3.0 METHODOLOGY

3.1 Waste Analysis

Waste analysis involved the determination of physical, chemical and biological characteristics of selected waste including organic and non-organic waste. All analysis was conducted according to the USEPA standard methods. Among the analysis conducted including pH, salinity and conductivity.

3.1.1 Fieldsite Background Primary Data Collection

Field study was carried out at Jeram Sanitary Landfill (JSL) located at Lot No. 1595,2958, 2959 Tuan Mee Estate in Jeram Town, Kuala Selangor District (Plate 3.1) . JSL started its operation on 1st January 2007 with 16-years expected lifespan depending on the amount of wastes received. The landfill concessionaire (Worldwide Holdings Pvt. Ltd.) has currently been awarded with a 25 years privatization cum-concession for the construction. This award include the operation and maintenance of a 65 hectares area by the Selangor State Government. The total operation area was 48 hectares. The landfill receives an average 2100 tonne of municipal solid waste per day though the design capacity is only for 1,250 tonne per day with the equivalent of 8 million cubic metre airspace. The types of waste received are domestic waste, bulky waste, garden waste and domestic sewage sludge only. JSL management has also provided waste tonnage on a monthly basis from 2005 until 2010 The landfill caters for seven major municipalities in Klang Valley namely Kuala Selangor (MPKS), Subang Jaya, Klang (MPK), Petaling Jaya (MBPJ), Shah Alam (MBSA), Ampang Jaya (MPAJ) and Selayang (MPS).

Plate 3.1: Satellite Image shows the JSL location. (Source: Google Earth, map not according to scale).

3.1.2 Sampling of Municipal Solid Waste (MSW)

Waste segregation was done to determine quantity and quality of waste composition deposited at the landfill sites. To characterize MSW, sampling was done to deal with heterogeneity and the seasonal variability of the waste material. The segregation work was done by sorting the waste according to the classification by Tchobanoglous *et. al.* (1994). The amount of waste from these lorries ranged from 10 to 15 tonnes. Quartering methods were applied. This was done by quartering waste from randomly selected compactors delivered into four portions. Two quarters will be retained while remaining two were rejected. The selected quarters were quartered again where half of the section was selected to achieve approximately 100 to 250 kg of waste per section. The quartering method applied in the study allowed a more random waste sampling since waste collections by the lorries were conducted based on designated routes. Sampling of compost was performed by grab samples. The finished, mature compost were dried and 5-g laboratory of samples were taken for total carbon and nitrogen analysis.

3.1.3 Chemical Analysis for MSW characterization

For laboratory analysis purpose, solid waste samples were taken at random. Samples were analyzed for : Total Organic Carbon (APHA 5310 B), Inorganic Carbon (ASTM E 949), Total Nitrogen (ASTM E778-87), Ammoniacal Nitrogen (APHA 4500 NH3 B&C), Organic Nitrogen (APHA 4500-N_{org}Kjeldahl Method) and Inorganic Nitrogen (APHA 4500-N_{inorg}Kjeldahl Method). In each sampling occasion, four soil samples were also collected at random using a shovel. Soil samples taken were topsoil at 15 cm deep and semi-marine clay from Cell 20. Then the soil was dried at 45^{o}C for 3 days and powdered. Analysis were conducted for Total Organic Carbon (APHA 5310 B), Inorganic Carbon (ASTM E 949), Total Nitrogen (ASTM E778-87), Ammoniacal Nitrogen (APHA 4500 NH3 B&C), Organic Nitrogen (APHA 4500-N_{org}Kjeldahl Method) and Inorganic Nitrogen (APHA 4500-N_{inorg}Kjeldahl Method) and elements for P, K, Mg, Ca, Mn, Al and Fe using Inductive-Coupled Plasma Optical Emission Spectrometry (ICP-OES) machine. Data were collected and calculated into mass and elements concentrations (C and N flow). Determination method was from JSL record, measurement, laboratory analysis, literature and mass balance. Activities in JSL were divided into processes based on literature, observation and interview. Data inventory and material flow were calculated and described.

3.1.4 Physical and Chemical Analysis for leachate and rainwater and gas.

Quality and quantity of rainfall at Jeram Sanitary Landfill was also acquired. The nearest rainfall station is located at Bukit Kerayong (Latitude 03° 10' 35’’ N, Longitude 101° 20' 40’’ E). The daily rainfall amount (0800-0800 Malaysian Standard Time) for a particular day is the amount collected over the 24-hour period beginning from 0800 am on the day. Raw leachate was collected directly from leachate treatment plant and kept inside an airtight bottle. NH_4-N test was conducted for raw leachate. Digestion and biological parameters were done *ex-situ*. Secondary data such as rainfall acquired from authoritative sources was useful. These data are meant to supplement primary data collected during site visit and field investigation as shown in Table 3.1.

Table 3.1: Available information on element flows in preparation for the landfill material balance in JSL.

No.	Elements	Origin Process	Destination Process	Available data used for calculation
1.	Waste	Waste receving	Landfill body	JSL management (Waste Tonnage)
2.	Rainfall	Atmosphere	Atmosphere/Landfill body/Leachate treatment	Department of Irrigation and Drainage (DID), Selangor
3.	Landfill Gas	Landfill body	Atmosphere	*In-situ* measurement
4.	Leachate	Landfill body	Leachate tretament	*In-situ* measurement & JSL management

In-situ gas analysis used Gas Analyser Model Binder GA-M (Plate 3.2) to obtain quantitative emissions of methane (CH_4), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen sulphide (H_2S) and ammonia (NH_3). The measurement recorded were in percentage (%) wet weight except for H_2S which is in ppm.

Plate 3.2 : Gas Analyser Model Binder GA-M

Analysis was carried out in the laboratory to determine the concentration using Gas Chromatograph (Model GC-8A Shimadzu) (Plate 3.3). Sampling of the landfill gases was done *in-situ* using Tedlar bag at the valve tip of gas wells and gas flaring unit.

Plate 3.3 :Gas Chromatograph (Model GC-8A Shimadzu).

