EASEWASTE

TECHNICAL UNIVERSITY OF DENMARK

User Manual

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1 Scenarios

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The scenario is the model of an actual waste management problem. Setting up of a scenario and the associated evaluations are first briefly described. This is followed by detailed instructions on how to do, involving waste generation, waste collection, treatment, recovery and disposal. Also LCI, LCIA, normalization, weighting, and sensitivity analysis are presented.

A scenario is a project or a study where the management of a certain amount of waste is assessed in terms of mass flows, LCI and LCA and where uncertainties and sensitivities can be assessed for the whole scenario (waste generation, collection and transport, treatment etc.) or for parts of the scenarios. It is also possible within a scenario to identify where important loads to the environment happen or where significant savings are obtained by recovering materials and energy.

Setting up and evaluating a scenario

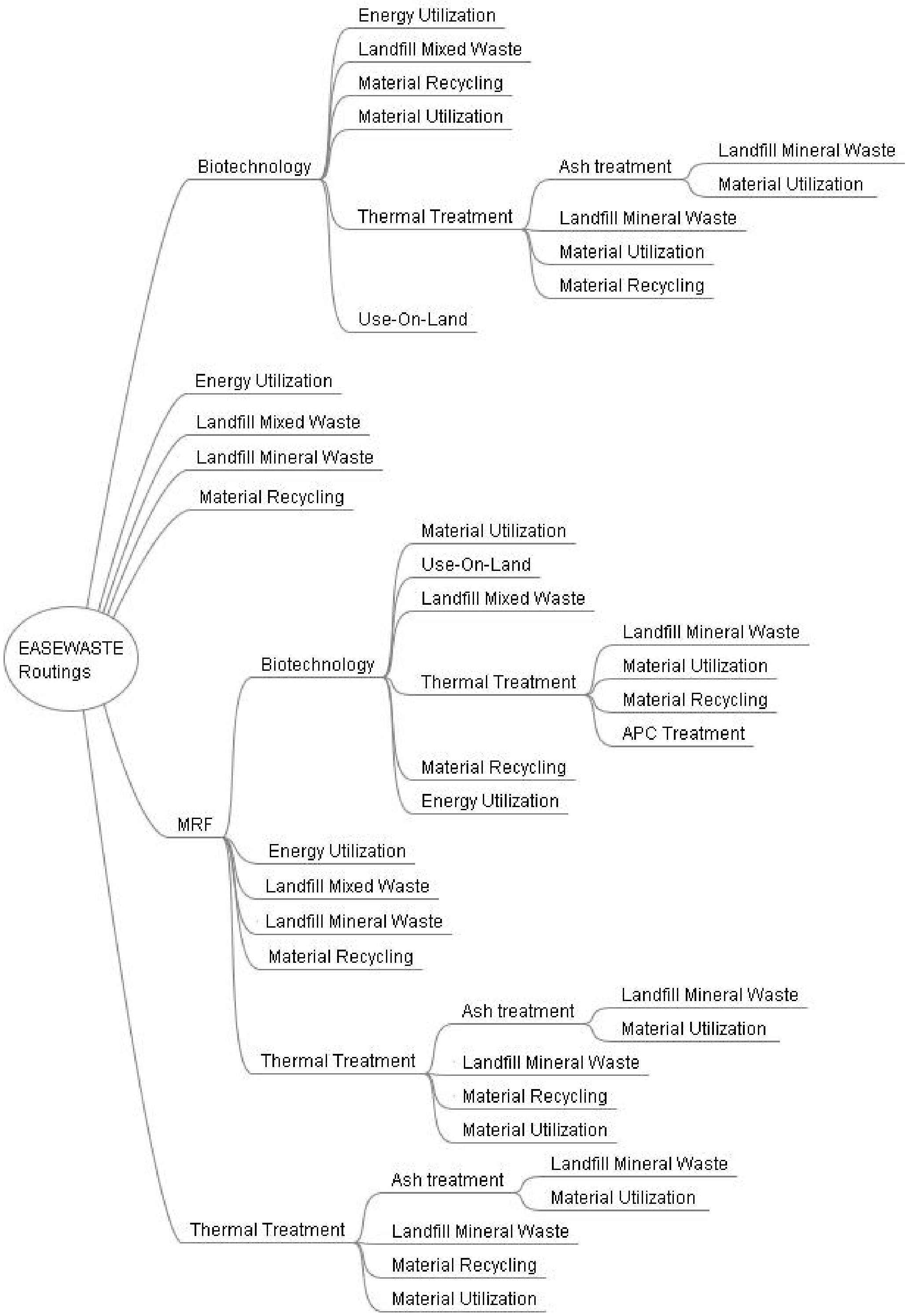
Setting up a scenario involves three phases: Defining the amount and composition of the waste to be managed (**Waste Generation**), defining the source segregation scheme and the type of waste collection (**Waste Collection**), and finally defining the managing of the separately collected waste streams, maybe routed through several treatment steps before recovery and or final disposal (**Treatment, Recovery & Disposal**). These steps must be defined so far that no significant waste stream is left unmanaged in the system. The model allows for truncation of the waste flows and for leaving out side streams if found appropriate for the problem being studied.

The evaluation of a scenario usually involves several steps:

- Material flows: The model calculates all masses of waste entering a process and all solid waste streams leaving a process, these be products or residues. The calculated mass flows should be compared with the mass flows of the actual case being modeled. If unacceptable discrepancies are observed, the model set up must be checked and modified until a reasonable match with the real case is obtained.
- Out-put composition: The model calculates the composition of the out-puts from each treatment process, e.g. the bottom ash from the waste incinerator or the compost composition from the composting plant. These calculated out-put compositions should be compared with measured compositions, when possible, in order to assess how well the model represents the real case. Adjustments in the model set-up may be needed. However, it is not always possible to find real data on out-put composition that are comparable to the ones calculated, because actual plants may simultaneously treat several waste streams, which also will be reflected in the composition of the out-puts.
- The LCI provides the account of all emissions and resource consumptions associated with the waste management system. The LCI can be organized with respect to substance, magnitude, or process. A sensitivity analysis can be made at LCI level.
- Impact Potentials are calculated according the chosen LCA method. The impact potentials can be related to substances or to processes and can be sorted according to magnitude. A sensitivity ratio can be calculated at this level.
- Normalization converts the Impact Potentials into person-equivalents. The normalized impacts can be related to substances or to processes and can be sorted according to magnitude. A sensitivity ratio can be calculated at this level
- Weighting introduces a political weight on the normalized impact potentials. These weighted values can be related to substances or to processes and can be sorted according to magnitude. A sensitivity ratio can be calculated at this level
- The final results may be expressed graphically or exported to Excel.

Possible routes

The way you can route the flows in EASEWASTE is hardcoded. This means that the individual modules can only be followed by specific other modules that fit into them.



User instruction

Adding a new scenario:

1. Select **[Scenario]** in the left pane window. Right click in the main window and press **[New]** to create a new scenario. A new window will open.
2. Give the scenario a **[name]**, usually the name of the project, city, country and year. The year refers to year that the dataset is valid. Save the dataset before entering further data.
3. Choose a **Scenario Type**. Choose "single family", "multi family" and SCBU" or any combination hereof. The listed names are fixed and reflect the most common way of using the model, but basically the issue is to choose how many parallel systems to model simulateously. A maximum of three can be chosen. The three parallel entrances may reflect urban setting with very different housing and waste collection system, the same city in three different years, etc. The most simple is to work with only one scenario type, because for each entrance the full scenario must be defined individually.

   For simplicity the following is described for "Single Family" only.

   The scenario contains three phases in sequence: **Waste Generation, Waste Collection, and Treatment, Recovery & Disposal.** The latter actually may contain sequences of treatment, recover, etc.
4. **[Waste Generation]**: Choose a waste generation data set from the database that opens up.. The data of the chosen dataset will appear in the window. The data can be edited and saved in the window. However, the only value carried on is the **Total Waste [tonnes].** Choose a waste composition data set from the database that opens up.. The data of the chosen dataset (material fraction distribution, chemical composition as found under [View Composition]) will appear in the window. The data can be edited and saved in the window. If any editing has been done you should push **[Update Data]** before moving on. Editing does not affect the original databases, only the data used in the scenario.
5. **[Waste Collection]**: This second phase is divided into **Waste Sorting** and **Waste Collection.** Select first **Waste Sorting** and choose a data set on **Sorting Efficiencies** from the database that opens up. The waste sorting data are used for source segregation of waste. Even if no source segregation is anticipated a (any) data set must be chosen.
6. Choose **Number of Sorting Fraction** from the scroll bar. A corresponding number of name slots open up. The lower one is always called Residual Waste. The chosen number of sorting fractions are named by selecting from the scroll bar. The names available are those used in the chosen dataset on sorting efficiencies.
7. The **[View]** button allows for inspecting and editing the actual sorting efficiencies for the actual sorting fractions. Editing must be followed by saving. Editing does not change the data base, only the data used in the scenario. Note that the first column represents the residual waste, and is calculated from the chosen sorting efficiencies so that 100% of the waste is present in the scenario.
8. **[Waste Collection]**: The second half of the second phase is also called **Waste Collection**. Here all the collection fractions including the residual waste are listed in terms of the amount of waste to be collected separately. Select a **Waste Collection Technology** for each **Collection Fraction** after double clicking in the respective box. The **[View]** button can be used to inspect the fuel consumption (litre of diesel per

tonne of wet waste) or the emission standards for the diesel combustion. Neither the fuel consumption nor the combustion technology can be edited within the scenario.

Specifying the second stage **Waste Collection** and **Transportation** is optional. The program can work without including this information, e.g. if only treatment technologies are to be assessed

9. **[Treatment, Recovery & Disposal]** addresses the further transport and management of the waste. For each **Collection Fraction** define a **Distance** for the transportation (one way distance in km), a **Transportation Technology**, the type of **Treatment, Recovery & Disposal,** and finally a **Technology** from the scroll bars that represent the available databases. The routing of the waste from collection to the first treatment step is not restricted by the model and should be chosen with due consideration of the nature of the collection fraction.

10. For each **Collection Fraction**, after specifying the first treatment step, the **[View]** button must be activated to specify the further routing of the waste after the first treatment step. The routings available are locked in order to minimize the risk for irrational management of the waste further downstream.

11. The technology activated by the **[View]** button should be inspected and edited to suit the purpose. After editing, saving is needed before closing the technology window. At the bottom of each technology window, residues and products are shown and should be routed further by repeating steps **9** and **10** until no significant waste stream is left within the waste management system

Editing an exiting scenario:

1. Open the scenario and edit any user-made specification. Save within each window before closing the window. Warnings are offered if the number and type of collection fractions are changed, because such changes will jeopardize the specifications made under **Treatment, Recovery & Disposal**.

Comparison of two to four scenarios:

1. It is possible to compare up to four scenarios. This is done by selecting the scenarios you are interested in by holding down CTRL and left clicking the scenarios of interest. You then right click and choose LCA evaluation and choose one of the two comparison options.

Technology evaluation within a scenario:

1. It is also possible to evaluate a technology within a scenario including the waste flow set up in a scenario. This is done by choosing **[Output]** in the top bar and then pressing **[LCA Evaluation]**.

2 Waste Composition

Document updated 29 November, 2007 by THC. Original document prepared by THC and controlled by CHR.

The module presents the composition of the waste at the point of generation in terms of the weight distribution of material fractions and the chemical composition of each material fraction. Each waste composition dataset may contain three different datasets regarding the distribution of material fractions, but only one chemical composition is included. The waste composition is the starting point for all routings of waste mass (e.g. in source segregation, material recovery and incineration), for calculation of energy content and recovery, and for all calculations of in-put specific emissions in the waste management system. The waste composition is also crucial for the calculation of the stored toxicity.

