne
  - Cement, concrete, asphalt 566 million tonne
- Ash and slag waste 762 million tonne
- Food waste 526 million tonne
- Iron waste 218 million tonne
- Plastic waste 167 million tonne
- Manure 157 million tonne
- Paper waste 113 million tonne

Construction waste mainly occur in the construction activity, but also in the industry and service activities construction waste occurs. This is in cases where it is these activities that buys the construction materials that become waste. Ash and slag waste primarily occur in the waste treatment activity (waste incineration). It should be noted that this figure is related to relatively large uncertainties; according to the **J** table, relatively large shares of waste goes to waste incineration. The J table is presented in deliverable D6.1 ‘Documentation of data consolidation, calibration and scenario parameterisation’. Since J-data varies significantly from country to country, and since the data for creating the J table are only based on 20 out of the EU-27 countries (38% of EU-27 GDP), the J-figures are relatively uncertain. Not surprising, food waste mainly occurs in the households and in the food industry. Iron waste occurs in the industry, construction, and service activities. The high generation of iron waste in the service activities is due to the high use of metal containing products as well as iron in construction materials purchased by the service sector. Plastic waste occurs in industry, service and construction activities. Also some 8% is generated in the food industry. This mainly reflects packaging waste. Manure waste only occurs in agriculture. Paper waste occurs in the service, industry and household activities. As in the case of plastic waste some 8% of the paper waste occurs in the food industry. This is mainly packaging waste.

3.2 Waste generation in EU-27 in year 2035

Table 3.2 below summarises the total quantities of generated waste in all scenarios.

		2003	Baseline, 2035			High growth, 2035			Low growth, 2035		
Waste category	**Waste fraction**	**Reference**	**Treatment**	**Recycling**	**Prevention**	**Treatment**	**Recycling**	**Prevention**	**Treatment**	**Recycling**	**Prevention**
Organic	Food waste	526	778	779	761	928	930	908	675	676	660
	Food waste to WWT	4	6	6	6	8	8	8	6	6	6
	Manure	157	183	184	176	203	204	196	175	176	168
	Wood waste	82	160	155	155	174	167	169	155	150	150
Textile	Textile waste	18	26	26	25	30	30	28	23	23	22
Paper	Paper waste	113	169	172	157	198	201	184	148	151	138
Plastic	Plastic waste	167	77	77	72	89	89	84	68	68	63
Glass	Glass waste	60	84	82	77	93	92	87	77	75	71
Construction and inert	Sand, stone, clay	1,657	3,125	3,335	2,972	3,190	3,414	3,032	3,071	3,276	2,925
	Cement, concrete, aspha	566	1,025	1,324	933	1,065	1,400	967	985	1,253	900
	Bricks waste	38	75	75	72	76	76	73	74	74	72
	Ash and slag waste	762	1,353	1,593	1,124	1,527	1,787	1,273	1,222	1,439	1,017
	Metal ore waste	90	116	115	111	135	135	129	101	100	96
Metal	Iron waste	218	306	313	280	337	345	310	282	289	258
	Aluminium waste	20	28	28	26	31	32	29	26	26	24
	Copper waste	6	8	8	8	9	9	9	8	8	7
	Metals nec waste	7	10	10	9	11	11	10	9	9	8
	Other materials (non meta	34	48	48	47	53	53	52	44	44	43
Special fractions	Special fractions	378	666	884	616	739	984	683	588	782	542
Total		4,904	8,242	9,215	7,627	8,896	9,967	8,231	7,734	8,624	7,169

Table 3.2: Waste generation in the EU-27 in the 2003 (reference year) and in 2035 for the nine scenarios. The unit is million tonne (dry weight).

3.2.1 Scenario 1: Baseline scenario, treatment waste scenario, year 2035

Waste generation in:
Region: EU27
Year: 2035
Macro-economic scenario: baseline
Waste treatment scenario: Treatment

Waste category	Waste fraction	Quantity, dry weight (Million t)	Sector: Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Organic	Food waste	778	3%	0%	0%	32%	3%	0%	0%	1%	11%	0%	50%	100%
	Food waste to WWT	6	0%	0%	0%	1%	2%	0%	0%	0%	19%	0%	77%	100%
	Manure	183	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
	Wood waste	160	1%	11%	1%	2%	23%	21%	0%	19%	8%	1%	14%	100%
Textile	Textile waste	26	0%	0%	0%	1%	15%	2%	0%	0%	11%	1%	69%	100%
Paper	Paper waste	169	0%	0%	0%	8%	27%	1%	0%	0%	40%	3%	20%	100%
Plastic	Plastic waste	77	2%	0%	1%	6%	25%	15%	2%	0%	19%	2%	28%	100%
Glass	Glass waste	84	2%	0%	2%	28%	22%	22%	1%	0%	12%	5%	5%	100%
Construction and inert	Sand, stone, clay	3,125	1%	0%	6%	1%	23%	50%	0%	0%	11%	6%	2%	100%
	Cement, concrete, asphalt	1,025	0%	0%	0%	2%	11%	75%	0%	0%	5%	2%	5%	100%
	Bricks waste	75	0%	0%	0%	0%	9%	72%	0%	0%	8%	2%	8%	100%
	Ash and slag waste	1,353	0%	0%	1%	0%	2%	0%	3%	14%	1%	76%	2%	100%
	Metal ore waste	116	0%	0%	2%	0%	77%	2%	0%	0%	17%	1%	0%	100%
Metal	Iron waste	306	2%	0%	1%	2%	46%	18%	1%	0%	17%	4%	9%	100%
	Aluminium waste	28	2%	0%	1%	4%	44%	16%	1%	1%	18%	4%	10%	100%
	Copper waste	8	1%	0%	0%	2%	52%	11%	1%	1%	18%	2%	11%	100%
	Metals nec waste	10	2%	0%	1%	2%	39%	15%	1%	1%	22%	5%	12%	100%
	Other materials (non metal)	48	0%	0%	0%	1%	17%	7%	1%	1%	30%	2%	41%	100%
Special fractions	Special fractions	666	7%	0%	0%	1%	25%	1%	31%	1%	10%	1%	22%	100%
Total		**8,242**												

Table 3.3: Waste generation in the EU-27 in 2035, scenario 1: Baseline, treatment.

3.2.2 Scenario 2: Baseline scenario, recycling waste scenario, year 2035

Waste generation in:
Region: EU27
Year: 2035
Macro-economic scenario: baseline
Waste treatment scenario: Recycling

			Sector											
Waste category	**Waste fraction**	**Quantity, dry weight (Million t)**	Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Organic	Food waste	779	3%	0%	0%	32%	3%	0%	0%	0%	11%	0%	50%	100%
	Food waste to WWT	6	0%	0%	0%	1%	2%	0%	0%	0%	19%	0%	77%	100%
	Manure	184	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
	Wood waste	155	1%	10%	1%	2%	24%	21%	0%	17%	9%	1%	14%	100%
Textile	Textile waste	26	0%	0%	0%	1%	15%	2%	0%	0%	11%	1%	69%	100%
Paper	Paper waste	172	0%	0%	0%	8%	28%	1%	0%	0%	39%	3%	20%	100%
Plastic	Plastic waste	77	2%	0%	1%	6%	26%	15%	2%	0%	19%	2%	28%	100%
Glass	Glass waste	82	2%	0%	1%	29%	22%	22%	1%	0%	13%	5%	5%	100%
Construction and inert	Sand, stone, clay	3,335	1%	0%	5%	1%	28%	47%	0%	0%	10%	5%	1%	100%
	Cement, concrete, asphalt	1,324	0%	0%	0%	2%	31%	58%	0%	0%	4%	1%	4%	100%
	Bricks waste	75	0%	0%	0%	0%	9%	72%	0%	0%	8%	2%	8%	100%
	Ash and slag waste	1,593	0%	0%	1%	0%	2%	0%	3%	10%	1%	82%	1%	100%
	Metal ore waste	115	0%	0%	2%	0%	77%	2%	0%	0%	17%	1%	0%	100%
Metal	Iron waste	313	2%	0%	1%	2%	48%	17%	1%	0%	16%	4%	9%	100%
	Aluminium waste	28	2%	0%	1%	4%	45%	16%	1%	1%	17%	4%	10%	100%
	Copper waste	8	1%	0%	0%	2%	53%	11%	1%	1%	18%	2%	11%	100%
	Metals nec waste	10	2%	0%	1%	2%	40%	15%	1%	1%	22%	5%	12%	100%
	Other materials (non metal)	48	0%	0%	0%	1%	17%	7%	1%	1%	30%	2%	41%	100%
Special fractions	Special fractions	884	6%	0%	0%	1%	44%	1%	23%	0%	8%	1%	17%	100%
Total		**9,215**												

Table 3.4: Waste generation in the EU-27 in 2035, scenario 2: Baseline, recycling.

3.2.3 Scenario 3: Baseline scenario, prevention waste scenario, year 2035

Waste generation in:
Region: EU27
Year: 2035
Macro-economic scenario: baseline
Waste treatment scenario: Waste prevention

Waste category	Waste fraction	Quantity, dry weight (Million t)	Sector: Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Organic	Food waste	761	3%	0%	0%	31%	3%	0%	0%	1%	11%	0%	51%	100%
	Food waste to WWT	6	0%	0%	0%	1%	2%	0%	0%	0%	19%	0%	77%	100%
	Manure	176	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
	Wood waste	155	1%	11%	1%	2%	22%	20%	0%	19%	9%	1%	14%	100%
Textile	Textile waste	25	0%	0%	0%	1%	15%	1%	0%	0%	12%	1%	69%	100%
Paper	Paper waste	157	0%	0%	0%	8%	24%	1%	0%	0%	42%	2%	22%	100%
Plastic	Plastic waste	72	2%	0%	1%	6%	25%	13%	2%	0%	20%	2%	30%	100%
Glass	Glass waste	77	2%	0%	2%	30%	22%	19%	1%	0%	13%	5%	5%	100%
Construction and inert	Sand, stone, clay	2,972	1%	0%	6%	1%	22%	50%	0%	0%	11%	6%	2%	100%
	Cement, concrete, asphalt	933	0%	0%	0%	3%	9%	75%	0%	0%	5%	2%	6%	100%
	Bricks waste	72	0%	0%	0%	0%	9%	72%	0%	0%	9%	2%	8%	100%
	Ash and slag waste	1,124	0%	0%	2%	0%	2%	0%	4%	16%	2%	72%	2%	100%
	Metal ore waste	111	0%	0%	3%	0%	78%	2%	0%	0%	17%	0%	0%	100%
Metal	Iron waste	280	2%	0%	1%	2%	47%	16%	1%	1%	18%	4%	10%	100%
	Aluminium waste	26	2%	0%	1%	4%	45%	14%	1%	1%	19%	4%	11%	100%
	Copper waste	8	1%	0%	0%	2%	53%	9%	1%	1%	19%	2%	12%	100%
	Metals nec waste	9	2%	0%	1%	3%	39%	13%	1%	1%	23%	4%	13%	100%
	Other materials (non metal)	47	0%	0%	0%	1%	16%	5%	1%	1%	31%	2%	43%	100%
Special fractions	Special fractions	616	8%	0%	0%	1%	22%	1%	31%	1%	11%	1%	24%	100%
Total		**7,627**												

Table 3.5: Waste generation in the EU-27 in 2035, scenario 3: Baseline, prevention.

3.2.4 Scenario 4: High growth scenario, treatment waste scenario, year 2035

Waste generation in:
Region: EU27
Year: 2035
Macro-economic scenario: high
Waste treatment scenario: Treatment

			Sector											
Waste category	**Waste fraction**	**Quantity, dry weight (Million t)**	Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Organic	Food waste	928	3%	0%	0%	33%	3%	0%	0%	0%	11%	0%	49%	100%
	Food waste to WWT	8	0%	0%	0%	1%	2%	0%	0%	0%	19%	0%	77%	100%
	Manure	203	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
	Wood waste	174	1%	11%	1%	2%	23%	19%	0%	20%	8%	1%	14%	100%
Textile	Textile waste	30	0%	0%	0%	1%	14%	2%	0%	0%	11%	1%	70%	100%
Paper	Paper waste	198	0%	0%	0%	8%	27%	1%	0%	0%	40%	2%	20%	100%
Plastic	Plastic waste	89	2%	0%	1%	6%	25%	14%	2%	0%	19%	2%	28%	100%
Glass	Glass waste	93	2%	0%	2%	29%	22%	21%	1%	0%	13%	5%	5%	100%
Construction and inert	Sand, stone, clay	3,190	1%	0%	6%	1%	23%	50%	0%	0%	11%	6%	2%	100%
	Cement, concrete, asphalt	1,065	0%	0%	0%	3%	11%	74%	0%	0%	5%	2%	5%	100%
	Bricks waste	76	0%	0%	0%	0%	9%	72%	0%	0%	8%	2%	8%	100%
	Ash and slag waste	1,527	0%	0%	1%	0%	2%	0%	3%	14%	2%	76%	2%	100%
	Metal ore waste	135	0%	0%	2%	0%	77%	2%	0%	0%	17%	0%	0%	100%
Metal	Iron waste	337	1%	0%	1%	2%	47%	17%	1%	0%	17%	4%	9%	100%
	Aluminium waste	31	2%	0%	1%	4%	45%	15%	1%	1%	18%	4%	10%	100%
	Copper waste	9	1%	0%	0%	2%	53%	11%	1%	1%	19%	2%	11%	100%
	Metals nec waste	11	2%	0%	1%	3%	40%	15%	1%	1%	22%	4%	12%	100%
	Other materials (non metal)	53	0%	0%	0%	1%	17%	6%	1%	1%	30%	2%	42%	100%
Special fractions	Special fractions	739	7%	0%	0%	1%	26%	1%	27%	1%	11%	1%	24%	100%
Total		**8,896**												

Table 3.6: Waste generation in the EU-27 in 2035, scenario 4: High growth, treatment.

3.2.5 Scenario 5: High growth scenario, recycling waste scenario, year 2035

Waste generation in:
Region: EU27
Year: 2035
Macro-economic scenario: high
Waste treatment scenario: Recycling

			Sector											
Waste category	**Waste fraction**	**Quantity, dry weight (Million t)**	Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Organic	Food waste	930	3%	0%	0%	33%	3%	0%	0%	0%	11%	0%	49%	100%
	Food waste to WWT	8	0%	0%	0%	1%	2%	0%	0%	0%	19%	0%	77%	100%
	Manure	204	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
	Wood waste	167	1%	10%	1%	2%	24%	20%	0%	18%	8%	1%	15%	100%
Textile	Textile waste	30	0%	0%	0%	1%	15%	2%	0%	0%	11%	1%	69%	100%
Paper	Paper waste	201	0%	0%	0%	8%	29%	1%	0%	0%	40%	2%	20%	100%
Plastic	Plastic waste	89	2%	0%	0%	6%	26%	14%	2%	0%	19%	1%	28%	100%
Glass	Glass waste	92	2%	0%	1%	30%	22%	21%	1%	0%	13%	5%	5%	100%
Construction and inert	Sand, stone, clay	3,414	1%	0%	5%	1%	29%	46%	0%	0%	10%	5%	1%	100%
	Cement, concrete, asphalt	1,400	0%	0%	0%	2%	33%	56%	0%	0%	4%	1%	4%	100%
	Bricks waste	76	0%	0%	0%	0%	9%	72%	0%	0%	8%	2%	8%	100%
	Ash and slag waste	1,787	0%	0%	1%	0%	2%	0%	2%	10%	1%	82%	1%	100%
	Metal ore waste	135	0%	0%	2%	0%	77%	2%	0%	0%	17%	0%	0%	100%
Metal	Iron waste	345	1%	0%	1%	2%	49%	16%	1%	0%	17%	3%	9%	100%
	Aluminium waste	32	2%	0%	1%	4%	46%	15%	1%	1%	18%	3%	10%	100%
	Copper waste	9	1%	0%	0%	2%	53%	11%	1%	1%	19%	2%	11%	100%
	Metals nec waste	11	2%	0%	1%	3%	41%	14%	1%	1%	22%	4%	12%	100%
	Other materials (non metal)	53	0%	0%	0%	1%	17%	6%	1%	1%	30%	2%	42%	100%
Special fractions	Special fractions	984	6%	0%	0%	1%	45%	1%	20%	0%	8%	1%	18%	100%
Total		**9,967**												

Table 3.7: Waste generation in the EU-27 in 2035, scenario 5: High growth, recycling.

3.2.6 Scenario 6: High growth scenario, prevention waste scenario, year 2035

Waste generation in:
Region: EU27
Year: 2035
Macro-economic scenario: High
Waste treatment scenario: Waste prevention

			Sector											
Waste category	**Waste fraction**	**Quantity, dry weight (Million t)**	Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Organic	Food waste	908	3%	0%	0%	32%	3%	0%	0%	0%	11%	0%	50%	100%
	Food waste to WWT	8	0%	0%	0%	1%	2%	0%	0%	0%	19%	0%	77%	100%
	Manure	196	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
	Wood waste	169	1%	11%	1%	2%	22%	19%	0%	20%	8%	1%	15%	100%
Textile	Textile waste	28	0%	0%	0%	1%	14%	1%	0%	0%	12%	1%	70%	100%
Paper	Paper waste	184	0%	0%	0%	8%	24%	1%	0%	0%	42%	2%	22%	100%
Plastic	Plastic waste	84	2%	0%	1%	6%	25%	12%	2%	0%	20%	1%	30%	100%
Glass	Glass waste	87	2%	0%	2%	31%	23%	18%	1%	0%	13%	4%	5%	100%
Construction and inert	Sand, stone, clay	3,032	1%	0%	6%	2%	23%	50%	0%	0%	11%	6%	2%	100%
	Cement, concrete, asphalt	967	0%	0%	0%	3%	9%	74%	0%	0%	6%	2%	6%	100%
	Bricks waste	73	0%	0%	0%	0%	9%	71%	0%	0%	9%	2%	9%	100%
	Ash and slag waste	1,273	0%	0%	2%	0%	2%	0%	3%	17%	2%	72%	2%	100%
	Metal ore waste	129	0%	0%	2%	0%	78%	2%	0%	0%	17%	0%	0%	100%
Metal	Iron waste	310	2%	0%	1%	2%	47%	15%	1%	1%	18%	3%	10%	100%
	Aluminium waste	29	2%	0%	1%	4%	46%	13%	1%	1%	19%	3%	11%	100%
	Copper waste	9	1%	0%	0%	2%	54%	9%	1%	1%	19%	2%	12%	100%
	Metals nec waste	10	2%	0%	1%	3%	40%	12%	1%	1%	23%	4%	13%	100%
	Other materials (non metal)	52	0%	0%	0%	1%	17%	5%	1%	1%	31%	2%	43%	100%
Special fractions	Special fractions	683	8%	0%	0%	1%	23%	1%	27%	1%	11%	1%	26%	100%
Total		**8,231**												

Table 3.8: Waste generation in the EU-27 in 2035, scenario 6: High growth, prevention.

3.2.7 Scenario 7: Low growth scenario, treatment waste scenario, year 2035

Waste generation in:
Region: EU27
Year: 2035
Macro-economic scenario: low
Waste treatment scenario: Treatment

Waste category	Waste fraction	Quantity, dry weight (Million t)	Sector: Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Organic	Food waste	675	3%	0%	0%	32%	3%	0%	0%	1%	11%	1%	49%	100%
	Food waste to WWT	6	0%	0%	0%	1%	2%	0%	0%	0%	18%	0%	77%	100%
	Manure	175	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
	Wood waste	155	1%	11%	1%	2%	23%	21%	0%	19%	8%	1%	13%	100%
Textile	Textile waste	23	0%	0%	0%	1%	15%	2%	0%	0%	11%	1%	68%	100%
Paper	Paper waste	148	0%	0%	0%	8%	28%	1%	0%	0%	39%	3%	20%	100%
Plastic	Plastic waste	68	2%	0%	1%	6%	26%	16%	2%	0%	18%	2%	27%	100%
Glass	Glass waste	77	2%	0%	2%	28%	22%	22%	1%	0%	12%	5%	5%	100%
Construction and inert	Sand, stone, clay	3,071	1%	0%	6%	1%	23%	50%	0%	0%	11%	6%	2%	100%
	Cement, concrete, asphalt	985	0%	0%	0%	2%	10%	75%	0%	0%	5%	2%	5%	100%
	Bricks waste	74	0%	0%	0%	0%	9%	72%	0%	0%	8%	2%	8%	100%
	Ash and slag waste	1,222	0%	0%	2%	0%	2%	0%	3%	15%	1%	75%	2%	100%
	Metal ore waste	101	0%	0%	2%	0%	78%	2%	0%	0%	16%	1%	0%	100%
Metal	Iron waste	282	2%	0%	1%	2%	46%	18%	1%	1%	16%	4%	9%	100%
	Aluminium waste	26	2%	0%	1%	3%	44%	16%	1%	1%	17%	4%	10%	100%
	Copper waste	8	1%	0%	0%	2%	53%	11%	1%	1%	18%	2%	11%	100%
	Metals nec waste	9	2%	0%	1%	2%	39%	15%	1%	1%	21%	5%	12%	100%
	Other materials (non metal)	44	0%	0%	0%	1%	17%	7%	1%	1%	30%	2%	41%	100%
Special fractions	Special fractions	588	8%	0%	0%	1%	25%	1%	31%	1%	10%	1%	22%	100%
Total		**7,734**												

Table 3.9: Waste generation in the EU-27 in 2035, scenario 7: Low growth, treatment.

3.2.8 Scenario 8: Low growth scenario, recycling waste scenario, year 2035

Waste generation in:
Region: EU27
Year: 2035
Macro-economic scenario: low
Waste treatment scenario: Recycling

			Sector											
Waste category	**Waste fraction**	**Quantity, dry weight (Million t)**	Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Organic	Food waste	676	3%	0%	0%	32%	3%	0%	0%	0%	11%	1%	49%	100%
	Food waste to WWT	6	0%	0%	0%	1%	2%	0%	0%	0%	18%	0%	77%	100%
	Manure	176	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
	Wood waste	150	1%	10%	1%	2%	23%	22%	0%	17%	9%	2%	13%	100%
Textile	Textile waste	23	0%	0%	0%	1%	15%	2%	0%	0%	11%	1%	68%	100%
Paper	Paper waste	151	0%	0%	0%	7%	29%	1%	0%	0%	39%	3%	19%	100%
Plastic	Plastic waste	68	2%	0%	1%	6%	26%	15%	2%	0%	18%	2%	27%	100%
Glass	Glass waste	75	2%	0%	1%	28%	22%	22%	1%	0%	12%	5%	5%	100%
Construction and inert	Sand, stone, clay	3,276	1%	0%	5%	1%	28%	47%	0%	0%	10%	5%	1%	100%
	Cement, concrete, asphalt	1,253	0%	0%	0%	2%	30%	59%	0%	0%	4%	1%	4%	100%
	Bricks waste	74	0%	0%	0%	0%	9%	72%	0%	0%	8%	2%	8%	100%
	Ash and slag waste	1,439	0%	0%	1%	0%	2%	0%	3%	11%	1%	81%	1%	100%
	Metal ore waste	100	0%	0%	2%	0%	78%	2%	0%	0%	16%	1%	0%	100%
Metal	Iron waste	289	2%	0%	1%	2%	48%	17%	1%	0%	16%	4%	9%	100%
	Aluminium waste	26	2%	0%	1%	3%	45%	16%	1%	1%	17%	4%	10%	100%
	Copper waste	8	1%	0%	0%	2%	53%	11%	1%	1%	18%	2%	11%	100%
	Metals nec waste	9	2%	0%	1%	2%	40%	15%	1%	1%	21%	5%	12%	100%
	Other materials (non metal)	44	0%	0%	0%	1%	17%	7%	1%	1%	30%	2%	41%	100%
Special fractions	Special fractions	782	6%	0%	0%	1%	44%	1%	23%	0%	7%	1%	16%	100%
Total		**8,624**												

Table 3.10: Waste generation in the EU-27 in 2035, scenario 8: Low growth, recycling.

3.2.9 Scenario 9: Low growth scenario, prevention waste scenario, year 2035

Waste generation in:
Region: EU27
Year: 2035
Macro-economic scenario: low
Waste treatment scenario: Waste prevention

Waste category	Waste fraction	Quantity, dry weight (Million t)	Sector: Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Organic	Food waste	660	3%	0%	0%	31%	3%	0%	0%	1%	11%	0%	50%	100%
	Food waste to WWT	6	0%	0%	0%	1%	2%	0%	0%	0%	18%	0%	77%	100%
	Manure	168	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
	Wood waste	150	1%	11%	1%	2%	22%	21%	0%	19%	8%	1%	13%	100%
Textile	Textile waste	22	1%	0%	0%	1%	15%	1%	0%	0%	12%	1%	69%	100%
Paper	Paper waste	138	0%	0%	0%	8%	25%	1%	0%	0%	41%	3%	21%	100%
Plastic	Plastic waste	63	2%	0%	1%	6%	26%	13%	2%	0%	19%	2%	29%	100%
Glass	Glass waste	71	2%	0%	2%	30%	23%	19%	1%	0%	13%	5%	5%	100%
Construction and inert	Sand, stone, clay	2,925	1%	0%	6%	1%	22%	50%	0%	0%	11%	6%	2%	100%
	Cement, concrete, asphalt	900	0%	0%	0%	2%	8%	76%	0%	0%	5%	2%	6%	100%
	Bricks waste	72	0%	0%	0%	0%	9%	72%	0%	0%	9%	2%	8%	100%
	Ash and slag waste	1,017	0%	0%	2%	0%	2%	0%	4%	17%	2%	71%	2%	100%
	Metal ore waste	96	0%	0%	2%	0%	78%	2%	0%	0%	17%	1%	0%	100%
Metal	Iron waste	258	2%	0%	1%	2%	47%	16%	1%	1%	17%	4%	10%	100%
	Aluminium waste	24	2%	0%	1%	4%	45%	14%	1%	1%	18%	4%	11%	100%
	Copper waste	7	1%	0%	0%	2%	54%	9%	1%	1%	18%	2%	12%	100%
	Metals nec waste	8	2%	0%	1%	3%	40%	13%	1%	1%	22%	5%	12%	100%
	Other materials (non metal)	43	0%	0%	0%	1%	17%	5%	1%	1%	30%	2%	43%	100%
Special fractions	Special fractions	542	8%	0%	0%	1%	22%	1%	31%	1%	10%	1%	23%	100%
Total		**7,169**												

Table 3.11: Waste generation in the EU-27 in 2035, scenario 9: Low growth, prevention.

4 Forecasts of the environmental impacts for each scenario for EU-27 the next 25 years

This chapter presents the model results regarding environmental impacts in 2003 (reference year) and for the nine scenarios in year 2035. The previous chapters have presented results of waste generation and accumulated stocks within the EU-27. The scope of the results in the present chapter is not limited to flows and stocks within the EU-27 because the results on environmental impacts are life cycle based, i.e. impacts within as well as outside the EU-27 are included. The functional unit of the results on environmental impacts is the final demand (household uses and export).