3.2 MFA framework in Sanitary Landfill System

3.2.1 System Analysis

The system border was adjusted suitably to the existing condition. Relevant processes and goods were identified. Inventory data were collected and analysed and the results coming out have shown the existing and/or potential problems and weak points in term of sanitary landfill problems. This result will be used as the existing situation of the study. All existing activities in JSL were divided into 5 processes and included in the system border as follow:

1) Waste Landfilling
2) Landfill Gas Facility
3) Composting Facility (small-scale)
4) Leachate Treatment Plant
5) Recycling Process (small-scale)

Development of a mathematical model for a specific MFA system consists of the following typical steps (Baccini & Bader,1996). This steps include definition of problem and specific objectives, selection of relevant substances, system boundaries, processes, and goods, assessment of mass flows of goods, assessment of substance concentrations in the goods, calculation of substance flows, consideration of uncertainties, presentation of the results and simulation of scenarios. Substance flow in this MFA study are carbon and nitrogen. Concentrations are determined for both element for every type of waste. Then, data were computed into STAn software for mass balance. One unique function of this software programming is error calculation. Short description on STAn operation in discussed in subchapter for Short Operating Program Description. Proposed procedure for the analysis (Brunner and Rechberger, 2004, modified) in a flow chart is shown in Figure 3.1

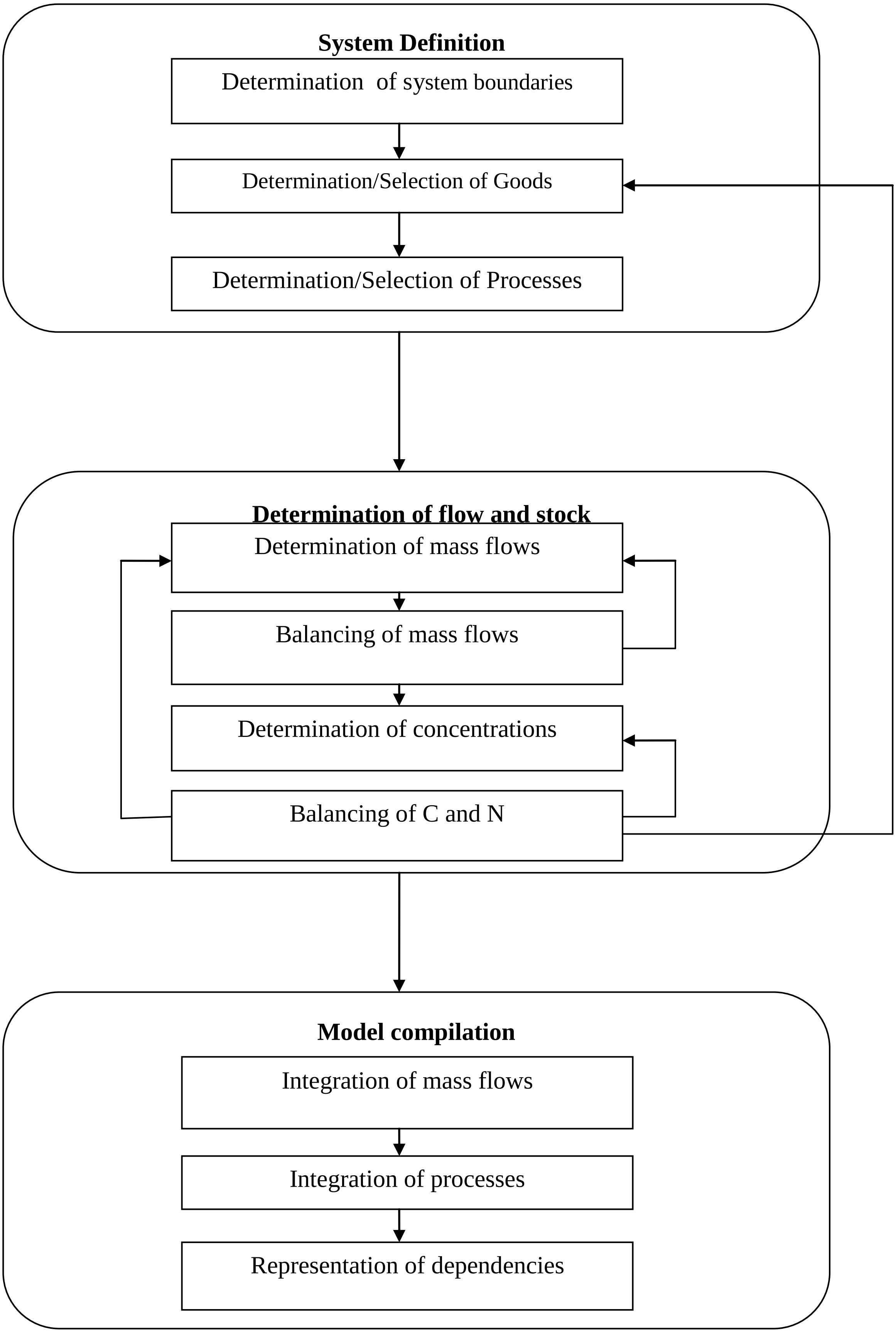


Figure 3.1: Proposed procedure for the analysis (Brunner and Rechberger, 2004, modified)

3.2.2 Municipal Solid Waste (MSW) Degradation: The stoichiometric model.

The stoichiometric model is based on chemical reaction of substance, in which the reactants in the waste are represented by an empirical chemical formula (Eq. 1). The end-products in gas form include CH_4, CO_2, NH_3 and H_2S. The complete stoichiometric conversion of biodegradable solids to CH_4, CO_2, NH_3, H_2S was calculated based on the formula proposed by Buswell and Mueller (1952) (Eq. 1). The oxygen content was derived from the average content found in the literature (Barlaz *et. al.,* 1989; Tchobanoglous & Kreith, 2002)

$$C_{1.995}H_{3.58}O_{1.256}N_{0.115}S_{0.047} + 0{:}581H_2O \rightarrow 1.08CH_4 + 0.92CO_2 + 0{:}115NH_3 + 0{:}047H_2S + \text{energy} \qquad \text{(Eq. 1)}$$

Where $C_aH_bO_cN_d$ is an empirical formula of biodegradable organic matter from which the municipal waste is considered and $C_5H_7O_2N$ is the chemical formula of the microbial mass (Paraskaki & Lazaridis 2005). One limitation of the model is associated with the stoichiometric estimates of waste fractions which are not biodegradable (lignin, plastics etc).

3.2.3 Quantitative Analysis on Waste Input : MSW

Material flow analysis (MFA) and substance flow analysis (SFA) were performed by means of the mass-balance model STAN which performs MFA according to the Austrian standard ÖNorm 2096 S (MFA – Application in Waste Management) (Cencic & Rechberger, 2008). In STAN, the waste system or any other system of interest can be built to graphically display Sankey diagrams by adding known mass flows, concentrations and transfer coefficients. Simulations were performed by STAN to reconcile uncertain data and/or to compute parameters (e.g by Monte Carlo Simulations). SFAs was performed for C and N. The uncertainty of concentrations in the waste input was calculated based on data from Boldrin (2009) (as percentage of dry matter in the input mass) ; C = ±2.0 % and N= ±9.6% unless stated otherwise. The initial uncertainties of concentrations in the outputs were assumed to be 10% for both C and N (Andersen *et. al.*, 2010). The loss of materials to the atmosphere during the landfilling process was calculated using STAn software for C and N and presented in a flow diagram.