Approach

The waste composition is a key factor in determining the potential for source segregation and estimating energy recovery and emissions from the waste management system. Therefore it is crucial that the waste composition used in the modeling closely reflects the actual waste.

Waste composition is described by the wet weight distribution of material fractions and the chemical composition of each of these fractions. The three individual wet weight distributions for municipal waste are a priori defined as representing single family housing **[Single Family(%)]** multi-family housing **[Multi Family(%)]** and small commercial business units **[SCBU(%)].** These names cannot be changed, but they may represent any part of the waste management system with respect to variations in material faction composition, source segregation or waste management technology. EASEWASTE calculates flows and environmental assessment individually for the three material fraction distributions.

The material fraction distribution represents the wet waste prior to any source segregation of any kind. The 48 default material fractions are named according to the dataset on Danish household waste 2003 presented by Riber et al. (2008). Material fractions can be renamed but this will affect the source segregation efficiencies and transfer coefficients in all technology modules. If data are not available for a fraction the composition values can be set at zero.

The chemical composition is in most cases based on dry matter (TS: Total Solids), but in some cases on the basis of organic matter in terms of volatile solids (VS) or wet weight. The actual units are shown in each case. In addition to the chemical substances also water content, heating values (lower heating value on TS basis), methane potential are included. The chemical content is total content, which means that sample digestion prior to analysis must be very effective and any partial sample digestion is not recommended. If data are not available for a substance the values can be set at zero.

Literature

Riber, C., Rodushkin, I., Spliid, H. & Christensen, T.H. (2007): Method for fractional solid waste sampling and chemical analysis. *International Journal of Environmental Analytical Chemistry,* **87**, 321-335.

Riber, C., Petersen, C & Christensen, T.H. (2008): Chemical composition of material fractions in Danish household waste. (submitted).

User instructions

A new dataset is established by:

1. Select **[Waste generation] → [Composition]** in the left window pane of the screen.
2. Click the white sheet icon to make a new waste composition. It is also possible to modify an existing dataset or make a copy of one.
3. Enter a **[name]** of the waste composition. Waste compositions in the EASEWASTE database are named according to: waste type, country or region and year the data was collected, e.g. Household waste [SF + MF], DK, 2003.
4. Enter the material composition using either the 48 predefined names or new names. A new material fraction name is made by right clicking on a fraction name and select **[Open]** – then the name can be redefined. This will take effect everywhere in your EASEWASTE program, also in the saved scenarios; therefore this feature is rarely used.
5. The mass distribution of material fractions in percentages within each of the sub-systems are entered in the three columns called **[Single Family (%)]**, **[Multi Family (%)]**, and **[SCBU (%)].** If the sum of all material fractions does not equal 100%, then you must adjust the numbers so the sum of all material fractions is 100%.
6. Values for the chemical composition are entered in the remaining columns. The unit for each substance is stated in the head row. It can be either % of wet mass, % of TS, or % of VS.
7. H_2O plus TS is set to be 100 % of wet waste, and VS plus Ash is set to be 100% of TS. When one of them is keyed in, the other is automatically calculated. C-biological plus C-fossil is also set to be 100 % of C-total, but the value is given as %TS. These rules cannot be deviated.
8. In general, values are entered by selecting the cell pressing “enter” (or double click) and entering the value. After entering by pressing “enter” the next cell to the right will be selected and by using the arrows other directions can be chosen. Copy/paste works from one cell to another by marking the value; selecting copy; choosing a new cell; and selecting paste.
9. **Note!** Most predefined technology datasets in EASEWASTE are based on 48 fractions. Thus, a choice of more fractions will make the predefined technologies unavailable.

Data requirements

The user must assure that the waste composition reflects the actual waste, as this could be crucial for the LCA results. The distribution of material fractions and the chemical composition of each material fraction are highly correlated and should ideally be measured in the same investigation. It is recommended to be very careful when data are mixed from different sources. The sorting method of material fractions from waste is to some degree defining the chemical composition of the sorted fractions and even though the name is identical the composition could vary substantially.

3 Waste Quantity

Document updated November 29, 2007 by THC

The module presents the quantity of waste at the point of generation in terms of the wet weight. Each waste quantity dataset may contain three different sets of data, for example, representing three different sources of waste, collection systems, or years. The module offers help in calculating the mass of wet waste. The amount of waste (wet tonnes of waste) for each set of data constitutes the basis for all calculations within scenarios using the dataset.

Approach

The waste quantity is a key factor in modeling the waste management system. The model is linear with respect to waste quantity. Therefore it is crucial that the waste quantity used in the modeling closely reflects the actual waste management issues addressed.

Waste quantity is described by the wet weight. Three individual sources of wet weight for municipal waste are a priori defined as representing single family housing **[Single Family(%)]** multi-family housing **[Multi Family(%)]** and small commercial business units **[SCBU(%)].** These names cannot be changed, but they may represent any part of the waste management system with respect to variations source, waste management technology, or years. For example the three sets could represent Copenhagen 2007, Copenhagen 2012 and Copenhagen 2017. EASEWASTE calculates flows and environmental assessment individually for the three sets of data

Waste quantity in EASEWASTE does not have a unit of time. EASEWASTE deals only with a mass of waste. Since most data on waste quantity are associated with a time period (e.g. per year) it is important in the documentation of the actual data to specify the time issues.

Often the waste quantity is based on number of housing units, number of persons per unit and the unit generation rate per person. Data are entered via these parameters but only the final wet weight is used in the calculations in the model.

Literature

No specific literature

User instructions

A new dataset is established by:

1. Select **[Waste generation] → [Waste quantities]** in the left window pane of the screen.
2. Click the white sheet icon to make a new waste quantity dataset. It is also possible to modify an existing dataset or make a copy of one.
3. Enter a **[name]** of the waste quantity dataset. Waste quantity datasets in the EASEWASTE database are named according to: waste type, country or region and year the data was collected, e.g. Household waste [SF + MF], DK, 2003.
4. Enter **[No. of Units], [people/Unit]**, and **[Waste]** (the latter in kg/pers.) so they reflect the actual waste generation or any combination that results in the amount of waste that should be modelled (e.g. 1000 tonnes). **Total Waste (tons)** is the amount of wet waste used in the further calculation.

Data requirements

The user must assure that the waste quantities represent the actual waste management issue addressed.

4 Sorting efficiencies

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The module deals with source segregation of material fractions within a waste type. The module provides a database on how much of a material fraction is segregated into a sorting fraction collected separately at the source (here named sorting efficiencies) and thus defines the separate waste streams to be managed in a scenario. The sorting efficiencies represent the average performance of the area modelled. If a fraction was defined as being subject to source segregation and all citizens all the year followed the guideline 100%, then the sorting efficiency would be 100%. Sorting efficiencies appear in two ways:

- As a dataset under Waste Generation with a range of possible sorting fractions with potentially a range of sorting efficiencies. The database should include realistic sorting efficiencies for alternative source segregation schemes.

- In the scenarios where the number of sorting fractions can be defined and the corresponding sorting efficiencies can be selected from the above-mentioned database.

In the scenario the sorting percentages for each fraction are cumulative and the remaining waste not defined as subject to source segregation is routed to residual waste in order to ensure mass conservation.

Approach

At the source of waste generation it is important within a single waste type to define the waste streams that shall be collected separately. This is done by defining sorting efficiencies for each material fraction defined in the waste type. The sorting efficiency defines how much of the material fraction is segregated into the defined sorting fraction in average for the area modeled. In this way the sorting efficiency differs from the participation rate, because participating citizens may not participate all year round and may not sort the waste 100% correct according to the sorting guideline.

Source segregation should be defined to obtain a sound routing of the segregated fractions in the waste management system, i.e. through collection, transport, treatment etc. Source segregation is often introduced by providing the citizens with sorting guidelines specifying which material fractions in the waste go into which sorting fractions (e.g. paper, packaging, organics, etc.). The sorting efficiencies depend on the sorting fractions defined (e.g. as described in the sorting guideline given to the citizen), on the collection system available (a full service system collecting the recyclables at the house or must the citizen bring the source segregated material to a recycling station), and the general engagement of the citizen (level of information, means of paying for waste service etc.).These factors are however all correlated: A meaningful and clear sorting guideline requiring a minimum of effort by the citizen combined with a collection system that makes it easy to deliver the recyclables should give high sorting efficiencies (maybe 80-90%), while less user friendly systems may have much lower sorting efficiencies.

In the Waste Generation database sorting efficiencies can be defined for a range of systems relevant for an area. In the database the sorting fractions and efficiencies may represent alternative systems, because in the scenario any combination of sorting fractions can be selected from the database (note that you will get an error message, if you choose sorting options that together exceed 100% for one waste fraction). In the scenario the sorting fractions must be complementary representing a realistic system, and the material fractions not included in the source segregation and the part of the material fractions not successfully segregated at the source are automatically routed to the residual fraction in order to ensure mass conservation at the source.

Sorting efficiencies can also be used to include foreign items in a sorting fraction (e.g. cardboard that mistakenly was placed in a newspaper sorting fraction)

Literature

No specific literature

User instructions

Adding a new dataset (outside the scenario):

1. Select **[Waste Generation] → [Sorting efficiencies]** in the left window pane. Right click in the main window and press **[New]** to create a new dataset. A new window will open.
2. Give the dataset a **[name]**. Sorting efficiencies in the EASEWASTE database are named according to: focus of the source segregation system, the name of the city, country and year. The year refers to year that the dataset is valid. Save the dataset before entering further data.
3. Define for "single family", "multi family" and "SCBU" or only part of them which sorting fractions should be included. This is done by right clicking and adding the needed number of columns (click for each new sorting fraction). The names of the sorting fractions can be defined by right clicking and choosing **[Edit Fraction Name]**.
4. Alternative sorting fractions can be defined since there is no need to consider mass conservation here. This is done in the scenario. For each material fraction a percentages is defined showing how much of the material fraction (% of wet weight) in average will go to the defined sorting fraction. This may also apply to contaminants and mis-sorting

Supplementing an exiting dataset (outside the scenario):

1. Select **[Waste Generation] → [Sorting efficiencies]** in the left window pane of the screen. Click on an existing dataset.
2. File the edited dataset under a new name by "save as" .Give the edited dataset a **[name]**
3. Right click on the dataset and add the additional sorting fraction (click for each new sorting fraction). The names of the sorting fractions can be defined by right clicking and choosing **[Edit Fraction Name]**.

Use a sorting efficiency dataset in a scenario:

1. In a scenario, under "Waste Collection" , "Choose" the dataset for sorting efficiencies that you want to use.
2. Define "Number of sorting fraction" by the scroll bar (Number = number of source segregated sorting fractions plus the residual waste fraction).
3. Define the names of the sorting fractions as they appear by the scroll bar. The last sorting fraction is always named "Residual Waste".

4. By clicking “View” the corresponding sorting efficiencies appear. The “residual waste fraction” is calculated by the model to ensure mass conservation.
5. Close the window and move on with the modeling.

Editing a sorting efficiency dataset in a scenario:

1. In a scenario, under “Waste Collection” click “View” to see the original dataset.
2. Change any number in the sorting efficiencies and the model will recalculate the “residual waste” fraction. Save before moving on with the edited dataset. The dataset will remain changed in the scenario also when the scenario is opened later. The original sorting efficiency dataset will not be changed.