It should be noted that the impact related to imported products is presumed to be equal to domestically produced products. Further, it should be noted that the model results are based on data collection from 20 out of the 27 EU-27 countries, and subsequently the ratio between domestic supply and imported products is also based on these 20 countries. Therefore, uncertainties in the environmental impact outside and inside the EU-27 are present. Uncertainties are further described in deliverable 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’

For all scenarios, the environmental is given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003). When calculating the environmental impacts, the following emissions have been included:

- Carbon dioxide (CO_2), fossil as well as biogenic
- Resource extraction of biogenic carbon
- Nitrogen oxides (NO_x)
- Methane (CH_4)
- Sulphur dioxide (SO_2)
- Dinitrogen monoxide (N_2O)
- Carbon monoxide (CO)
- Non-methane volatile organics (NMVOC)

The LCIA-method, Stepwise 2006 method, version 1.2, has been used for calculating environmental indicators per midpoint impact category and as aggregated, monetarised values. The method is described and documented in Weidema et al. (2007) and Weidema (2009). The method can be downloaded as a CSV-file for import in the LCA software SimaPro at: http://www.lca-net.com/projects/stepwise_ia/. It should be noted that 1 kg fossil and 1 kg biogenic CO_2 emission cause the same impact. Resource extraction of 1 kg biogenic carbon causes an impact of -3.66 kg CO_2-eq. Thus, the growing of an agricultural crop containing 1 kg carbon will cause the effect 3.66 kg CO_2-eq, and when it is digested or disposed of it will cause the effect of 3.66 kg CO_2-eq (if we assume that all carbon contained in the product is released as CO_2).

The results tables provided in the following shows the impacts per activity in economy. In this respect it should be noted that the impact represents the impact caused by the direct emissions of a given activity, e.g.

an impact in the aluminium activity does not include the emissions related to the use of electricity in aluminium manufacturing. These emissions are included in the electricity and heat activity.

The results tables are divided in a column that shows impact from virgin production and the impact from recycling. The sum of the virgin column and the recycling column represents the sun of the current activity. The recycling column specifies the impact from the substances emitted from the recycling activities. Thus, a high impact in the recycling column indicate a high impact from the recycling activity. Also, high impacts in the recycling column indicates high recycling rates. The reason why the emissions from recycling activities are specified separately is, that the FORWAST project is dedicated analysing waste treatment scenarios. In this respect the recycling column allows seeing how the impact from recycling differs between the scenarios. It should be noted that the life cycle impact per unit of supply for virgin is higher than for recycling for most materials. This is further described in deliverable 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’.

4.1 Environmental impacts in EU-27 in year 2003

Table 4.1 below shows, the environmental impacts for EU-27 final demand.

2003 Reference				
	GHG-emissions (million tonne CO2-e)		Environmental impact (GEUR)	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	1,235		110	
Agriculture, plants	-1,298		-100	
Forest	-856	0.005	-70	0.0004
Fish	30		5	
Minerals and metals extraction	271		29	
Food	120		14	
Textiles	61		6	
Pulp and paper	154	0.3	17	0.03
Refined petroleum and gas	328		37	
Plastic	112	0.9	13	0.1
Glass	54	1.1	7	0.1
Cement	271	0.1	27	0.01
Iron	427	70	46	7
Aluminium	53	15	6	2
Copper	28	10	3	1.3
Other metals	17	0.7	2	0.1
Other industry	838		94	
Electricity and heat	2,362		288	
Service and transport	1,914		308	
Waste incineration	1,224		115	
Composting and biogas	111		9	
Waste water	1.0		0.1	
Landfill	968		86	
Households	944		96	
Sum	**9,369**	**98**	**1,152**	**11**
Sum all	**9,467**		**1,162**	

Table 4.1: Environmental impacts related to the EU-27 final uses in 2003. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

It appears from **Table 4.1** that the most significant emissions occur in the following activities:

- Electricity and heat
- Service and transport
- Agriculture, animals
- Waste incineration

Also the emissions in ‘agriculture, plants’ are significant, but this cannot be seen in the table, because the negative contribution to global warming from the resource extraction of carbon overrules the impact. If this biogenic carbon extraction is taken out of the impact from ‘agriculture, plants’, the impact would be 573 million tonne CO_2-eq.

The recycling columns in **Table 4.1** specify the impact from the substances emitted from the recycling activities. Thus, a high impact in the recycling column indicate a high impact from the recycling activity. Also, high impacts in the recycling column indicates high recycling rates. It should be noted that the impact per unit of supply for virgin is higher than for recycling for most materials. This is further described in deliverable 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'.

The total monetarised impact at 1,162 GEUR in **Table 4.1** is distributed on the impact categories given in **Table 4.2** below.

Impact category	Mid-point impact	Unit	End-point impact	Unit
Global warming	9,467	million tonne CO2-eq	786	GEUR
Respiratory inorganics	4.74	million tonne PM2.5-eq	320	GEUR
Photochemical ozone, vegetat.	104,545	billion m2*ppm*hours	39.0	GEUR
Eutrophication, terrestrial	799	billion m2UES	10.0	GEUR
Acidification	544	billion m2UES	4.21	GEUR
Respiratory organics	10.8	billion pers*ppm*h	2.76	GEUR
Eutrophication, aquatic	1.70	million tonne NO3-eq	0.172	GEUR
Total			**1,162**	**GEUR**

Table 4.2: Environmental impacts related to the EU-27 final uses in 2003. The impacts are given in mid-point units (characterised results) as well as end-point units (weighted results).

The monetarised impact at 1,162 GEUR can be compared with the EU-27 GDP in 2003 which was 10,108 GEUR (Eurostat 2009).However, it should be noted that part of the environmental impact takes place outside the EU-27.

The total impact on global warming at 9,467 million tonne CO_2-eq is distributed on 7,622 million tonne CO_2-eq in the EU-27 and 1,845 million tonne CO_2-eq outside the EU-27. Thus, 81% of the GHG-emissions related to EU-27 final uses take place domestically.

4.2 Environmental impacts in EU-27 in year 2035

Table 4.3 below summarises the total monetarised environmental impacts in all scenarios.

Activity	Environmental impact (GEUR) Reference year	Sc1: Baseline, treatment	Sc2: Baseline, recycling	Sc3: Baseline, prevention	Sc4: High growth, treatment	Sc5: High growth, recycling	Sc6: High growth, prevention	Sc7: Low growth, treatment	Sc8: Low growth, recycling	Sc9: Low growth, prevention
Agriculture, animals	110	165	162	157	198	195	189	141	139	135
Agriculture, plants	-100	-146	-144	-143	-176	-174	-171	-126	-124	-123
Forest	-70	-154	-120	-142	-181	-133	-168	-134	-109	-124
Fish	5	8	8	8	10	10	9	7	7	7
Minerals and metals extraction	29	92	81	83	108	93	97	80	71	72
Food	14	30	30	28	36	36	33	26	25	24
Textiles	6	10	10	9	13	12	11	9	8	8
Pulp and paper	17	35	23	28	41	23	33	31	22	25
Refined petroleum and gas	37	105	97	94	124	114	111	90	83	80
Plastic	13	20	18	18	24	22	22	17	16	16
Glass	7	14	12	12	17	14	14	12	10	10
Cement	27	52	27	40	65	34	50	44	23	34
Iron	53	77	72	69	90	84	81	67	63	60
Aluminium	8	14	13	13	17	16	15	12	12	11
Copper	4	7	7	6	8	8	8	6	6	6
Other metals	3	4	4	4	5	5	5	4	4	3
Other industry	94	193	170	162	232	202	194	169	149	142
Electricity and heat	288	1,042	866	1,008	1,231	982	1,194	904	770	874
Service and transport	308	841	801	767	1,007	957	918	719	684	656
Waste incineration	115	257	145	173	367	200	244	188	107	127
Composting and biogas	9	15	146	13	22	220	20	10	104	10
Waste water	0	0	0	0	0	0	0	0	0	0
Landfill	86	61	41	122	87	62	181	45	30	88
Households	96	211	211	201	251	251	239	182	182	173
Sum	**1,162**	**2,954**	**2,680**	**2,730**	**3,596**	**3,234**	**3,327**	**2,504**	**2,283**	**2,312**

Table 4.3: Monetarised environmental impact in the EU-27 in the 2003 (reference year) and in 2035 for the nine scenarios. The unit is billion EUR2003.

4.2.1 Scenario 1: Baseline scenario, treatment waste scenario, year 2035

2035	Baseline, treatment			
	GHG-emissions (million tonne CO2-e)		**Environmental impact (GEUR)**	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	1,840		165	
Agriculture, plants	-1,890		-146	
Forest	-1,890	0.007	-154	0.001
Fish	52		8	
Minerals and metals extraction	885		92	
Food	295		30	
Textiles	100		10	
Pulp and paper	343	0.6	35	0.1
Refined petroleum and gas	940		105	
Plastic	170	1.9	19	0.2
Glass	119	3	14	0.3
Cement	528	0.6	52	0.1
Iron	536	189	58	19
Aluminium	79	49	9	5
Copper	42	21	4	3
Other metals	29	1.7	4	0.2
Other industry	1,835		193	
Electricity and heat	8,223		1,042	
Service and transport	7,325		841	
Waste incineration	2,755		257	
Composting and biogas	174		15	
Waste water	1.7		0.1	
Landfill	658		61	
Households	2,228		211	
Sum	**25,376**	**267**	**2,927**	**27**
Sum all	**25,643**		**2,954**	

Table 4.4: Environmental impacts in EU-27 in 2035: Scenario 1. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

From 2003 to 2035	Baseline, treatment			
	GHG-emissions (million tonne CO2-e)		**Environmental impact (GEUR)**	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	605		54	
Agriculture, plants	-592		-46	
Forest	-1,034	0.002	-84	0.0002
Fish	22		3	
Minerals and metals extraction	615		63	
Food	174		16	
Textiles	40		4	
Pulp and paper	189	0.3	18	0.03
Refined petroleum and gas	612		68	
Plastic	58	0.9	7	0.1
Glass	65	1.6	7	0.2
Cement	256	0.5	25	0.04
Iron	109	119	13	11
Aluminium	26	34	3	3
Copper	15	11	1.5	1.3
Other metals	12	1.0	2	0.1
Other industry	997		98	
Electricity and heat	5,861		754	
Service and transport	5,411		533	
Waste incineration	1,531		142	
Composting and biogas	62		5	
Waste water	0.7		0.1	
Landfill	-310		-26	
Households	1,283		115	
Sum	**16,007**	**169**	**1,775**	**16**
Sum all	**16,176**		**1,792**	

Table 4.5: Difference in environmental impacts in EU-27 in 2035 and 2003: Scenario 1. Positive values indicate a growth in impact and negative values indicate a reduction. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

4.2.2 Scenario 2: Baseline scenario, recycling waste scenario, year 2035

2035	Baseline, recycling			
	GHG-emissions (million tonne CO2-e)		**Environmental impact (GEUR)**	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	1,810		162	
Agriculture, plants	-1,865		-144	
Forest	-1,480	0.006	-120	0.001
Fish	52		8	
Minerals and metals extraction	776		81	
Food	292		30	
Textiles	98		10	
Pulp and paper	211	2.2	23	0.2
Refined petroleum and gas	870		97	
Plastic	155	3.1	18	0.3
Glass	98	6	11	0.6
Cement	277	0.2	27	0.01
Iron	544	133	59	13
Aluminium	80	39	10	4
Copper	43	19	4	2
Other metals	28	1.5	4	0.2
Other industry	1,611		170	
Electricity and heat	6,834		866	
Service and transport	6,963		801	
Waste incineration	1,446		145	
Composting and biogas	1,490		146	
Waste water	1.6		0.1	
Landfill	476		41	
Households	2,228		211	
Sum	**23,037**	**203**	**2,660**	**21**
Sum all	**23,240**		**2,680**	

Table 4.6: Environmental impacts in EU-27 in 2035: Scenario 2. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

From 2003 to 2035	Baseline, recycling			
	GHG-emissions (million tonne CO2-e)		Environmental impact (GEUR)	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	575		52	
Agriculture, plants	-567		-44	
Forest	-624	0.002	-51	0.000
Fish	22		3	
Minerals and metals extraction	505		52	
Food	172		16	
Textiles	37		4	
Pulp and paper	57	1.9	5	0.18
Refined petroleum and gas	542		60	
Plastic	43	2.2	5	0.2
Glass	44	4.9	4	0.5
Cement	6	0.03	0.4	0.002
Iron	117	62	14	6
Aluminium	28	24	3	2
Copper	15	9	1.5	1.1
Other metals	11	0.7	1.3	0.1
Other industry	773		75	
Electricity and heat	4,471		578	
Service and transport	5,048		493	
Waste incineration	222		29	
Composting and biogas	1,378		136	
Waste water	0.6		0.1	
Landfill	-492		-45	
Households	1,283		115	
Sum	**13,668**	**105**	**1,508**	**10**
Sum all	**13,773**		**1,518**	

Table 4.7: Difference in environmental impacts in EU-27 in 2035 and 2003: Scenario 2. Positive values indicate a growth in impact and negative values indicate a reduction. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

4.2.3 Scenario 3: Baseline scenario, prevention waste scenario, year 2035

2035	Baseline, prevention			
	GHG-emissions (million tonne CO2-e)		**Environmental impact (GEUR)**	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	1,756		157	
Agriculture, plants	-1,845		-143	
Forest	-1,753	0.006	-142	0.001
Fish	45		8	
Minerals and metals extraction	788		83	
Food	269		28	
Textiles	88		9	
Pulp and paper	273	0.4	28	0.04
Refined petroleum and gas	843		94	
Plastic	158	1.5	18	0.2
Glass	100	2	12	0.2
Cement	403	0.5	40	0.04
Iron	517	122	57	12
Aluminium	77	35	9	3
Copper	41	16	4	2
Other metals	27	1.2	4	0.2
Other industry	1,524		162	
Electricity and heat	7,958		1,008	
Service and transport	6,530		767	
Waste incineration	1,788		173	
Composting and biogas	161		13	
Waste water	1.4		0.1	
Landfill	1,357		122	
Households	2,108		201	
Sum	**23,213**	**178**	**2,712**	**18**
Sum all	**23,391**		**2,730**	

Table 4.8: Environmental impacts in EU-27 in 2035: Scenario 3. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

From 2003 to 2035	Baseline, prevention			
	GHG-emissions (million tonne CO2-e)		**Environmental impact (GEUR)**	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	521		47	
Agriculture, plants	-547		-42	
Forest	-897	0.001	-73	0.0001
Fish	15		2	
Minerals and metals extraction	518		54	
Food	149		14	
Textiles	27		3	
Pulp and paper	119	0.2	11	0.01
Refined petroleum and gas	515		57	
Plastic	46	0.6	5	0.1
Glass	46	1.0	5	0.1
Cement	131	0.3	13	0.03
Iron	91	52	11	5
Aluminium	24	20	3	2
Copper	13	6	1.4	0.7
Other metals	10	0.5	1.2	0.1
Other industry	685		67	
Electricity and heat	5,596		720	
Service and transport	4,616		459	
Waste incineration	564		58	
Composting and biogas	50		4	
Waste water	0.3		0.03	
Landfill	390		35	
Households	1,163		105	
Sum	**13,844**	**80**	**1,561**	**8**
Sum all	**13,924**		**1,568**	

Table 4.9: Difference in environmental impacts in EU-27 in 2035 and 2003: Scenario 3. Positive values indicate a growth in impact and negative values indicate a reduction. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

4.2.4 Scenario 4: High growth scenario, treatment waste scenario, year 2035

2035	High growth, treatment			
	GHG-emissions (million tonne CO2-e)		Environmental impact (GEUR)	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	2,213		198	
Agriculture, plants	-2,276		-176	
Forest	-2,228	0.009	-181	0.001
Fish	62		10	
Minerals and metals extract	1,037		108	
Food	354		36	
Textiles	123		13	
Pulp and paper	398	0.9	41	0.1
Refined petroleum and gas	1,111		124	
Plastic	202	2.7	23	0.3
Glass	142	4	16	0.4
Cement	656	0.9	65	0.1
Iron	582	267	63	26
Aluminium	86	68	10	6
Copper	47	28	5	4
Other metals	34	2.4	5	0.3
Other industry	2,212		232	
Electricity and heat	9,716		1,231	
Service and transport	8,770		1,007	
Waste incineration	3,964		367	
Composting and biogas	263		22	
Waste water	2.3		0.2	
Landfill	952		87	
Households	2,644		251	
Sum	**31,067**	**373**	**3,558**	**38**
Sum all	**31,441**		**3,596**	

Table 4.10: Environmental impacts in EU-27 in 2035: Scenario 4. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

From 2003 to 2035	High growth, treatment			
	GHG-emissions (million tonne CO2-e)		Environmental impact (GEUR)	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	978		87	
Agriculture, plants	-978		-75	
Forest	-1,372	0.005	-111	0.0004
Fish	32		5	
Minerals and metals extract	766		79	
Food	234		22	
Textiles	63		6	
Pulp and paper	244	0.6	24	0.06
Refined petroleum and gas	783		87	
Plastic	90	1.7	10	0.2
Glass	88	2.8	9	0.3
Cement	384	0.7	38	0.06
Iron	155	197	18	19
Aluminium	33	53	4	5
Copper	19	19	1.9	2.2
Other metals	17	1.7	2	0.2
Other industry	1,374		138	
Electricity and heat	7,354		943	
Service and transport	6,856		699	
Waste incineration	2,740		251	
Composting and biogas	151		13	
Waste water	1.3		0.1	
Landfill	-15		1.2	
Households	1,700		155	
Sum	**21,699**	**275**	**2,407**	**27**
Sum all	**21,974**		**2,434**	

Table 4.11: Difference in environmental impacts in EU-27 in 2035 and 2003: Scenario 4. Positive values indicate a growth in impact and negative values indicate a reduction. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

4.2.5 Scenario 5: High growth scenario, recycling waste scenario, year 2035

2035	High growth, recycling			
	GHG-emissions (million tonne CO2-e)		Environmental impact (GEUR)	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	2,179		195	
Agriculture, plants	-2,247		-174	
Forest	-1,636	0.008	-133	0.001
Fish	62		10	
Minerals and metals extract	884		93	
Food	351		36	
Textiles	120		12	
Pulp and paper	204	3.2	23	0.3
Refined petroleum and gas	1,020		114	
Plastic	184	4.5	21	0.5
Glass	115	8	13	0.9
Cement	346	0.2	34	0.02
Iron	599	192	65	19
Aluminium	88	54	11	5
Copper	47	26	5	3
Other metals	32	2.0	4	0.3
Other industry	1,921		202	
Electricity and heat	7,748		982	
Service and transport	8,322		957	
Waste incineration	2,018		200	
Composting and biogas	2,256		220	
Waste water	2.2		0.2	
Landfill	713		62	
Households	2,644		251	
Sum	**27,973**	**290**	**3,205**	**29**
Sum all	**28,264**		**3,234**	

Table 4.12: Environmental impacts in EU-27 in 2035: Scenario 5. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

From 2003 to 2035	High growth, recycling			
	GHG-emissions (million tonne CO2-e)		Environmental impact (GEUR)	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	944		85	
Agriculture, plants	-949		-73	
Forest	-780	0.003	-63	0.0003
Fish	32		5	
Minerals and metals extract	613		64	
Food	231		22	
Textiles	59		6	
Pulp and paper	50	2.9	5	0.29
Refined petroleum and gas	692		77	
Plastic	72	3.6	8	0.4
Glass	61	7.3	6	0.7
Cement	75	0.1	7.2	0.01
Iron	172	122	20	12
Aluminium	36	38	4	4
Copper	19	16	1.9	1.9
Other metals	15	1.3	1.9	0.2
Other industry	1,083		108	
Electricity and heat	5,386		694	
Service and transport	6,408		649	
Waste incineration	794		85	
Composting and biogas	2,144		211	
Waste water	1.1		0.1	
Landfill	-255		-24	
Households	1,700		155	
Sum	**18,605**	**192**	**2,053**	**19**
Sum all	**18,797**		**2,072**	

Table 4.13: Difference in environmental impacts in EU-27 in 2035 and 2003: Scenario 5. Positive values indicate a growth in impact and negative values indicate a reduction. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

4.2.6 Scenario 6: High growth scenario, prevention waste scenario, year 2035

2035	High growth, prevention			
	GHG-emissions (million tonne CO2-e)		Environmental impact (GEUR)	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	2,111		189	
Agriculture, plants	-2,218		-171	
Forest	-2,068	0.008	-168	0.001
Fish	53		9	
Minerals and metals extract	923		97	
Food	323		33	
Textiles	107		11	
Pulp and paper	317	0.6	33	0.06
Refined petroleum and gas	994		111	
Plastic	188	2.2	22	0.2
Glass	118	3	14	0.3
Cement	499	0.6	50	0.05
Iron	579	172	64	17
Aluminium	86	47	10	5
Copper	46	21	5	3
Other metals	31	1.7	4	0.2
Other industry	1,832		194	
Electricity and heat	16,308		1,194	
Service and transport	7,814		918	
Waste incineration	2,535		244	
Composting and biogas	244		20	
Waste water	1.8		0.2	
Landfill	2,023		181	
Households	2,502		239	
Sum	**35,349**	**249**	**3,301**	**25**
Sum all	**35,598**		**3,327**	

Table 4.14: Environmental impacts in EU-27 in 2035: Scenario 6. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

From 2003 to 2035	High growth, prevention			
	GHG-emissions (million tonne CO2-e)		Environmental impact (GEUR)	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	876		78	
Agriculture, plants	-920		-71	
Forest	-1,212	0.003	-98	0.0003
Fish	23		4	
Minerals and metals extract	653		68	
Food	203		20	
Textiles	47		5	
Pulp and paper	163	0.3	15	0.03
Refined petroleum and gas	666		74	
Plastic	76	1.3	9	0.1
Glass	64	1.9	7	0.2
Cement	228	0.5	22	0.04
Iron	152	102	18	10
Aluminium	33	32	4	3
Copper	18	11	1.9	1.4
Other metals	14	0.9	1.9	0.1
Other industry	993		100	
Electricity and heat	13,946		905	
Service and transport	5,900		610	
Waste incineration	1,311		128	
Composting and biogas	133		11	
Waste water	0.8		0.1	
Landfill	1,055		94	
Households	1,557		143	
Sum	**25,980**	**151**	**2,150**	**15**
Sum all	**26,131**		**2,165**	

Table 4.15: Difference in environmental impacts in EU-27 in 2035 and 2003: Scenario 6. Positive values indicate a growth in impact and negative values indicate a reduction. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

4.2.7 Scenario 7: Low growth scenario, treatment waste scenario, year 2035

2035	Low growth, treatment			
	GHG-emissions (million tonne CO2-e)		**Environmental impact (GEUR)**	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	1,582		141	
Agriculture, plants	-1,628		-126	
Forest	-1,649	0.006	-134	0.0005
Fish	45		7	
Minerals and metals extract	766		80	
Food	253		26	
Textiles	84		9	
Pulp and paper	302	0.4	31	0.04
Refined petroleum and gas	802		90	
Plastic	147	1.4	17	0.2
Glass	103	2	12	0.2
Cement	443	0.5	44	0.04
Iron	489	140	53	14
Aluminium	73	38	9	4
Copper	40	17	4	2
Other metals	26	1.3	4	0.2
Other industry	1,604		169	
Electricity and heat	7,134		904	
Service and transport	6,263		719	
Waste incineration	2,015		188	
Composting and biogas	124		10	
Waste water	1.4		0.1	
Landfill	486		45	
Households	1,917		182	
Sum	**21,424**	**201**	**2,484**	**20**
Sum all	**21,625**		**2,504**	

Table 4.16: Environmental impacts in EU-27 in 2035: Scenario 7. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

From 2003 to 2035	Low growth, treatment			
	GHG-emissions (million tonne CO2-e)		Environmental impact (GEUR)	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	348		31	
Agriculture, plants	-331		-25	
Forest	-792	0.001	-64	0.0001
Fish	15		2	
Minerals and metals extract	495		51	
Food	133		12	
Textiles	23		2	
Pulp and paper	147	0.2	14	0.02
Refined petroleum and gas	474		52	
Plastic	35	0.5	4	0.0
Glass	49	0.9	5	0.1
Cement	172	0.4	17	0.03
Iron	63	70	8	7
Aluminium	21	23	2	2
Copper	12	7	1.2	0.8
Other metals	9	0.6	1.1	0.1
Other industry	766		74	
Electricity and heat	4,772		616	
Service and transport	4,349		411	
Waste incineration	791		73	
Composting and biogas	13		1.0	
Waste water	0.3		0.0	
Landfill	-482		-41	
Households	973		86	
Sum	**12,055**	**103**	**1,332**	**10**
Sum all	**12,158**		**1,342**	

Table 4.17: Difference in environmental impacts in EU-27 in 2035 and 2003: Scenario 7. Positive values indicate a growth in impact and negative values indicate a reduction. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

4.2.8 Scenario 8: Low growth scenario, recycling waste scenario, year 2035

2035	Low growth, recycling			
	GHG-emissions (million tonne CO2-e)		Environmental impact (GEUR)	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	1,555		139	
Agriculture, plants	-1,607		-124	
Forest	-1,341	0.005	-109	0.000
Fish	45		7	
Minerals and metals extract	681		71	
Food	251		25	
Textiles	81		8	
Pulp and paper	206	1.5	22	0.2
Refined petroleum and gas	745		83	
Plastic	136	2.3	16	0.3
Glass	86	4	10	0.5
Cement	232	0.1	23	0.01
Iron	490	96	53	10
Aluminium	74	30	9	3
Copper	40	15	4	2
Other metals	25	1.1	3	0.2
Other industry	1,418		149	
Electricity and heat	6,076		770	
Service and transport	5,950		684	
Waste incineration	1,071		107	
Composting and biogas	1,060		104	
Waste water	1.3		0.1	
Landfill	343		30	
Households	1,917		182	
Sum	**19,534**	**151**	**2,268**	**15**
Sum all	**19,685**		**2,283**	

Table 4.18: Environmental impacts in EU-27 in 2035: Scenario 8. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

From 2003 to 2035	Low growth, recycling			
	GHG-emissions (million tonne CO2-e)		Environmental impact (GEUR)	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	320		29	
Agriculture, plants	-309		-24	
Forest	-485	0.000	-39	0.000
Fish	15		2	
Minerals and metals extract	410		42	
Food	131		12	
Textiles	21		2	
Pulp and paper	51	1.3	4	0.12
Refined petroleum and gas	417		46	
Plastic	24	1.4	3	0.1
Glass	32	3.4	3	0.3
Cement	-39	-0.01	-4.1	-0.002
Iron	63	26	8	2
Aluminium	22	15	2	1
Copper	12	6	1.2	0.6
Other metals	8	0.4	0.9	0.05
Other industry	580		55	
Electricity and heat	3,713		482	
Service and transport	4,036		376	
Waste incineration	-153		-8	
Composting and biogas	949		94	
Waste water	0.3		0.02	
Landfill	-625		-57	
Households	973		86	
Sum	**10,165**	**53**	**1,116**	**5**
Sum all	**10,218**		**1,121**	

Table 4.19: Difference in environmental impacts in EU-27 in 2035 and 2003: Scenario 8. Positive values indicate a growth in impact and negative values indicate a reduction. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

4.2.9 Scenario 9: Low growth scenario, prevention waste scenario, year 2035

2035	Low growth, prevention			
	GHG-emissions (million tonne CO2-e)		**Environmental impact (GEUR)**	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	1,510		135	
Agriculture, plants	-1,591		-123	
Forest	-1,527	0.005	-124	0.0004
Fish	39		7	
Minerals and metals extract	681		72	
Food	231		24	
Textiles	73		8	
Pulp and paper	240	0.3	25	0.03
Refined petroleum and gas	719		80	
Plastic	137	1.2	16	0.1
Glass	87	2	10	0.2
Cement	339	0.4	34	0.03
Iron	462	92	51	9
Aluminium	71	27	9	3
Copper	38	13	4	2
Other metals	24	0.9	3	0.1
Other industry	1,337		142	
Electricity and heat	6,894		874	
Service and transport	5,582		656	
Waste incineration	1,314		127	
Composting and biogas	114		10	
Waste water	1.1		0.1	
Landfill	979		88	
Households	1,814		173	
Sum	**19,567**	**136**	**2,298**	**14**
Sum all	**19,703**		**2,312**	

Table 4.20: Environmental impacts in EU-27 in 2035: Scenario 9. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

From 2003 to 2035	Low growth, prevention			
	GHG-emissions (million tonne CO2-e)		Environmental impact (GEUR)	
Activity	Virgin	Recycling	Virgin	Recycling
Agriculture, animals	275		25	
Agriculture, plants	-293		-23	
Forest	-671	0.0002	-54	0.00002
Fish	9		1	
Minerals and metals extract	410		42	
Food	111		10	
Textiles	12		1	
Pulp and paper	86	0.05	7	0.003
Refined petroleum and gas	392		43	
Plastic	25	0.2	3	0.02
Glass	33	0.5	3	0.04
Cement	68	0.2	7	0.02
Iron	35	21	5	2
Aluminium	18	12	2	1.0
Copper	10	3	1.0	0.3
Other metals	7	0.2	0.8	0.02
Other industry	498		48	
Electricity and heat	4,532		585	
Service and transport	3,667		347	
Waste incineration	90		12	
Composting and biogas	3		0.2	
Waste water	0.03		0.003	
Landfill	11		2	
Households	870		77	
Sum	**10,198**	**38**	**1,147**	**3**
Sum all	**10,236**		**1,150**	

Table 4.21: Difference in environmental impacts in EU-27 in 2035 and 2003: Scenario 9. Positive values indicate a growth in impact and negative values indicate a reduction. Environmental impacts are given in GHG units (million tonne CO2-eq) as well as in monetarised units (billion EUR2003, i.e. GEUR2003).