3.2.4 Carbon Mass Balance

Chosen reference is Total Organic Carbon (TOC). Carbon released was identified to be via two pathway namely leachate and gas. The following formula quantify the landfill gas generation (Fellner & Laner, 2012) based on Total Organic Carbon. The raw input were then computed in STAn software for calculation and data reconcilation.

3.2.5 Nitrogen Mass Balance

4 parameters namely NO_3-N, NO_2-N, NH_3-N and TKN concentrations were measured with an electrode (Orion, model 95-12) using the known addition method Standard Methods for the Examination of Water and Wastewater, American Public Health Association (APHA) (1995), Washington, USA. As for solid waste, complete analysis on different type of nitrogen were done namely Total Nitrogen (ASTM E778-87), Ammoniacal Nitrogen (APHA 4500 NH_3 B&C), Organic Nitrogen (APHA 4500-N_{org} Kjeldahl Method) and Inorganic Nitrogen (APHA 4500-N_{inorg} Kjeldahl Method). Chosen reference is Total Kjeldahl Nitrogen (TKN) which become the raw input, were then computed in STAn software for calculation and data reconcilation.

3.3 Quantitative Analysis on Waste Output : Leachate and Greenhouse Gases (GHG)

3.3.1 Water Balance Factor in Landfill

With respect to infiltration through the waste cover material, Water Balance is based on the holistic and classic water balance approach (Thornthwaite & Mather, 1955). The balance considers daily rainfall and potential evapotranspiration (PET), and proposes that actual evapotranspiration (AET) be equal to PET (corrected by a coefficient to account for the type of vegetation on the cover if available). Such model for instance, the global model for landfill hydrologic balance (MOBYDEC) model applied the same concept (Guyonnet & Bounn, 1994; Guyonnet *et. al*., 1998).

3.3.2 Conceptual Model

Water balances is crucial for sanitary landfill operation. Figure 3.2 shows a simplified system to show water balance in a sanitary landfill condition. The calculation of the water balance showed that evapotranspiration and storage of water are two major processes.

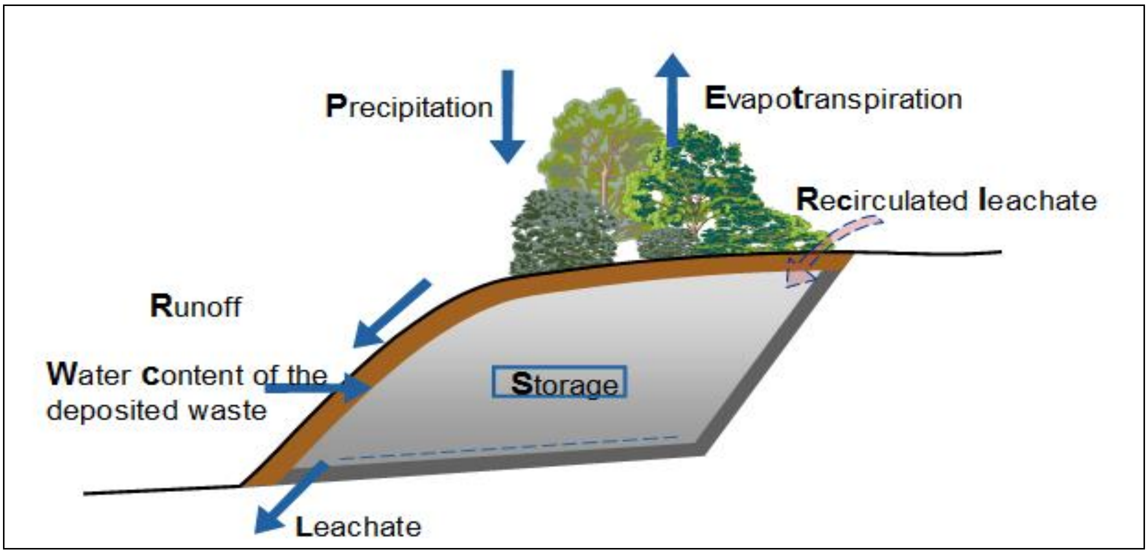


Figure 3.2: A simplified system to show water balance in a sanitary landfill condition (Fellner & Laner, 2012).

Based on law of mass conservation, a simplified theoretical equation for water balance in a sanitary landfill condition were derived (Eq. 2).

Input for the water balance are the water content of the landfilled MSW (W), water added during landfilling (A), precipitation (P), and re-circulated water (R). The output consists of surface runoff (SR), evapotranspiration (ET), leachate (L) and condensation (C), which leaves the landfill with gas. Stored water (S) have to be considered as well.

3.3.3 Water Balance Modelling (WBM)

This method is simple and has been used to predict the generated leachate within landfills (São Mateus *et. al.*, 2011). The basic configuration of this method is that the landfill consists of a covered surface, a compacted waste compartment, and a lining system, as shown in Figure 3.3.