Data requirements

Following issues must be considered when collecting data for creation of dataset with sorting efficiencies:

- The sorting guidelines available for actual systems with source segregation may be a source of inspiration.
- It is important to focus on how the sorting fraction is managed afterwards. How clean must it be, is moisture a problem for storage etc. The material fractions to be included in a sorting fraction must reflect this and respect the citizens’ ability to understand the guideline.
- Data from existing systems regarding collected tonnes and “mis-sortings” may be useful in setting up realistic sorting efficiencies.

Technical calculations

Mass conservation is introduced in the scenario so that all waste in source separated fractions and the residual fraction make up 100% of the mass.

Equation 1
The amount of a material fraction that is routed to the next technology (tonne); it is assumed that the water content does not change:

$$Material\_frac = Input\_mass * Input\_frac * Sorting\_frac$$

Each material fraction is kept separate throughout the system, but is added up for routing a total mass to the next technology.

Economics

Not yet available

Variables and Constants

Input_frac		Amount of each material fraction in %
Input_mass		Input of waste to the sorting system (tonne ww)

Material_frac		Material_fraction sent on to a new technology (tonne ww)
Sorting_frac		Amount of each input fraction sorted into a sorting category in %.

5 Waste collection

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The module represents collection of waste in trucks in terms of the fuel consumption and the exhaust emissions caused by the fuel combustion. Use of fuel is considered the predominant environmental load from waste collection. The environmental load from producing and using bins, sacks, containers and from producing and maintaining trucks is not included in the technology. Collection is defined in terms of the fuel consumption per tonne of wet waste from the first stop on the collection route to the final stop on the collection route. Fuel spent on driving from the garage to the start of the collection route, driving from the final stop on the collection route to the unloading point, and driving from that point back to the garage is considered part of transportation and can be modelled in the transportation module. The emissions associated with combustion of the fuel are obtained from the external process database.

Approach

Each waste collection dataset represents collection of a certain type of wet waste (mixed, residual, paper, etc.) and is characterized by the type of container (size, type), the type of vehicle (size, emission standards), and layout of the collection route within a defined neighborhood (density of bins, bins per stop, traffic, and access to bins). The specific fuel consumption per tonne of wet waste can be estimated from approaches suggested in the literature or by direct measurements, e.g. Larsen et al. (2008) shows the measurements of collection of several kinds of household waste.

Fuel and its combustion is the major environmental load from waste collection. The most important exhaust emissions are carbon dioxide, sulphur dioxide and heavy metals, which are related to the chemical composition of the fuel, and nitrogen oxides, carbon monoxide, non-combusted hydrocarbons (NMVOC) and particles, which depends on the engine operations. Environmental loads from infrastructure, wear on vehicles and maintenance of vehicles are not included.

The fuel consumption depends on parameters such as type of truck, engine size of the truck, compaction of the waste, capacity use, distance between stops, amount of waste collected per stop, and acceleration, speed and braking between stops. The fuel consumption of a vehicle is also influenced by the type of road (whether it is urban or rural collection) and by the mechanical bin lifting devices. The fuel consumption is expressed for a given combination of truck, route and waste as an average consumption of diesel per tonne of wet waste. It is not necessary to obtain data for all abovementioned parameters, as these are aggregated into one parameter for diesel consumption. If fuel is spent locally on collection of waste by small tractors or by vacuum collection systems the corresponding fuel consumption must be converted to fuel consumption per tonne of wet waste and included in the waste collection fuel consumption. The default unit is liters of diesel, but other types of fuel can as well be chosen, e.g. Nm^3 gas or kWh electricity; all must be per tonne of wet waste.

Production and maintenance of bins, containers and trucks are not included in this approach for waste collection.

Literature

Larsen, A., Vrcog, M. & Christensen, T.H. (2008): Diesel Consumption in Waste Collection and Transport. (in preparation).

User instructions

A new dataset is established by choosing a fuel combustion technology and a value for the fuel consumption per tonne of wet waste:

12. Select **[Waste Management] → [Collection]** in the left window pane of the screen.
13. To create a new waste collection technology, right click anywhere on the window and select New. Provide a **[name]** for the technology. Collection technologies in the EASEWASTE database are named according to: type of waste collected, the type of residency or collection technology, city, country and year. The year refers to when the main data behind the technology were collected, e.g. "Paper, drop-off-containers, Aarhus, DK, 2004". Save the technology before entering further data.
14. **[Fuel combustion technology]** is used for calculation of the environmental load from production and combustion of 1 litre of fuel. It is an external process which is chosen in the database. Any new combustion processes must be added in the external process database.
15. **[Fuel consumption]** is the parameter value for the specific fuel consumption in a new waste collection dataset. The default unit is liter of diesel per tonne of wet waste.

In a scenario, the waste collection dataset is chosen by double clicking in the cell **[Waste Collection Technology]**, located in the waste collection window under the waste collection sub tab. The number and type of collection fractions are defined in the waste sorting tab.

Data requirements

Creating a new waste collection dataset requires two parameters:

- The input data in **[Fuel combustion technology]** are external processes, which should emphasize at least production and combustion of the fuel. Data on production are most often included in LCI databases. Exhaust emissions from the combustion process depends on engine technologies and operations and can be obtained from standard tables on emissions or transport simulation software. Some emission substances depend on the chemical composition of the fuel, while other depends on operation of the combustion engine.
- **[Fuel consumption]** can be measured directly on real collection schemes by following a standard measurement procedure. Alternatively, the specific fuel consumption can be estimated from the waste collection operator's statistics on fuel consumption and model estimates on how much fuel is used on transportation outside the collection area, e.g. driving from the garage and back and between the collection area and the point of unloading.

Technical calculations

Calculation of LCI tables for waste collection is performed in the Waste Collection Window. Datasets for waste collection are given as fuel consumption per tonne of wet waste and are multiplied with the mass of a chosen collection fraction. Within the dataset, the fuel consumption parameter is multiplied with an LCI table for the chosen external process for fuel production and combustion. The resulting equation is:

Equation 1

$$\overline{LCI\_col} = Output\_mass \cdot \overline{Ext\_LCI} \cdot Fuel\_collect$$

Economics

Not yet available

Variables and Constants

Ext_LCI	LCI table of an external process (kg/tonne)
Fuel_collect	The fuel consumption parameter used in waste collection (liter/tonne)
LCI_col	LCI table of waste transportation (kg/tonne)
Output_mass	Wet output mass from a collection fraction or a technology (tonne)

6 Waste transportation

Document updated November 29, 2007 by AWL. Original document prepared by AWL and HKL and controlled by THC

The module represents transportation of waste by truck, ship and railway. Waste transportation is defined as transportation of waste between treatment facilities after collection of the waste. Collection is therefore not a part of the transportation, but it can be modeled separately in the collection module. The datasets each includes a fuel consumption value expressed in the unit liters of fuel per tonne of waste per traveled km as well as a process for production and combustion of the fuel. The processes are obtained in the external process database. The most important impacts from transportation are considered to be consumption of fuel and the exhaust emissions caused by fuel combustion. Transportation can be added once in each step of the waste treatment system.

Approach

Transportation represents the fuel consumption for the transport of the collected waste to the point of unloading, e.g. at the treatment facilities or landfill. Transportation can be characterized by the means of transportation (e.g. truck, ship or railway), capacity use, engine technology, etc. The transportation can be assessed precisely if the transportation route between the collection point and the point of unloading is known in terms of the physical distance between waste management facilities. However, if the waste is exported, regionally or globally, the transportation means and routes may vary significantly and estimates will be uncertain. Since transportation accounts for only a minor part of the environmental impact from waste management, the modeling of it should be kept simple. Therefore, only one type of transportation can be added between two waste treatment facilities.

Fuel and its combustion is the major environmental load from transportation of waste. The most important emissions are carbon dioxide, sulphur dioxide and heavy metals, which are related to the chemical composition of the fuel, and nitrogen oxides, carbon monoxide and non-combusted hydrocarbons (NMVOC) and particles, which depend on the operation of the engine and actual emission standards. Emissions are regulated for road vehicles, for example by European Emission Standards. Environmental loads from production and maintenance of means of transportation, infrastructure and tire wear are most often not included.

The fuel consumption is expressed as a unit fuel consumption corresponding to the amount of fuel used for transporting 1 tonne of waste a distance of 1 km. That has by default the unit [liter/(ton·km)], but it could also be expressed in, e.g. Nm^3 gas or kWh electricity, all per tonne of wet waste per km. The fuel consumption depends on many different parameters such as type and size of the means of transportation, volume weight of material, capacity use, combustion engine technologies, and traffic conditions on the transportation route. All these conditions are aggregated into one parameter for fuel consumption. Datasets for various kinds of transport are found in the external process database.

The distance traveled for the waste is the length of a travel route in km from where collection was complete and to the point of unloading. This one-way distance is also the distance in km used for calculating the fuel consumption. This means that any fuel used on driving from the garage to the collection area and from the point of unloading back to the garage should be accounted for in the fuel consumption value.

Literature

No specific literature

User instructions

A new dataset is established by:

1. Select **[Waste Management] → [Transportation]** in the left window pane of the screen.
2. To create a new transportation technology, right click anywhere on the window and select New. Provide a **[name]** for the technology. Transportation technologies that refer to a specific kind of waste collection are named according to: the type of truck, type of waste collected, type of residency or collection technology, city, country and year. The year refers to when the main data behind the technology were collected, e.g. "Collection truck, paper, drop-off-containers, Aarhus, DK, 2004". Datasets for more generic types of transportation should be named according to: the type of means of transport, size, waste type, region, year, e.g. "Long haul truck, 25 tonne, generic, global, 2007". Save the technology before entering further data.
3. **[Fuel combustion technology]** is used for calculation of the environmental load from production and combustion of 1 liter of fuel. It is an external process which is chosen from the database. Any new processes must be added in the external process database.
4. **[Fuel consumption]** is the parameter value for the specific fuel consumption in a new waste transportation dataset. The default unit is liter of fuel per tonne of wet waste per km.

In a scenario, the waste collection dataset is chosen in the cell **[Transportation Technology]** and linked to a mass of waste either between collection and the first waste technology or between successive waste technologies. The transportation distance is entered in the cell **[Distance]** in connection with the chosen dataset. This distance is the one-way distance in km.

Data requirements

Creating a new waste transportation dataset requires two parameters:

- The input data in **[Fuel combustion technology]** are external processes, which should emphasize production and combustion of the fuel. Data on production are often included in LCI databases. Exhaust emissions from the combustion process depends on engine technologies and operations and can be obtained from standard tables on emissions or transport simulation software. Some emission substances depend on the chemical composition of the fuel, while other depends on operation of the combustion engine.
- The parameter value for **[Fuel consumption]** can be obtained in different ways. Datasets for transportation by truck, ship and railway are found in various LCI databases. These will most often include a value for fuel consumption that can be converted to the default value liter per tonne per km. The value can also be calculated in transport simulation software and linked to a combustion process. Other possibilities are to perform measurements on real vehicles or to calculate it from operators' fuel consumption statistics.

Technical calculations

Calculation of LCI tables for transportation is done by multiplying the dataset with a mass of wet waste and a given distance. Within the dataset, the fuel consumption parameter is multiplied with an LCI table for the chosen external process for fuel production and combustion. The resulting equation is:

Equation 1

$$\overline{LCI\_trans} = Output\_mass \cdot \overline{Ext\_LCI} \cdot Fuel\_trans \cdot Dist$$

Economics

Not yet available

Variables

Dist	Waste transportation distance (km)
Ext_LCI	LCI table of an external process (kg/tonne)
Fuel_transp	The fuel consumption parameter used in waste transportation (liter/tonne/km)
LCI_trans	LCI table of waste transportation (kg/tonne)
Output_mass	Wet output mass from a collection fraction or a technology (tonne)

7 Ash Treatment

Document updated 08-01-2008 by AND. Original document prepared by THA and controlled by THC.