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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

Contract number: 044409

Deliverable n° 6-3

Title:

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.

Authors:

Jannick H. Schmidt, 2.-0 LCA consultants

Due date of deliverable: 31th October 2009
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Revision: final
Dissemination level: PU (Public)

Project home page: http://forwast.brgm.fr/

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 EU-27 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 EU-27.

These inventory and assessment results are provided as an output of a Leontief-type environmentally extended, quasi-dynamic, physical input-output model covering the EU-27, 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 6-3 is to present a contribution analysis, an uncertainty assessment, the results of identifying priority material flows and wastes for waste prevention, recycling and choice of waste treatment options as well as policy recommendations.

2 Contribution analysis and interpretation: Waste flows

The waste generation in EU-27 in year 2003 and in year 2035 in nine different scenarios is presented in deliverable 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’. This section further analyses and interprets these results.

2.1 Contribution analysis: waste quantities and generating activities in year 2003

Table 2.1 presents the total quantity of generated waste of 19 different waste fractions in EU-27 in year 2003 and its distribution on 11 groups of activities in the economy that generate the waste. In the following each of the 19 waste fractions are explained, and the generating activities are identified.

Waste generation in:
Region: EU27
Year: 2003

			Sector											
Waste category	**Waste fraction**	**Quantity, dry weight (Million t)**	Agriculture and fishery	Forestry	Ressource extraction	Food industry	Industry	Construction	Refineries and gas	Electricity and heat	Service	Waste treatment	Household	All sectors
Organic	Food waste	526	4%	0%	0%	32%	3%	0%	0%	0%	11%	1%	50%	100%
	Food waste to WWT	4	0%	0%	0%	1%	2%	0%	0%	0%	18%	0%	77%	100%
	Manure	157	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
	Wood waste	82	1%	12%	1%	2%	25%	21%	0%	11%	9%	2%	16%	100%
Textile	Textile waste	18	1%	0%	0%	1%	16%	2%	0%	0%	11%	2%	68%	100%
Paper	Paper waste	113	0%	0%	0%	8%	27%	1%	0%	0%	39%	3%	20%	100%
Plastic	Plastic waste	167	2%	0%	0%	8%	24%	24%	1%	0%	19%	3%	19%	100%
Glass	Glass waste	60	2%	0%	2%	27%	22%	23%	0%	0%	12%	6%	5%	100%
Construction and inert	Sand, stone, clay	1,657	1%	0%	6%	1%	23%	50%	0%	0%	10%	6%	2%	100%
	Cement, concrete, asphalt	566	0%	0%	0%	2%	10%	75%	0%	0%	5%	2%	5%	100%
	Bricks waste	38	0%	0%	0%	0%	8%	73%	0%	0%	8%	2%	8%	100%
	Ash and slag waste	762	0%	0%	1%	0%	3%	0%	1%	7%	2%	83%	2%	100%
	Metal ore waste	90	0%	0%	3%	0%	80%	2%	0%	0%	14%	1%	0%	100%
Metal	Iron waste	218	2%	0%	1%	2%	46%	19%	1%	0%	16%	5%	9%	100%
	Aluminium waste	20	2%	0%	1%	3%	44%	17%	1%	0%	17%	5%	10%	100%
	Copper waste	6	1%	0%	0%	2%	53%	12%	0%	0%	18%	3%	11%	100%
	Metals nec waste	7	2%	0%	1%	2%	38%	16%	1%	0%	21%	6%	12%	100%
	Other materials (non metal)	34	0%	0%	0%	1%	17%	7%	0%	1%	30%	3%	42%	100%
Special fractions	Special fractions	378	11%	0%	0%	1%	28%	2%	17%	0%	12%	2%	26%	100%
Total		**4,904**												

Table 2.1: Waste generation in the EU-27 in 2003.

2.1.1 Food waste

The total quantity of food waste in EU-27 in year 2003 was 526 million tonne (dry weight). Inputs of food/feed products to an activity becomes:

- Supply of products, e.g. inputs of rapeseed to an oil mill becomes supply of vegetable oil and animal feed
- Emissions, when food/feed is digested it becomes respiratory emissions – mainly CO_2, H_2O and some CH_4
- Waste: Human excretion and urine, i.e. originating from digested food by humans. This fraction belongs to the waste fraction 'Food waste to WWT', see section 2.1.2
- Waste: Manure, i.e. originating from digested feed by animals. This fraction belongs to the waste fraction 'Manure', see section 2.1.3
- Waste: All outputs that are not included in the above bullets, i.e. non-digested food residuals. This fraction belongs to the waste fraction '2.1.1' which is further described below

Since the waste fraction 'Food waste to WWT' is calculated based on the human metabolism and the number of inhabitants in the EU countries, only excretion and urine are included in this fraction. Thus, no non-digested food is present in the 'Food waste to WWT' fraction. Since this does not fully reflect reality, too much food waste is present in 'Food waste' and too little is present in 'Food waste to WWT'.

Food waste originates from the uses of the following products:

- Bovine meat and milk
- Pigs
- Poultry and animals n.e.c.
- Grain crops
- Crops n.e.c.
- Fish
- Meat and fish products
- Dairy products
- Fruits and vegetables, processed
- Vegetable and animal oils and fats
- Flour
- Sugar
- Animals feed
- Food preparations n.e.c.
- Beverages

50% of the food waste occurs in the households, 32% in the food industry, and 11% in service activities (mainly hotels and restaurants). It should be noted that the quantity of food waste does not say anything about the potential for minimising loss because it includes usable wastes (e.g. food that has expired its shelf life) as well as non usable wastes (e.g. non-edible parts of food).

2.1.2 Food waste to WWT

The total quantity of 'food waste to WWT' in EU-27 in year 2003 was 4 million tonne (dry weight). The characteristics of the waste fraction is described in section 2.1.1. 'Food waste to WWT' occurs in the activities where food is eaten, i.e. mainly in the households and in service (hotels and restaurants).

2.1.3 Manure

The total quantity of 'manure' in EU-27 in year 2003 was 157 million tonne (dry weight). The characteristics of the waste fraction is described in section 2.1.1. 'Manure' occurs in animal production activities in agriculture; 'Bovine meat and milk', 'Pigs' and 'Poultry and animals nec.'.

2.1.4 Wood waste

The total quantity of 'wood waste' in EU-27 in year 2003 was 82 million tonne (dry weight). Wood waste originates from the use of the following products:

- Forestry products (except waste of forestry products occurring in pulp manufacturing, this is partly discarded with waste water, partly landfilled, and partly incinerated; these wastes are included in the 'Special fractions', see Table 2.1)
- Tobacco products (insignificant, but included here to ensure that it is included)
- Wood products, except furniture

In addition, a part of the waste fraction 'Other materials (non metal)' in Table 2.1 (total quantity at 34 million tonne) is wood waste contained in waste of:

- Fabricated metal products, except machinery
- Machinery and equipment n.e.c.
- Office machinery and computers
- Electrical machinery n.e.c.
- Radio, television and communication equipment
- Instruments, medical, precision, optical, clocks
- Furniture; other manufactured goods n.e.c.

However, since the total quantity of 'Other materials (non metal)' is 34 million tonne (compared to total wood waste at 82 million tonne), and since only a small fraction of the above mentioned products is non-metal materials, this additional quantity of wood waste is considered as being insignificant.

Wood waste includes both waste of wood products and ash from combusted wood (biomass). Thus, wood waste in the electricity activity is mainly ash.

Wood waste mainly occurs in industry (wood products manufacturing, pulp manufacturing, and manufacturing of furniture).

2.1.5 Textile waste

The total quantity of 'textile waste' in EU-27 in year 2003 was 18 million tonne (dry weight). Textile waste originates from the use of the following products:

- Textiles
- Wearing apparel and furs
- Leather products, footwear

In addition, a minor part of the waste fraction 'Other materials (non metal)' in Table 2.1 (34 million tonne) is textile waste. See description in section 2.1.4. However, this is considered as insignificant compared to the quantity of textile waste at 18 million tonne.

Textile waste mainly occurs in households (clothing and housing – the latter includes textiles such as floor carpets etc.).

2.1.6 Paper waste

The total quantity of 'paper waste' in EU-27 in year 2003 was 113 million tonne (dry weight). Paper waste originates from the use of the following products:

- Pulp, virgin (except waste of pulp occurring in pulp and paper manufacturing, this is partly discarded with waste water, partly landfilled, and partly incinerated; these wastes are included in the 'Special fractions', see Table 2.1)
- Paper and paper products
- Printed matter and recorded media

It should be noted that a minor share of the last bullet above includes CDs, DVDS etc. This has not been separated from the 'paper waste' fraction.

Waste originating from the use of paper products in the household activity 'hygiene' is not included as 'paper waste' since this waste is regarded as being discarded via waste water. In Table 2.1, this tissue paper in waste water is included in the waste fraction 'Special fractions'.

In addition, a minor part of the waste fraction 'Other materials (non metal)' in Table 2.1 (34 million tonne) is paper waste. See description in section 2.1.4. However, this is considered as insignificant compared to the quantity of paper waste at 113 million tonne.

Paper waste mainly occurs in service industry (mainly in 'Business services nec.', wholesale and retail), industry (mainly in 'Printed matter and recorded media' and 'Paper and paper products'), and households (mainly leisure).

2.1.7 Plastic waste

The total quantity of 'plastic waste' in EU-27 in year 2003 was 167 million tonne (dry weight). Plastic waste originates from the use of the following products:

- Plastics basic, virgin
- Rubber and plastic products

In addition, a minor part of the waste fraction 'Other materials (non metal)' in Table 2.1 (34 million tonne) is plastic waste. See description in section 2.1.4. However, this is considered as insignificant compared to the quantity of plastic waste at 167 million tonne.

Plastic waste mainly occurs in households (waste of plastic products), construction (in construction materials), service (mainly packaging waste in wholesale and retail), and industry (mainly in packaging material in 'Chemicals nec.' and plastic industry). Also note that 8% of the plastic waste occurs in the food industry (Table 2.1); this is mainly packaging waste.

2.1.8 Glass waste

The total quantity of 'glass waste' in EU-27 in year 2003 was 60 million tonne (dry weight). Glass waste originates from the use of the following products:

- Glass, mineral wool and ceramic goods, virgin

In addition, a minor part of the waste fraction 'Other materials (non metal)' in Table 2.1 (34 million tonne) is glass waste. See description in section 2.1.4. However, this is considered as insignificant compared to the quantity of glass waste at 60 million tonne.

Glass waste mainly occurs in the food industry (packaging waste), construction (window glass), and industry (motor vehicles and the glass manufacture industry.

2.1.9 Sand, stone, clay waste

The total quantity of 'sand, stone, clay waste' in EU-27 in year 2003 was 1,657 million tonne (dry weight). 'Sand, stone, clay waste' originates from the use of the following products:

- Sand, gravel and stone from quarry
- Clay and soil from quarry
- Minerals from mine n.e.c.

In addition, a minor part of the waste fraction 'Other materials (non metal)' in Table 2.1 (34 million tonne) is 'sand, stone, clay waste'. See description in section 2.1.4. However, this is considered as insignificant compared to the quantity of 'sand, stone, clay waste' at 1,657 million tonne.

'Sand, stone, clay waste' mainly occurs in the construction industry (sand and stone used as foundation, and sand and stone mixed with cement to produce concrete on site or mixed with asphalt), and various other activities where sand, stone if used for construction purposes.

2.1.10 Cement, concrete asphalt waste

The total quantity of 'cement, concrete asphalt waste' in EU-27 in year 2003 was 566 million tonne (dry weight). 'Cement, concrete asphalt waste' originates from the use of the following products:

- Cement, virgin
- Concrete, asphalt and other mineral products

In addition, a minor part of the waste fraction 'Other materials (non metal)' in Table 2.1 (34 million tonne) is 'cement, concrete asphalt waste'. See description in section 2.1.4. However, this is considered as insignificant compared to the quantity of 'cement, concrete asphalt waste' at 566 million tonne.

'Cement, concrete asphalt waste' mainly occurs in the construction industry (waste of construction materials). 75% of the 'cement, concrete asphalt waste' occurs in the construction sector. The remaining originates from other activities' uses of construction materials.

2.1.11 Bricks waste

The total quantity of 'bricks waste' in EU-27 in year 2003 was 38 million tonne (dry weight). 'Bricks waste' originates from the use of the following products:

- Bricks

'Bricks waste' mainly occurs in the construction industry (waste of construction materials). 73% of the 'bricks waste' occurs in the construction sector. The remaining originates from other activities' uses of bricks.

2.1.12 Ash and slag waste

The total quantity of 'ash and slag waste' in EU-27 in year 2003 was 762 million tonne (dry weight). 'Slag and ash waste' originates from the use of the following products:

- Coal, lignite, peat

and from the supply of the following services:

- Incineration of waste: Food
- Incineration of waste: Paper
- Incineration of waste: Plastic
- Incineration of waste: Metals
- Incineration of waste: Glass/inert
- Incineration of waste: Textiles
- Incineration of waste: Wood
- Incineration of waste: Oil/Hazardous waste

It should be noted that slag and ash from the burning of other materials than coal and waste, e.g. biomass, is included in the model as e.g. waste of forest products in case of ash from burning of biomass.

'Slag and ash waste' mainly occurs in the waste incineration activities (mainly incineration of inert materials, metals and food waste) and 'electricity, steam and hot water'. It should be noted that the amount of slag and ash waste from waste incineration may be overestimated due to a too high share of waste sent to incineration. The shares of waste fractions sent to waste incineration is based on an weighted average of the 20 EU countries for which data collection has been available for inclusion for the calculation of model results. Especially, the shares of inert wastes may be overestimated because, the share of waste sent to incineration may be calculated based on the actual quantity incinerated divided by an underestimated total amount of inter waste. The shares can be seen in the so-called J matrix (see chapter 4 in deliverable D6-1 'Documentation of the data consolidation and calibration exercise, and the scenario parameterisation'). See section 4.10 for further details on the uncertainties relating to the J matrix.

2.1.13 Metal ore waste

The total quantity of 'metal ore waste' in EU-27 in year 2003 was 90 million tonne (dry weight). 'Metal ore waste' originates from the use of the following products:

- Iron ores from mine
- Bauxite from mine
- Copper from mine
- Metals from mine n.e.c.

'Metal ore waste' mainly occurs in industry (manufacture of basic metals).

2.1.14 Iron waste

The total quantity of 'iron waste' in EU-27 in year 2003 was 218 million tonne (dry weight). 'Iron waste' originates from the use of the following products:

- Iron basic, virgin
- Iron, after first processing
- *Iron contained in:* Fabricated metal products, except machinery
- *Iron contained in:* Machinery and equipment n.e.c.
- *Iron contained in:* Office machinery and computers
- *Iron contained in:* Electrical machinery n.e.c.
- *Iron contained in:* Radio, television and communication equipment
- *Iron contained in:* Instruments, medical, precision, optical, clocks
- *Iron contained in:* Furniture; other manufactured goods n.e.c.

The seven last bullets above concern products which are composed of different waste fractions. In the model, disassembly is applied, see description in section 4 in deliverable D6-1 'Documentation of the data consolidation and calibration exercise, and the scenario parameterisation'.

'Iron waste' mainly occurs in industry (mainly in iron processing and transport vehicles), construction (iron in construction materials), and service activities (iron in machinery and equipment etc.).

2.1.15 Aluminium waste

The total quantity of 'aluminium waste' in EU-27 in year 2003 was 20 million tonne (dry weight). 'Aluminium waste' originates from the use of the following products:

- Aluminium basic, virgin
- Aluminium, after first processing
- *Aluminium contained in:* Fabricated metal products, except machinery
- *Aluminium contained in:* Machinery and equipment n.e.c.
- *Aluminium contained in:* Office machinery and computers
- *Aluminium contained in:* Electrical machinery n.e.c.
- *Aluminium contained in:* Radio, television and communication equipment
- *Aluminium contained in:* Instruments, medical, precision, optical, clocks
- *Aluminium contained in:* Furniture; other manufactured goods n.e.c.

The seven last bullets above concern products which are composed of different waste fractions. In the model, disassembly is applied, see description in section 4 in deliverable D6-1 'Documentation of the data consolidation and calibration exercise, and the scenario parameterisation'.

'Aluminium waste' mainly occurs in industry (mainly in aluminium processing and transport vehicles), construction (aluminium in construction materials), and service activities (aluminium in machinery and equipment etc.).

2.1.16 Copper waste

The total quantity of 'copper waste' in EU-27 in year 2003 was 5.9 million tonne (dry weight). 'Copper waste' originates from the use of the following products:

- Copper basic, virgin
- Copper, after first processing
- *Copper contained in:* Fabricated metal products, except machinery
- *Copper contained in:* Machinery and equipment n.e.c.
- *Copper contained in:* Office machinery and computers
- *Copper contained in:* Electrical machinery n.e.c.
- *Copper contained in:* Radio, television and communication equipment
- *Copper contained in:* Instruments, medical, precision, optical, clocks
- *Copper contained in:* Furniture; other manufactured goods n.e.c.

The seven last bullets above concern products which are composed of different waste fractions. In the model, disassembly is applied, see description in section 4 in deliverable D6-1 'Documentation of the data consolidation and calibration exercise, and the scenario parameterisation'.

'Copper waste' mainly occurs in industry (mainly in copper processing and transport vehicles), construction (copper in construction materials), and service activities (copper in machinery and equipment etc.).

2.1.17 Metals nec. waste

The total quantity of 'metals nec. waste' in EU-27 in year 2003 was 7.0 million tonne (dry weight). 'Metals nec. waste' originates from the use of the following products:

- Metals nec. basic, virgin
- Metals nec., after first processing
- *Metals nec. contained in:* Fabricated metal products, except machinery
- *Metals nec. contained in:* Machinery and equipment n.e.c.
- *Metals nec. contained in:* Office machinery and computers
- *Metals nec. contained in:* Electrical machinery n.e.c.
- *Metals nec. contained in:* Radio, television and communication equipment
- *Metals nec. contained in:* Instruments, medical, precision, optical, clocks
- *Metals nec. contained in:* Furniture; other manufactured goods n.e.c.

The seven last bullets above concern products which are composed of different waste fractions. In the model, disassembly is applied, see description in section 4 in deliverable D6-1 'Documentation of the data consolidation and calibration exercise, and the scenario parameterisation'.

'Metals nec. waste' mainly occurs in industry (mainly in metals nec. processing and transport vehicles), construction (metals nec. in construction materials), and service activities (metals nec. in machinery and equipment etc.).

2.1.18 Waste of other materials (non metal)

This waste fraction represents all non-metal materials contained in:

- Fabricated metal products, except machinery
- Machinery and equipment n.e.c.
- Office machinery and computers
- Electrical machinery n.e.c.
- Radio, television and communication equipment
- Instruments, medical, precision, optical, clocks
- Furniture; other manufactured goods n.e.c.

The waste fraction includes plastic parts, glass parts, textiles, paper/cardboard parts, wooden parts, mineral parts etc. Since this waste fraction covers many different materials not classified elsewhere in the results, it is less interesting describing where in economy it occurs.

2.1.19 Special waste fractions

Special waste fractions includes:

- Hazardous waste (waste of fertilisers and chemicals)
- Oil waste (waste of crude oil and refined petroleum products)
- Residue of wood recycling
- Residue of paper recycling
- Residue of recycling of waste oil
- Residue of plastic recycling
- Residue of recycling of slag and ash
- Residue of recycling of inert materials and metals
- Paper waste to WWT from pulp/paper manufacturing
- Paper waste to WWT (tissue paper) in households: hygiene
- Wood waste: Residues from pulp manufacturing waste to Landfill

Since this waste fraction covers many different materials not classified elsewhere in the results, it is less interesting describing where in economy it occurs.

2.2 Waste flows in the FORWAST model versus waste flows in statistics

The model output on waste flows of the FORWAST model can be compared with national waste statistics on waste generation. Appropriate statistics for this purpose have been identified for Denmark (Miljøstyrelsen 2005). The FORWAST model outputs on waste generation in Denmark is based on the Danish data collection, see deliverable D3-1 'Report describing data processing and validation'. Figure 2.1 below shows the comparison for which appropriate data are available in the Danish waste statistics.

Model results		Waste statistics
Waste fraction	1000 tonnes (dry weight)	1000 tonnes (dry weight)
Food waste, MSW	8,337	
Food waste, Waste water	100	211
Wood waste	745	74
Ash and slag waste	5,541	2,182
Inert waste (sand, stone, cl	32,743	3,785
Oil waste	785	
Textile waste	211	
Paper waste	1,948	1,367
Plastic waste	3,163	
Hazardous waste	2,384	
Glass waste	665	219
Bricks waste	386	228
Metal waste	2,797	788

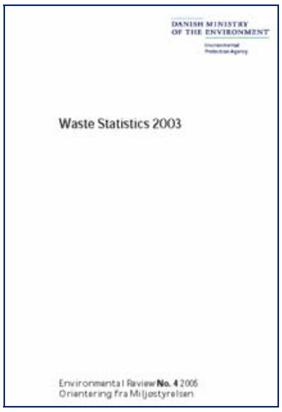

Figure 2.1: Comparison of FORWAST model results on waste generation (left) with Danish waste statistics (right) in year 2003.

In the following, each of the items for which comparison has been possible in Figure 2.1 is commented.

2.2.1 Food waste, waste water

The comparison shows that the FORWAST results corresponds to approximately 50% of the quantities in the waste statistics. As described in section 2.1.2 the reason for this is that no non-digested food is present in the 'Food waste to WWT' fraction. Since this does not fully reflect reality, too much food waste is present in 'Food waste' and too little is present in 'Food waste to WWT'.

2.2.2 Wood waste

It appears from Figure 2.1 that the model results on wood waste generation are a factor 10 higher than the figures reported in Danish waste statistics. The main reason for the difference is related to differences in definitions of wastes. In the FORWAST model all uses of forest products and wood products in activities, that is not present in the supply of products or in emissions, will become waste. Since the supply of wood chips from saw mills is not recorded as supply of products in the FORWAST model (it is wood waste), whereas wood chips are not recoded as waste in waste statistics, the model results show higher figures. Another explanation of the difference is related to the life time expectancy of wood products in the model. If the actual life time is longer, the waste generation is lower than calculated in the model.

2.2.3 Ash and slag waste

The generation of ash and slag waste is a factor 2.5 higher in the model results than in the waste statistics. The main reason for this difference is the fact that waste treatment information on the share of especial construction waste that is sent to incineration may be overestimated, see section 2.1.12.

2.2.4 Inert waste (sand stone, clay, concrete etc.)

Inert waste is a factor 10 higher in the FORWAST results compared to waste statistics. The main cause of the difference is estimated to be related to what is recorded in waste statistics, e.g. when roads and buildings reach the end of their lifetimes, most of the foundation material will remain on the ground and not be recorded in waste statistics. When leaving such material on the ground this can be seen as a kind of landfill not recorded in waste statistics. Another reason for the difference may be that the lifetimes of construction materials in the model is underestimated.

2.2.5 Paper waste

The comparison in Figure 2.1 shows that paper waste generation in the FORWAST model is approx 42% higher than what is recorded in waste statistics. It is estimated that the difference is related to underestimation of the life time of paper products as well as underestimated figures in waste statistics on the amount of paper waste present in mixed municipal solid waste.

2.2.6 Glass waste

Glass waste generation in the model results is approx a factor 3 higher than the recorded quantity in waste statistics. The explanation of this significant difference is that glass bottles sent to direct reuse is recorded as waste in the FORWAST model whereas it is not in waste statistics. A mass flow analysis of glass in Denmark 1999 (Holm et al. 2002, p 93) shows that the total glass waste was 845,000 tonnes of which 689,000 tonnes is sent to direct reuse. Thus, the amount of glass waste, excluding glass waste to direct reuse, is 156,000 tonnes. According to Figure 2.1, this amount has grown to 211,000 tonnes in year 2003.

2.2.7 Bricks waste

The quantity of bricks waste in the model results is a factor 1.7 higher than what is reported in the statistics. The most likely reason for the difference is related to the estimation of product life time of bricks. But also the fact that not all bricks waste is registered in statistics may contribute to the difference.

2.2.8 Metal waste

Metal is a factor 3.5 higher in the FORWAST results compared to waste statistics. The main causes of the difference are estimated to be related to:

- lifetimes of metal products in the model is underestimated
- waste statistics have insufficient information on metal waste sent to municipal incineration and landfill
- corrosion (emissions of iron) is not taken into account

2.2.9 Conclusion of the comparison with statistics

The comparison of FORWAST results with waste statistics showed significant differences, in almost all cases the FORWAST results shows significant higher waste quantities. The main causes of the differences are identified as flows which are not registered/recorded in the statistics and uncertainties in the estimation of product life times. For some waste fractions it has been possible to identify the specific causes of the difference, e.g. the glass waste fraction, where the difference between FORWAST results and statistics can be explained by the fact that used glass bottles for direct reuse is not recorded in waste statistics.