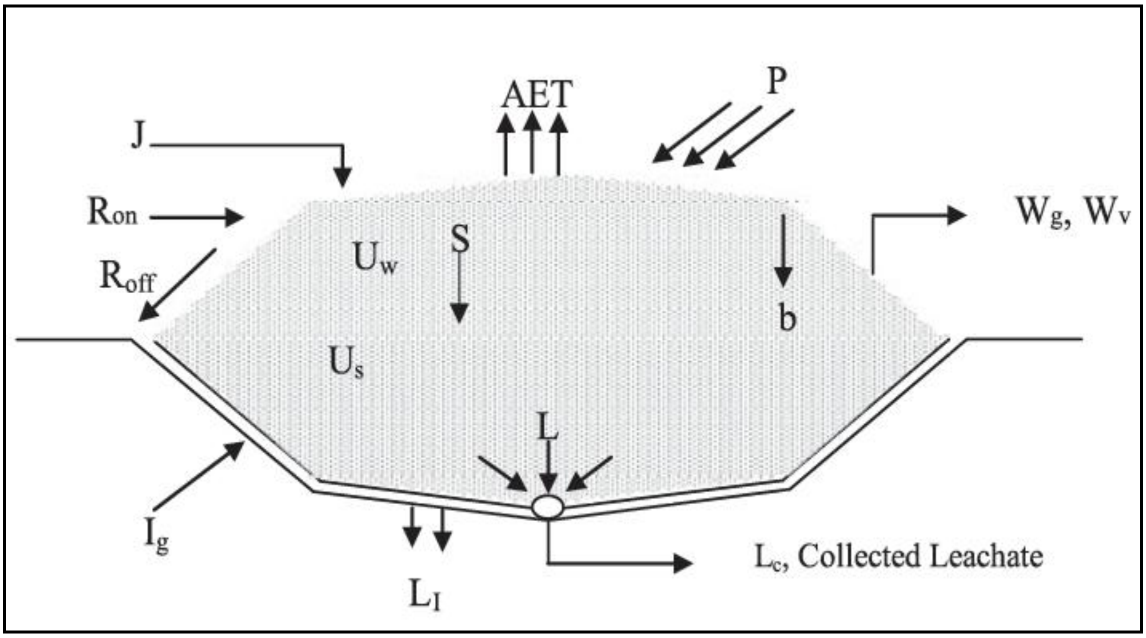


Figure 3.3: Hydrologic balance of landfill. (Reproduced from Jagloo, 2002).

Where AET= actual evapotranspiration; b= water production by biodegradation of waste; I_g= water from underground; J=leachate recirculation; L= leachate generated;

L_c= collected leachate; L_I=leachate infiltration in clay liner; P=precipitation; R_{off}= runoff; R_{on}= run-on; S=water in sludge; U_w= water content in wastes; U_s= water content is soil cover; W_g= water consumed in the formation of landfill gas;W_v= water lost as water vapor.

The water balance of the landfill was derived; making use of assumptions in instances where it is applicable that infiltration through the top of the waste pile is calculated using equation (2).

$I= P+ J +R_{on} +R_{off-}AET \pm U_s$ (Eq.2)

where:

I: Infiltration (mm/year)

P: Precipitation (mm/year)

J: Leachate recirculation (mm/year)

R_{off}: Runoff (mm/year)

R_{on}: Run-on (mm/year)

AET: Actual evapotranspiration (mm/year)

U_s: Water content in soil cover (mm/year)

Assuming that:

1. The final soil cover is existent and the moisture content of the daily thin layers of soil is assumed to be at field capacity, and is assumed to not contribute significantly to the total moisture content of the cells (U_s=0)

2. The landfill has been designed so that water from outside the site does not enter (R_{on} = 0).

Therefore, infiltration (I) through the top part of the waste pile becomes:

$I = P + J - R_{off} - AET$ (3)

Where the change in waste water volume, due to external sources (PL), is computed as:

$P_L= I + I_g$ (4)

where Ig: is the water from the aquifers entering the landfill (mm/year). Assuming that water entering the landfill from aquifers is negligible ($I_g = 0$), the change in waste water volume, due to external sources (P_L), is computed as:

$$P_L = I \qquad (5)$$

Then, the total leachate production is computed as:

$$L = P_L \pm U_W + b \qquad (6)$$

where b is water production by the biodegradation of waste (m^3/year) and U_w is the water content in waste (at field capacity) (m^3/year). The water produced, due to the biodegradation of waste, is assumed to be very small and negligible (b = 0). Therefore:

$$L = P_L \pm U_W \qquad (7)$$

Water percolating through from the surface of a landfill tends to be absorbed by the waste until field capacity is reached. It is only when the infiltration of water exceeds this value that movement of water through the waste occurs initially under unsaturated conditions or, if sufficient water is present, under saturated conditions.

3.4 The Landfill Gas Emission (LandGEM) software application

3.4.1 GHG projection in landfill condition

The LandGEM (landfill gas emissions model) is developed by the Control Center technology of the American Environmental Protection Agency (US EPA 1998), which is a software for quantifying landfills gas emissions. The method for the estimation of gaseous emissions using the model is based on a simple degradation equation. The model determines the mass of methane generated using the methane generation capacity and the mass of waste deposited. The LandGEM emission method can be described mathematically by (Eq. 8):

$$Q_{\mathrm{CH4}} = \left(\sum_{i=1}^{n} \sum_{j=0.1}^{1} k L_0 \right) \left(\frac{M_i}{10} \right) \left(\mathrm{e}^{-k t_{i,j}} \right) \tag{8}$$

where Q_{CH4} is the annual methane generation in the year of calculation (m^3 year^{-1}); *i* is the yearly time increment; n is the difference: (year of the calculation) – (initial year of waste acceptance); *j* is the 0.1 year time increment; *k* is the methane generation constant (year–1); L_0 is the potential methane generation capacity (m^3 Mg^{-1}); $M_i$is the mass of waste in the *i*-th year (Mg); t_i, *j* is the age of the *j*-th section of waste M_i accepted in the *i*-th year (decimal years).

3.5 Data Modelling approach : Substance Analysis software (STAn)

3.5.1 Short Operating Program Description: Flow analysis and Mass Balance

The following descriptions refer to STAN version 1.1.3. Graphic User Interface or GUI consists of windows that can be arranged arbitrarily. A few tool bars enable fast access to the most important commands (Figure 3.4). Each element of the model has properties that can be changed in the Properties window. This is also the place where data are supposed to be entered manually. The trace output window displays calculation related messages. These equations could contain unknown, measured and exactly known (constant) variables.