The module represents treatment of ashes originating from thermal treatment of waste. The module focuses on the treatment process itself. Treated ashes can be routed further to material utilization or landfilling. Examples of ash treatment processes that the module may be used to evaluate are: extraction processes, chemical stabilization processes, solidification processes, and thermal treatment processes. All processes produces as minimum a single solid output that may either be utilized or landfilled. Transfer coefficients can be defined for each output material.

Approach

The module represents treatment of ashes from thermal treatment of waste. The module can be used for modelling of various kinds of ash treatment, e.g. extraction processes, chemical stabilization, solidification, as well as vitrification and melting of the ashes. Useful solid outputs from the ash treatment process may be routed further to material utilization and/or landfilling.

Each ash treatment dataset represents a full treatment plant as defined by the type of process and technology used. The module includes process-specific auxiliary material and energy use as well as process-specific emissions originating from the process itself and based on the ash input quantity (i.e. ash routed from a thermal treatment plant). Transfer coefficients are used to link substances in the ash input and with substances in the defined material outputs, e.g. the treated residues and any secondary waste streams.

Process-specific and input-specific emissions are categorized according to the receiving environmental compartments (air, surface water, soil) and/or material outputs. The transfer coefficients are defined for each output material fraction (the module only has a single input) and are distributing the input to the defined outputs. All transfer coefficients should add up to 100 %.

As ashes may be quenched or wetted at the thermal treatment plant in order to avoid dusting during transportation, the dry matter content specified in the thermal treatment module (TS in % of WW) for an individual material output is carried over to the ash treatment module and automatically gives the amount of TS and WW. As the treated ashes may also contain water, a dry matter content can be specified for each material output defined.

Literature

Astrup T, Fruergaard T, Christensen TH: Life-cycle assessment of residue treatment technologies: methodology. (In preparation).

Fruergaard T, Astrup, T. Life-cycle assessment of residue treatment technologies: case-studies. (In preparation).

User instruction

A new dataset is established by:

1. Give the technology a **[name]**. In the EASEWASTE database ash treatment plants are named according to: Process type, name of the plant or process (if any), city, country and year. The year refers to when the main data behind the technology were collected, e.g. “Chemical stabilization, Ferrox, Copenhagen, Denmark, 2006”. Save the technology before entering further data.
2. One to ten outputs are defined **[Number of Outputs]** in the top part of the screen.
3. The type/name of the outputs is defined in the bottom of the screen **[Output Materials].**
4. Specify the TS-content of each output, i.e. the dry-matter content of the output after the ash treatment process (**[TS in % of WW]** of each output).
5. For all outputs and substances specify **[Transfer Coefficients]**.These coefficients represent the percentage of an individual **[substance]** in the input ash being transferred to the defined outputs. Unlike the thermal treatment module, the ash treatment module does not include input specific air emissions and does not allow **[Transfer Coefficients]** to be defined for air emissions. In this module, air emissions (if any) should be specified as process specific emissions.
6. **[Input – Material and Energy]** is used to list materials and energy that are consumed in the ash treatment process and the operation of the facility (process specific data).
7. **[Input – Resources and Raw Materials]** is used to list materials that are used in the process but are not contributing to any significant emissions during their extraction, production, transport and consumption. These materials are only counted as resource use.
8. **[Output – “Compartment”]** is used to list the direct process specific emissions to various environmental compartments (kg/tonne of wet waste).
9. **In a scenario**, the user can route the **[Output materials]** to either material utilization or landfilling.

Data requirements

When collecting data for creating a new ash treatment process the following important parameters should be considered:

- **[Input – material and energy]** may have a significant impact on the overall evaluation of the ash treatment process, in particular when comparing different treatment processes, as for example, energy consumptions can indirectly contribute with relative large impacts. Relevant units are typically kg, kWh, l (liter) or MJ /tonne.
- **[Output – “Compartment”]** represent direct emissions from the process itself; these emissions may for some processes be significant compared with the impacts related to materials and energy consumptions. Required unit is kg/tonne.

- **[Transfer coefficients]** are typically of less relative importance for the evaluation of the ash treatment process itself; however the coefficients may have significant impact on emissions from the treated ashes when routed to material utilization or landfilling as these coefficients define the composition of the treated ashes. It should however be realized that a good mass balance of a treatment plant is necessary, in particular to make sure that all relevant mass flows are accounted for. The unit of transfer coefficients is a percentage of the input.

Technical calculations

The main calculations performed in the ash treatment module are shown below. For calculations regarding definition of the ash input to the module, please refer to the information available for the thermal treatment module.

Equation 1
The amount of a substance in a specific material output (such as treated ash) is calculated. The word “output” in the equation below may be exchanged with the name of specific outputs (e.g. treated ash, secondary waste stream, etc.) and the word “substance” may be changed to a specific substance (e.g. Cd, Cu, etc.).

*Subs_output = Input_mass*TS_input*Sub_input*Subs_output_TFC*

The input mass of ashes is converted into TS and the fraction of a specific substance in % of TS in the ash is calculated. This is then multiplied with the transfer coefficient for the material output in question thereby yielding the amount of a substance in the specific output.

Equation 2
The amount of a given output is calculated from routing of the dry waste amount, TS % in the output defined in the technology window:

*Output_mass = input_mass*TS_input*TS_output*

The mass of an output is calculated as the TS in the input multiplied with the TS fraction routed to the output in question. This TS fraction is specified within the transfer coefficients window. Please note that the user can specify the dry matter content ("Output_TS") of the output itself as it leaves the ash treatment process (i.e. to account for water added to avoid dusting, etc.). This value does not affect routing of mass to the individual outputs.

Equation 3
LCI calculation for a substance is the sum of all process specific emissions and the LCI of all external processes. The overall equation is as follows:

$$\mathrm{LCI} = \left(\mathrm{Input\_mass} \times \sum_{\mathrm{processes}} \left(\mathrm{Process\_amount} \times \overline{\mathrm{Ext\_LCI}} \right) \right)$$

The LCI for ash treatment includes process specific emissions to air, soil and water as described in the equation above. Any use of materials or energy (like additives or electricity) is added to the

LCI as well with the related emissions. For further description of the equation see the document on LCI.

Equation 4
It should be noted that substance concentrations in the outputs are not part of a LCA method but are provided in EASEWASTE to facilitate the evaluation and comparison of results with monitoring data usually expressed in concentrations.

The output substance concentration is defined as the ratio between total mass of a material output and the quantity of a substance routed to this material output (e.g. grammes of mercury per tonne of treated ash).

$$\text{Output\_subs} = \frac{\text{Subs\_output}}{\text{Output\_mass}}$$

Economics

The general approach and user instruction for the economic part are described in the feature document “Documentation: Economics”.

Variables and Constants

Variables

Ext_LCI		LCI table of a external process (unit/tonne)
Input_mass		Input of ash to the technology (tonne ww)
LCI		LCI table of a treatment process (kg/tonne)
Output_mass		Mass of a material output in TS (tonne)
Output_TS		User defined TS in percent for an output (%)
Process_amount		??
Sub_input		Amount of a substance as a percent of TS in the incoming ashes (%)
Subs_output		Amount of a substance in a material output (tonne)
Subs_output_TFC		Transfer coefficient in percent for a substance to a given material output (%)
TS_input		Percent of total solids (TS) in the incoming ashes (%)
TS_output		Percent of total solids (TS) in a material output (%)

8 Biotechnology: Biogas & Composting

Document updated November 28, 2007 by ALB. Original document prepared by ALB and controlled by JAM.

The module represents biological conversion of waste resulting in emissions to air, water and soil as well as solid outputs and for anaerobic digestion also in energy production. The module addresses degradation of organic matter, transfer of materials to defined outputs and any process specific emission to air, water and soil. Use of the degraded waste in terms of compost or digest is not included in the module. Any solid output must be routed further downstream. The module focuses on composting, anaerobic digestion or a combination hereof. The module may potentially also be used for biotechnological production of ethanol, hydrogen and methane gas for a market. Based on the chemical composition, water content and methane potential of the material fractions present in the input waste, the module calculates the biogas production (if any) for a defined degradation rate, composition of outputs based on degradation of organic matter and material-based transfer coefficients for defined outputs. Energy recovery, process specific emissions, off-gas cleaning and losses of methane, nitrous oxide and ammonia can be specified. The type of energy production avoided as a consequence of the energy recovered by the anaerobic digestion must be specified to provide crediting of saved emissions and resource use.

Approach

Each biotechnological treatment dataset represents a full plant, including the technology of the plant and the operation of the plant. If supplementary technologies, e.g. additional screening of compost or magnetic metal removal, are needed, this can only be modelled by establishing a new dataset where the considered add-on-technology is an integrated part of the dataset.

The module employs process-specific (mass per tonne of waste processed) material and energy use as well as process-specific emissions. Process-specific emissions are categorized according to the receiving compartment (air, surface water, soil, etc.). The degradation of the organic waste is user defined and is expressed as percent degradation of volatile solids (VS) for each material fraction by composting (aerobic process) and/or digestion (anaerobic process). Ash is not degraded during biologic process, (i.e., the degradation coefficient for this fraction should be set to zero). Transfer coefficients are used to transfer the non-degraded part of each material fraction to defined outputs. The number and type of outputs can be specified for each individual technology. The transfer coefficients are mass conserving (after degradation) and, considering all outputs, add up to 100%.

Other non-solid outputs, emissions and pollution control devices are specific for the chosen treatment among three technologies: composting, anaerobic digestion and a combination hereof. The composting module includes a sub-module for emissions to air of nitrogen-compounds and carbon-compounds. The total amount of nitrogen lost (as % of total N) and its distribution among ammonia (NH_3), nitrous oxide (N_2O) and nitrogen (N_2) is user specified. The amount of methane released to the atmosphere, which depends on how the plant is operated, is also user defined as a percent of the degraded C. The module calculates by default the degraded C and CO_2 emission to air using the degradation percentages specified by the user. These gaseous emissions can be treated in a gas-cleaning device (e.g. biofilter). Removal efficiencies (as percent) for NH_3, N_2O and CH_4 can be specified.

Anaerobic digestion has biogas as an output. Methane production is calculated based on methane potentials included in the waste composition and the VS degradation specified by the user. The methane content in the biogas is also user defined. Unburned CH_4 is the amount of methane lost in the process due to imperfect gas-tightness of reactor and pipes, incomplete combustion, etc. It is defined as percent of produced CH_4 (and not produced biogas!).

The module calculates the energy content of the biogas based on its methane content and, through user-specified energy recovery (to be defined in a separate window as percent of the energy content in the produced biogas), calculates the electricity and/or heat recovered. The user must specify the avoided energy production in order to obtain the credits for saving in resource use and emissions. The energy recovery is the gross energy recovery, since the plant's own use of energy is accounted for in the tables on material and energy input.

If the combined composting and anaerobic digestion module is chosen, all these features are present in the same window and a degradation table with two columns is to be defined, one related to anaerobic digestion and the other to composting.

Normally, the input waste for these technologies will be source-sorted organic household waste. EASEWASTE, however, also includes the possibility to insert a Material Recovery Facility (MRF) before the biotech module to model separation of different material fractions in unsorted waste.

Literature

Hansen, T.H., Sommer, S.G., Gabriel, S. & Christensen, T.H. (2006) Methane Production during Storage of Anaerobically Digested Municipal Organic. *Journal of Environmental Quality* 35: 830–836.