3 Contribution analysis and interpretation: Environmental impacts

This section presents a contribution analysis of the environmental impacts caused by EU-27 production and consumption. It should be noted that the results are calculated in a life cycle perspective including environmental impacts caused by emissions outside the EU-27.

3.1 Methodology and data used for the calculation of environmental impacts

This section analyses the environmental impact from EU-27 production and consumption which is presented in deliverable 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’. The functional unit of the results on environmental impacts is the final demand (household uses and export), see dark grey boxes in Figure 3.1. This is also referred to as ‘EU-27 production and consumption’.

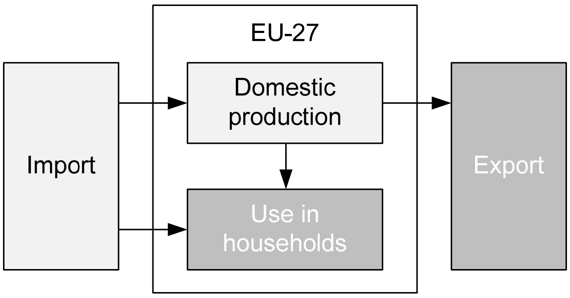

Figure 3.1: Illustration of major commodity flows. Total supply (output of import and domestic production) is equal to total use (input to use in households and export). The latter is used as functional unit (driving vector) in the model.

It should be noted that the impact per imported products is presumed to be equal to domestically produced products. Further, it should be noted that the model results are based on data collection from 20 out of the 27 EU-27 countries, and subsequently the ratio between domestic supply and imported products is also based on these 20 countries. Therefore, uncertainties in the environmental impact outside and inside the EU-27 are present. Uncertainties are further described in section 4 ‘Uncertainty assessment’.

When calculating the environmental impacts, the following emissions have been included:

- Carbon dioxide (CO_2), fossil as well as biogenic
- Resource extraction of biogenic carbon
- Nitrogen oxides (NO_x)
- Methane (CH_4)
- Sulphur dioxide (SO_2)
- Dinitrogen monoxide (N_2O)
- Carbon monoxide (CO)
- Non-methane volatile organics (NMVOC)

The LCIA-method, Stepwise 2006 method, version 1.2, has been used for calculating environmental indicators per midpoint impact category and as aggregated, monetarised values. The method is described and documented in Weidema et al. (2007) and Weidema (2009). The method can be downloaded as a CSV-file for import in the LCA software SimaPro at: http://www.lca-net.com/projects/stepwise_ia/. It should be noted that 1 kg fossil and 1 kg biogenic CO_2 emission cause the same impact. Resource extraction of 1 kg biogenic carbon causes an impact of -3.66 kg CO_2-eq. Thus, the growing of an agricultural crop containing 1 kg carbon will cause the effect 3.66 kg CO_2-eq, and when it is digested or disposed of it will cause the effect of 3.66 kg CO_2-eq (if we assume that all carbon contained in the product is released as CO_2).

3.2 Contribution analysis: EU-27 production and consumption year 2003

3.2.1 Identification of significant environmental impact categories and contributing emissions

The total monetarised impact from EU-27 production and consumption in 2003 is 1,162 GEUR. The contributions to this total impact from individual impact categories is given in Table 3.1 below.

Impact category	Mid-point impact	Unit	End-point impact	Unit
Global warming	9,467	million tonne CO2-eq	786	GEUR
Respiratory inorganics	4.74	million tonne PM2.5-eq	320	GEUR
Photochemical ozone, vegetat.	104,545	billion m2*ppm*hours	39.0	GEUR
Eutrophication, terrestrial	799	billion m2UES	10.0	GEUR
Acidification	544	billion m2UES	4.21	GEUR
Respiratory organics	10.8	billion pers*ppm*h	2.76	GEUR
Eutrophication, aquatic	1.70	million tonne NO3-eq	0.172	GEUR
Total			**1,162**	**GEUR**

Table 3.1: Environmental impacts related to the EU-27 final uses in 2003. The impacts are given in mid-point units (characterised results) as well as end-point units (weighted results).

It appears from **Table 3.1** that the most significant impact categories are global warming (68% of the total impact) and respiratory inorganics (28% of the total impact). The other impact categories account for the remaining 4% of the total impact.

In the following, more attention is given to the contributing to the total impacts in Table 3.1 above.

Global warming

The total contribution to global warming is caused by the emissions shown in Table 3.2. It should be noted that GHG-emissions related to land use change (direct and indirect) are not included.

Substance	Amount (million tonne CO2-eq)	Compartment
Carbon dioxide, crude oil and natural gas carb	5,294	Emission to air
Carbon dioxide, coal carbon	2,397	Emission to air
Carbon dioxide, food carbon	1,856	Emission to air
Methane	1,791	Emission to air
Dinitrogen monoxide	737	Emission to air
Carbon dioxide, fibre carbon	572	Emission to air
Carbon dioxide, carbonate	216	Emission to air
Carbon monoxide	88	Emission to air
Fibre carbon	-1,177	Carbon sequestration from air
Food carbon	-2,307	Carbon sequestration from air
Total	**9,467**	

Table 3.2: Emissions contribution to global warming.

It appears from Table 3.2 that the most significant GHG-emissions are CO_2 originating from combustion of oil, gas and coal (these account for 101% of the total), also methane and dinitrogen monoxide are important; 19% and 8% respectively. It also appears that, in a 100 year perspective, extraction of biogenic carbon contributes to a net carbon sequestration. For biogenic carbon, the balances are as follows:

- Food carbon: Sequestration (-2,307 million tonne CO2-eq) + emission (1,856 million tonne CO2-eq) = -451 million tonne CO2-eq, i.e. only 80% of the carbon in agricultural products is released again during 100 years
- Fibre carbon: Sequestration (-1,177 million tonne CO2-eq) + emission (572 million tonne CO2-eq) = -605 million tonne CO2-eq, i.e. only 49% of the carbon in fibre products (wood, paper and textile) is released again during 100 years

The figures given in the two bullets above do not take into account that some carbon is released as methane. The release of carbon as methane during the first 100 years after landfill are: food waste (7%), paper waste (5%), textile waste (3%), and wood waste (0.4%). These figures are calculated based on carbon content in wastes, waste degradability during 100 years (see Table 3.3) and emission factors obtained from Doka et al. (2007).

The high figures on net carbon sequestration above are mainly due to long degradation times in landfills, and consequently, the figures are subject to the uncertainties that are related to the degradation times of food and fibre products in landfills. The applied waste degradation times for food and fibre wastes are obtained from data provided by Johann Fellner, Technical University of Vienna. The data are given in Table 3.3 below.

Waste fraction	Share that is degraded during 100 years
Landfill of food waste	27%
Landfill of paper waste	27%
Landfill of textile waste	12%
Landfill of wood waste	1.6%

Table 3.3: Waste degradation times of food and fibre carbon containing waste fractions.

Respiratory inorganics

The total contribution to respiratory inorganics is caused by the emissions shown in Table 3.4.

Substance	Amount (million tonne PM2.5-eq)	Compartment
Nitrogen dioxide	3.08	Emission to air
Sulfur dioxide	1.60	Emission to air
Carbon monoxide	0.0586	Emission to air
Total of all compartments	**4.74**	

Table 3.4: Emissions contribution to respiratory inorganics.

The most significant emission contributing to respiratory, inorganics is nitrogen dioxide. In this respect, it should be noted that the probably most significant emission has not been included in the FORWAST emissions inventories; namely emissions of particles (Weidema 2009; Jolliet et al. 2003; Goedkoop and Spriensma 2001). Therefore, it may be expected that the monetarised impact related to respiratory effects is more significant than specified in Table 3.1.

Photo chemical ozone

The total contribution to photochemical ozone formation is caused by the emissions shown in Table 3.5.

Substance	Amount (billion m2*ppm*hours)	Compartment
Nitrogen dioxide	38,751	Emission to air
Carbon monoxide	34,229	Emission to air
Methane	24,145	Emission to air
NMVOC	7,421	Emission to air
Total	**104,545**	

Table 3.5: Emissions contribution to photochemical ozone formation.

Eutrophication, terrestrial

The only contributing emissions is nitrogen dioxide.

Acidification

The total contribution to acidification is caused by the emissions shown in Table 3.6.

Substance	Amount (billion m2 UES)	Compartment
Sulfur dioxide	389	Emission to air
Nitrogen dioxide	155	Emission to air
Total	**544**	

Table 3.6: Emissions contribution to acidification.

Respiratory, organics

The total contribution to respiratory organics is caused by the emissions shown in Table 3.7.

Substance	Amount (billion pers*ppm*h)	Compartment
Carbon monoxide	4.26	Emission to air
Methane	2.96	Emission to air
Nitrogen dioxide	2.66	Emission to air
NMVOC	0.925	Emission to air
Total	**10.8**	

Table 3.7: Emissions contribution to respiratory, organics.

Eutrophication, aquatic

The only contributing emissions is nitrogen dioxide.

3.2.2 Identification of significant causes of environmental impacts

The final uses (functional unit of the study) includes uses by 10 categories of household activities and export of the remaining 135 product categories included in the model. A full list of the 145 included product categories in the model is provided in the appendix 1.

In the following the cause of the total impact is traced, i.e. following the significant flows in Figure 3.2.

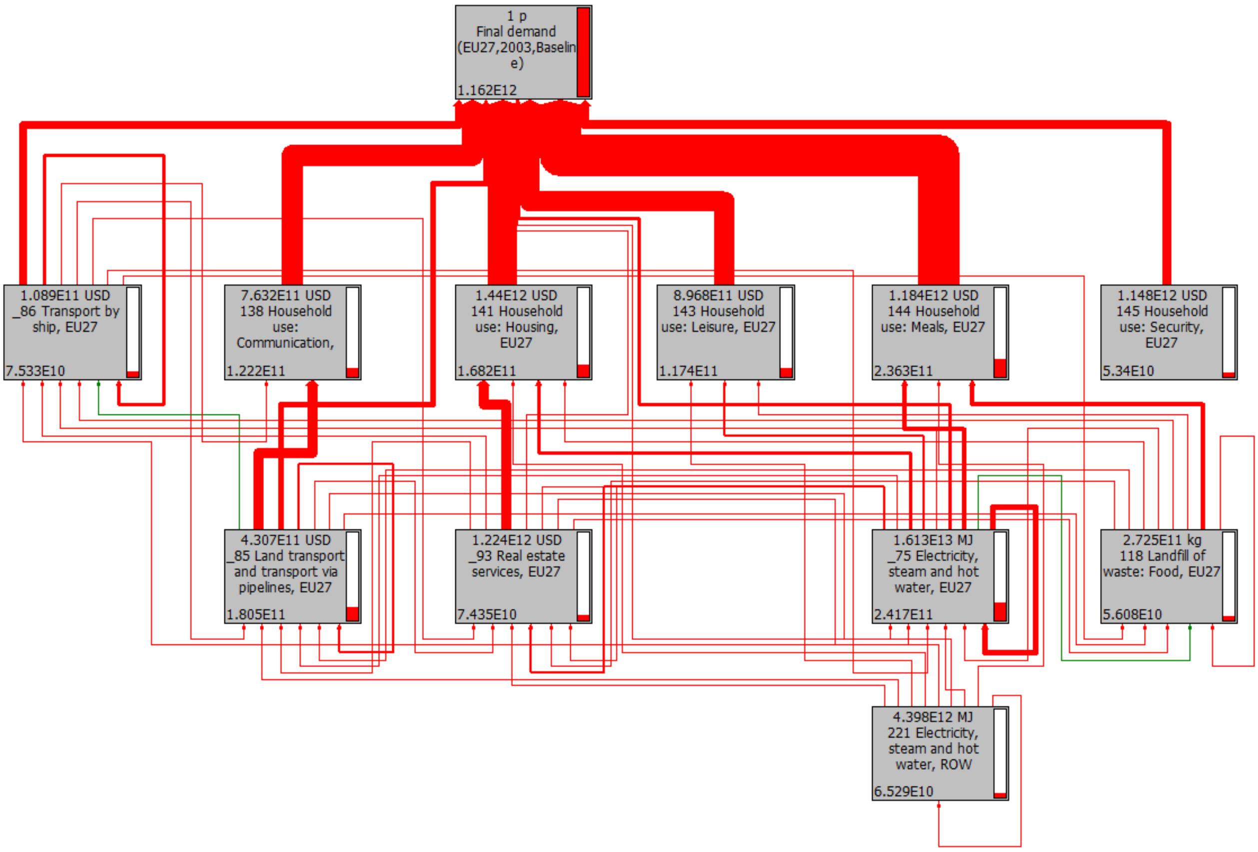

Figure 3.2: Illustration of the major causes of the total monetarised impact at 1,162 GEUR. The thickness of the arrows represents the significant of the flows. The value in the top of the boxes show the quantity of the flows measured in the hybrid units used in the model. The values in the bottom of the boxes show the monetarised impact of each product plus all upstream (in the product life cycle) impacts.

When focussing on the environmental impacts caused by the final uses (household uses and export), the most significant impacts are caused by household uses (74% of total monetarised impact) and the remaining is caused by the production of exported products (26% of total monetarised impact), see Table 3.8 for more details.

EU-27 final uses: household uses and exports			
Causes of the total monetarised impact (GEUR)		**Causes of the total GHG-emissions (million tonne CO2-eq)**	
Households	**75%**	**Households**	**78%**
- Meals	21%	- Meals	24%
- Housing	15%	- Housing	16%
- Communication	11%	- Leisure	10%
- Leisure	11%	- Communication	10%
- Security	4.8%	- Security	4.8%
- Other household uses	12%	- Other household uses	12%
Exports	**25%**	**Exports**	**22%**
- Transport by ship	3.9%	- Land transport and transport via pipeli	2.3%
- Land transport and transport via pipelines	2.8%	- Transport by ship	2.1%
- Electricity, steam and hot water	1.8%	- Electricity, steam and hot water	1.8%
- Wholesale trade	1.5%	- Wholesale trade	1.4%
- Iron basic, virgin	1.1%	- Iron basic, virgin	1.2%
- Other exports	14%	- Other exports	13%
Total (%)	**100%**	**Total (%)**	**100%**
Total (GEUR)	**1,162**	**Total (million tonne CO2-eq)**	**9,467**

Table 3.8: Causes of the total impact related to EU-27 final uses (household uses and export) both as monetarised total environment impact and as GHG-emissions (mid-point impact).

It appears that the most significant activity causing environmental impacts is the household activity ‘Meals’ followed by the activity housing. The causes of the environmental impacts from these two products/services are illustrated in Table 3.9 and Table 3.10.

EU-27 Household activity: Meals			
Causes of the monetarised impact (GEUR)		**Causes of the GHG-emissions (million tonne CO2-eq)**	
Hotels and restaurants	13%	Landfill of waste: Food	15%
Electricity, steam and hot water	12%	Dairy products	12%
Landfill of waste: Food	12%	Hotels and restaurants	12%
Dairy products	11%	Electricity, steam and hot water	11%
Meat and fish products	8.2%	Incineration of waste: Food	10%
Beverages	7.2%	Meat and fish products	8.2%
Food preparations n.e.c.	7.0%	Food preparations n.e.c.	6.8%
Incineration of waste: Food	6.9%	Beverages	6.7%
Other inputs	21%	Other inputs	17%
Household, meals: Direct emissions	1.5%	Household, meals: Direct emissions	1.8%
Total (%)	**100%**	**Total (%)**	**100%**
Total (GEUR)	**236**	**Total (million tonne CO2-eq)**	**2,176**

Table 3.9: Causes of the impact related to EU-27 household use group ‘meals’, both as monetarised total environment impact and as GHG-emissions (mid-point impact).

It appears from the table that the most significant causes of the impact related to the household activity ‘meals’ are related to ‘hotels and restaurants’ (primary dining), electricity (for food preparation and storage), landfill of food waste (mainly methane emissions). It also appears that the use of meat and dairy products together is the main cause of environmental impacts relating to the household activity ‘meals’.

EU-27 Household activity: Housing			
Causes of the monetarised impact (GEUR)		**Causes of the GHG-emissions (million tonne CO2-eq)**	
Real estate services	49%	Real estate services	50%
Electricity, steam and hot water	19%	Electricity, steam and hot water	19%
Textiles	3.5%	Textiles	3.6%
Furniture and other manufactured goods n.e.c.	2.8%	Gas	3.0%
Gas	2.7%	Chemicals n.e.c.	2.6%
Chemicals n.e.c.	2.6%	Plastics basic, virgin	2.6%
Plastics basic, virgin	2.5%	Incineration of waste: Oil/Hazardous waste	2.5%
Incineration of waste: Oil/Hazardous waste	2.3%	Furniture and other manufactured goods n.e.c.	2.4%
Other inputs	13%	Other inputs	9%
Household, meals: Direct emissions	3.2%	Household, meals: Direct emissions	4.4%
Total (%)	**100%**	**Total (%)**	**100%**
Total (GEUR)	**168**	**Total (million tonne CO2-eq)**	**1,483**

Table 3.10: Causes of the impact related to EU-27 household use group 'housing', both as monetarised total environment impact and as GHG-emissions (mid-point impact).

It appears from the table that the most significant causes of the impact related to the household activity 'housing' are related to 'real estate services'. The impacts related to real estate services are mainly caused by the use of buildings, energy and construction materials in this activity. Other significant causes of the environmental impact related to housing are direct emissions (when fuels are burned for heating in the households), energy (electricity and district heating) and textiles and furniture.

3.3 Contribution analysis: per product in the hybrid IO-model

This section presents the environmental impact per unit of product in a cradle to gate perspective. Environmental impacts are presented as monetarised impacts in EUR2003 (end-point impact) and GHG-emissions in kg CO_2-eq (mid-point impact). These impacts can be compared with results of traditional LCA-studies.

It should be noted that the environmental impacts in the FORWAST model are calculated without distinguishing between fossil CO_2 and biogenic CO_2. I.e. the emission of 1 kg fossil CO_2 contributes the same as the emissions of 1 kg biogenic CO_2. In addition, plant or animal uptake of atmospheric CO_2 contributes with minus CO_2 emissions (removal of CO_2 from the atmosphere).

In the Kyoto accounting system (UNFCCC) as well as in many LCAs and carbon footprint studies, annual uptake of atmospheric carbon in standing forests, agricultural products and fishery are not included (the effect of this carbon uptake is a negative contribution to GHG-emissions). Also the emissions of biogenic CO_2 are not included, i.e. respiratory CO_2 from humans and animals, CO_2 from burning of biomass, and CO_2 from other degradation of organic material (the effect of these CO_2 emissions is a positive contribution to GHG-emissions). In life cycle assessment and carbon footprint, it is often assumed that the two above mentioned effects equals each other out. However, this is not always a good assumption, especially not regarding degradation of organic materials in landfills (also see Table 3.2). In the time horizon for which emissions are included from landfill sites in the FORWAST model (100 years after the waste is landfilled), not all of the carbon contained in the wastes is released. Therefore, given time horizon at 100 years, the Kyoto approach is likely to overestimate the total GHG emissions.

Another difference between 1) not distinguishing between fossil and biogenic CO_2, and 2) presume that biogenic CO_2 is not associated with impacts on global warming, is the environmental impact per product. This is present for activities that are associated with burning/other degradation of organic material, and for activities that are associated with uptake of atmospheric carbon.

If biogenic carbon is included in the calculation of GHG emissions, especially agricultural crops, fish and forestry products will show a negative contribution to global warming (this is also valid for products where agricultural crops, fish and forestry products are present upstream in the product system). Also waste treatment services which are typically regarded as being not associated with CO_2 emissions will appear as having a significant larger contribution to global warming (due to emissions of biogenic CO_2); e.g. waste incineration of organic material, waste water treatment, composting, land application of manure, landfill of organic waste.

To facilitate comparison with other LCAs and carbon footprint studies, the environmental impacts per product is shown using both of the abovementioned approaches in the two subsections below. In section 3.3.1 the impacts using the FORWAST approach are shown, and in section 3.3.2 the impacts using the Kyoto approach are shown.

The tables below specifies the impacts for 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

In the tables, the product type is indicated with colour codes, see below:

Product type
Physical
Service
Waste treatment
Household

3.3.1 Environmental impacts per unit of products

In the table below the environmental impacts (monetarised and GHG-emissions) are shown per unit for all products in the FORWAST model. GHG-emissions are calculated without distinguishing between biogenic and fossil CO_2, and plant uptake of atmospheric carbon is included as CO_2 emission with negative sign.

Product no.	Product name	Product type	Unit	Monetarised environmental impact per unit pf product (EUR2003)	GHG-emissions per unit of product (kg CO2-eq)
1	Bovine meat and milk	Physical	kg (dry weight)	1.51	15.56
2	Pigs	Physical	kg (dry weight)	0.83	8.00
3	Poultry and animals n.e.c.	Physical	kg (dry weight)	1.21	11.40
4	Grain crops	Physical	kg (dry weight)	-0.08	-1.11
5	Crops n.e.c.	Physical	kg (dry weight)	0.02	-0.15
6	Agricultural services n.e.c.	Service	EUR2003	0.24	1.83
7	Forest products	Physical	kg (dry weight)	-0.13	-1.58
8	Recycling of waste wood	Waste treatment	kg waste (dry weight)	0.14	1.68
9	Fish	Physical	kg (dry weight)	1.37	8.34
10	Coal, lignite, peat	Physical	kg (dry weight)	0.01	0.09
11	Crude petroleum and natural gas	Physical	kg (dry weight)	0.01	0.13
12	Iron ores from mine	Physical	kg (dry weight)	0.01	0.05
13	Bauxite from mine	Physical	kg (dry weight)	0.04	0.36
14	Copper from mine	Physical	kg (dry weight)	0.03	0.21
15	Metals from mine n.e.c.	Physical	kg (dry weight)	0.02	0.19
16	Sand, gravel and stone from quarry	Physical	kg (dry weight)	0.00	0.01
17	Clay and soil from quarry	Physical	kg (dry weight)	0.00	0.01
18	Minerals from mine n.e.c.	Physical	kg (dry weight)	0.00	0.02
19	Meat and fish products	Physical	kg (dry weight)	1.98	18.15
20	Dairy products	Physical	kg (dry weight)	1.91	18.86
21	Fruits and vegetables, processed	Physical	kg (dry weight)	0.43	3.46
22	Vegetable and animal oils and fats	Physical	kg (dry weight)	0.14	0.95
23	Flour	Physical	kg (dry weight)	-0.02	-0.54
24	Sugar	Physical	kg (dry weight)	0.14	0.94
25	Animal feeds	Physical	kg (dry weight)	0.10	0.55
26	Food preparations n.e.c.	Physical	kg (dry weight)	1.02	9.00
27	Beverages	Physical	kg (dry weight)	1.40	12.08
28	Tobacco products	Physical	kg (dry weight)	0.75	6.15
29	Textiles	Physical	kg (dry weight)	1.10	9.33
30	Wearing apparel and furs	Physical	kg (dry weight)	2.07	17.48
31	Leather products, footwear	Physical	kg (dry weight)	2.19	18.83
32	Wood products, except furniture	Physical	kg (dry weight)	-0.04	-0.98
33	Pulp, virgin	Physical	kg (dry weight)	-0.02	-0.77
34	Recycling of waste paper	Waste treatment	kg waste (dry weight)	0.08	1.24
35	Paper and paper products	Physical	kg (dry weight)	0.17	0.98
36	Printed matter and recorded media	Physical	kg (dry weight)	0.51	3.73
37	Refined petroleum products and fuels	Physical	kg (dry weight)	0.05	0.41
38	Recycling of waste oil	Waste treatment	kg waste (dry weight)	-0.04	-0.37
39	Fertiliser, N	Physical	kg (dry weight)	0.39	3.63
40	Fertiliser, other than N	Physical	kg (dry weight)	0.15	1.29
41	Plastics basic, virgin	Physical	kg (dry weight)	0.37	3.11
42	Recycling of plastics basic	Waste treatment	kg waste (dry weight)	-0.23	-2.00
43	Chemicals n.e.c.	Physical	kg (dry weight)	0.25	2.06
44	Rubber and plastic products	Physical	kg (dry weight)	0.86	7.19
45	Glass, mineral wool and ceramic goods, vi	Physical	kg (dry weight)	0.23	1.87
46	Recycling of glass, mineral wool and ceram	Waste treatment	kg waste (dry weight)	-0.13	-1.03
47	Cement, virgin	Physical	kg (dry weight)	0.09	0.88
48	Recycling of slags and ashes	Waste treatment	kg waste (dry weight)	-0.07	-0.74
49	Concrete, asphalt and other mineral produ	Physical	kg (dry weight)	0.02	0.20
50	Recycling of concrete, asphalt and other m	Waste treatment	kg waste (dry weight)	0.02	0.14

Table 3.11 (part 1 of 3): Environmental impact (monetarised and GHG-emissions) per unit of all products in the FORWAST model. GHG-emissions are calculated without distinguishing between biogenic and fossil CO_2, and plant uptake of atmospheric carbon is included as CO_2 emission with negative sign.

Product no.	Product name	Product type	Unit	Monetarised environmental impact per unit pf product (EUR2003)	GHG-emissions per unit of product (kg CO2-eq)
51	Bricks	Physical	kg (dry weight)	0.04	0.32
52	Recycling of bricks	Waste treatment	kg waste (dry weight)	-0.04	-0.31
53	Iron basic, virgin	Physical	kg (dry weight)	0.23	2.06
54	Recycling of iron basic	Waste treatment	kg waste (dry weight)	-0.07	-0.63
55	Aluminium basic, virgin	Physical	kg (dry weight)	0.98	8.15
56	Recycling of aluminium basic	Waste treatment	kg waste (dry weight)	-0.65	-5.22
57	Copper basic, virgin	Physical	kg (dry weight)	0.79	6.76
58	Recycling of copper basic	Waste treatment	kg waste (dry weight)	-0.21	-2.20
59	Metals basic, n.e.c., virgin	Physical	kg (dry weight)	0.36	2.29
60	Recycling of metals basic, n.e.c.	Waste treatment	kg waste (dry weight)	-0.22	-1.28
61	Iron, after first processing	Physical	kg (dry weight)	0.34	3.03
62	Aluminium, after first processing	Physical	kg (dry weight)	1.80	14.87
63	Copper, after first processing	Physical	kg (dry weight)	0.96	8.14
64	Metals n.e.c., after first processing	Physical	kg (dry weight)	1.72	12.70
65	Fabricated metal products, except machin	Physical	kg (dry weight)	0.53	4.51
66	Machinery and equipment n.e.c.	Physical	kg (dry weight)	0.77	6.40
67	Office machinery and computers	Physical	kg (dry weight)	3.55	29.24
68	Electrical machinery n.e.c.	Physical	kg (dry weight)	0.65	5.45
69	Radio, television and communication equip	Physical	kg (dry weight)	1.22	10.03
70	Instruments, medical, precision, optical, cl	Physical	kg (dry weight)	2.91	23.41
71	Motor vehicles and trailers	Service	EUR2003	0.10	0.81
72	Transport equipment n.e.c.	Service	EUR2003	0.07	0.56
73	Furniture and other manufactured goods n.	Physical	kg (dry weight)	0.40	2.80
74	Recycling services	Service	EUR2003	0.54	4.29
75	Electricity, steam and hot water	Physical	kWh	0.06	0.51
76	Gas	Physical	kg (dry weight)	0.05	0.46
77	Water, fresh	Service	EUR2003	0.15	1.24
78	Buildings, residential	Service	EUR2003	0.11	0.97
79	Buildings, non-residential	Service	EUR2003	0.10	0.87
80	Infrastructure, excluding buildings	Service	EUR2003	0.18	1.51
81	Trade and repair of motor vehicles and serv	Service	EUR2003	0.07	0.54
82	Wholesale trade	Service	EUR2003	0.07	0.52
83	Retail trade and repair services	Service	EUR2003	0.06	0.51
84	Hotels and restaurants	Service	EUR2003	0.10	0.90
85	Land transport and transport via pipelines	Service	EUR2003	0.53	3.64
86	Transport by ship	Service	EUR2003	1.05	4.56
87	Air transport	Service	EUR2003	0.28	2.01
88	Cargo handling, harbours and travel agenci	Service	EUR2003	0.13	0.96
89	Post and telecommunication	Service	EUR2003	0.05	0.39
90	Financial intermediation	Service	EUR2003	0.03	0.26
91	Insurance and pension funding	Service	EUR2003	0.04	0.32
92	Services auxiliary to financial intermediatio	Service	EUR2003	0.03	0.29
93	Real estate services	Service	EUR2003	0.08	0.64
94	Renting of machinery and equipment etc.	Service	EUR2003	0.03	0.29
95	Computer and related services	Service	EUR2003	0.05	0.42
96	Research and development	Service	EUR2003	0.07	0.56
97	Business services n.e.c.	Service	EUR2003	0.05	0.44
98	Public service and security	Service	EUR2003	0.06	0.46
99	Education services	Service	EUR2003	0.05	0.38
100	Health and social work	Service	EUR2003	0.05	0.41

Table 3.11 (part 2 of 3): Environmental impact (monetarised and GHG-emissions) per unit of all products in the FORWAST model. GHG-emissions are calculated without distinguishing between biogenic and fossil CO_2, and plant uptake of atmospheric carbon is included as CO_2 emission with negative sign.