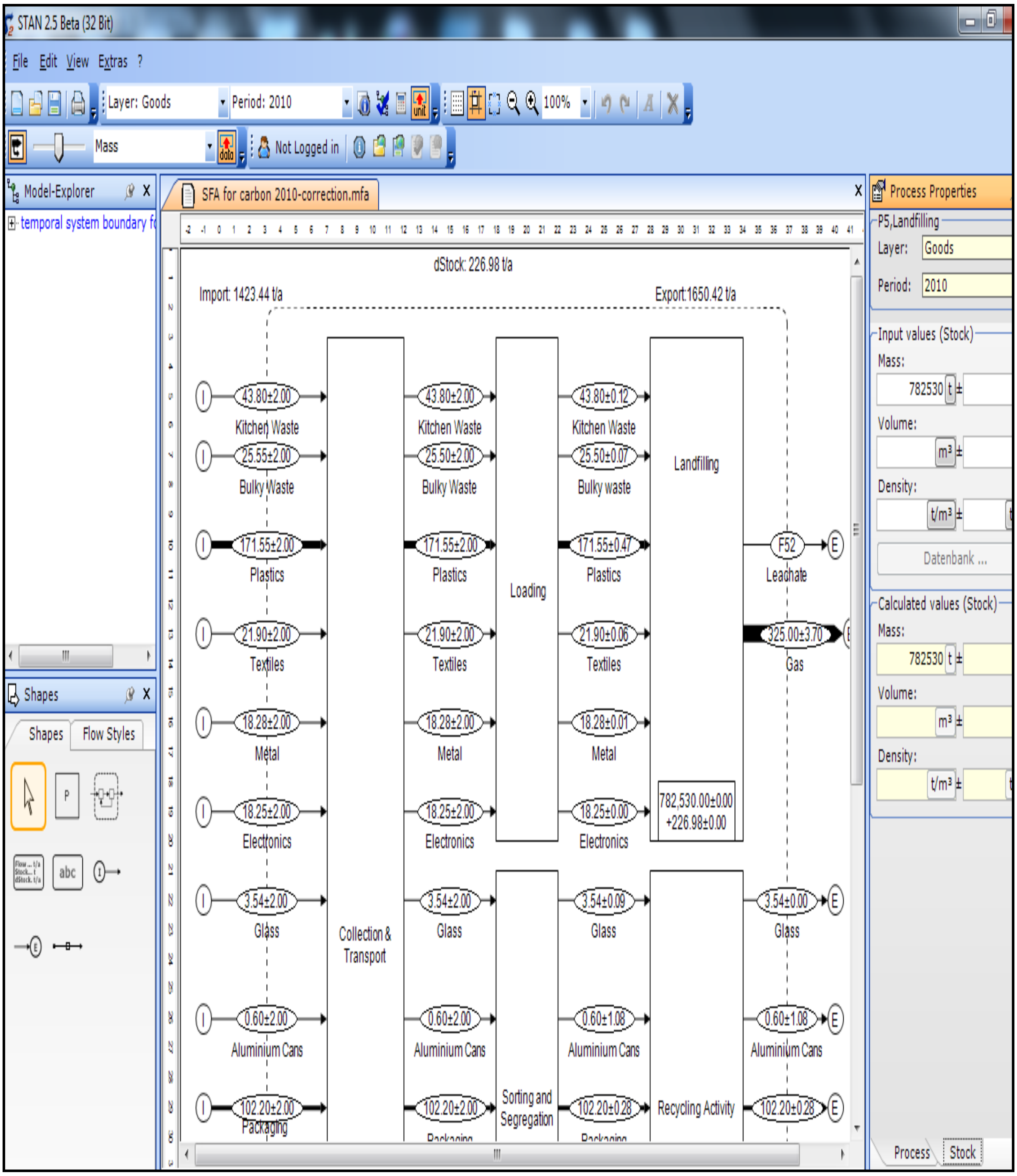
During calculation a graphical model was created with STAn is automatically translated into a mathematical model using four types of equations (Eqs. 9-12). Afterwards, if desired, they can be converted into processes with stocks or subsystems. But in this study, the landfill is the system analysis where all this equation embedded in STAn .

Balance equation: Σ inputs = Σ outputs + change in stock (Eq. 9)

Transfer coefficient equation: $\text{output}_x = \text{transfer coefficient}_{\text{to output x}} \cdot \Sigma$ inputs (Eq. 10)

Stock equation: $\text{stock}_{\text{Period i+1}} = \text{stock}_{\text{Period i}} + \text{change in stock}_{\text{Period i}}$ (Eq. 11)

Concentration equation: $\text{mass}_{\text{substance}} = \text{mass}_{\text{good}} \cdot \text{concentration}_{\text{substance}}$ (Eq. 12)



STAN 2.5 Beta (32 Bit)

Layer: Goods

Period: 2010

100%

Mass

Not Logged in

SFA for carbon 2010-correction.mfa

Process Properties

P5,Landfilling

Layer: Goods

Period: 2010

Input values (Stock)

Mass: 782530 t ±

Calculated values (Stock)

Mass: 782530 t ±

Figure 3.4: Graphical User Interface or GUI of STAn.

A graph of the model with flows displayed as Sankey arrows (for example the width of a flow is proportional to its value) can be printed or exported into various graphical formats for example in JPEG or MS Excel. Statistical tests are used to detect gross errors in a given data set. A system for this study is a sanitary landfill. A material balance was prepared for the period of one-year of landfilling. In any one system, each flow-through is associated with the origin and the destination process which need to be clearly identified. System boundaries define the temporal and spatial delimitation of system under investigation.

3.5.2 Overall Mass Balance in Sanitary Landfill System

The spatial system boundaries for this study includes the landfill body, landfill surface and processes or cycles within a tropical sanitary landfill loop. This system includes facilities for gas and leachate treatment. Material flow to a system are imports while those from the system are known as exports. The system boundaries does not include the collection and transportation of waste to and from landfill. A typical example of a sanitary landfill system analysis shown in Figure 3.5. Processes are represented by simple boxes and flows by arrows. Models are designed from predefined elements such as processes, flows, system boundaries, and text fields in a graphical way (Figure 3.5).