Hansen, T.H., Svärd, Å., Angelidaki, I., Schmidt, J.E., la Cour Jansen, J. & Christensen, T.H. (2003) Chemical characteristics and methane potentials of source-separated and pre-treated organic municipal solid waste. *Water Science and Technology* 48: 205–208.

Hansen, T.H., Schmidt, J.E., Angelidaki, I., Marca, E., la Cour Jansen, J., Mosbæk, H. & Christensen, T.H. (2004) Method for determination of methane potentials of solid organic waste. *Waste Management* 24: 393–400.

Boldrin, A., & Christensen T.H. Life Cycle Assessment Models for Biowaste Management (in preparation).

User instructions

A new dataset is established by:

1. Select **[Waste Management] → [Technologies] → [Biotechnology]** in the left window pane of the screen.
2. Give the technology a **[name].** In the EASEWASTE database biotechnologies are named according to: Type of treatment, technology and waste, city, country and year. The year refers to when the main data behind the technology were collected, e.g.

"Anaerobic digestion (household waste+green waste), "city", "country", "year". Save the technology before entering further data.

3. The type of treatment is defined **[Type]** in the top part of the screen. Three alternatives are available: Anaerobic Digestion, Composting, Anaerobic & Composting.
4. The degradation percentages are defined in **[Degradation]** for each material fraction in the waste composition**.** In case of anaerobic digestion, the percentage is to be interpreted as methane yield based on the methane potential, e.g., 60% degradation of the vegetable food waste fraction means that the methane yield is 60% of the methane potential of this waste fraction. In case of composting the number is to be interpreted as percent of VS degraded during the process. In the combined technology two columns are to be defined. The first column reporting the methane yield during the anaerobic stage and the second defining VS degradation during composting, their sum can theoretically exceed 100 %.
5. One to eight outputs are defined **[Number of Outputs]** in the top part of the screen.
6. The type/name of the outputs is defined in the bottom of the screen **[Solid Outputs - Output materials].** The TS content of each of the outputs must be specified (**[TS in % of wet weight]** of each output).
7. The **[Arrow]** button placed beside **[Number of Outputs]** opens a new window where **[Distribution of TS after Degradation]** are defined for each substance for all outputs and represent the percent of the **[substance]** in each material fraction transferred to the defined outputs. There is no distinction between ash and VS.
8. Depending on technology type chosen at point [1], several other parameters are to be defined:
    a. For anaerobic digestion the **[methane content in biogas - % of CH_4]** and **[Unburned methane - % of CH_4 produced]**. (**[Methane production – Nm^3]** and **[Energy in biogas – MJ]** are calculate by the module). **[Biogas Utilization]** is used to define the technology used for biogas combustion (columns) and the energy substituted (lines). As the recovered energy refers to a specific technology, a single percentage per line can be entered. The sum of all percentages corresponds to the total recovery efficiency of the energy contained in the biogas.
    b. For composting the size of nitrogen-emissions as **[Total N – loss - % of Total N]** and its distribution **[Distribution of N – loss % - Ammonia NH_3]**, **[Distribution of N – loss % - Nitrous Oxide N_2O]**, **[Distribution of N – loss % - Nitrogen N_2]**. For carbon-emissions only the methane loss has to be defined **[CH_4 - % of Degraded C]**, while CO_2 is calculated by the module. If gas cleaning devices are present, additional parameters to be defined are the removal efficiencies (in percent) for the single gases: **[NH_3 - % Removal]**, **[N_2O - % Removal]**, **[CH_4 - % Removal]**.
    c. For combined technology all the parameters at both 7.a and 7.b have to be defined.
9. **[Input – material and energy]** is used to list materials and energy that are consumed in the biological process and the operation of the facility.

10. **[Input – resources and raw materials]** is used to list materials that are used in the process but are not contributing to any significant emissions during their extraction or production, transport and consummation. These materials are only accounted for as resource use.
11. **[Output – Compartment]** is used to list the direct process specific emissions to various environmental compartments (kg/tonne of wet waste).

In a scenario, the user must route all outputs (except emissions to air) to further downstream technological modules including a specification of the means of transport and transport distance. The routings available appear in separate documentation file on the EASEWASTE website.

Data requirements

When collecting data for creating a new biological treatment technology there are a number of crucial parameters:

- **[Degradation]** has large impact because the conversion of VS determines the biogas production (in case of anaerobic digestion) or the emissions of NH_3, N_2O and CH_4 (composting).
- **[Unburned methane - % of CH_4 produced]** influences the impact on global warming. Although measured data for this parameter are usually not available, for an average well functioning plant this value should be fairly low (a few percent).
- The amount and distribution of N-compounds and C-compounds in **[Composting]** can have an impact on the assessment.
- **[Biogas Treatment]** regarding the recovered energy is also very important. Both in terms of the percentage of energy recovered and in terms of the type of energy recovered. It has a significant impact whether the substituted energy is based on coal, gas or an energy mix. The choice of a substitution process for the electricity production might often be based on regional consensus on which process is substituted, since electricity often is fed into a transnational grid. Selecting a substitution process for heat production delivered to a local district heating grid requires detailed information on the alternative production processes in the distribution net. In some cases a process representing the local heat substitution will not be present in the database and specific information must be gathered and a new process must be entered in the database for external processes.
- **[Gas Cleaning]** in composting can substantially decrease the environmental impact of gas emissions, as compounds with high impact can be removed or transformed to less harmful substances. On the other hand, studies have shown that N_2O can actually be produced in biofilters. In this case a negative removal coefficient for N_2O is defined.
- **[Transfer coefficients]** have a large impact on the overall evaluation of the technology, in particular the transfer coefficients controlling the amount of heavy metals released to the compost fraction. It is therefore very important to obtain reliable data on transfer coefficients. Information on chemical characterization of all outputs from the technology as well as a precise mass balance is pre-requisite to make good estimates of the transfer coefficients.
- **[Methane content in biogas - % of CH_4]** is an important parameter for anaerobic digestion, as equations for mass balance, carbon balance and VS degradation are based on it. When possible, it is recommended to use values measured at the real plant under assessment.

Beside this, a parameter highly influencing the impact of biological treatments is the content of VS in the waste, because methane production in case of anaerobic digestion and emissions of greenhouse gases in case of composting are directly related to this parameter.

Technical calculations

The main calculations performed in the biological treatment module are shown below. Calculations that are necessary for generating data on the waste fed to the technology are not shown, as these calculations are identical to those specified for the out-put from the preceding technological modules. Most of the equations are working only inside a scenario. Every equation is contained in a summation sign, meaning that the calculation is iterated for each material fraction defined in the waste composition and the results are aggregated. In those equations using an input in tonnes and calculating the result in kilograms, a factor 1000 is used for the conversion.

Equation 1
Amount of total carbon emitted to the atmosphere during the anaerobic digestion (kg):

$$C\_output\_air = Input\_mass \times \sum_{material\ fraction} \left(\frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \frac{VS\_input\_frac}{100} \times \times \frac{\frac{Meth\_yield}{100} \times CH4\_pot}{\frac{CH4\_\%\_biogas}{100} \times Vol\_idealgas} \times Molar\_C \right)$$

Carbon is contained in the biogas in different forms and from there emitted to atmosphere. The assumption is that the carbon degradation (and C-release to the atmosphere) is proportional to the methane yield. Methane yield is a function of the methane potential of the specific fraction and the VS degradation rate.

Multiplication of the upper terms of the fraction calculates the amount of produced methane. Using the content of methane in the biogas (user defined) the whole fraction calculates the amount of carbon contained in the biogas and hence emitted to atmosphere.

Equation 2
Amount of CO_2 emitted to atmosphere from anaerobic digestion (kg):

$$CO2\_output\_air = \frac{Input\_mass \times \sum_{material\ fraction} \left(\frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \frac{VS\_input\_frac}{100} \times \times \frac{Meth\_yield}{100} \times CH4\_pot \right)}{Vol\_idealgas} \times \left(\frac{100}{CH4\_\%\_biogas} - \frac{CH4\_unburned}{100} \right) \times Molar\_CO2$$

As in (Hansen et al., 2006) the assumption is that methane production from anaerobic digestion is proportional to degraded volatile solids (VS). Biogas produced during anaerobic digestion is mainly composed of methane and CO_2. The CO_2 emitted to atmosphere is the sum of the CO_2 contained in biogas and that resulting from combustion of the methane contained in the biogas. The first bracket calculates the amount of methane produced during the anaerobic digestion stage. The first term in the second bracket (multiplied by Molar_CO_2) calculates the amount of CO_2 contained in the biogas, while the second terms calculates the amount of CO_2 produced form the methane combustion.

Equation 3
Amount of CH_4 produced in anaerobic digestion which is not burnt but emitted to the atmosphere (kg):

$$CH4\_output\_air = Input\_mass \times \sum_{material\ fraction} \left(\begin{array}{l} \frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \frac{VS\_input\_frac}{100} \times \\ \times \frac{Meth\_yield}{100} \times CH4\_pot \times \frac{CH4\_unburned}{100} \times \frac{Molar\_CH4}{Vol\_idealgas} \end{array} \right)$$

The methane produced during anaerobic digestion is burnt and hence released to the atmosphere as CO_2. A percentage of it is anyway escaping as fugitive methane loss.
The multiplication of the first 6 terms calculates the amount of methane produced. The second last term accounts for the unburned methane.

Equation 4
Energy content in the methane produced in anaerobic digestion and burned for energy recovery (MJ):

$$Energy\_process = Input\_mass \times \sum_{material\ fraction} \left(\begin{array}{l} \frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \frac{VS\_input\_frac}{100} \times \\ \times \frac{Meth\_yield}{100} \times CH4\_pot \times \left(1 - \frac{CH4\_unburned}{100} \right) \times \\ \times Energy\_CH4 \times \frac{Prod\_eff\_avoid}{100} \end{array} \right)$$

Substitution of an external process due to energy production is defined by a substitution process and a related percentage expressing the efficiency of the energy recovery process. The overall available energy amount is a multiplication of the methane produced by anaerobic digestion (subtracted by the unburned methane) and the specific energy content of methane. The energy substitution is then calculated by multiplying the available energy with the substitution process-related production efficiency. The equation is valid also in the case of combined technology.

Equation 5
Amount of total carbon emitted to the atmosphere during the composting process (kg):

$$C\_output\_air = Input\_mass \times \sum_{material\ fraction} \left(\frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \frac{C\_input\_frac}{100} \times \times \frac{Deg\_rate}{100} \times 1000 \right)$$

The assumption is that carbon degradation (and C-release to the atmosphere) is proportional to both the carbon content in the waste and the VS degradation. The degraded carbon is emitted to the atmosphere in different gaseous forms. Multiplication of the first four terms calculates the amount of carbon contained in the feedstock to the process. The second two terms calculate the amount of VS degraded. The multiplication of all of them gives the amount of carbon emitted to the atmosphere.

Note: the equation is based on total carbon. Ideally, the release of fossil carbon and the impact related to it should be calculated separately. Anyway, this is a very small issue, as material fractions such as organic waste have a relatively small content of C-fossil and, moreover, degradation of C-fossil during the processes under consideration is insignificant.

Equation 6
Amount of CO_2 emitted to atmosphere during the composting process (kg):

$$CO2\_output\_air = C\_output\_air \times \left(\left(1 - \frac{CH4\_degr\_C}{100} \right) + \left(\frac{CH4\_degr\_C}{100} \times \frac{CH4\_clean}{100} \right) \right) \times \times \frac{Molar\_CO2}{Molar\_C}$$

In the composting process CO_2 is produced from degradation of organic matter under aerobic conditions or from degradation of CH_4 (or other volatile organic molecules not included in the model) in the gas cleaner. The first term of the sum contained in the brackets account for CO_2 directly from composting, while the second one accounts for the CO_2 from the gas-cleaning device.