Product no.	Product name	Product type	Unit	Monetarised environmental impact per unit pf product (EUR2003)	GHG-emissions per unit of product (kg CO2-eq)
101	Incineration of waste: Food	Waste treatment	kg waste (dry weight)	0.14	1.76
102	Incineration of waste: Paper	Waste treatment	kg waste (dry weight)	0.09	1.21
103	Incineration of waste: Plastic	Waste treatment	kg waste (dry weight)	0.13	1.74
104	Incineration of waste: Metals	Waste treatment	kg waste (dry weight)	0.01	0.12
105	Incineration of waste: Glass/inert	Waste treatment	kg waste (dry weight)	0.01	0.12
106	Incineration of waste: Textiles	Waste treatment	kg waste (dry weight)	0.13	1.70
107	Incineration of waste: Wood	Waste treatment	kg waste (dry weight)	0.13	1.68
108	Incineration of waste: Oil/Hazardous waste	Waste treatment	kg waste (dry weight)	0.35	3.01
109	Manure treatment, conventional storage	Waste treatment	kg waste (dry weight)	0.34	4.08
110	Manure treatment, biogas	Waste treatment	kg waste (dry weight)	0.23	3.13
111	Biogasification of food waste	Waste treatment	kg waste (dry weight)	-0.03	0.14
112	Biogasification of paper	Waste treatment	kg waste (dry weight)	0.04	0.88
113	Biogasification of sewage slugde	Waste treatment	kg waste (dry weight)	-0.03	0.14
114	Composting of food waste	Waste treatment	kg waste (dry weight)	0.18	2.11
115	Composting of paper and wood	Waste treatment	kg waste (dry weight)	0.17	2.04
116	Waste water treatment, food	Waste treatment	kg waste (dry weight)	0.29	3.05
117	Waste water treatment, other	Waste treatment	kg waste (dry weight)	0.24	2.43
118	Landfill of waste: Food	Waste treatment	kg waste (dry weight)	0.21	2.34
119	Landfill of waste: Paper	Waste treatment	kg waste (dry weight)	0.15	1.73
120	Landfill of waste: Plastic	Waste treatment	kg waste (dry weight)	0.02	0.17
121	Landfill of waste: Iron	Waste treatment	kg waste (dry weight)	0.01	0.07
122	Landfill of waste: Alu	Waste treatment	kg waste (dry weight)	0.01	0.07
123	Landfill of waste: Copper	Waste treatment	kg waste (dry weight)	0.01	0.07
124	Landfill of waste: Metals nec	Waste treatment	kg waste (dry weight)	0.01	0.07
125	Landfill of waste: Glass/inert	Waste treatment	kg waste (dry weight)	0.01	0.07
126	Landfill of waste: Mine waste	Waste treatment	kg waste (dry weight)	0.01	0.07
127	Landfill of waste: Textiles	Waste treatment	kg waste (dry weight)	0.09	1.05
128	Landfill of waste: Wood	Waste treatment	kg waste (dry weight)	0.02	0.21
129	Landfill of waste: Oil/Hazardous waste	Waste treatment	kg waste (dry weight)	0.01	0.07
130	Landfill of waste: Slag/ash	Waste treatment	kg waste (dry weight)	0.01	0.07
131	Land application of manure	Waste treatment	kg waste (dry weight)	0.08	1.15
132	Land application of compost	Waste treatment	kg waste (dry weight)	0.14	1.76
133	Membership organisations	Service	EUR2003	0.08	0.67
134	Recreational and cultural services	Service	EUR2003	0.07	0.58
135	Services n.e.c.	Service	EUR2003	0.07	0.64
136	Household use: Clothing	Household	EUR2003	0.18	1.57
137	Household use: Communication	Household	EUR2003	0.18	1.33
138	Household use: Education	Household	EUR2003	0.05	0.40
139	Household use: Health care	Household	EUR2003	0.06	0.49
140	Household use: Housing	Household	EUR2003	0.13	1.17
141	Household use: Hygiene	Household	EUR2003	0.38	3.62
142	Household use: Leisure	Household	EUR2003	0.15	1.21
143	Household use: Meals	Household	EUR2003	0.23	2.09
144	Household use: Security	Household	EUR2003	0.05	0.43
145	Household use: Social care	Household	EUR2003	0.05	0.43

Table 3.11 (part 3 of 3): Environmental impact (monetarised and GHG-emissions) per unit of all products in the FORWAST model. GHG-emissions are calculated without distinguishing between biogenic and fossil CO_2, and plant uptake of atmospheric carbon is included as CO_2 emission with negative sign.

3.3.2 Environmental impacts per unit of products (special case where biogenic CO2 is regarded having no impacts)

In the table below the environmental impacts (monetarised and GHG-emissions) are shown per unit for all products in the FORWAST model. GHG-emissions are calculated without inclusion of negative impacts from plant uptake of atmospheric carbon and positive impacts from emissions of biogenic CO_2.

Note: Impacts from plant uptake of atmospheric carbon and emissions of biogenic CO2 are excluded					
Product no.	Product name	Product type	Unit	Monetarised environmental impact per unit pf product (EUR2003)	GHG-emissions per unit of product (kg CO2-eq)
1	Bovine meat and milk	Physical	kg (dry weight)	1.88	20.07
2	Pigs	Physical	kg (dry weight)	1.06	10.68
3	Poultry and animals n.e.c.	Physical	kg (dry weight)	1.51	15.07
4	Grain crops	Physical	kg (dry weight)	0.06	0.59
5	Crops n.e.c.	Physical	kg (dry weight)	0.16	1.57
6	Agricultural services n.e.c.	Service	EUR2003	0.24	1.88
7	Forest products	Physical	kg (dry weight)	0.01	0.07
8	Recycling of waste wood	Waste treatment	kg waste (dry weight)	0.00	-0.01
9	Fish	Physical	kg (dry weight)	1.51	10.03
10	Coal, lignite, peat	Physical	kg (dry weight)	0.01	0.09
11	Crude petroleum and natural gas	Physical	kg (dry weight)	0.01	0.13
12	Iron ores from mine	Physical	kg (dry weight)	0.01	0.05
13	Bauxite from mine	Physical	kg (dry weight)	0.04	0.38
14	Copper from mine	Physical	kg (dry weight)	0.03	0.23
15	Metals from mine n.e.c.	Physical	kg (dry weight)	0.02	0.20
16	Sand, gravel and stone from quarry	Physical	kg (dry weight)	0.00	0.01
17	Clay and soil from quarry	Physical	kg (dry weight)	0.00	0.02
18	Minerals from mine n.e.c.	Physical	kg (dry weight)	0.00	0.02
19	Meat and fish products	Physical	kg (dry weight)	2.34	22.54
20	Dairy products	Physical	kg (dry weight)	2.30	23.58
21	Fruits and vegetables, processed	Physical	kg (dry weight)	0.61	5.71
22	Vegetable and animal oils and fats	Physical	kg (dry weight)	0.29	2.84
23	Flour	Physical	kg (dry weight)	0.14	1.34
24	Sugar	Physical	kg (dry weight)	0.30	2.93
25	Animal feeds	Physical	kg (dry weight)	0.27	2.58
26	Food preparations n.e.c.	Physical	kg (dry weight)	1.34	12.80
27	Beverages	Physical	kg (dry weight)	1.70	15.66
28	Tobacco products	Physical	kg (dry weight)	0.97	8.85
29	Textiles	Physical	kg (dry weight)	1.19	10.42
30	Wearing apparel and furs	Physical	kg (dry weight)	2.20	19.06
31	Leather products, footwear	Physical	kg (dry weight)	2.36	20.92
32	Wood products, except furniture	Physical	kg (dry weight)	0.11	0.80
33	Pulp, virgin	Physical	kg (dry weight)	0.13	1.00
34	Recycling of waste paper	Waste treatment	kg waste (dry weight)	-0.05	-0.25
35	Paper and paper products	Physical	kg (dry weight)	0.28	2.32
36	Printed matter and recorded media	Physical	kg (dry weight)	0.63	5.20
37	Refined petroleum products and fuels	Physical	kg (dry weight)	0.05	0.41
38	Recycling of waste oil	Waste treatment	kg waste (dry weight)	-0.04	-0.37
39	Fertiliser, N	Physical	kg (dry weight)	0.40	3.74
40	Fertiliser, other than N	Physical	kg (dry weight)	0.15	1.30
41	Plastics basic, virgin	Physical	kg (dry weight)	0.37	3.16
42	Recycling of plastics basic	Waste treatment	kg waste (dry weight)	-0.25	-2.14
43	Chemicals n.e.c.	Physical	kg (dry weight)	0.26	2.24
44	Rubber and plastic products	Physical	kg (dry weight)	0.87	7.40
45	Glass, mineral wool and ceramic goods, vi	Physical	kg (dry weight)	0.23	1.92
46	Recycling of glass, mineral wool and ceran	Waste treatment	kg waste (dry weight)	-0.13	-1.07

Table 3.12 (part 1 of 3): Environmental impact (monetarised and GHG-emissions) per unit of all products in the FORWAST model. GHG-emissions are calculated without inclusion of negative impacts from plant uptake of atmospheric carbon and positive impacts from emissions of biogenic CO_2.

Note: Impacts from plant uptake of atmospheric carbon and emissions of biogenic CO2 are excluded					
Product no.	Product name	Product type	Unit	Monetarised environmental impact per unit pf product (EUR2003)	GHG-emissions per unit of product (kg CO2-eq)
47	Cement, virgin	Physical	kg (dry weight)	0.09	0.88
48	Recycling of slags and ashes	Waste treatment	kg waste (dry weight)	-0.07	-0.73
49	Concrete, asphalt and other mineral produ	Physical	kg (dry weight)	0.02	0.21
50	Recycling of concrete, asphalt and other m	Waste treatment	kg waste (dry weight)	0.02	0.15
51	Bricks	Physical	kg (dry weight)	0.04	0.34
52	Recycling of bricks	Waste treatment	kg waste (dry weight)	-0.04	-0.32
53	Iron basic, virgin	Physical	kg (dry weight)	0.23	2.08
54	Recycling of iron basic	Waste treatment	kg waste (dry weight)	-0.07	-0.63
55	Aluminium basic, virgin	Physical	kg (dry weight)	1.00	8.30
56	Recycling of aluminium basic	Waste treatment	kg waste (dry weight)	-0.66	-5.33
57	Copper basic, virgin	Physical	kg (dry weight)	0.80	6.87
58	Recycling of copper basic	Waste treatment	kg waste (dry weight)	-0.21	-2.25
59	Metals basic, n.e.c., virgin	Physical	kg (dry weight)	0.36	2.32
60	Recycling of metals basic, n.e.c.	Waste treatment	kg waste (dry weight)	-0.22	-1.29
61	Iron, after first processing	Physical	kg (dry weight)	0.34	3.06
62	Aluminium, after first processing	Physical	kg (dry weight)	1.82	15.17
63	Copper, after first processing	Physical	kg (dry weight)	0.97	8.28
64	Metals n.e.c., after first processing	Physical	kg (dry weight)	1.75	13.07
65	Fabricated metal products, except machin	Physical	kg (dry weight)	0.54	4.62
66	Machinery and equipment n.e.c.	Physical	kg (dry weight)	0.79	6.64
67	Office machinery and computers	Physical	kg (dry weight)	3.63	30.20
68	Electrical machinery n.e.c.	Physical	kg (dry weight)	0.66	5.63
69	Radio, television and communication equip	Physical	kg (dry weight)	1.26	10.53
70	Instruments, medical, precision, optical, cl	Physical	kg (dry weight)	3.01	24.64
71	Motor vehicles and trailers	Service	EUR2003	0.10	0.84
72	Transport equipment n.e.c.	Service	EUR2003	0.07	0.59
73	Furniture and other manufactured goods n.	Physical	kg (dry weight)	0.53	4.33
74	Recycling services	Service	EUR2003	0.56	4.51
75	Electricity, steam and hot water	Physical	kWh	0.06	0.51
76	Gas	Physical	kg (dry weight)	0.05	0.47
77	Water, fresh	Service	EUR2003	0.15	1.27
78	Buildings, residential	Service	EUR2003	0.12	1.04
79	Buildings, non-residential	Service	EUR2003	0.11	0.95
80	Infrastructure, excluding buildings	Service	EUR2003	0.19	1.64
81	Trade and repair of motor vehicles and ser	Service	EUR2003	0.07	0.57
82	Wholesale trade	Service	EUR2003	0.07	0.56
83	Retail trade and repair services	Service	EUR2003	0.06	0.55
84	Hotels and restaurants	Service	EUR2003	0.11	1.03
85	Land transport and transport via pipelines	Service	EUR2003	0.53	3.68
86	Transport by ship	Service	EUR2003	1.05	4.59
87	Air transport	Service	EUR2003	0.28	2.03
88	Cargo handling, harbours and travel agenci	Service	EUR2003	0.13	1.00
89	Post and telecommunication	Service	EUR2003	0.05	0.41
90	Financial intermediation	Service	EUR2003	0.03	0.28
91	Insurance and pension funding	Service	EUR2003	0.04	0.34
92	Services auxiliary to financial intermediatio	Service	EUR2003	0.04	0.31
93	Real estate services	Service	EUR2003	0.08	0.68
94	Renting of machinery and equipment etc.	Service	EUR2003	0.03	0.31
95	Computer and related services	Service	EUR2003	0.05	0.45
96	Research and development	Service	EUR2003	0.07	0.59
97	Business services n.e.c.	Service	EUR2003	0.06	0.47
98	Public service and security	Service	EUR2003	0.06	0.48
99	Education services	Service	EUR2003	0.05	0.40
100	Health and social work	Service	EUR2003	0.05	0.43

Table 3.12 (part 2 of 3): Environmental impact (monetarised and GHG-emissions) per unit of all products in the FORWAST model. GHG-emissions are calculated without inclusion of negative impacts from plant uptake of atmospheric carbon and positive impacts from emissions of biogenic CO_2.

Note: Impacts from plant uptake of atmospheric carbon and emissions of biogenic CO2 are excluded					
Product no.	Product name	Product type	Unit	Monetarised environmental impact per unit pf product (EUR2003)	GHG-emissions per unit of product (kg CO2-eq)
101	Incineration of waste: Food	Waste treatment	kg waste (dry weight)	-0.02	-0.14
102	Incineration of waste: Paper	Waste treatment	kg waste (dry weight)	-0.02	-0.15
103	Incineration of waste: Plastic	Waste treatment	kg waste (dry weight)	0.13	1.75
104	Incineration of waste: Metals	Waste treatment	kg waste (dry weight)	0.02	0.13
105	Incineration of waste: Glass/inert	Waste treatment	kg waste (dry weight)	0.02	0.13
106	Incineration of waste: Textiles	Waste treatment	kg waste (dry weight)	-0.02	-0.14
107	Incineration of waste: Wood	Waste treatment	kg waste (dry weight)	-0.02	-0.18
108	Incineration of waste: Oil/Hazardous waste	Waste treatment	kg waste (dry weight)	0.35	3.04
109	Manure treatment, conventional storage	Waste treatment	kg waste (dry weight)	0.24	2.84
110	Manure treatment, biogas	Waste treatment	kg waste (dry weight)	0.13	1.96
111	Biogasification of food waste	Waste treatment	kg waste (dry weight)	-0.19	-1.73
112	Biogasification of paper	Waste treatment	kg waste (dry weight)	-0.07	-0.53
113	Biogasification of sewage slugde	Waste treatment	kg waste (dry weight)	-0.19	-1.73
114	Composting of food waste	Waste treatment	kg waste (dry weight)	0.02	0.20
115	Composting of paper and wood	Waste treatment	kg waste (dry weight)	0.01	0.11
116	Waste water treatment, food	Waste treatment	kg waste (dry weight)	0.27	2.78
117	Waste water treatment, other	Waste treatment	kg waste (dry weight)	0.22	2.24
118	Landfill of waste: Food	Waste treatment	kg waste (dry weight)	0.18	2.09
119	Landfill of waste: Paper	Waste treatment	kg waste (dry weight)	0.14	1.54
120	Landfill of waste: Plastic	Waste treatment	kg waste (dry weight)	0.02	0.18
121	Landfill of waste: Iron	Waste treatment	kg waste (dry weight)	0.01	0.08
122	Landfill of waste: Alu	Waste treatment	kg waste (dry weight)	0.01	0.08
123	Landfill of waste: Copper	Waste treatment	kg waste (dry weight)	0.01	0.08
124	Landfill of waste: Metals nec	Waste treatment	kg waste (dry weight)	0.01	0.08
125	Landfill of waste: Glass/inert	Waste treatment	kg waste (dry weight)	0.01	0.08
126	Landfill of waste: Mine waste	Waste treatment	kg waste (dry weight)	0.01	0.08
127	Landfill of waste: Textiles	Waste treatment	kg waste (dry weight)	0.08	0.94
128	Landfill of waste: Wood	Waste treatment	kg waste (dry weight)	0.02	0.20
129	Landfill of waste: Oil/Hazardous waste	Waste treatment	kg waste (dry weight)	0.01	0.08
130	Landfill of waste: Slag/ash	Waste treatment	kg waste (dry weight)	0.01	0.08
131	Land application of manure	Waste treatment	kg waste (dry weight)	-0.05	-0.34
132	Land application of compost	Waste treatment	kg waste (dry weight)	-0.02	-0.19
133	Membership organisations	Service	EUR2003	0.08	0.70
134	Recreational and cultural services	Service	EUR2003	0.07	0.63
135	Services n.e.c.	Service	EUR2003	0.08	0.70
136	Household use: Clothing	Household	EUR2003	0.19	1.61
137	Household use: Communication	Household	EUR2003	0.18	1.36
138	Household use: Education	Household	EUR2003	0.05	0.42
139	Household use: Health care	Household	EUR2003	0.06	0.52
140	Household use: Housing	Household	EUR2003	0.14	1.22
141	Household use: Hygiene	Household	EUR2003	0.39	3.66
142	Household use: Leisure	Household	EUR2003	0.16	1.34
143	Household use: Meals	Household	EUR2003	0.26	2.45
144	Household use: Security	Household	EUR2003	0.06	0.46
145	Household use: Social care	Household	EUR2003	0.05	0.45

Table 3.12 (part 3 of 3): Environmental impact (monetarised and GHG-emissions) per unit of all products in the FORWAST model. GHG-emissions are calculated without inclusion of negative impacts from plant uptake of atmospheric carbon and positive impacts from emissions of biogenic CO_2.

4 Uncertainty assessment

In this section limitations of the model and uncertainties are assessed. This includes a specification of the sources of uncertainty in the model, and an assessment of each of these sources.

4.1 Sources of uncertainty

Throughout the following deliverables, uncertainties has been described when they are present relating to the specific issues covered in these reports:

- D3-1 'Report describing data processing and validation': 4 countries
- D4-1 'Report describing data processing and validation': 23 countries
- D6-1 'Documentation of the data consolidation and calibration exercise, and the scenario parameterisation'
- 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'
- 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'
- D6-4 'Documentation of the final model used for the scenario analyses'

The list below summarises the main sources of uncertainty in the FORWAST model:

1. Limitations in data collection
2. National monetary supply-use tables
3. Conversion to basic prices
4. Data on physical domestic supply and trade
5. Disaggregation of monetary SUTs
6. Data on the physical use of products
7. Emissions
8. Resources
9. Waste treatment mix for different waste fractions
10. Scenario implementation: Physical and non-physical products
11. Scenario implementation: Energy efficiencies
12. Waste module
13. Life time of products
14. Level of aggregation

4.2 Limitations in data collection

The model calculations are based on data collection for 20 of the 27 EU-27 countries, see Table 4.1.

Country code	Country	Included (x)	Data level	GDP share
AT	Austria		117x117	2%
BE	Belgium	x	57x57	3%
BG	Bulgaria	x	57x57	0.2%
CY	Cyprus	x	57x57	0.1%
CZ	Czech Republic	x	57x57	1%
DE	Germany		117x117	21%
DK	Denmark	x	117x117	2%
EE	Estonia	x	57x57	0%
ES	Spain		117x117	8%
FI	Finland	x	57x57	1%
FR	France	x	117x117	16%
GR	Greece	x	117x117	2%
HU	Hungary	x	57x57	1%
IE	Ireland		57x57	1%
IT	Italy		57x57	13%
LT	Lithuania	x	57x57	0.2%
LU	Luxembourg	x	57x57	0.3%
LV	Latvia	x	57x57	0.1%
MT	Malta	x	57x57	0.04%
NL	Netherlands	x	117x117	5%
PL	Poland	x	117x117	2%
PT	Portugal	x	57x57	1%
RO	Romania	x	57x57	1%
SE	Sweden	x	117x117	3%
SI	Slovenia		117x117	0.3%
SK	Slovakia	x	57x57	0.3%
UK	United Kingdom		117x117	16%
38% of EU27 GDP is included				**100%**

Table 4.1: Overview of the data used for the creation of the EU-27 supply-use table used in the model calculations.

The effect of this limitation in the data used for the creation of the EU-27 supply-use table used in the model calculations has the following effects on uncertainties in the model:

- The ratio between domestic production (in EU-27) and import (to EU-27) is based on the data available for the 20 of the EU-27 countries on which the EU-27 is created. These countries only represent 38% of the EU-27 GDP. Therefore, large uncertainties on the split between domestic production and import are present; the volume of domestic production and related wastes and emissions is therefore uncertain
- The representativeness of results (waste and emissions) is based on 38% of EU-27 economy

4.3 National monetary supply-use tables

The starting point for the data collection for most countries is national supply-use tables (SUT) from Eurostat at level 60 products x 60 activities. Some SUTs were not available for the reference year 2003. In these cases the nearest year has been chosen, and the SUTs are scaled due to GDP for that year relative to year 2003. Other SUTs from Eurostat are not complete, i.e. some columns or rows are empty. These missing data have been filled using data from other countries combined with other data concerning the specific products/activities.

Generally, the 60x60 SUTs have been complete and available for 2003. Therefore, the uncertainties related to the above mentioned operations are assessed as being insignificant.

4.4 Conversion to basic prices

The procedure for converting the use table in purchasers prices to basic prices is described in deliverable D6-4. The procedure is a generalised method which does not take into account that margins and taxes may be different over activities. Therefore, uncertainties in the transactions in the monetary use table may occur. This may affect the use of service products (monetary) as well as it may indirectly affect the use of physical products because the monetary uses to some extent are used to distribute the physical use into the physical use table. In this respect it should be noted that uncertainties in the use of service products does only have an effect on the environmental impacts – not the generation of waste and accumulated stocks. The use of physical products is further adjusted as part of ensuring consistency in physical SUTs. The uncertainties related to the conversion to basic prices are assessed as not being significant.

4.5 Data on physical domestic supply and trade

Physical SUTs are created based on data on physical domestic supply and trade. Data on trade with physical products is generally good. For domestic production, data availability and data quality is assessed as being good for the following product categories:

- Agriculture
- Forestry
- Fishery
- Mining of metals
- Extraction of energy resources (coal, gas and crude oil)
- Refined petroleum products
- Electricity
- Pulp and paper
- Cement
- Basic metals

Data on the following product categories are assessed of being on a poorer level of quality, and often these data are not available for domestic production:

- Extraction of sand, gravel and non-metal minerals
- Food products from food industry
- Textiles
- Plastics
- Glass
- Chemicals
- Fertilisers
- Wood products
- Construction materials
- Machinery, equipment, instruments, furniture etc.

According to deliverable D6-2, the most significant environmental impacts are caused by emissions taking place within the activities for which data quality is good. Regarding waste, the most significant waste flows are related to construction waste and sand, gravel. Therefore, significant uncertainties are present in this respect.

4.6 Disaggregation of monetary SUTs

For most countries the starting point for data collection is the 60x60 monetary SUTs from Eurostat. These tables are disaggregated into 117x117 tables in order to fit with FORWAST product and activity categories. This is done for the countries which follow work package 3 (WP3) scope of data collection:

- Denmark
- France
- Greece
- Netherlands
- Poland
- Sweden

The remaining countries are disaggregated based on disaggregation factors obtained from the above mentioned scope WP3 countries.

The procedure for disaggregation is described in D6-4, and it ensures maintenance of product and activity balances and it prevents inconsistencies in economy to be introduced, e.g. that the total sum of all disaggregated products/activities is the same as the starting point and that it is prevented that some activities uses too much of certain products so that other activities would have to have negative uses.

Generally, there are three types of input data for the disaggregation of monetary SUTs:

1. Total supply (domestic production and import per product category)
2. Coefficients specifying the distribution of supplies
3. Coefficients specifying the distribution of uses

The **first type** of input data for disaggregation are the total monetary supply (domestic production + import) of all products. These disaggregation coefficients are most often based on detailed national and trade statistics as well as physical statistics combined with price information. Generally, there are good data on trade, but for some product categories information on domestic production is not available in some cases. Categories where this apply are (all the Eurostat categories that are disaggregated can be seen in Appendix 2: Disaggregation of Eurostat 60x60 SUTs):

- Food products and beverages => disaggregated to 12 categories
- Chemicals, chemical products and man-made fibres => disaggregated to 5 categories
- Other non-metallic mineral products => disaggregated to 8 categories

In some cases this lack of data has been compensated for by assuming a similar distribution of the total supply of products within the category to be disaggregated as for other countries. In other cases, physical data have been identified, and this has then been converted to monetary supplies using price information.