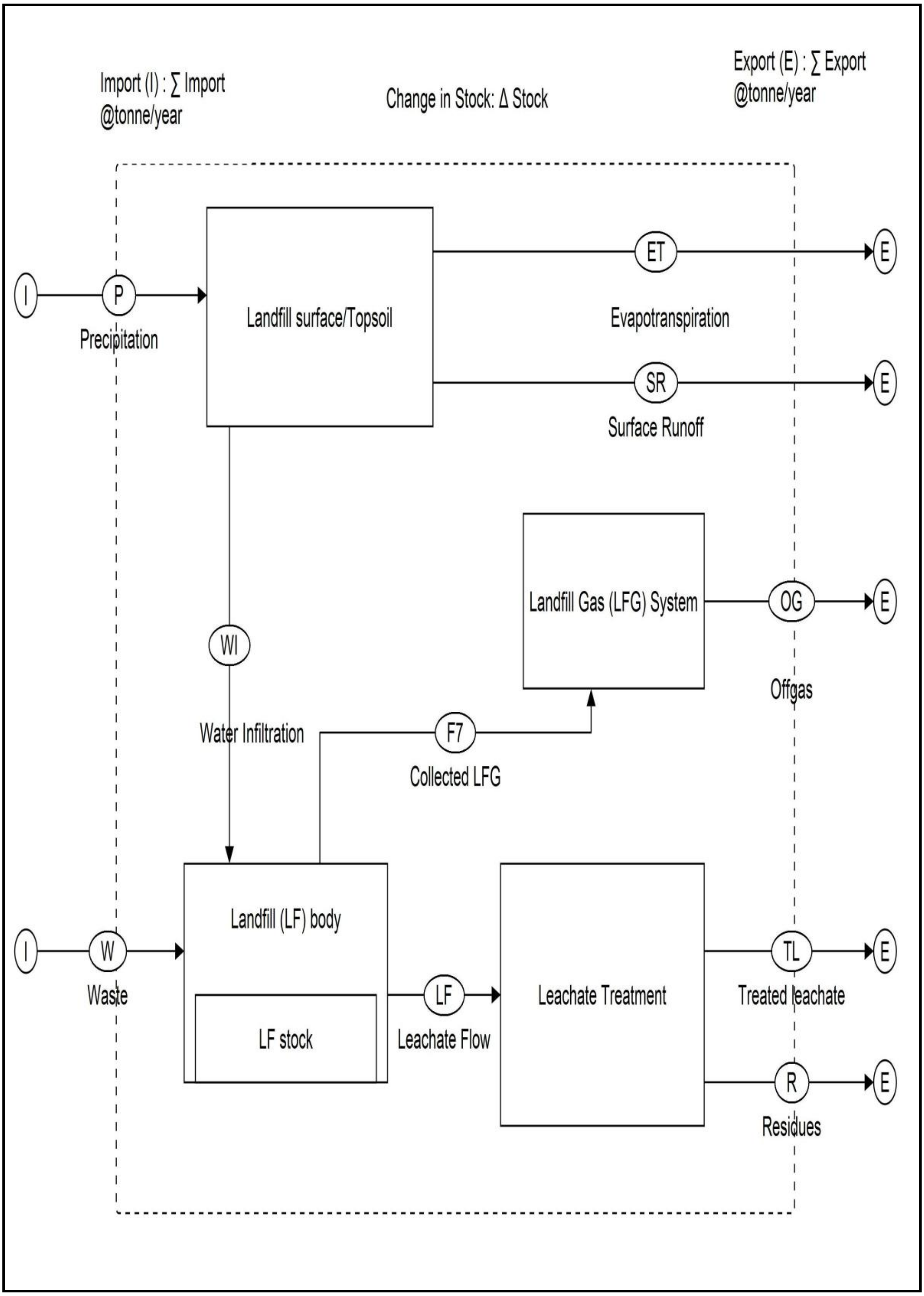


Figure 3.5: MFA system definition and analysis shown in a graphic representation of qualitative system analysis of JSL created with STAn software.

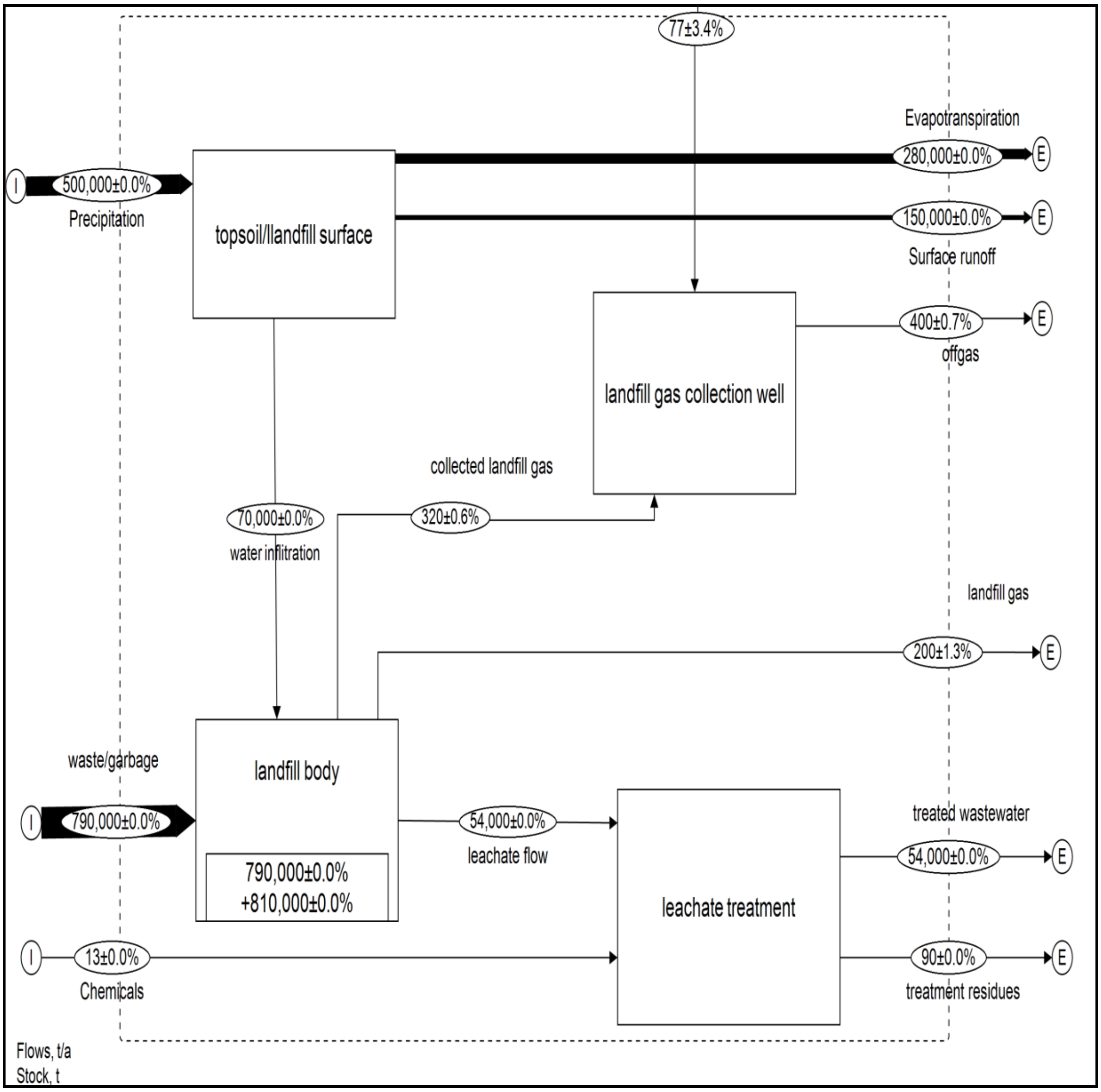
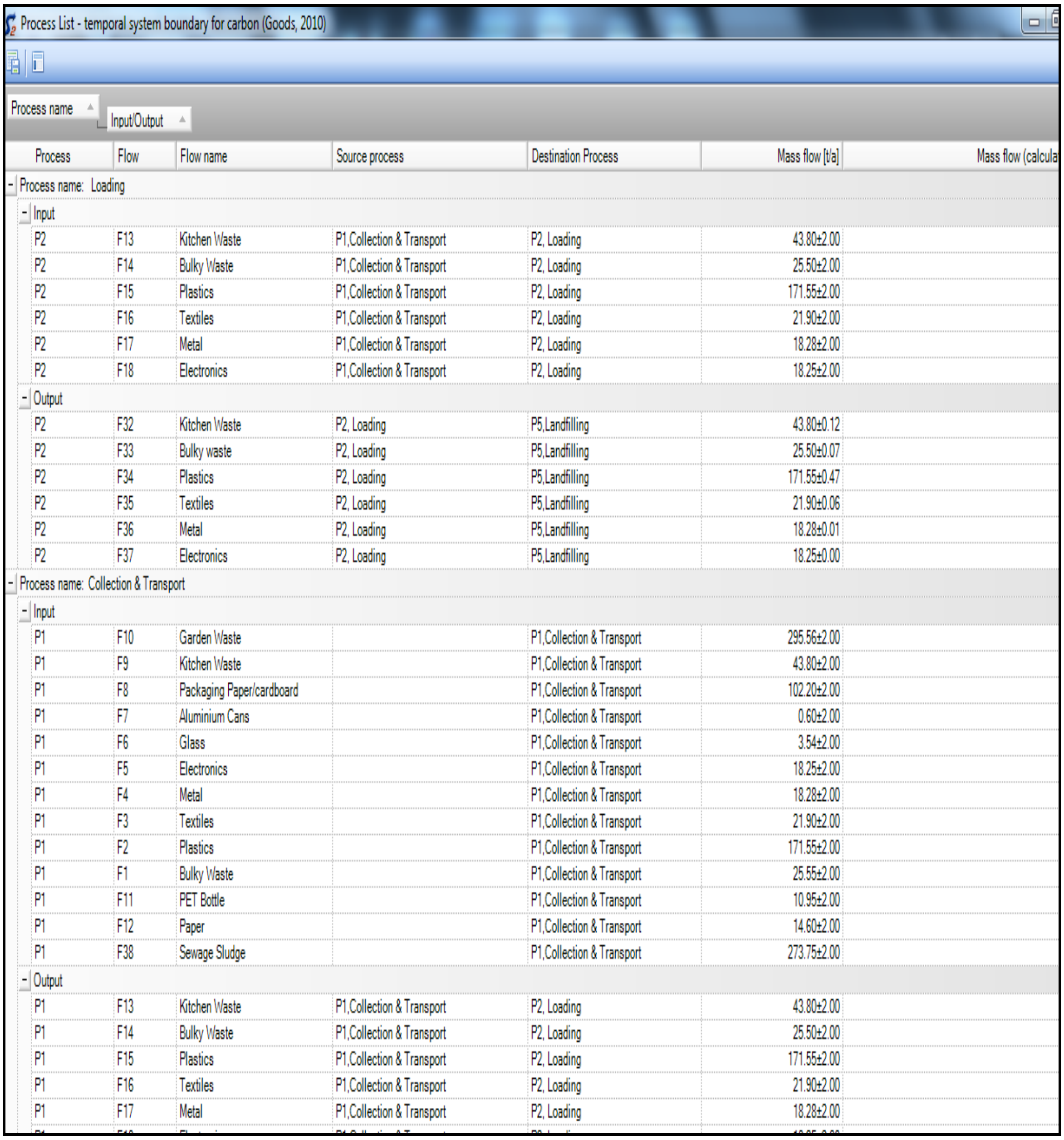