Equation 7
Amount of methane emitted to atmosphere during composting process (kg):

$$CH4\_output\_air = C\_output\_air \times \frac{CH4\_degr\_C}{100} \times \left(1 - \frac{CH4\_clean}{100}\right) \times \frac{Molar\_CH4}{Molar\_C}$$

Composting can result in methane emissions due to transient anaerobic conditions in the compost matrix. The first term of the equation is the total carbon emitted to air and previously calculated. The second term calculates the percentage of the carbon emitted as CH_4. This coefficient is user-defined and might depend on the specifics of the facility. The third term is accounting for the gas cleaning.

Equation 8
Amount of total carbon emitted to the atmosphere from the combined technology (kg):

$$C\_output\_air = Input\_mass \times \sum_{material\ fraction} \left(\begin{array}{l} \frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \\ \times \left(\begin{array}{l} \frac{\frac{VS\_input\_frac}{100} \times \frac{Meth\_yield}{100} \times CH4\_pot}{\frac{CH4\_\%\_biogas}{100} \times Vol\_idealgas} \times Molar\_C + \\ + \frac{C\_input\_frac}{100} \times \frac{Deg\_rate}{100} \times 1000 \end{array} \right) \end{array} \right)$$

The combined plant is the sum of the two technologies: anaerobic digestion and composting. For both types calculations have been previously described. The equation is a sum of two parts: one for the anaerobic digestion and one for composting.

The first term of the sum (in brackets) in the second line is accounting for C contained in the biogas (as product of degradation process), calculated using the methane content in biogas (user defined). The third line is calculating the carbon degraded during composting and emitted to air (in different forms).

Equation 9
Amount of CO_2 emitted to atmosphere from the combined technology (kg):

$$CO2\_output\_air = \sum_{material\_fraction} Input\_mass \times \frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \left(\left[\frac{\frac{VS\_input\_frac}{100} \times \frac{Meth\_yield}{100} \times CH4\_pot}{Vol\_idealgas} \times \left(\frac{100}{CH4\_\%\_biogas} - \frac{CH4\_unburned}{100} \right) \times Molar\_CO2 \right] + \left[\frac{C\_input\_frac}{100} \times \frac{Deg\_rate}{100} \times \left(\left(1 - \frac{CH4\_degr\_C}{100} \right) + \left(\frac{CH4\_degr\_C}{100} \times \frac{CH4\_clean}{100} \right) \right) \times \frac{Molar\_CO2}{Molar\_C} \right] \right)$$

The combined plant is the sum of the two technologies: anaerobic digestion and composting. For both types calculations have been previously described. The equation is a sum of two parts: one for the anaerobic digestion and one for composting. The terms contributing to CO_2 emissions are hence four. The first term of the sum (in brackets) in the third line is accounting for CO_2 contained in biogas, while the second term is calculating the CO_2 emissions from the combustion of methane in biogas (subtracted of the unburned methane).

The fourth line is calculating the CO_2 emissions from composting, as produced from the process in itself and the degradation of CH_4 in the gas cleaning device respectively with the two terms in the sum contained in the round brackets.

Equation 10
Amount of CH_4 emitted to atmosphere from the combined technology (kg):

$$CH4\_output\_air = Input\_mass \times \sum_{material\ fraction} \left[\begin{pmatrix} \frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \frac{VS\_input\_frac}{100} \times \frac{Deg\_rate}{100} \times \\ \times CH4\_pot \times \frac{CH4\_unburned}{100} \times \frac{Molar\_CH4}{Vol\_idealgas} \times 1000 \end{pmatrix} + \\ + \begin{pmatrix} \frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \frac{C\_input\_bio\_frac}{100} \times \frac{Deg\_rate}{100} \times \\ \times \frac{CH4\_degr\_C}{100} \times \frac{Molar\_CH4}{Molar\_C} \times \left(1 - \frac{CH4\_clean}{100}\right) \times 1000 \end{pmatrix} \right]$$

The combined plant is the sum of the two technologies: anaerobic digestion and composting. For both types description on how calculations are performed for the single plant has been previously provided. The equation is a sum of two parts: one for the anaerobic digestion and one for composting. The first term of the sum is accounting for CH_4 contained in biogas and not burned but released to atmosphere, while the second term is calculating the CH_4 produced during the composting process and not removed by the gas cleaning device.

Equation 11
Total N emitted to atmosphere during composting (kg):

$$N\_output\_air = Input\_mass \times \sum_{material\ fraction} \begin{pmatrix} \frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \\ \times \frac{N\_input}{100} \times \frac{Total\_N\_Deg\_rate}{100} \times 1000 \end{pmatrix}$$

The equation is valid also for the combined technology. In that case the input mass is the output from the anaerobic reactor transferred to the composting facility.

The first five terms are calculating the amount of nitrogen contained in the input material. The degradation rate is based on total nitrogen and is user defined. This degradation rate can be estimated with a nitrogen balance on the plant.
The nitrogen is then released to atmosphere in different forms. The amounts of ammonia and nitrous oxide emitted are calculated according to the next equations. In each of them, the second term is user defined as the percentage of degraded N emitted in the specific form. The last term accounts for the gas cleaning device.

$$NH3\_output\_air = N\_output\_air \times \frac{NH3\_degr\_N}{100} \times \frac{Molar\_NH3}{Molar\_N} \times \left(1 - \frac{NH3\_clean}{100}\right)$$

$$N2O\_output\_air = N\_output\_air \times \frac{N2O\_degr\_N}{100} \times \frac{Molar\_N2O}{Molar\_N2} \times \left(1 - \frac{N2O\_clean}{100}\right)$$

Equation 12

Amount of outputs from anaerobic digestion (tonnes in ww):

$$Output\_mass = \frac{Input\_mass * \sum_{material\ fraction} \left(\frac{Input\_frac}{100} * \frac{TS\_input\_frac}{100} * \left(\frac{Ash\_input\_frac}{100} + \frac{VS\_input\_frac}{100} * \left(1 - \frac{\frac{Meth\_yield}{100} * CH4\_pot}{\frac{CH4\_\%\_biogas}{100} * Vol\_ideal\_gas} * \frac{Molar\_C}{1000} * 1.89\right)\right) * \frac{Subs\_output\_TFC\_frac}{100}\right)}{\frac{Output\_TS}{100}}$$

It is assumed that degradation of VS is proportional to the carbon degradation.
Using the total solids (TS), the equation is calculating the output from the process. TS in the input material are calculated with multiplication of the first three terms. The sum in the internal square brackets is accounting for the ash content (which is not degraded) and the amount of VS contained in the output after degradation has taken place. The multiplication of 1.89 is the TS loss per kg CH4 formation. The last term is accounting for the distribution of TS among different outputs. The denominator is converting from total solid (TS) to wet weight. The total solid content is user defined.

Equation 13
Amount of outputs from composting (kg in ww):

$$Output\_mass = \frac{Input\_mass \times \sum_{material\ fraction} \left(\frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \left(\frac{Ash\_input\_frac}{100} + \left(\frac{100\text{-}Deg\_rate}{100}\right) \times \frac{VS\_input\_frac}{100} \right) \times \frac{Subs\_output\_TFC\_frac}{100} \right)}{\frac{Output\_TS}{100}}$$

Using the total solids (TS), the equation is calculating the output from the process. TS in the input material are calculated with multiplication of the first three terms. The sum in the internal brackets is accounting for the ash content (which is not degraded) and the amount of VS contained in the output after degradation has taken place. The last term is accounting for the distribution of TS among different outputs. The denominator is converting from total solid (TS) to wet weight. The total solid content is user defined.

Equation 14
Amount of outputs from combined technology (tonnes in ww):

$$Output\_mass = \frac{Input\_mass * \sum_{material\ fraction} * \left(\frac{Input\_frac}{100} * \frac{TS\_input\_frac}{100} * \left(\frac{Ash\_input\_frac}{100} + \frac{VS\_input\_frac}{100} \left(1 - \frac{\frac{Meth\_yield}{100} * CH4\_pot}{\frac{CH4\_\%\_biogas}{100} * Vol\_ideal\_gas} * \frac{Molar\_C}{1000} * 1.89 - \frac{Deg\_rate}{100}\right)\right) * \frac{Subs\_output\_TFC\_frac}{100}\right)}{\frac{Output\_TS}{100}}$$

Using the total solids (TS), the equation is calculating the output from the process. TS in the input material are calculated with multiplication of the first three terms. The sum in the internal square brackets is accounting for the ash content (which is not degraded) and the amount of VS contained in the output after degradation has taken place, after both anaerobic digestion and composting. The multiplication of 1.89 is the TS loss per kg CH4 formation. The last term is accounting for the distribution of TS among different outputs. The denominator is converting from total solid (TS) to wet weight. The total solid content is user defined.

Equation 15
Amount of nitrogen in the output from composting or combined technology (kg):

$$N\_output = Input\_mass \times \sum_{material\ fraction} \left(\frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \frac{N\_input}{100} \times \frac{100\text{-}Total\_N\_deg\_rate}{100} \times \frac{Subs\_output\_TFC\_frac}{100} \times 1000 \right)$$

The calculation of the output composition is presented here. For biological treatments degradation depends on the considered compound (some compounds such as heavy metals are not degraded at all) and the process (aerobic-anaerobic, etc). Therefore, it is not possible to calculate the composition of the outputs from the treatments with a single equation.

The equation calculates the amount of nitrogen not lost during the process and still contained in the output material from a composting plant or a combined technology. The first four terms calculate the total nitrogen in the input. The fifth term accounts for the nitrogen not degraded. The second last term is accounting for the distribution of TS among different outputs.

Equation 16
Amount of nitrogen in the output from anaerobic digestion (kg):

$$N\_output = Input\_mass \times \sum_{material\ fraction} \left(\frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \frac{N\_input}{100} \times \frac{Subs\_output\_TFC\_frac}{100} \times 1000 \right)$$

The equation calculates the amount of nitrogen contained in the output material from an anaerobic digestion plant. The assumption is that no nitrogen is lost during the process. The first four terms calculate the total nitrogen in the input. The second last term is accounting for the distribution of TS among different outputs.

Equation 17
Amount of biological carbon in the output from anaerobic digestion (kg):

$$C\_output\_bio = Input\_mass \times \sum_{material\ fraction} \left(\begin{array}{l} \frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \\ \times \left(\begin{array}{l} \frac{C\_input\_bio\_frac}{100} - \\ - \frac{\frac{VS\_input\_frac}{100} \times \frac{Meth\_yield}{100} \times CH4\_pot}{\frac{CH4\_\%\_biogas}{100} \times Vol\_idealgas} \times \frac{Molar\_C}{1000} \end{array} \right) \times \\ \times \frac{Subs\_output\_TFC\_frac}{100} \times 1000 \end{array} \right)$$

The equation calculates the amount of biological carbon not degraded during the process and still contained in the output material from anaerobic digestion treatment. The first three terms calculate the total solids in the input. The internal brackets calculate the remaining carbon as difference between the input carbon and the degraded one. The second last term is accounting for the distribution of TS among different outputs.

Equation 18
Amount of biological carbon in the output from composting (kg):

$$C\_output\_bio = Input\_mass \times \sum_{material\ fraction} \left(\begin{array}{l} \frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \frac{C\_input\_bio\_frac}{100} \times \\ \times \left(1 - \frac{Deg\_rate}{100} \times \frac{C\_input\_frac}{C\_input\_bio\_frac} \right) \times \\ \times \frac{Subs\_output\_TFC\_frac}{100} \times 1000 \end{array} \right)$$

The equation calculates the amount of biological carbon not degraded during the process and still contained in the output material from composting treatment. The first three terms calculate the biological carbon in the input. The internal brackets calculate the remaining carbon as difference between the input carbon and the degraded one. The second last term is accounting for the distribution of TS among different outputs.