The uncertainties related to the lack of data and estimates described above are generally not significant; uncertainties in the total supply will only move some products from one activity to another, and the production functions (inputs and outputs per supply of an activity) is not affected by this.

The **second type** of data input to the disaggregation are the coefficients specifying the distribution of supplies. The major role of these data are 1) within the disaggregated products, to distinguish between domestically produced products and imported products, and 2) to distinguish virgin production (diagonal supply) from recycled supply (off-diagonal supply of a product from a recycling activity). The data sources used for specifying the import of products are trade data. These data are generally of a good quality. The data sources used to distinguish virgin from recycled production are typically production statistics and waste statistics. The preferable data source is production statistics because this directly specifies the split between virgin and recycled. These data are typically available for pulp (CEPI 2004), but for other materials which are supplied both from virgin production and recycling, such data are generally not available. In these cases, data on the amount collected for recycling in waste statistics have been used. These data are then multiplied with a factor representing the efficiency of the recycling process, e.g. 0.9 means than 90% of the recycled iron scrap becomes supply of new iron. Data on collected waste for recycling is available for some waste flows in most countries; typically glass waste, plastic waste, and metal waste. Very little information exists on the recycling of wood and demolition waste as well as slag and ash waste. Hence, the latter is estimated for some countries.

The uncertainties described above influences the split between recycling and virgin product, and also indirectly how much waste is sent to other waste treatment activities (if iron waste is recycled, then it is not sent to e.g. landfill). Therefore, these uncertainties have a significant effect on the quantity of waste sent to recycling, incineration, landfill, and the derived effects of this on the environmental impacts. In traditional IO-analysis, the overall impact should not be affected, but in the FORWAST project, the waste treatment activities (incineration, landfill, biogas) are created as normalised modules, meaning that a full coherence with national emissions accounts are not ensured. However, as in the case of the first type of disaggregation data, this does not affect the production functions of the activities (inputs and outputs per supply of an activity).

The **third type** of data input to the disaggregation are the coefficients specifying the distribution of uses. The major role of these data are to specify the production function of the activities, i.e. the inputs and outputs per unit of supply. The main adjustments are carried out for the use of different feedstocks, e.g. when agriculture is disaggregated, it is ensured that ‘pigs’ use animal feed, and ‘grain crops’ do not. Also the uses of fuels and electricity is specified, e.g. when the activity virgin production of aluminium uses more electricity per unit of supply of aluminium than recycling of aluminium waste. This type of input data to the disaggregation is based on engineering/chemical/agronomic knowledge on different manufacturing processes (often obtained from life cycle assessments). The physical information obtained from engineering/chemical/agronomic knowledge is converted to monetary units using price information.

The uncertainties related to the determination of coefficients specifying the distribution of uses are significant. The data sources are seldom country specific, e.g. data on fuel uses in cement production in an LCA (ecoinvent 2007) may not correspond to the specific mix of fuels used in the different countries for which monetary SUTs are disaggregated. However, it should be noted, that the uncertainty only concerns the distribution of products within the disaggregated product categories, therefore, an underestimated use of coal in cement production will then result in an overestimation of the use of coal for glass, concrete, and bricks. Thus, the overall waste generation and environmental impacts of the model is not affected by this – the uncertainty only concerns which activities are contributing with waste generation and emissions.

4.7 Data on the physical use of products

Generally, data on the use of products are not available or they are of poor quality. Monetary uses have to some extent been used to distribute the total physical domestic use over activities in economy. The uncertainty related to this does not differ from an ordinary monetary input-output based life cycle analysis, which by definition does not take into account differences in prices over activities. Differences in prices becomes an issue when dealing with supply-use tables in physical units. This uncertainty is eliminated/minimised for all uses of feedstock products since the accounting framework described in deliverable 6-4 allows for the calculation of feedstock efficiencies (the **D** table) and the calculation of the supply of residuals ($\mathbf{W_V}$ table). For all feedstocks it is ensured that 1) no negative waste occurs, and 2) the feedstock efficiency lies within normal range, e.g. approx 10% of the feed input to bovines become bovine meat and milk. Further, it is checked whether the fuel uses and electricity uses lies within normal ranges. Normal ranges for feedstock efficiencies, fuel uses, and electricity uses are identified based on general experiences, and in various life cycle assessment studies, mainly in the ecoinvent database (ecoinvent 2007).

In most cases, the use of feedstocks and energy contributes to the most significant environmental impacts. The uncertainties related to these issues are minimised through the above mentioned procedure. Still some uncertainties may be present for environmental impacts.

For waste generation, the uncertainties relating to the distribution of physical use of products only affect where in economy the waste is generated – not the total quantity.

4.8 Emissions

For most countries, the national emissions tables (for 60 or 117 activities in economy) are created based on country submissions to the UNFCCC. The activities for which emissions data are specified in the UNFCCC national accounts are more aggregated than the FORWAST activity categories. Therefore, data on emissions within a certain aggregated activity, e.g. agriculture, have been disaggregated in to the FORWAST categories of agriculture using animal metabolism for respiratory emissions (e.g. enteric fermentation), physical uses of fuels for emissions originating from coal, refined petroleum, and gas etc. Thus, uncertainties in emissions are related to the same uncertainties as the UNFCCC emissions inventories, the physical uses of fuels in the physical use tables, as well as animal metabolism balances. Therefore, emissions data does not add new uncertainties into the model – it is rather the physical data in the model (supply-use), that determines the uncertainties in emissions.

4.9 Resources

Resource uses are obtained from production statistics and resource statistics, and resource inputs are aligned with the supply from resource extracting activities, e.g. a mining activity supplies the same amount of mining products as the activity extracts (when not taking into account the loss of resource inputs as emissions and waste).

4.10 Waste treatment mix for different waste fractions

Waste generation is a model output. All generated waste per activity is categorised into waste fractions, and the waste fractions are directed to different waste treatments; recycling, incineration landfill etc. The direction of the waste fractions is based on information in the so-called residuals distribution table (**J**-table) which is created as part of the data collection exercise for each country. For each type of waste in the model, the **J**-table specifies the waste treatment, e.g. 30% to recycling, 40% to incineration, 10% to landfill, and 20% exported for recycling. The sum is 100%. The creation of the **J**-table is based on information in national waste statistics. For many waste fractions, national waste statistics are incomplete, i.e. less waste than actual flows are reported (see section 2.2). Especially, non registered landfill of construction materials, and unauthorised disposal of food waste (home composting, and other unauthorised disposal) is lacking in national waste statistics. This means that when national statistics report that X tonne of food waste is incinerated, and that the total quantity of food waste is Y, then the percentage directed to waste incineration in the **J**-table will be too large because the denominator (Y) is underestimated. Since it is most often unauthorised landfill that is lacking in the waste statistics, then it is likely, that other waste treatment options than landfill will be overestimated, and landfill will be underestimated.

The above mentioned uncertainty only relates to the distribution between the following waste treatments:

- Incineration
- Biogasification
- Composting
- Landfill

All other waste treatments are based on either the supply table (the supply table specifies the quantity of recycled material = supply of recycled material / recycling efficiency) or the fact that 100% of a given waste fraction is directed to a certain waste treatment, e.g. 100% of manure is sent to manure treatment.

The above mentioned uncertainties are identified as being significant for the following waste fractions:

- The share of food waste sent to incineration is overestimated
- The share of chemical/hazardous waste sent to incineration is overestimated
- The share of construction/demolition waste sent to incineration is overestimated

For food waste the implication is that a significant proportion of food related products are related to incineration of food. If the **J**-table provided better information, it is expected that more food waste would be landfilled, disposed via waste water and more food waste would be disposed of unauthorised to home composting and other places (in nature).

If the **J**-table provided better information for chemical/hazardous waste, it is expected that more chemical waste would be landfilled.

The implication of the fact that the share of construction/demolition waste sent to incineration is overestimated is that the generation of slag and ash from waste incineration is significantly overestimated, e.g. see generation of slag and ash in activity 'waste treatment' in Table 2.1.

4.11 Scenario implementation: Physical and non-physical products

The scenario implementation of the nine scenarios in the FORWAST project is described in deliverable D6-1: ‘Documentation of data consolidation, calibration and scenario parameterisation’. In the macro-economic scenarios all physical activities are scaled with an aggregated TMR-factor (see D6-1) and all service activities are scaled with a GDP-factor. The use of the same TMR-factor for all physical activities, corresponds to assuming the all these activities have developed equally. This assumption is related to uncertainties.

4.12 Scenario implementation: Energy-efficiencies

The scenario implementation of the nine scenarios in the FORWAST project is described in deliverable D6-1. In the macro-economic scenarios, the changes in energy efficiencies for different activities over time are identified using two different data sources for the numerator (use of energy by the activity) and the denominator (supply of products by the activity) in the calculation of energy use per supply. This introduces a source of uncertainty. In D6-1 a cross check with other data sources shows relative good coherence between emissions calculated in the applied method and in the data cross check approach. However, some emissions turn out to be significant larger in the applied approach: CO_2 per kWh from coal fires power plants in year 2035. This uncertainty is estimated as being significant.

4.13 Waste module

The waste module describing all inputs and outputs for waste treatment activities is described in deliverable D5-4: ‘Description of the environmental pressures from waste treatment’. Especially two issues relating to the waste modules are regarded as being related to large uncertainties:

1. Energy efficiency of waste incineration: It is assumed that 10% of the calorific value (lower heat value) of the incinerated waste is recovered and supplied as ’75 Electricity, steam and hot water’. This is highly uncertain; Danish incineration plants utilise approx 90% of the energy content in waste while some countries have incineration plants which do not recover the energy in waste.
2. Manure treatment: It is assumed that the used technology can be represented by anaerobic pond (storage) and broad spreading for land application technique. This does apply to to the used technology in all countries. Another issue which is related to uncertainties is the dry matter content of manure. The data used for estimating emission factors from storage assume 4% DS content while the manure in the FORWAST project operates with 7-12% DS. Therefore, the emissions per wet weight which determines the emissions in the used data, are overestimated in the FORWAST project.

The uncertainties referred to above are assessed as being significant.

4.14 Life time of products

The life time of products are used to determine when uses of products become waste. Since the economic growth is increasing, underestimation of life times results in overestimation of waste generation. As described in section 2.2 many discrepancies between FORWAST results on waste generation and figures in waste statistics are assessed to be related to underestimated product life times.

4.15 Level of aggregation

The FORWAST model includes 145 product categories of which 59 are measured in physical mass, i.e. these products are sources of waste. Given the high number of waste fractions, especially for hazardous wastes, it is clear that the FORWAST categories for these wastes are not sufficient for a good description. Therefore, the FORWAST model, at the current level of detail, is only sufficient in providing information on bulk wastes (non-hazardous). And still within these bulk wastes, there are special fractions that are not described in the model, e.g. different qualities of wastes and scrap fro recycling.

4.16 Conclusion on the uncertainty assessment

Based on the description of uncertainties presented in this section, the following uncertainties are regarded as the most significant:

- Uncertainties relating to the split between EU-27 domestic production and import to the EU-27 causes uncertainties relating to figures on waste generation occurring within the EU-27 versus waste generation occurring outside the EU-27
- Uncertainties relating to disaggregation of monetary supply-use tables and data on physical uses causes uncertainties in waste and emissions per unit of supply for the product categories in the FORWAST model
- Applied waste treatment mix overestimates to share of waste sent to waste incineration (especially food and construction)
- Scenario implementation leads to overestimation of emissions related to coal based electricity in future scenarios
- Uncertainties in waste module causes overestimated emissions from manure treatment and uncertain modelling relating to energy recovery of waste incineration (large variability depending on country)
- Underestimated product life times (especially construction materials) causes overestimation of waste quantities
- The level of aggregation of the FORWAST model prevents the approach for being used for providing data on special waste fractions and hazardous waste

Significant uncertainties have been identified. But still, model results on future scenarios can be used for obtaining information on the developments in waste flows and environmental impacts given different macro-economic developments and different waste treatment strategies. Especially, the relative differences between scenarios are not affected by the major sources of uncertainties. Also information on the environmental impacts per product for year 2003 are appropriate for use in input-output and hybrid LCA. In this respect, it should be noted that the uncertainties in the FORWAST model are estimated as being less significant than in traditional economic input-output tables because the FORWAST model takes into account differences in prices over activities as well as physical inconsistencies are eliminated.

5 Identification of priority material flows

This section analyses the potential effects of different police instrument applied on different material flows. When identifying priority materials, the criteria is minimisation of the total monetarised environmental impact. This is composed of two factors:

1. Environmental impact per unit of product applying the desired technology
2. Total quantity of the material flow at which the desired technology is applied (this is a combination of the total quantity and the constraints for applying the desired technology on 100% of the material flow)

The identification of priority material flows is carried out in two sections in the following. The first section focuses on priority materials for waste treatment and recycling, and the second section focuses on priority materials for prevention.

5.1 Identification of priority material flows for treatment and recycling

This section analyses the potential reductions in environmental impact by different means of recycling/treatment. The analysis presented in the following is based on the reduction if 100% recycling is achieved. This does not represent realistic recycling rates in reality, but the analysis indicates theoretical potentials which can be used to prioritise future policy interventions.

Table 5.1 shows the total quantity of all waste fractions for which different treatment technologies are considered within the FORWAST project. The waste fractions and their quantity are specified in the columns: ‘Waste fraction’ and ‘Quantity, dry weight (million tonne)’. The column ‘Waste treatment’ specifies the current mix of specific waste treatment options for each waste fraction in year 2003 in EU-27. The column ‘Specific impact (EUR/kg)’ specifies the monetarised impact per dry kilogram of treated waste for different waste treatment options and waste fractions. The column ‘Impact (billion EUR)’ is calculated by multiplying the following three columns:

- ‘Quantity, dry weight (million tonne)’
- ‘Waste treatment’ (%)
- ‘Specific impact (EUR/kg)’

The sum of the column ‘Impact (billion EUR)’ in the bottom of the table shows the total monetarised impact related to the treatment of the waste fractions in the table in EU-27 in year 2003.

The column ‘Impact if all waste is treated with specific waste treatment (billion EUR)’ specifies the monetarised impact if 100% of the waste fraction is treated using the treatment technology in the row, e.g. if 100% of all ‘Food waste’ is landfilled, then the impact associated with this would be 108 billion EUR. The next column ‘Potential, if all waste is treated with specific treatment minus current mix (billion EUR)’ specifies the theoretical potential environmental effect, if the current mix of treatments of a given waste fraction is displaced with the treatment in a given row. E.g. if all ‘Food waste’ is landfilled, then this would increase the current environmental impact from treatment of food waste from 53+31+7.8-0.013= 92 to 108, i.e. an increase by 16 billion EUR. Positive values represent an increase in environmental impact, and negative values represent a reduction in environmental impact. The blue arrows in the table specify, per waste fraction, which waste treatment option that is associated with the largest theoretical potential for reduction of the environmental impact.

Waste category	Waste fraction	Quantity, dry weight (million t)	Waste treatment	Specific impact (EUR/kg)	Impact (billion EUR)	Impact if all waste is treated with specific waste treatment (billion EUR)	Potential, if all waste is treated with specific treatment minus currect mix (billion EUR)
Organic	Food waste	526	49% Landfill	0.21	53	108	16
			43% Incineration	0.14	31	74	-19
			8.3% Composting	0.18	7.8	93	1.2
			0.07% Biogas	-0.035	-0.013	-18	-110
	Manure	157	100% Conventional storage	0.34	53	53	0
			0% Biogas	0.23	0	36	-18
	Wood waste	82	2.5% Recycling	0.14	0.28	11	6.2
			34% Incineration	0.13	3.6	11	5.8
			64% Landfill	0.021	1.1	1.7	-3.3
Textile	Textile waste	18	55% Incineration	0.13	1.4	2.4	0.33
			45% Landfill	0.094	0.8	1.7	-0.41
Paper	Paper waste	113	15% Recycling	0.076	1.3	8.5	-6.4
			15% Incineration	0.094	1.6	11	-4.3
			70% Landfill	0.15	12	17	2.3
Plastic	Plastic waste	167	2.6% Recycling	-0.23	-1.0	-39	-48
			39% Incineration	0.13	8.1	21	12
			59% Landfill	0.017	1.7	2.9	-5.9
Glass	Glass waste	60	4.6% Recycling	-0.13	-0.35	-8	-7.9
			21% Incineration	0.015	0.19	0.88	0.66
			74% Landfill	0.0086	0.39	0.52	0.30
Construction and inert	Construction waste	2,261	0.6% Recycling	0.016	0.21	37	17
			99% Landfill	0.0086	19	19	-0.099
	Ash and slag waste	762	3% Recycling	-0.074	-1.4	-56	-61
			98% Landfill	0.0086	6.4	6.6	1.6
Metal	Iron waste	218	46% Recycling	-0.070	-7.1	-15	-9.4
			15% Incineration	0.015	0.46	3.2	9.1
			39% Landfill	0.0086	0.73	1.9	7.8
	Aluminium waste	20	41% Recycling	-0.65	-5.3	-13	-7.8
			22% Incineration	0.015	0.064	0.29	5.5
			37% Landfill	0.0086	0.064	0.17	5.4
	Copper waste	6	40% Recycling	-0.21	-0.48	-1.2	-0.76
			23% Incineration	0.015	0.019	0.085	0.53
			37% Landfill	0.0086	0.019	0.051	0.50
	Metals nec waste	7	41% Recycling	-0.22	-0.61	-1.5	-0.94
			22% Incineration	0.015	0.022	0.10	0.67
			37% Landfill	0.0086	0.022	0.060	0.62
Total	**Total**	**4,398**			**189**		

Table 5.1: Estimation of theoretical potentials for reducing the environmental impact for different waste treatments and recycling. The figures in the table applied to EU-27 in year 2003.

The total current impact related to the treatment of all waste fractions in Table 5.1 is 189 billion EUR. This should be compared with the total EU-27 environmental impact at 1,162 billion EUR. This is a higher share of the total environmental impact caused by waste treatment than typically referred to (in national NAMEAs). The reason for the high share is that biogenic CO_2 is included in the calculation of the contribution to global warming; this makes landfilling of food waste and manure treatment to some of the most significant contributors.

For **food waste**, the largest potential for reduction of the environmental impacts is by treating the waste using biogas technology. It should be noted that it is likely that the actual potential is lower than the specified -110 billion EUR. This is because there may be some physical, logistical and financial constraints in achieving the theoretical potential. Examples of constraints are: if the food waste is mixed with other waste, it is often costly/difficult to separate it, and the fact that food waste is generated in many activities and throughout the economy, in many forms (solid, liquid etc.), and in many geographical locations makes collection and biogasification difficult and costly.

For **manure** there is a significant reduction potential at -18 billion EUR by using biogasification.

Wood waste provides a potential at -3.3 billion EUR, if the current mix of waste treatment of primarily landfill and incineration is changed to 100% landfill. The reason that landfilling of wood waste causes less environmental impacts than incineration relates to two facts: 1) the degradation rate of wood waste landfilled during 100 years in the FORWAST model is very low (only 1.6% of the landfilled wood waste degrades during 100 years), and 2) the energy recovery rate of waste incineration is relatively low; only 10% of the energy content, lower heating value, is recovered. Therefore, the reduction potential for landfill is probably overestimated, and the reduction potential for incineration of wood waste is probably underestimated.

The reduction potential for **textile waste** is insignificant.

For **paper waste** the reduction potential is largest for recycling, but also incineration provides a significant opportunity for reducing the environmental impact compared with the current treatment mix (with 70% landfill).

Plastic waste provides a significant reduction potential at -48 billion EUR if recycling is increased from 2.6% to 100%. It should be noted that the current recycling rate at 2.6% is significant lower than what is typically reported in waste statistics. The reason for this is, that waste statistics typically only focuses on packaging waste, and not plastic waste contained in products (electronic products, toys etc.) and building material (windows, wall tightening membranes etc.). Also the recycling rate at 2.6% is related to uncertainties.

For **glass waste** the potential for reductions is -7.9 billion EUR if all glass waste is sent to recycling.

Construction waste does not provide significant reduction potentials. Also recycling of construction waste shows to be related to higher environmental impacts than landfill. This mainly relates to the fact that recycling of construction waste is associated with uses of energy (transportation etc.) and that the recovered material does not displace environmentally significant virgin materials (sand, gravel). However, it should be noted that some of the main reasons for recycling construction waste are to reduce the amount of waste sent to landfill, and to reduce exploitation of new materials. These two effects are not directly monetarised in the applied impact assessment method.

The theoretical reduction potential for **ash and slag** waste is -61 billion EUR. This may be well overestimated since physical and economical constraints may be present. When recycling ash and slag waste in cement production, the ash and slag is used as a substitute for clinker, which is very energy intensive. However, not all slag (residuals from incineration of inert materials) can be used as a clinker substitute, and there are limits for how much clinker that can be substituted, and also there may be economic constraints related to the transportation of slag and ash. Further, it should be noted that the total quantity of ash and slag from waste incineration is overestimated in the model, see section 2.1.12.

For **metal wastes**, reduction potentials are present for especially **iron waste** (-9.4 billion EUR) and **aluminium waste** (-7.8 billion EUR). The potential for copper and other metals is less significant.

Summing up, the following material flows can be identified as significant regarding reduction potentials for environmental impacts (the theoretical reduction potential is given is brackets):

- Food waste (-110 billion EUR)
- Ash and slag (-61 billion EUR), Note: probably overestimated
- Plastic waste (-48 billion EUR)
- Manure (-18 billion EUR)
- Iron waste (-9.4 billion EUR)
- Glass waste (-7.9 billion EUR)
- Aluminium waste (-7.8 billion EUR)
- Paper waste (-6.4 billion EUR)

5.2 Identification of priority material flows for prevention

This section analyses the potential reductions in environmental impact by different means of Prevention. The analysis presented in the following is based on the estimated change in scenario parameters as described in deliverable D5-3: ‘Report with description of three what-if scenarios of waste treatment policies and their interplay with the macro-economic scenarios’. Therefore, the reduction potentials presented in the following are not directly comparable with the potentials presented in section 5.1 which represents 100% implementation of the analysed means (100% recycling).

Table 5.2 provides an overview of the scenario implementation of the prevention scenario. Each of the seven rows in Table 5.2 represents a means of prevention as described in deliverable D5-3. The first column specify the type of prevention, the second column specifies in which activities the prevention means are implemented. The third and fourth column species the parameters which are changed in the prevention scenario, and the changes of parameter values (year 2003 = index 100) are specified in the last two columns.

In Table 5.3, the effect of each of the means of prevention is quantified. In order to illuminate and isolate the effect of each means of prevention, all other parameters in the model are kept constant, i.e. time parameters is set to year 2003. This means that there is no effect of macro-economic parameters. The last column specifies the total reduction potential in units of monetarised environmental impacts (billion EUR). The second to the fourth columns specify the affected products and the total quantity of these products in year 2003. The fifth and sixth columns specify the total monetarised impact for the products for which prevention means are implemented without and with the prevention means. The last column is calculated as the difference between the two latter columns.

Means of prevention	Activity	Changed parameter		2003	2035
Reduce the use of meat, reduce manure	Household	Use	Meat use	100	81
		Use	Flour use	increased correspondingly by dry mass	
Reduce processing waste in food industry	Food industry	Use, waste	Fruit and veg. Use & waste	100	81
		Use, waste	Grain crops & waste	100	97
		Use, waste	Crops nec & waste	100	81
Reduce packaging waste	Beverages industry	Use, waste	Use of plastic & waste	100	88
		Use, waste	Use of glass & waste	100	88
Reduce waste of textiles, wearing and apperal, leather	Household	Use, waste	Textiles, wearing and apperal, leather & waste	100	93
Reduce paper waste	All, except household	Use, waste	Printed matter	100	90
Reduce use of petrol	All, except refinery industry	Use, waste, emissions	Use of refined petroleum, waste, and emissions	100	93
Reduce metals waste	All, except machinery product activities	Use, waste	Machinery and equipment n.e.c.	100	93
		Use, waste	Office machinery and computers	100	93
		Use, waste	Electrical machinery n.e.c.	100	93
		Use, waste	Radio, television and communication equipment	100	93
		Use, waste	Instruments, medical, precision, optical, clocks	100	93

Table 5.2: Overview of the means of prevention, and the changed parameters in the prevention scenario. Note that detailed scenario descriptions can be found in deliverable 5.3 ‘Report chapter with description of three what-if scenarios of waste treatment policies and their interplay with the macro-economic scenarios’.

Means of prevention	Products	Quantity of affected pool	Unit	Total impact without prevention (GEUR)	Total impact with prevention (GEUR)	Reduction potential (GEUR)
Reduce the use of meat, reduce manure	Household use: Meals	1,184	GEUR	269	263	-5.7
Reduce processing waste in food industry	Fruits and vegetables, processed	14	million tonne (dry)	5.9	5.2	-0.78
	Flour	97	million tonne (dry)	-1.8	-1.8	-0.048
	Sugar	56	million tonne (dry)	7.6	7.5	-0.10
	Food preparations n.e.c.	24	million tonne (dry)	24.2	24.1	-0.10
	Animal feeds	132	million tonne (dry)	12.9	12.8	-0.069
	Beverages	16	million tonne (dry)	22.4	22.3	-0.060
Reduce packaging waste	Beverages	16	million tonne (dry)	22	22	-0.48
Reduce waste of textiles, wearing and apperal, leather	Household use: Housing	1,440	GEUR	191	191	-0.26
	Household use: Clothing	196	GEUR	275	275	-0.73
Reduce paper waste	Printed matter and recorded media	16	million tonne (dry)	0.010	0.0062	-0.0037
Reduce use of petrol	Refined petroleum products and fuels	290	million tonne (dry)	90	83	-6.7
Reduce metals waste	Machinery and equipment n.e.c.	22	million tonne (dry)	17	16	-1.3
	Office machinery and computers	0.87	million tonne (dry)	3.1	2.9	-0.23
	Electrical machinery n.e.c.	11	million tonne (dry)	7.0	6.5	-0.53
	Radio, television and communication equipment	2.2	million tonne (dry)	2.7	2.5	-0.20
	Instruments, medical, precision, optical, clocks	0.89	million tonne (dry)	2.6	2.4	-0.19

Table 5.3: Quantification of the reduction potential of the means of prevention in units monetarised environmental impacts (billion EUR).

Based on the last column in Table 5.3, the following material flows can be identified as priority flows concerning prevention: Substitution of meat with non-meat food, and reduction of the use of petrol. This identification is in line with the identified most environmental significant activities within the EU-27 economy in Table 3.8 (p 22).

It should be noted that the prevention scenario does not represent an exhaustive list of means of prevention. Therefore, the reduction potentials in Table 5.3 should be seen as examples of reduction potentials. Further, it should be noted that the reductions specified in Table 5.2 (last column) are based on estimates described in deliverable D5-3 ‘Report with description of three what-if scenarios of waste treatment policies and their interplay with the macro-economic scenarios’. It is likely, that prevention means could achieve more significant reductions than specified in Table 5.2 – especially in light of post Kyoto interventions.

6 Priority material flows and policy recommendations

Based on the scenario results in deliverable D6-2 and the contribution analysis presented in the current report, priority materials and policy recommendations are given in this section.