Figure 3.6 : The typical results display for a sanitary landfill.

The data input (MSW_{input}) into this model were 790,000 ± 10% . The output exported mainly as landfill gas and leachate. It is assumed that in the beginning of 2010 the landfill was empty and that during the period no change in stock occurred (Figure 3.6). Data (mass flows, stocks, concentrations and transfer coefficients) can be entered manually with units and data uncertainties for different data layers (1 × goods, n × substances) and time periods. Given units can be applied or defined. If other units than those displayed are needed, the keyboard can be used to enter them directly after the values. The display unit is always offered with default. For the model graph mass flows and stocks will be automatically converted to display units. Uncertain data are assumed to be normally distributed given by mean value and standard deviation. In order to simplify the data entry a data table for all input data is available (Figure 3.7). With the help of this table it is possible to group data and import or export it from or to Microsoft Excel. The design of STAn accomplished in Excel (graphical interpretation of data, spreadsheet calculation) is shown below.



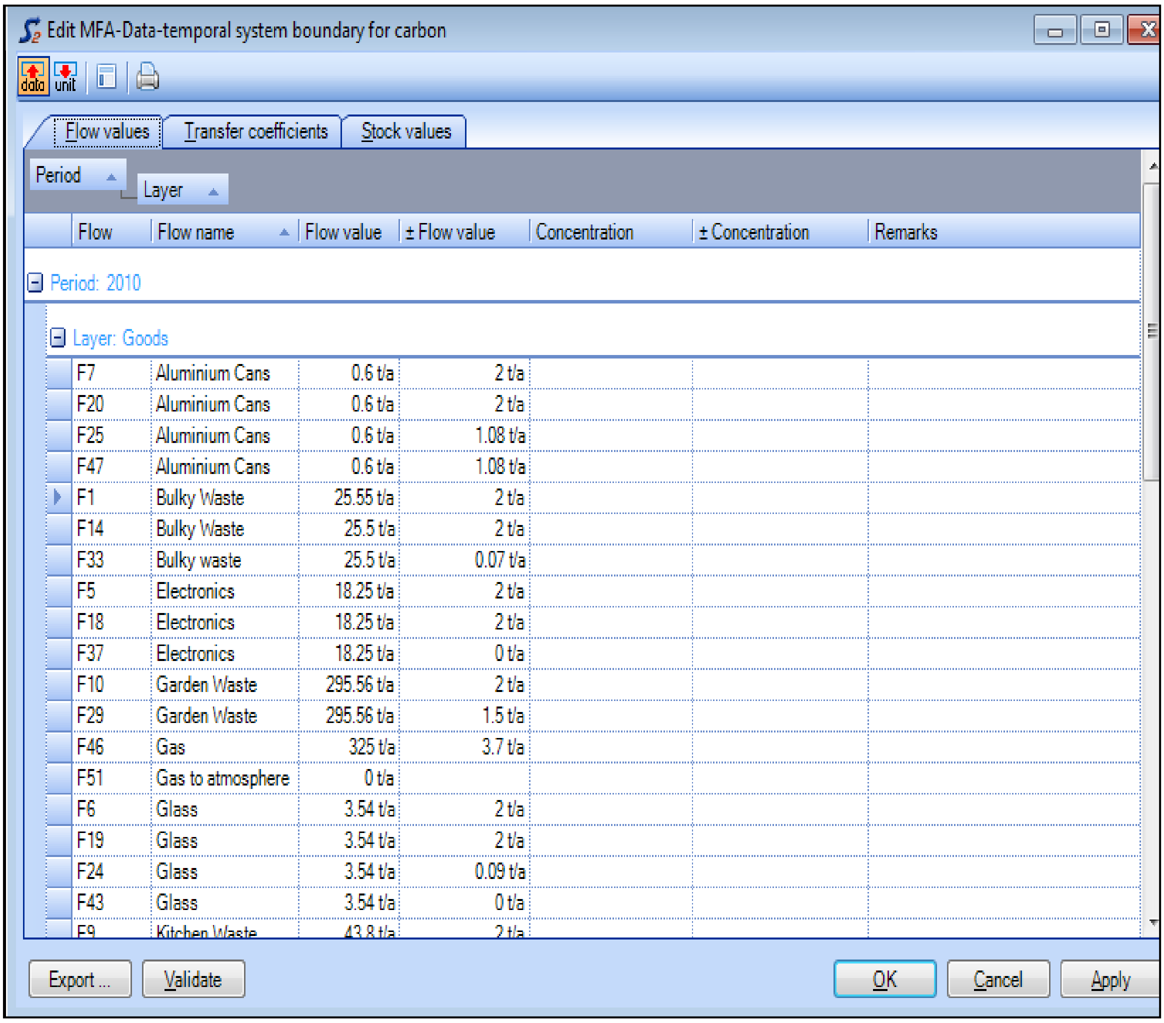
Process List - temporal system boundary for carbon (Goods, 2010)