Equation 19
Amount of biological carbon in the output from the combined technology (kg):

$$C\_output\_bio = Input\_mass \times \sum_{material\ fraction} \left(\begin{array}{l} \frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \\ \times \left(\begin{array}{l} \frac{C\_input\_bio\_frac}{100} \times \left(1 - \frac{Deg\_rate}{100} \times \frac{C\_input\_frac}{C\_input\_bio\_frac}\right) - \\ - \frac{\frac{VS\_input\_frac}{100} \times \frac{Meth\_yield}{100} \times CH4\_pot}{\frac{CH4\_\%\_biogas}{100} \times Vol\_idealgas} \times \frac{Molar\_C}{1000} \end{array} \right) \times \\ \times \frac{Subs\_output\_TFC\_frac}{100} \times 1000 \end{array} \right)$$

The equation calculates the amount of biological carbon not degraded during the process and still contained in the output material from the combined treatment. The two terms in the first line calculate the total solids in the input. The internal brackets calculate the remaining carbon as difference between the input carbon, carbon degraded in the anaerobic stage and carbon degraded in the composting process. The second last term is accounting for the distribution of TS among different outputs.

Equation 20
Amount of fossil carbon in the output from a biological treatment (kg):

$$C\_output\_fossil = Input\_mass \times \sum_{material\ fraction} \left(\begin{array}{l} \frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \frac{C\_input\_fossil\_frac}{100} \times \\ \times \frac{Subs\_output\_TFC\_frac}{100} \times 1000 \end{array} \right)$$

The equation calculates the amount of fossil carbon contained in the output material from a biological treatment. The assumption is that no fossil carbon is degraded during the process. The first four terms calculate the total nitrogen in the input. The second last term is accounting for the distribution of TS among different outputs.

Equation 21
Amount of any substance except C an N in the output from a biological treatment (kg):

$$Subs\_output = Input\_mass \times \sum_{material\ fraction} \left(\begin{array}{l} \frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \frac{Sub\_input\_frac}{100} \times \\ \times \frac{Subs\_output\_TFC\_frac}{100} \times 1000 \end{array} \right)$$

The equation calculates the amount of substances contained in the output material from a biological treatment, which are not undergoing any degradation (e.g.: heavy metals). The first four terms calculate the amount of a specific substance in the input. The second last term is accounting for the distribution of TS among different outputs.

Equation 22
Total amount of carbon in the output from a biological treatment (kg):

$$C\_output\_total = C\_output\_bio + C\_output\_fossil$$

It is calculated as sum of biogenic and fossil carbon.

Equation 23
The chemical composition of the produced outputs in the technology is the sum of all the substance concentrations in the output. The word output could be changed to any output name.

$$Output\_subs = \frac{Subs\_output}{Output\_mass}$$

The chemical composition of one of the outputs can be seen right-clicking on the output line (any point) and choosing **[Output Composition]** from the list of options; a new table with the chemical composition of the output will then pop-up.

Equation 24
The LCI calculation is the sum of process specific emissions, the LCI of external processes used and substitution of external processes. The overall equation is:

$$LCI = \left(Input\_mass \times \sum_{Emissions} \overline{Specific\_emis} \right) + \left(Input\_mass \times \sum_{processes} \left(Process\_amount \times \overline{Ext\_LCI} \right) \right) + \\ + \sum_{Substances} \left(\sum_{compartment} \left(\overline{Subs\_output\_comp} \right) \right) - \sum_{Processes} \left(Process\_avoid \times \overline{Ext\_LCI} \right) \\ - \left(avoid\_mass \times \sum_{Emissions} \overline{Specific\_emis} \right)$$

The LCI for biological treatment includes emissions to air, soil or water related to the waste input (e.g, emissions to air of SO_2 and NO_x in anaerobic digestion) described in the first bracket in the LCI equation. The use of materials or energy (e.g. diesel or electricity for the machineries) is added to the LCI with the emissions related in the second bracket. If any waste specific emissions are present in form of a transfer coefficient (e.g. CH_4 or N_2O to air related to C and N content in the waste) the related emission is added to the LCI in the third bracket. Emissions to air related directly to the waste input of a substance are those calculated in equations 2, 3, 5, 6, 7, 8, 9. Any products that substitute a process (e.g. heat and power production from biogas) are subtracted from the LCI with regards to the avoided emissions in the fourth bracket. The last bracket accounts for output substituting other materials (e.g. compost replacing peat or commercial fertilizers utilization). For further description of the equation see the document on LCI.

Economic calculations

Not yet available

Variables and Constants

Constants

Energy_CH4	Energy content of methane (37 MJ/STPm^3)
Molar_C	Molar weight of carbon (12.01 g/mole)
Molar_CH4	Molar weight of methane (16.042 g/mole)
Molar_CO2	Molar weight of carbon dioxide (44.01 g/mole)
Molar_N	Molar weight of nitrogen (14.01 g/mole)
Molar_N2	Molar weight of molecular nitrogen (28.02 g/mole)
Molar_N2O	Molar weight of nitrous oxide (44.02 g/mole)
Molar_NH3	Molar weight of ammonia (17.03 g/mole)
Vol_idealgas	Ideal volume of 1 mole of gas (22,414 l at 273,15 K)

Variables

Ash_input_frac	Percent Ash in TS in a material fraction (%)
C_input_bio_frac	Biological carbon as a percent of TS (%)
C_input_fossil_frac	Fossil carbon as a percent of TS (%)
C_input_frac	Total carbon as a percent of TS (%)
C_output_air	Amount of carbon emitted to air (kg)
C_output_bio	Amount of biological carbon in the output from a technology (kg)
C_output_fossil	Amount of fossil carbon in the output from a technology (kg)
C_output_total	Amount of total carbon in the output from a treatment (kg)
CH4_%_biogas	Methane content in biogas (%)
CH4_clean	CH_4 removal efficiency in gas cleaning device (%)
CH4_degr_C	Percent of the emitted C in CH_4 form (%)
CH4_output_air	Amount of CH_4 emitted to air (kg)
CH4_pot	Experimentally determined maximum methane potential relative to the content of organic matter (VS) in the sample at the beginning of the experiment
CH4_unburned	Percent of CH_4 not burned and lost to atmosphere (%)
CO2_output_air	Amount of CO_2 emitted to air (kg)
Deg_rate	Percent of total VS in waste degraded in the composting process (%)
Energy_process	The energy amount that substitute a given external process (MJ or kWh)
Ext_LCI	LCI table of a external process (unit/tonne)
Input_frac	Percent of each material fraction in generated waste (%)

9 Energy Utilization

Document updated November 28, 2007 by THF. Original document prepared by THF and AND and controlled by THC.

The module represents the utilization for energy purposes outside the waste management system of products or waste fractions with a high calorific content. This could be refuse-derived fuel (RDF) from a material recycling facility (MRF) used in a power plant or a cement kiln, landfill gas converted to fuel for vehicles, or ethanol produced in a biotechnological waste treatment facility and sold on the market. RDF is in this documentation paper used as general term for all incoming waste fractions to this module. The module typically handles products sold on a market and utilized by a general technology rather than on a specific plant. All emissions counted are general, process-specific emissions and do as such not represent the detailed chemical composition of the waste. The database for a certain type of technology may contain several datasets representing different performance levels (e.g. low quality RDF from a mechanical-biological treatment (MBT) plant used in a cement kiln with limited flue gas cleaning). The energy produced is quantified as a percentage of the lower heating value of the RDF. The type of energy production avoided as a consequence of the energy utilization obtained in the module must be specified to provide crediting of saved emissions and resource use. The module neglects any environmental aspects from residues from the conversion of the energy containing material, i.e. solid outputs like for example bottom ash cannot be further routed.

Approach

Each energy utilization module represents a full plant, including the technology of the plant and the operation of the plant, or a general technology if the utilization is distributed among many units. An example of the former could be a specific cement kiln. The latter can be exemplified by upgraded landfill gas used as car fuel.

The module employs process-specific material and energy use as well as process-specific emissions. The material and energy use is relevant if further upgrading of the input takes place before the actual energy utilization, if significant amounts of energy are used in the up-start, and if additional materials are added in order to limit emissions. Process-specific emissions are categorized according to the receiving compartment (air, surface water, soil, etc.). The emissions are thus the overall emissions representing the quality of the incoming RDF as well as the quality of the plant or technology utilizing the energy content in the RDF.

The module uses the lower energy content of the RDF or a value defined by the user, and a user-specified percentage energy recovery (percentage of calorific content in RDF) to calculate the electricity, heat, gas or fuel utilization. The user must specify the avoided energy production or use in order to obtain the credits for savings in resource consumption and emissions. The energy recovery is the gross energy recovery, since the plant’s own use of energy is accounted for in the tables on material and energy use.

Literature

No specific literature

User instruction

A new dataset is established by:

1. Choose **[Waste Management]** → **[Technologies]** → **[Energy Utilization]**. Right click in the main window and press **[New],** or choose the "blank page" button to create a new technology. A new technology window will open. Name the technology according to type of RDF, utilization technology, substituted energy and year.
2. Define an **[Amount]** in tonnes. This is as default set to 1 tonne as it will be multiplied with the incoming material in tonnes when used in a scenario.
3. Define an **[Input Type].** It can either be *User Defined* or *Waste Related*. *User Defined* is chosen if the user wants to define the lower heating value of the incoming material himself. *Waste Related* is chosen if the incoming material from a previous module is routed to the *Energy Utilization* module.
4. **[Input – Material and Energy]** is used to list materials and energy that are consumed in the processing and the utilization of the material. These processes are chosen from the list of external processes, and if an existing external process does not cover the needed input, it is necessary to create a new external process. See the External Process feature for more information. The materials included under **[Input – material and energy]** are all LCI's and therefore have an associated set of emissions which will be included in the LCI for the utilization process.
5. **[Output – Material and Energy]** is used to list the energy process(es) substituted by the energy recovered in the energy utilization process. The substituted process is chosen from the external processes. **[Amount]** shows the percentage of the energy in the RDF being substituted. The sum of all **[Amounts]** corresponds to the total energy efficiency of the plant.
6. **[Input – Resources and Raw Materials]** is used to list materials that are used in the process but are not contributing to any significant emissions during their extraction, production, transport and consummation. These materials are only accounted as resource use.
7. **[Output – *Compartment*]** is used to list the direct process specific emissions valid for the actual combination of RDF and energy utilization technology to various environmental compartments (kg/tonne of wet waste).

Data requirements

Collection of data for creating a new energy utilization technology should focus on the following parameters:

- The **[Substitution Process]** chosen among the external processes must closely correspond to the actual utilization process. For electricity and heat production this is trivial, but for utilization as fuels much less data is available.
- The **[Output – *Compartment*]** must closely reflect the emissions related to the conversion of the actual RDF in the actual energy utilization process.

Technical calculations

Equation 1

Lower heating value (LHV) of the RDF received in the energy utilization module (GJ/tonne ww). LHV is calculated on basis of each material fraction received:

$$LHV = \sum_{Frac} (Heat\_input\_frac * \frac{TS\_input\_frac}{100} - H2O\_constant * \frac{H2O\_input\_frac}{100})$$

LHV of the received RDF is based on the wet weight of the source separated waste and the available energy of the wet waste, calculated in the second bracket. Multiplication of the heating value of TS in the source separated fraction by the TS amount followed by subtracting the energy needed to evaporate the water content gives the available energy of the wet waste. The sum of the energy contributions of all fractions equals the LHV of the received waste.