6.1 Priority materials for treatment, recycling and prevention

Three "what-if-scenarios on waste treatment" regarding treatment (increasing waste incineration), recycling (increasing recycling), and prevention (minimising losses throughout the product chain) has been analysed. In most cases, the three analysed scenarios on waste treatment do not exclude each other, and therefore, this study does not provide the basis for recommending one strategy over the other. The FORWAST project can be used to identify the overall contributing activities to waste generation and environmental impacts in the EU-27, and to identify the causes (upstream in the product life cycle) of environmental impact of demanding different products and services. Also, within each of the three strategies on waste treatment, the FORWAST project can be used to identify priority material flows.

In general all analysed means of improvements in the three waste treatment scenarios contributes to reductions in environmental impacts. However, there are a few exceptions, e.g. increased composting of food waste causes higher environmental impacts than the current practise, and landfilling of plastic waste is preferable over incineration. The latter is related to a relatively low energy recovery rate in the incineration of waste activity. Therefore, the figures are related to uncertainties. Also recycling of construction waste shows to related to higher environmental impacts than landfill.

The priority materials listed in the following are identified based on a combination of the total quantity of material and the environmental impact per unit of treatment/recycling/prevention.

Within **treatment** technologies (mechanical biological technologies, incineration and landfill), the largest potentials for improvements can be found within:

- Biogasification of food waste
- Incineration of food waste (biogasification is related to higher potentials)
- Biogasification of manure

Within **recycling**, the largest potentials for improvements can be found within:

- Recycling of plastic waste
- Recycling of iron waste
- Recycling of glass waste
- Recycling of aluminium waste

Within the analysed prevention means, the largest improvement potentials can be found for the following materials:

- Reduction of fuel uses by increased energy efficiencies in motor vehicles
- Displacement of meat by other food items
- Reduce the use of metals by eco-efficiency/optimising design etc.

The different policy options, instruments and technologies are further described in deliverable D5-3 'Report with description of three what-if scenarios of waste treatment policies and their interplay with the macro-economic scenarios'.

6.2 The role of macro-economic development - waste generation and environmental impacts

The scenario results in deliverable D6-2 show that the macro-economic development has a significant impact on the waste generation as well as environmental impacts. Thus, there is a strong relation between economic growth and waste generation, and between economic growth and environmental impacts.

Three scenarios of macro-economic development are analysed; baseline growth, high growth, and low growth. In the baseline scenario, the total waste generation is 70% higher in 2035 than in 2003. In the high and low growth scenarios the waste generation is 84% and 60% higher than in year 2003 respectively.

The growth in waste generation and environmental impact from year 2003 to 2035 due to economical growth cannot be compensated by the assessed means of reductions in the three "what-if-scenarios on waste treatment" regarding treatment, recycling, and prevention. Since the three "what-if-scenarios on waste treatment" do not represent an exhaustive list of means of improvements and since changes in scenario parameters (e.g. recycling rate that will be achieved in year 2035) are estimated rather than investigated (taking into account economical, physical and social constraints for achieving means of improvement), it cannot be concluded that the increasing tendency in waste generation and environmental impact cannot be turned into a decreasing tendency.

The strong relation between economic growth on the one hand and environmental impacts and waste generation on the other emphasise that a further decoupling between economic growth and externalities is needed if political goals on net reductions in environmental impacts should be fulfilled.

6.3 The role of the FORWAST model in enhancing waste statistics in the future

The comparison of FORWAST model results on waste generation and Danish waste statistics shows significant differences for most waste flows. The main reasons for the differences are identified as non-recorded waste in waste statistics, differences in waste definitions (the FORWAST model uses a broader definition), and uncertainties in estimates of product life times in the FORWAST model (further needs for calibration). In addition some uncertainties are also present in the model inputs on resource inputs, product flows, and emission outputs. However, the statistical data (resource statistics, production statistics, national emissions accounts) on these items are generally more complete and of significant better quality than waste statistics.

The fundamental mass balance principle used in the FORWAST project enables calculating the waste flows using the above mentioned good data, and to compare with waste statistics. The FORWAST project has demonstrated that the data inputs to the model exists and are accessible, and that the model is practically applicable to national economies. Referring to the above mentioned comparison of the FORWAST results and Danish waste statistics, the following issues should be addressed in future uses of the FORWAST model:

- Better data/emphasis on calibration of product life times to determine when inputs of products to economy comes out as waste. This should include an identification of the determining factors on product life times.
- More interplay with national waste statistics to improve data quality of the applied waste treatment mix
- Better national data on total production distinguishing between virgin and recycled production are needed. This will also improve data quality of the applied waste treatment mix as referred to above
- Better national statistical data on the use of products by different activities. Statistical data are generally good on production, export and import. But for uses of products by different activities in economy, data availability and quality are generally poor. The use of products is therefore to some extent determined based on monetary use (obtained from use table). This implies potentially significant uncertainties.

The FORWAST model shows advantages for bulk materials (non-toxic waste flows), but for hazardous wastes, the approach is less useful. The level of aggregation, i.e. the number of different product and waste types included in the model defines a limit for which waste flows are described. E.g. chemical products in the FORWAST model mainly belong to the product category ‘Chemicals nec.’. This means that waste originating from the use of chemicals comes out as model results in terms of quantities of ‘waste of chemicals nec.’. A considerable share of this waste fraction may belong to hazardous waste, but the category also contains large amounts of non-hazardous materials. Thus, the current model results does not provide valuable results on hazardous waste. Related to this, the current version of the model does not include toxic substances (product flows, waste flows and emissions). If the model should provide a useful description of hazardous wastes including toxic substances, it would require enormous quantity data which are currently not directly accessible.

6.4 Outlook, the role of the FORWAST model in future integrated accounting systems

The FORWAST model demonstrates an integration of economic accounts (supply-use tables), emissions accounts (NAMEA and national inventory submissions under the UNFCCC), and various sector specific production (and use) accounts (agriculture, forestry, fishery, metals and mineral extraction, energy). Currently, the methodologies used for these accounts are not standardised, i.e. there are no common standard specifying which activities, trade partners, products, substances to be included, no standards specify the units of measurement (energy, mass, water content etc.). Further, the accounts are not using a common accounting framework, e.g. supply use framework, and mass balance/energy balance framework.

In future work on harmonising accounts, experiences from the FORWAST model can be used. FORWAST demonstrates an example of a fully harmonised way of integrating all the above mentioned accounts. The key characteristics of the accounting framework in the FORWAST model can briefly be described as:

- Supply use framework
- Balanced economy and physical transactions for products and activities
- Physical transactions are measured in dry weight
- Physical inputs to the economy are resources
- Physical outputs from the economy are emissions and stocks of waste in landfills (and unauthorised placement of waste)
- Waste treatment/recycling activities supplies the service to treat or recycle waste (measured in mass unit), and most waste treatment activities supply by-products: recycled material or recovered energy
- The same convention of material inputs (resources), intra economy transactions (products, stock changes and waste), and material outputs (emissions and stocks of waste) is used for all transactions, which enables mass balance: inputs to any activity (resources, products, waste) = outputs (products, stock additions, waste, emissions)
- Intermediate flows of oxygen in combustion processes (resource input of oxygen and output of oxygen in CO_2) are not included in the mass balance

It is recommended to use the principles developed through the FORWAST model for establishing and refining future integrated accounting systems. The accounting system used in the FORWAST model also provides the option to directly establish hybrid unit input-output tables including physical transactions of waste flows. In this respect the FORWAST model is the first of its kind. The latter provides a powerful life cycled based tool for hotspot identification and for prioritising environmental and waste policy interventions.

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Appendix 1: Included product groups in the model

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: 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 c	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 instrur
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 gooc	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, distrib	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 t	Wholesale trade and commission tra
0					Retail trade services, except of m	Retail trade services, except of motc
1		1	84	55	Hotel and restaurant services	Hotel and restaurant services
1		1	85	60	Land transport; transport via pipelir	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, exc
1		1	91	66	Insurance and pension funding ser	Insurance and pension funding servic
1		1	92	67	Services auxiliary to financial interr	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 ec
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

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

Contract number: 044409

Deliverable n° 6-4

Title:
Documentation of the final model used for the scenario analyses

Authors:

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

Due date of deliverable: 31th January 2009
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Organisation name of lead contractor for this deliverable: 2.-0 LCA consultants, Denmark
Revision: draft 4
Dissemination level: PU (Public)

Project home page: http://forwast.brgm.fr/

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-ΔS). 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**.

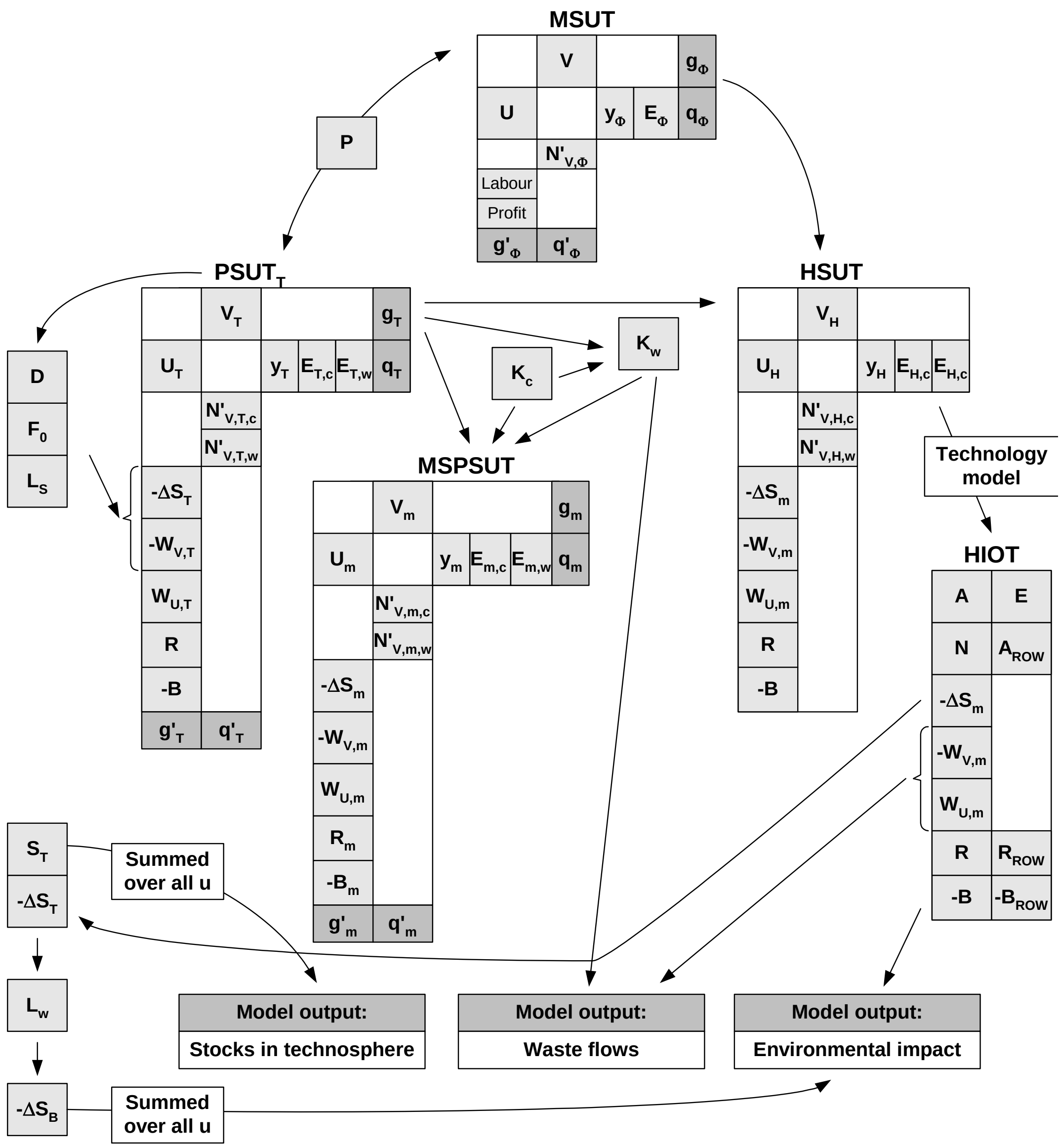

Figure 1: Model overview.

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), $\mathbf{V}_{\mathrm{T}}$ (total physical supply table covering all materials, m) and $\mathbf{V}_{\mathrm{Fe}}$ (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 (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 (N_c) and residuals (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 (E_c) and residuals (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 (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 (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 (G_c, G_w, and 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 ($\mathbf{A}_{N,upscaled}$), upscaled:
Input of imported products and product outputs, per product, for a specified period and geographical area.
$\mathbf{A}_{N,upscaled}$ = ($\mathbf{scale}^T$ I) .* $\mathbf{A}_N$ (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. ≥ 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	$[\mathbf{A}\vert\mathbf{I}]\sim[\mathbf{I}\vert\mathbf{A}^{-1}]$ 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	$\mathbf{A} = \begin{bmatrix} a & c \\ b & d \end{bmatrix}$, $\mathbf{B} = \begin{bmatrix} e & g \\ f & h \end{bmatrix}$ $\mathbf{A} \,./\, \mathbf{B} = \begin{bmatrix} a/e & c/g \\ b/f & d/h \end{bmatrix}$
det(**A**)	Determinant of square matrix **A**	$\mathbf{A} = \begin{bmatrix} k & l \\ m & n \end{bmatrix} \Rightarrow \det(\mathbf{A}) = kn - lm$

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.

Monetary use table	Activities (a)	Final uses			Total
Products (c)	$\mathbf{U_o}$	$\mathbf{y_0}$	Capital formation	$\mathbf{E_c}$	**q**
Primary inputs	Labour				
	Taxes				
	Use of fixed capital				
	Profit				
Total	**g'**				

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.

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

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**.

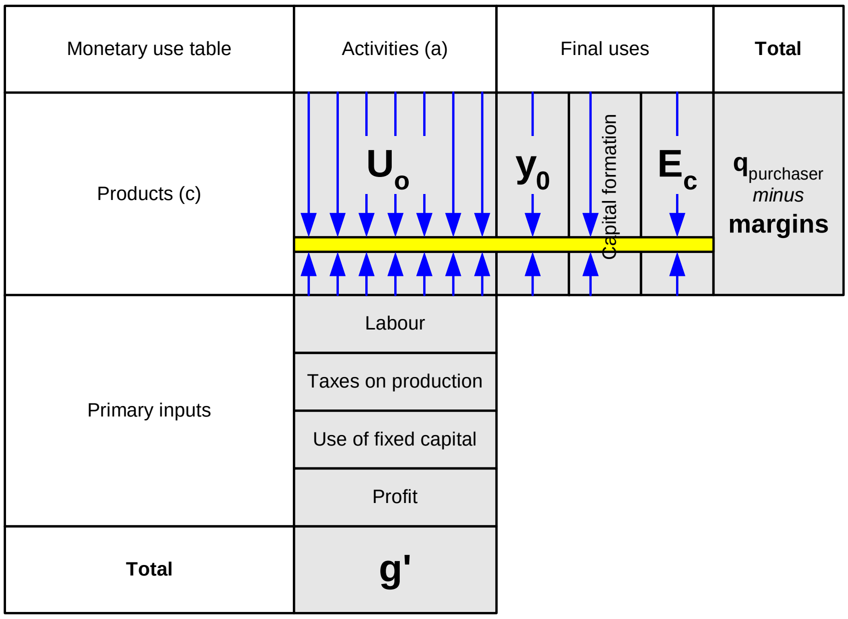

Figure 5: Use table. The blue arrows illustrate that the reduced values due to elimination of transport and trade margins are deducted in the rows representing transport and trade products. The resulting use table is a table in purchaser's prices minus transport and trade margins.

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.

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

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**.

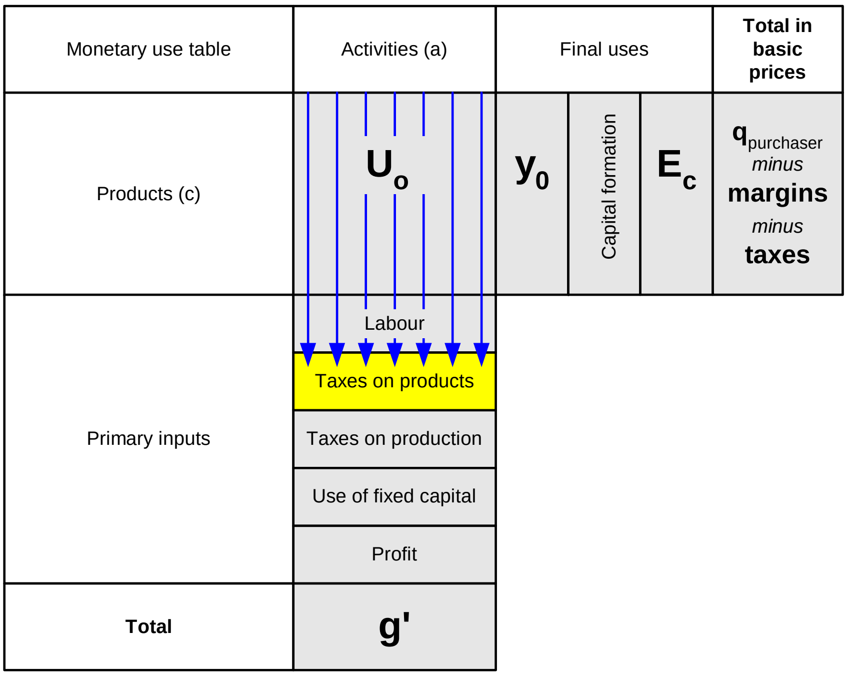

Figure 6: Use table. The blue arrows illustrate that the reduced values due to elimination of taxes are deducted in a new row representing taxes on products. The resulting use table is a table in basic prices, i.e. purchaser's prices minus transport and trade margins and minus taxes.

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 ($\mathbf{g}_{DK,1999}$) in Denmark in 1999, see (4). In (4) the Danish investment matrix for the year 1999 is denoted $\mathbf{U}_{investment,DK,1999}$.

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

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

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

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**.

Balanced MSUT	Activities (a)	Import	Needs fulfilment	Export	Total
Products (c)	**V'**	$\mathbf{N_c}$			**q**
Total	**g'**				
Products (c)	**U**		**y**	$\mathbf{E_c}$	**q**
Primary inputs	Labour				
	Taxes				
	Profit				
Total	**g'**				

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)	$\mathbf{U}$	$\mathbf{y}$	$\mathbf{E_c}$	$\mathbf{E_w}$	$\mathbf{q}$
Stock changes	$\mathbf{-\Delta S}$				
Supply of residuals	$\mathbf{-W_V}$				
Use of residuals	$\mathbf{W_U}$				
Resources	$\mathbf{R}$				
Emissions	$\mathbf{-B}$				
Total	$\mathbf{g'}$				

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 $\in [0,1]$.

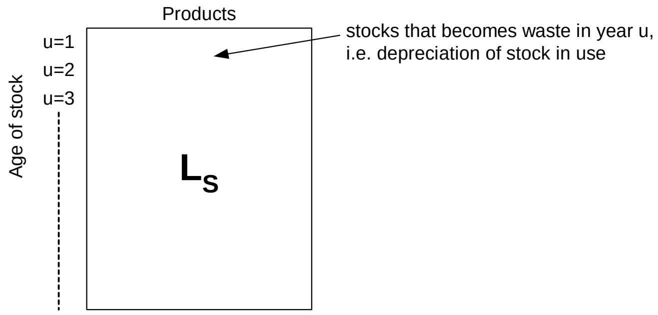

Figure 10: Format of the stock degradation matrix ($\mathbf{L_S}$).

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**.

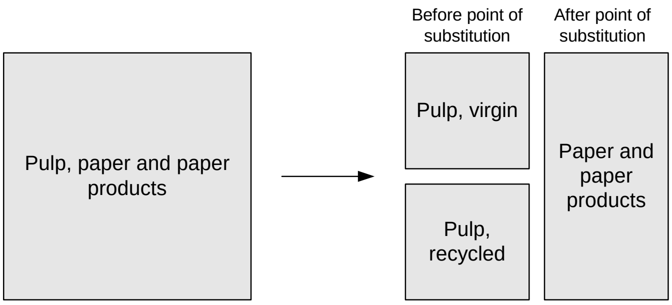

Figure 11: Disaggregation of activities by point of substitution and by recycled/virgin, using pulp, paper and paper products as example.

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).

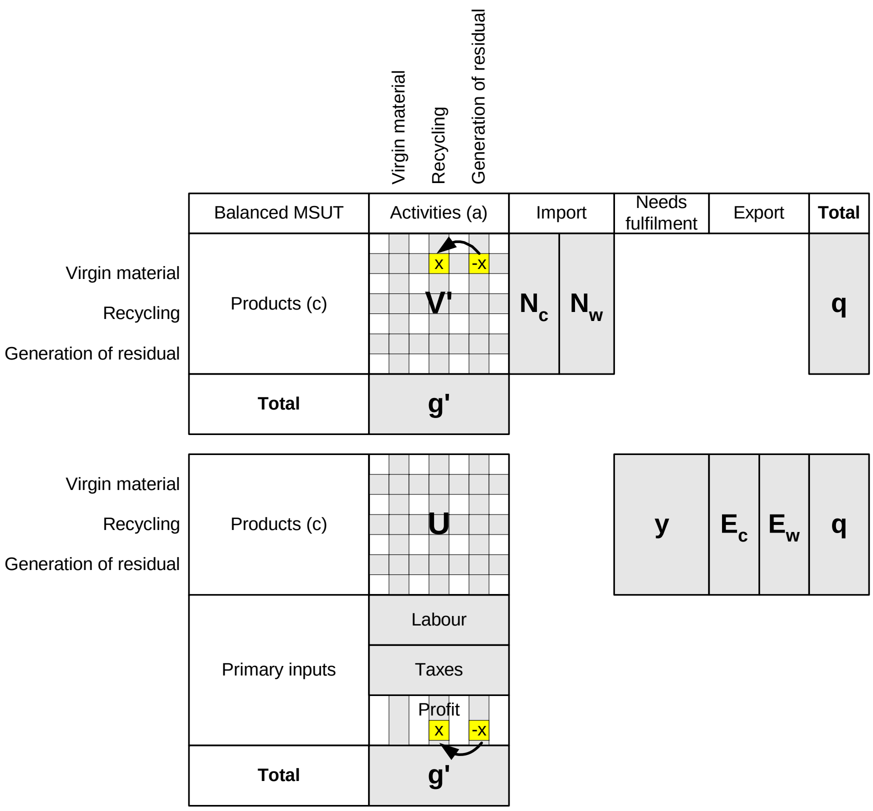

Figure 12: Modification of the MSUTs due to off-diagonal products being residuals. The off-diagonal entry 'x' is moved from a residual generating activity to a recycling activity.

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**.

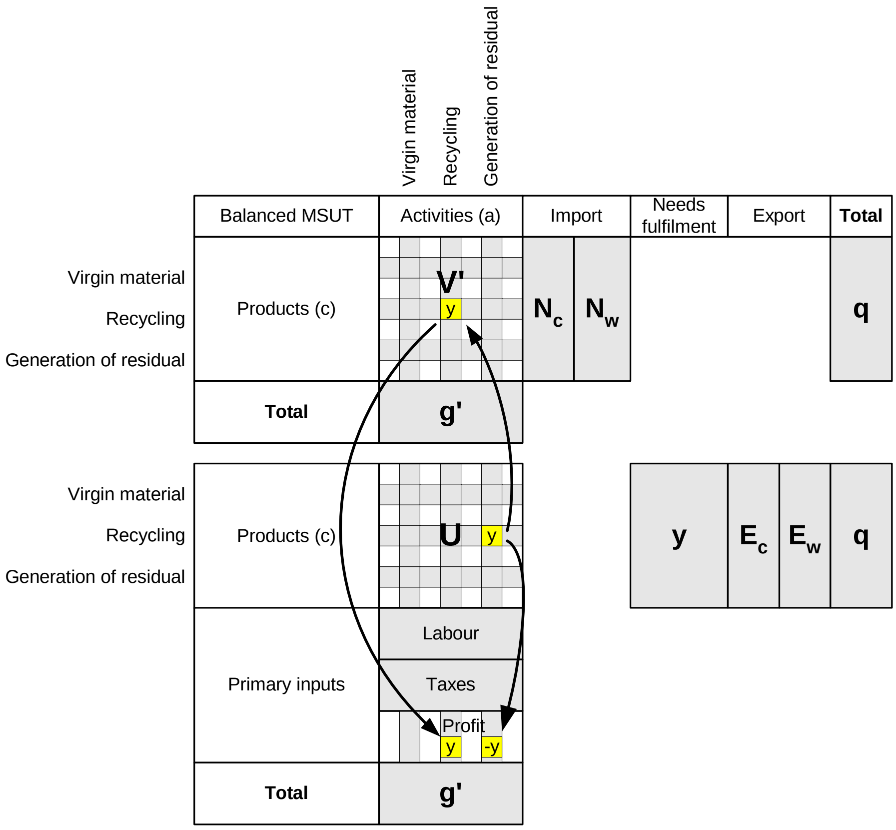

Figure 13: Modification of MSUTs in order to include the use and supply of the recycling service to process residuals into products. The increase in the use and the supply is 'y'. In order to maintain balance, the profit is adjusted correspondingly.

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 $\mathbf{V}_{T}$ and $\mathbf{U}_{T}$ 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 **q** and the balance for **g** is maintained with an increase in the output from recycling and a corresponding reduction in the output of 'Generation of residual'.