Process	Flow	Flow name	Source process	Destination Process	Mass flow [t/a]	Mass flow (calcula
- Process name: Loading						
- Input						
P2	F13	Kitchen Waste	P1,Collection & Transport	P2, Loading	43.80±2.00	
P2	F14	Bulky Waste	P1,Collection & Transport	P2, Loading	25.50±2.00	
P2	F15	Plastics	P1,Collection & Transport	P2, Loading	171.55±2.00	
P2	F16	Textiles	P1,Collection & Transport	P2, Loading	21.90±2.00	
P2	F17	Metal	P1,Collection & Transport	P2, Loading	18.28±2.00	
P2	F18	Electronics	P1,Collection & Transport	P2, Loading	18.25±2.00	
- Output						
P2	F32	Kitchen Waste	P2, Loading	P5,Landfilling	43.80±0.12	
P2	F33	Bulky waste	P2, Loading	P5,Landfilling	25.50±0.07	
P2	F34	Plastics	P2, Loading	P5,Landfilling	171.55±0.47	
P2	F35	Textiles	P2, Loading	P5,Landfilling	21.90±0.06	
P2	F36	Metal	P2, Loading	P5,Landfilling	18.28±0.01	
P2	F37	Electronics	P2, Loading	P5,Landfilling	18.25±0.00	
- Process name: Collection & Transport						
- Input						
P1	F10	Garden Waste		P1,Collection & Transport	295.56±2.00	
P1	F9	Kitchen Waste		P1,Collection & Transport	43.80±2.00	
P1	F8	Packaging Paper/cardboard		P1,Collection & Transport	102.20±2.00	
P1	F7	Aluminium Cans		P1,Collection & Transport	0.60±2.00	
P1	F6	Glass		P1,Collection & Transport	3.54±2.00	
P1	F5	Electronics		P1,Collection & Transport	18.25±2.00	
P1	F4	Metal		P1,Collection & Transport	18.28±2.00	
P1	F3	Textiles		P1,Collection & Transport	21.90±2.00	
P1	F2	Plastics		P1,Collection & Transport	171.55±2.00	
P1	F1	Bulky Waste		P1,Collection & Transport	25.55±2.00	
P1	F11	PET Bottle		P1,Collection & Transport	10.95±2.00	
P1	F12	Paper		P1,Collection & Transport	14.60±2.00	
P1	F38	Sewage Sludge		P1,Collection & Transport	273.75±2.00	
- Output						
P1	F13	Kitchen Waste	P1,Collection & Transport	P2, Loading	43.80±2.00	
P1	F14	Bulky Waste	P1,Collection & Transport	P2, Loading	25.50±2.00	
P1	F15	Plastics	P1,Collection & Transport	P2, Loading	171.55±2.00	
P1	F16	Textiles	P1,Collection & Transport	P2, Loading	21.90±2.00	
P1	F17	Metal	P1,Collection & Transport	P2, Loading	18.28±2.00	

Figure 3.7: Data table with grouped input data.

3.5.3 Substance flow Analysis for Carbon and Nitrogen

SFAs was performed for C and N. The uncertainty of concentrations in the waste input was calculated based on data from Boldrin (2009) (as percentage of dry matter in the input mass) ; C = ±2.0 % and N= ±9.6% unless stated otherwise. The initial uncertainties of concentrations in the outputs were assumed to be 10% for both C and N (Andersen *et. al.*, 2010). The loss of materials and compounds to the atmosphere during the landfilling process was estimated by STAn for C and N. Average concentration of each waste identified were multiplied by tonnage received to give the value of respective concentration inside landfill body in a year. The input data and calculated data presented in a systematic flow of material for each type of waste (Figure 3.8).



Period: 2010

Layer: Goods

Flow	Flow name	Flow value	± Flow value	Concentration	± Concentration	Remarks
F7	Aluminium Cans	0.6 t/a	2 t/a			
F20	Aluminium Cans	0.6 t/a	2 t/a			
F25	Aluminium Cans	0.6 t/a	1.08 t/a			
F47	Aluminium Cans	0.6 t/a	1.08 t/a			
F1	Bulky Waste	25.55 t/a	2 t/a			
F14	Bulky Waste	25.5 t/a	2 t/a			
F33	Bulky waste	25.5 t/a	0.07 t/a			
F5	Electronics	18.25 t/a	2 t/a			
F18	Electronics	18.25 t/a	2 t/a			
F37	Electronics	18.25 t/a	0 t/a			
F10	Garden Waste	295.56 t/a	2 t/a			
F29	Garden Waste	295.56 t/a	1.5 t/a			
F46	Gas	325 t/a	3.7 t/a			
F51	Gas to atmosphere	0 t/a				
F6	Glass	3.54 t/a	2 t/a			
F19	Glass	3.54 t/a	2 t/a			
F24	Glass	3.54 t/a	0.09 t/a			
F43	Glass	3.54 t/a	0 t/a			
F9	Kitchen Waste	43.8 t/a	2 t/a			

Figure 3.8 : Calculation box for C and N input