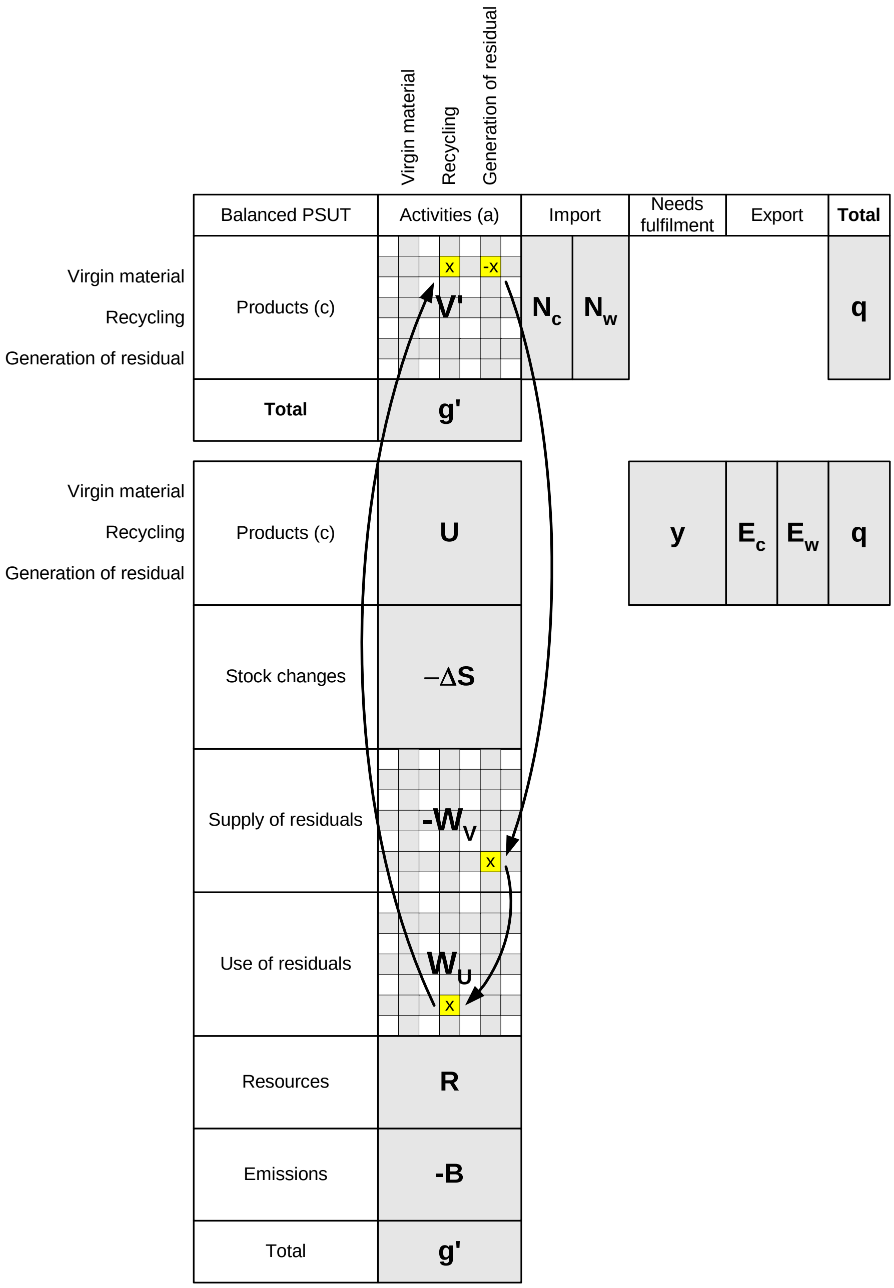

Figure 14: The figure illustrates the effects on the supply and use of residuals ($\mathbf{W_V}$ and $\mathbf{W_U}$) in the PSUT when an off-diagonal being a residual in $\mathbf{V_T}$ is moved from one activity (residual generating) to another (recycling activity).

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**.

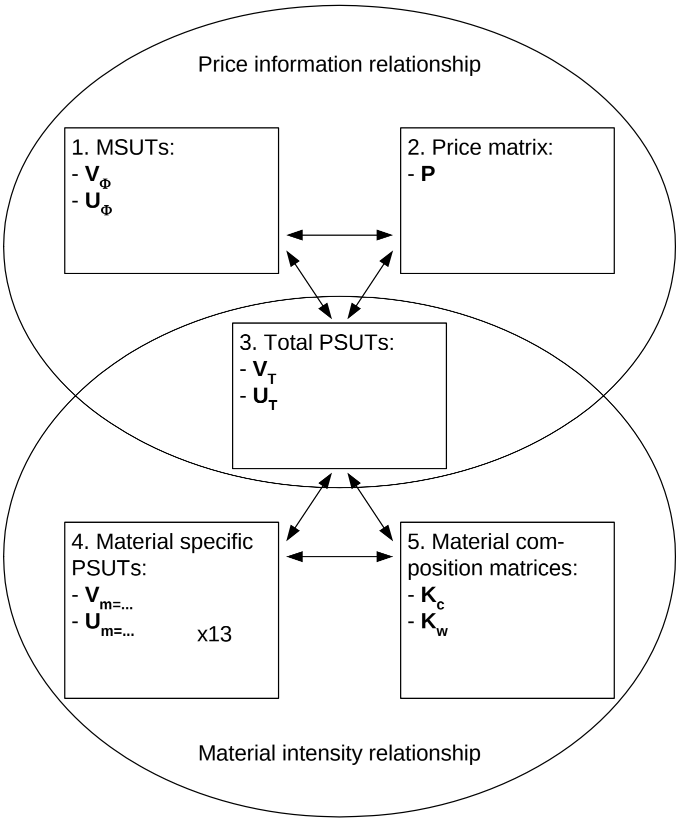

Figure 15: Five different data sources and their relationships.

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

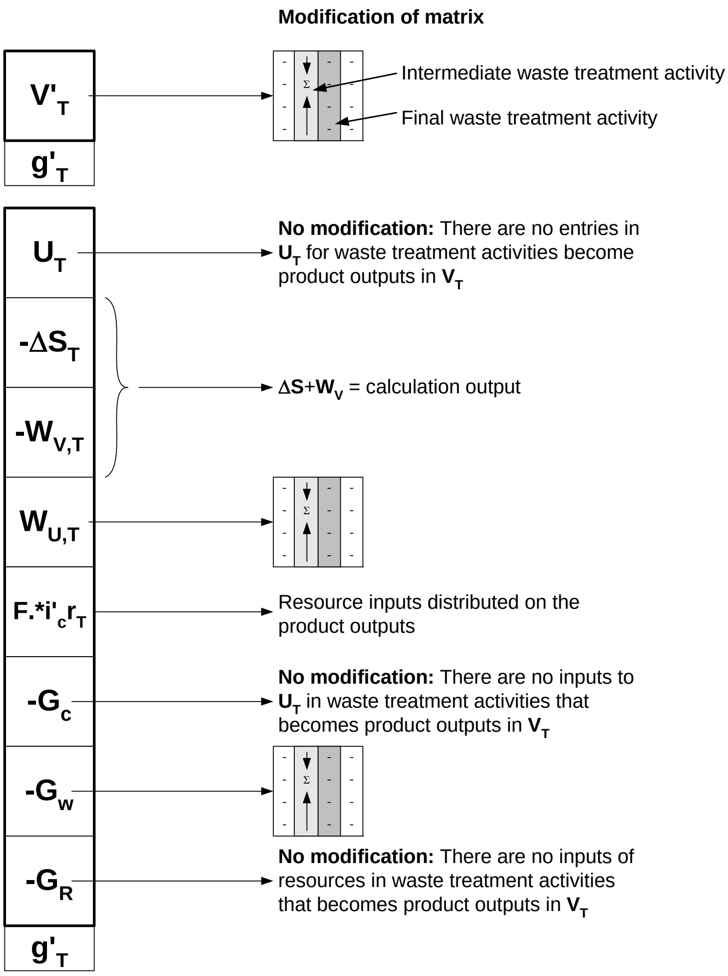

Figure 16: Mass balance used for the determination of stock changes ($\mathbf{\Delta S_T}$) and supply of residuals ($\mathbf{W_{V,T}}$).

Figure 16 enables the establishing of a mass balance:

$$\mathbf{V'_T = U_T - \Delta S_{T,u=1} - W_V + W_{U,T} + \left(F\ .*\ i'_c\ r_T\right) - G_c - G_w - G_R} \tag{6}$$

The mass balance in (6) and in **Figure 16** is the starting point for calculating $\mathbf{\Delta S_T + W_{V,T}}$. However, this mass balance only enables to balance the totals per activity. Thus, (6) does not enable us to specify $\mathbf{\Delta S_T + W_{V,T}}$ 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 $\mathbf{\Delta S_T + W_{V,T}}$ in terms of the products from which it originates, requires a specification of how much of the inputs in $\mathbf{U_T}$, ($\mathbf{F.*i'_c r_T}$) 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, $\mathbf{\Delta S_T+W_{V,T}}$ can be expressed as a function: $f(\mathbf{V'_T,U_T,W_{U,T},R,G_c,G_w,G_R,D,F,F_0})$. The principle of the calculation is a balanced $PSUT_T$, where $\mathbf{\Delta S+W_V}$ is the unknown to be determined, see **Figure 16**.

Before $\mathbf{\Delta S_T+W_{V,T}}$ is expressed as a function $f(\mathbf{V'_T,U_T,W_{U,T},r_T,G_c,G_w,G_R,D,F,F_0})$ 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 $\mathbf{F.{*}i'_c r_T}$ is the total input of resources distributed on the products of the activity. $\mathbf{F}$ 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. $\mathbf{F}$ is a normalised version of $\mathbf{F_0}$ meaning that the sum of each column in $\mathbf{F}$ is 1. Thus, $\mathbf{F}$ can be directly derived from $\mathbf{F_0}$. This is shown in (7).

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

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

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

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):

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

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 $\mathbf{W_{U,T} - G_W}$. 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).

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

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).

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

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):

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

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 $\mathbf{i'_a(h_i+h_f)}$ 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 **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, **D** can be calculated using (13).

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

For $\mathbf{D}_{1,ij} = 1$ in (13), the calculation of **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).

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

6.1.5 Calculation of ΔS_T+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), $\mathbf{\Delta S_T}$+$\mathbf{W_V}$ can be calculated as shown in (15).

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

$\mathbf{\Delta S_T}$ 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 $\left(\mathbf{F} \;.\!*\; \mathbf{i'_c}\, \mathbf{r_T}\right) - \left[\mathbf{F_0} \;.\!*\left(\mathbf{F} \;.\!*\; \mathbf{i'_c}\, \mathbf{r_T}\right)\right]$ 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 $\mathbf{W}_{V,T}$

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 $\mathbf{W}_{V,T}$ here is equal to the number of products and activities in $\mathbf{V}$ and $\mathbf{U}$, i.e. $\mathbf{W}_{V,T}$ 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, $\Delta\mathbf{S}_T$ and $\mathbf{W}_{V,T}$, is determined solely by the stock degradation matrix $\mathbf{L}_S$. The residuals degradation matrix $\mathbf{L}_w$ does not affect the relationship between $\Delta\mathbf{S}_T$ and $\mathbf{W}_{V,T}$ because $\mathbf{L}_w$ only concerns degradation of stocks of residuals after year u = 1.

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

- The inputs of products in $\mathbf{U}_T$ can become either residuals or stocks. Therefore, in (16) the terms of (15) that concern $\mathbf{U}_T$ are multiplied with the $\mathbf{L}_{S,u=1}$ 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 $\mathbf{r}_T$, 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 $\mathbf{W}_{U,T}$ for intermediate waste treatment activities (specified by $\mathbf{h}_i$), 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 $\mathbf{W}_{U,T}$ for final waste treatment activities (specified by $\mathbf{h}_f$) are not entering the formula for $\mathbf{W}_{V,T}$ in (16)

$$\begin{aligned}
\mathbf{W}_{V,T} &= f\left(\mathbf{W}_V + \Delta\mathbf{S}_{u=1}, \mathbf{L}_S\right) \Rightarrow \\
\mathbf{W}_{V,T} &= \left[\mathbf{U}_T - \left(\mathbf{D} .* \mathbf{U}_T\right) - \mathbf{G}_c\right] .* \mathbf{L'}_{S,u=1}\,\mathbf{i}_c + \left(\mathbf{F} .* \mathbf{i'}_c\,\mathbf{R}_T\right) - \left[\mathbf{F}_0 .* \left(\mathbf{F} .* \mathbf{i'}_c\,\mathbf{R}_T\right)\right] - \mathbf{G}_R \\
&\quad + \left(\mathbf{i'}_a\,\mathbf{h}_i\right) .* \left[\mathbf{mdiag}\left(\mathbf{i}_c\left(\mathbf{W}_{U,T} - \mathbf{G}_w - \mathbf{V'}_T\right)\right)\right]
\end{aligned} \tag{16}$$

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

The $\mathbf{W}_{V,T}$ 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 $\mathbf{W}_{V,T}$ matrix are added. The number of activities (columns) is unchanged. Thus, the disaggregation of residuals has the consequence that the $\mathbf{W}_{V,T}$ 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 $\mathbf{W}_{V,T}$ matrix is split into two or more rows. The $\mathbf{W}_{U,T}$ and **J** matrices are modified (split of rows) accordingly, and additional columns are added in the $\mathbf{K}_w$ 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 $\mathbf{W}_{V,T}$) and residual material composition (column in $\mathbf{K}_w$). In the standard model without disaggregating residuals $\mathbf{W}_{V,T}$ and $\mathbf{K}_w$ 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 $\mathbf{W}_{V,T}$) and residual material composition (column i_1 and i_2 in $\mathbf{K}_w$) are available, and specify this. In the following this fraction is referred to as the residual in row i_2 in $\mathbf{W}_{V,T}$
- Step 2: The entries in row i_1 in $\mathbf{W}_{V,T}$ is calculated as: $\mathbf{W}_{V,T,i1} = \mathbf{W}_{V,T,i} - \mathbf{W}_{V,T,i2}$

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 $\mathbf{W}_{V,T}$, $\mathbf{W}_{U,T}$ and $\mathbf{K}_w$ has changed dimensions as described above.

6.1.8 Calculation of ΔS_T

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

$$\begin{aligned}\Delta\mathbf{S}_{T,u=1} = & \left[\mathbf{U}_T - \left(\mathbf{D} .* \mathbf{U}_T\right) - \mathbf{G}_c\right] .* \left(\mathbf{i'}_c\, \mathbf{i}_c - \mathbf{L'}_{S,u=1}\, \mathbf{i}_c\right) \\ & + \left(\mathbf{i'}_a\, \mathbf{h}_f\right) .* \left[\mathbf{W}_{U,T} - \mathbf{G}_w - \mathbf{W}_{U,T} .* \left(\mathbf{i'}_c \left(\mathbf{i}_a \mathbf{V'}_T ./ \mathbf{i}_a \mathbf{W}_U\right)\right)\right]\end{aligned} \quad (17)$$

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:

$$\mathbf{U_T} = \mathbf{U_\Phi} \ ./\ \mathbf{P}_U \qquad (18)$$

and

$$\mathbf{V_T} = \mathbf{V_\Phi} \ ./\ \mathbf{P_V} \qquad (19)$$

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):

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

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

Sum of products (row vector)	$k_{c,m}U_T$
Sum of stock changes (row vector)	$k_{c,m}(-\Delta S_T)$
Sum of supply of residuals (row vector)	$k_{w,m}(-W_{V,T})$
Sum of use of residuals (row vector)	$k_{w,m}W_{U,T}$
Resource (m) (row vector)	R_m
Emissions (m) (row vector)	$-B_m$
Total (row vector)	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).

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

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):

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

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**.

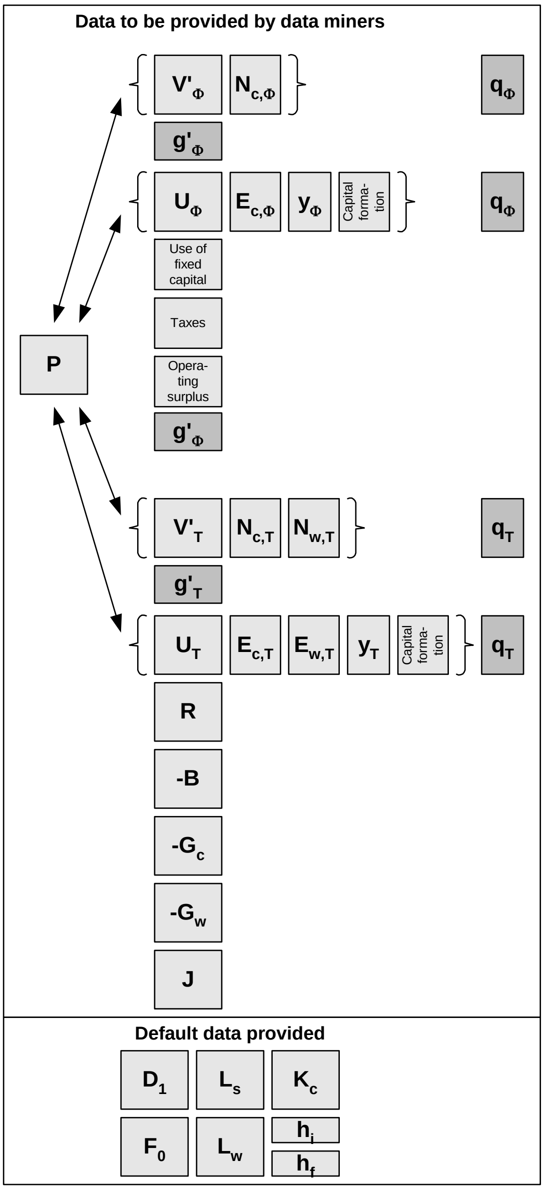

Figure 18: Overview of all input matrices required per geographical region (g) and per year (t) for the FORWAST model.

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

[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).

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

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).

$$\mathbf{A} = \mathbf{U}\mathbf{V}'^{-1} \tag{31}$$

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

$$\mathbf{A} = \mathbf{U}\mathbf{V}'^{-1} \Leftrightarrow \mathbf{U} = \mathbf{A}\mathbf{V}' \tag{32}$$

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 $\mathbf{U} = \mathbf{AV}'$.

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**.

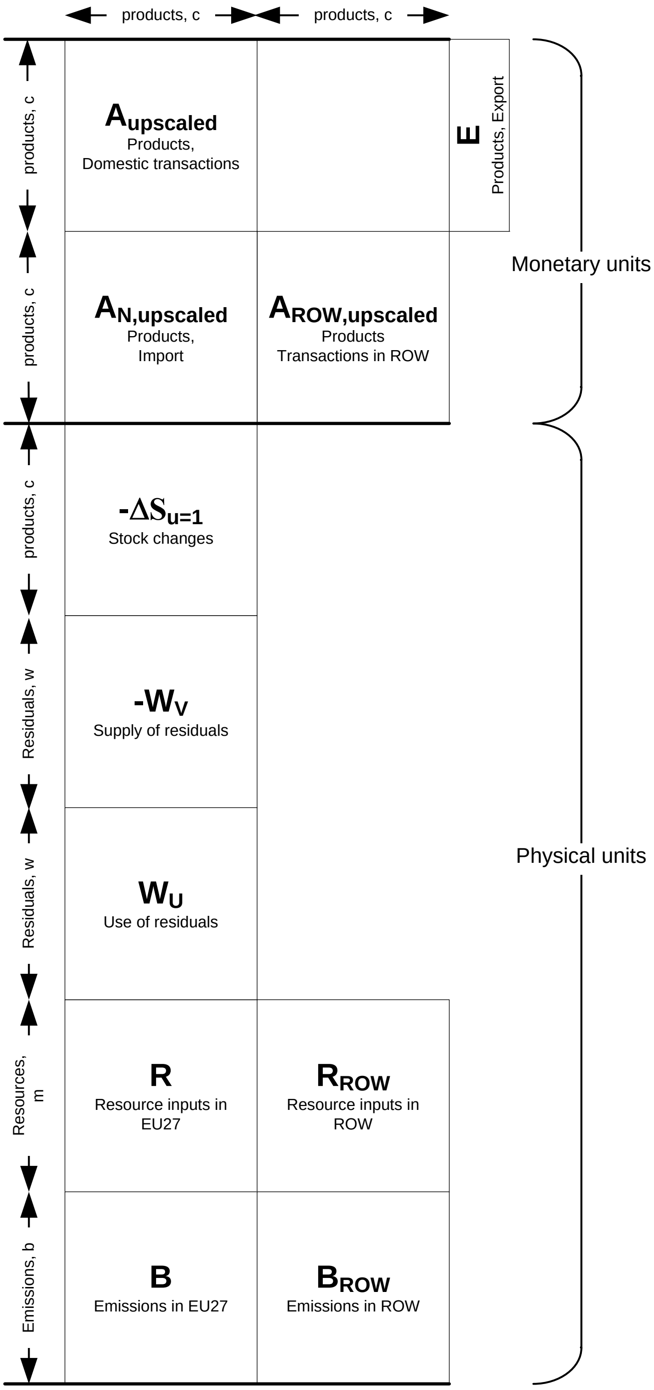

Figure 19: Illustration of the dimensions and composition of the MIOT.

The MIOT shown in **Figure 19** takes into account import and exports. $\mathbf{A_{ROW}}$ and $\mathbf{A_N}$ 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 (**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 **A**, and the normalised externalities matrices ($\Delta\mathbf{S}$, $\mathbf{W}_V$, **B**, **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**.

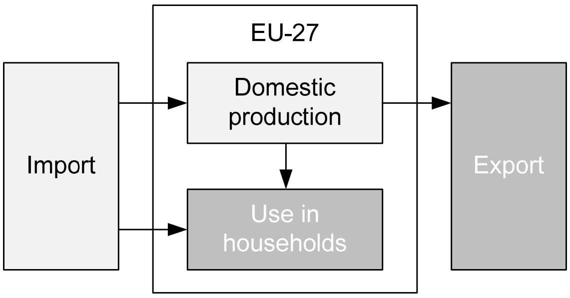

Figure 20: Illustration of major commodity flows. Total supply (output of import and domestic production) is equal to total use (input to use in households and export). The latter is used as functional unit (driving vector) in the model.

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**.

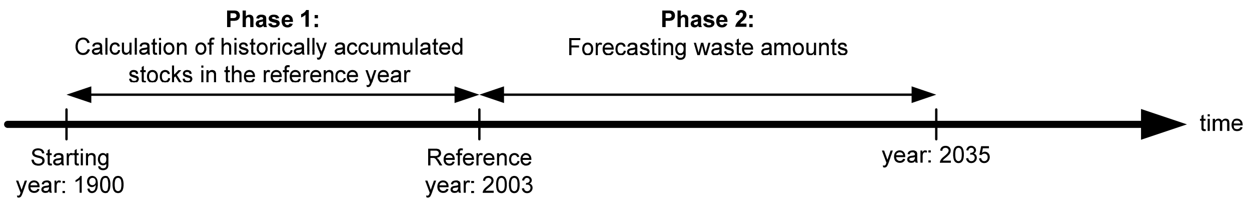

Figure 21: Two phases of the dynamic modelling.

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 ($\Delta\mathbf{S}$) 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.**

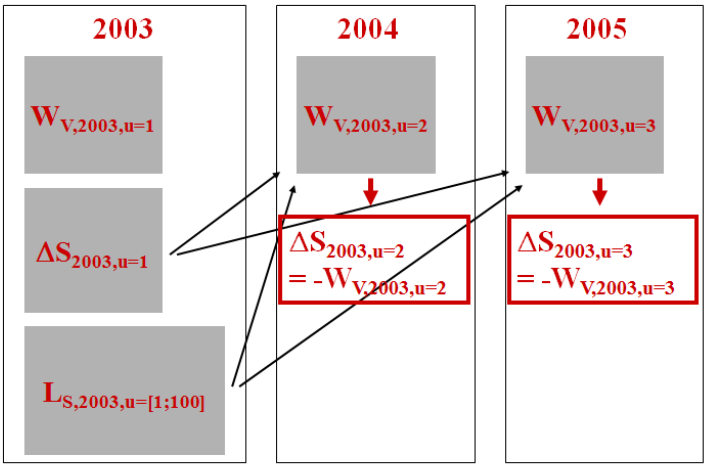

Figure 22: Principle of using stock addition table ($\Delta\mathbf{S}$) for a given year (2003) and lifetime table ($\mathbf{L}_S$) for estimating the future stock changes and supply of residuals. Here the stock changes originating from stock addition in year 2003 are shown for year 2004 and 2005.

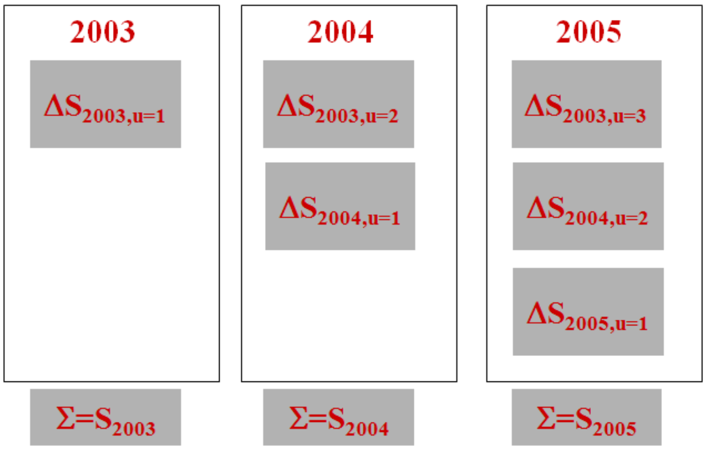

Figure 23: Principle of using time series of stock change tables (ΔS) for estimating the historically accumulated stocks. Here is the accumulated stock in year 2005 shown for year 2003 to 2005.

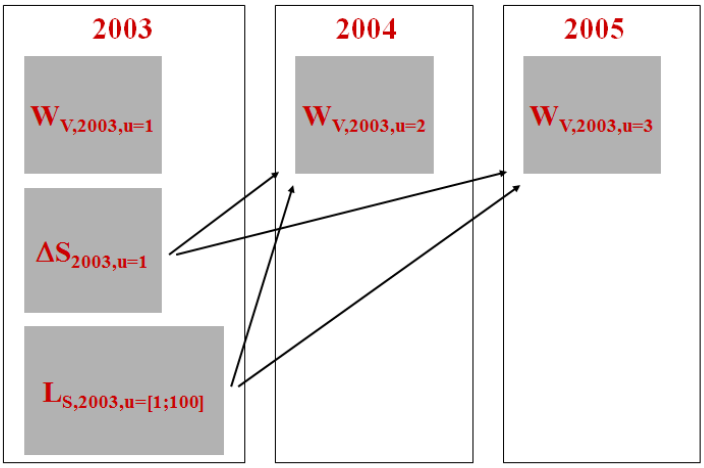

Figure 24: Principle of calculating supply of residuals originating from activities in year 2003. Here the supply of residuals originating from 2003 are shown for year 2003 to 2005.

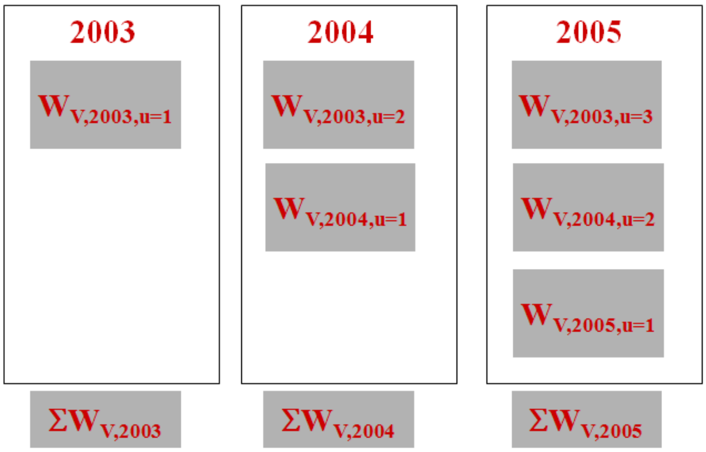

Figure 25: Principle of calculating accumulated supply of residuals originating from activities in several years. Here the supply of residuals in year 2005 originating from activities in year 2003 to 2005 are shown.

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:

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

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 $\mathbf{D}$ 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 $\mathbf{V_T}$, $\mathbf{U_T}$, $\mathbf{R}$ and ($\mathbf{W_{V,T}}+\Delta\mathbf{S_T}$). This is because the calculated part of $\mathbf{D}$ ensures this consistency (inconsistencies are placed as residuals in via the $\mathbf{D}$ 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:

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

Since $F_0 = 1$ for plant production then,

$D = ((R+x)\text{-}R) / U_{T,fertiliser}$
$x = D{*}U_{T,fertiliser}$
(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 c	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 Pro-duct 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 instrur
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 gooc	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, distrit	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 motc
1		1	84	55	Hotel and restaurant services	Hotel and restaurant services
1		1	85	60	Land transport; transport via pipelir	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, exc
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 ec
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