Equation 2

The total energy amount produced (GJ) and substituting an external process:

$$Energy\_process = Input\_mass * LHV * \frac{Prod\_eff\_process}{100}$$

Substitution of an external process due to LHV of received RDF is based on the available energy amount and a substitution percentage. The available energy amount is LHV times input mass. The substituted energy is then calculated by multiplying the available energy with the percentage of energy being recovered in the RDF.

Equation 3

LCI calculations are the sum of process specific and input specific emissions, LCI of external processes and substitution of external processes and the overall equation looks like this:

$$LCI = \left(Input\_mass * \sum_{Emissions} \overline{Specific\_emis} \right) + \left(Input\_mass * \sum_{Processes} \left(Process\_amount * \overline{Ext\_LCI} \right) \right) - \sum_{Processes} \left(Energy\_process * \overline{Ext\_LCI} \right)$$

The LCI for energy utilization includes emissions to air, water or soil related to the quality of the RDF or the quality of the technology utilizing the energy content of the RDF (first bracket in the LCI equation). The use of materials or energy is added to the LCI with the related emissions in the second bracket. Substitution of an external process with regard to avoided emissions and resources is subtracted the LCI in the third bracket.

Economic calculations

Not yet available.

Variables

Energy_process	The energy amount that substitutes an given external process (MJ or kWh)
Ext_LCI	LCI table of a external process (unit/tonne)
H2O_constant	Evaporation heating constant for H_2O at 25^{o}C (2.435 MJ/kg)
H2O_input_frac	Percent of H_2O per wet material fraction (%)
Heat_input_frac	Heating value for the specific waste fraction (GJ/tonne TS)
Input_mass	Input of wet mass to the technology (tonne ww)
LCI_tech	LCI table of an technology (unit/tonne ww)
LHV	Lower Heating Value in wet input waste (GJ/tonne ww)
Material_frac	Percent of each material fraction in generated waste (%)
Process_amount	Amount of a material, raw material or energy (tonne)
Prod_eff_process	Percent of input that substitutes a given external process (%)
Sorting_frac	Percent of a material fraction sorted at source (%)
Specific_emis	Emission specified for the process related only to the waste amount (kg/tonne ww)
TS_input_frac	Percent of total solids (TS) in wet material fraction (%)

Input_mass	Input of wet waste to the technology (tonne ww)
Material_amount	Mass of an input or raw material routed to the output (tonne)
Meth_yield	Methane yield (fraction of the methane potential developed) (%)
N_input	Nitrogen as a percent of TS (%)
N_output	Amount of nitrogen in the output from a technology (kg)
N_output_air	Amount of nitrogen emitted to air (kg)
N2O_clean	N_2O removal efficiency in gas cleaning device (%)
N2O_degr_N	Percent of the emitted N in N_2O form (%)
N2O_output_air	Amount of nitrous oxide emitted to air (kg)
NH3_clean	NH_3 removal efficiency in gas cleaning device (%)
NH3_degr_N	Percent of the emitted N in NH_3 form (%)
NH3_output_air	Amount of ammonia emitted to air (kg)
Output_mass	Wet output mass from a technology (kg)
Output_subs	Table of chemical composition of an output from a technology (g/tonne)
Output_TS	User defined TS in percent for an output (%)
Prod_eff_avoid	Percent of an input that substitutes a given external process (%)
Subs_input_frac	Percent substance in TS in a material fraction (%)
Subs_output	Substance amount in an output (tonne)
Subs_output_TFC_frac	Transfer coefficient in percent for a substance to a given output from technology for a material fraction (%)
Total_N_deg_rate	Percent of Total-N degraded in the process (%)
TS_input_frac	Percent of TS in wet material fraction (%)
VS_input_frac	Volatile solids (VS) as a percent of total solids (%)

10 Landfill: Mixed waste

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The module represents landfilling of mixed waste containing organic matter in a conventional landfill or a landfill designed and operated as a bioreactor, a flushing bioreactor or a semi-aerobic reactor landfill. The module can also be used to represent a landfill for mechanically-biologically pretreated waste. If the landfilled waste contains no organic matter and the gas production is therefore marginal, then the technology “Landfill: Mineral Waste” should be used. The module addresses landfill gas as well as leachate. The module may also account for any use of soil or flexible membranes for lining and energy used for earth works, operation etc. The amount and composition of gas and leachate as well as the efficiencies of technical measures (liners, gas collection, etc.) can be set for four time periods defined individually for each factor. The sum of periods in years represents the full life time of the landfill considered in the inventory and thus the time horizon of the life-cycle-impact-assessment. All emissions are counted equally, regardless of the moment they occur within the defined time period. A mass balance calculates the amount of toxic elements in terms of heavy metals left in the landfill at the end of the considered time horizon. The module accounts for gas generation, gas utilization (credits calculated for energy savings), gas flaring and gas oxidation in landfill covers. The module accounts for leachate generation, leachate entering into treatment plant as well as leachate migrating into surface water and groundwater.

Approach

Each landfill dataset represents a full plant, including the technology of the plant and the operation of the plant. If supplementary technologies, e.g. additional leachate treatment are needed, this can only be modeled by establishing a new dataset where the considered add-on-technology is an integral part of the dataset.

The landfill module is based on two key assumptions:

- the amount of gas generated in the landfill is directly related to the methane potential in the waste landfilled, while the composition of the gas (methane as well as trace gasses) is set at typical values within each period
- the amount of leachate generated is set as typical values (mm/year) representing the hydrological conditions (precipitation, evapotranspiration, run-off, etc.) at the site and the composition of leachate (main constituents as well as trace components) is set as typical values within each period. This means that the leachate composition is not directly related to the waste composition

The module employs process specific (mass or energy per ton of waste landfilled) material and energy use as well as process specific emissions. Process specific emissions are categorized according to the receiving compartment (air, surface/marine/ground-water, soil). Input specific emissions are not employed since emissions to the various environmental compartments depend principally on the way the landfill is designed and operated (conventional, bioreactor, etc.) rather than the quality of waste landfilled. If the receiving waste to the landfill to a great extent deviate from an average waste composition this should be described in detail in both the name of the landfill and in the documentation.

Handling of landfill gas is structured in two sets of independent time periods. The first set of time periods is assumed to address gas generation, composition and oxidation in soil top cover. The second set of time periods addresses gas collection and treatment. Durations of time periods and selected values for parameters within each time period are independent.

The chief parameter defining the gas generation is the fraction of the total methane potential in waste landfilled that is actually generated within each time period. The choice of this fraction within each time period and the length of the time period should reflect the specific way the landfill is operated. For a time period representing for instance the methanogenic stage of degradation, both duration of the time period and methane generation within the period (in term of fraction of methane potential in waste) should be set differently for a conventional landfill, a flushing landfill or another technology. Likewise, the time period subdivision considered for the gas collection depends on parameters that are strictly technology-specific, such as duration of the collection stage, way of disposing or treating the collected gas and emissions from the considered treatments.

An option for the utilization of the collected gas is to send it to an energy recovery facility. The model includes the options power plant and combined heat and power plant. The purpose is to exploit the energy content of the gas (mainly due the methane fraction) by producing electricity (power plant) or electricity and heat as a co-product (combined heat and power plant). The efficiency of the energy recovery is defined as the fraction of the total energy content in the gas that is actually recovered to produce electricity and/or heat, and it has to be specified by the user. The user must also specify the avoided energy production in order to obtain the credits for saving in resource use and emissions. In a life cycle perspective this leads to avoided impact to the environment. The energy recovery is the gross energy recovery, since the plant's own use of energy is accounted for in the tables on material and energy input. As the other gas utilization options, the energy recovery facilities provide treatment to the gas and the removal efficiencies of the gas constituents have to be specified by the user. For each treatment option a specific set of emission can be specified by the user.

Handling of landfill leachate is structured in three sets of independent time periods. These address leachate generation, leachate composition and leachate collection, respectively. The amount of leachate generated in time periods has to be specified by the user and does not only depend on the annual precipitation. In fact, amongst the various technical and environmental factors influencing leachate generation, the user should also consider the effect of the final soil cover in limiting the actual rain-water infiltration to the waste body. The composition of the generated leachate, defined by the user, should reflect the evolution of the waste degradation process. Leachate composition can be specified not only in terms of for instance BOD, COD, ammonia, salts, etc, but also in terms of heavy metal, organic and trace organic contents.

The subdivision in time periods for leachate collection should reflect the operational and post-closure stages of the considered landfill. Leachate collection efficiencies in time periods should reflect the technical measures adopted in each stage. Uncollected leachate is considered to reach the groundwater as it is or, eventually, somewhat purified because natural attenuation processes have occurred. Cleaning efficiencies of leachate constituents due to natural attenuation are user-defined. Collected leachate can either be discharged to soil, or sent to a plant for treatment, or any combination of the two options. Cleaning efficiencies achieved in the treatment plant have to be specified by the user for all constituents considered in the leachate composition. Emissions of treated leachate can be diverted to both surface water and marine water bodies in a proportion that is user defined.

In the impact category stored ecotoxicity, the model keeps account of how much is left of each toxic substance in the waste at the end of the time horizon and ascribes each substance the characterization factor for ecotoxicity to water and to soil, 50% to each. This inherently assumes that, in the long run, half of the toxic substances end up in the water compartment and the other half in the soil compartment. This is a somewhat arbitrary choice, but the intention of the stored toxicity is to represent the potential ecotoxicity of what is left in the landfill after the time horizon, were it to be released, perhaps abruptly due to later geological events or as slow leaching.

An overview of the flows of landfill gas and leachate in the specified time period is provided in the model by pressing the **[Gas & Leachate]** button. This brings the user to a table that gives the flows throughout the defined LCA time horizon. The first icon of the table, **[Gas Generation, Collection & Utilization]**, quantifies the volumetric flows of gas; the second icon **[Leachate Generation & Collection]** quantifies the volumetric flows of leachate; the third icon **[Gas, Leachate Composition & Treatment]** estimates the mass flows of each compound in the landfill gas and leachate.

Literature

Kirkeby, J.T., Birgisdóttir, H., Bhander, G.S., Hauschild, M.Z. & Christensen, T.H. (2007): Modeling of environmental impacts of solid waste landfilling in a life cycle perspective (EASEWASTE). *Waste Management*, (Accepted).

Hansen, E., Olsen, S.I., Schmidt, A., Hauschild, M., Hjelmar, O., Bendtsen, N., Poulsen, T.S., Hansen, H.H., Christensen, K. (2004); Life cycle assessment of landfilled waste (in Danish). Environmental project no. 971, Danish Environmental Protection Agency, Copenhagen, Denmark

User instructions

A new dataset is established by:

1. Select **[Waste Management]** → **[Technologies]** → **[Landfill Mixed Waste]** in the left window pane of the screen.
2. **[Leachate Substance]** in the bottom right pane of the screen is used to select the substances present in the landfill leachate and the compartments (fresh water, marine water and groundwater) receiving the emission of each substance.
3. Give the technology a **[name]**. In the EASEWASTE database Mixed Waste Landfills are named according to: Type, name of the landfill (if any), geographical area, country and year. The year refers to when the main data behind the technology were collected, e.g. "Conventional landfill with energy recovery, Faxe, DK, 2006". Save the technology before entering further data.
4. Once the **[Landfill Mixed Waste]** has been selected the button **[Leachate Substance]** appears in the bottom of the screen. It allows entering a table listing all the leachate constituents. From the table, the water-compartments that leachate constituents are potentially allowed to reach are selected. Additional leachate constituents can be added to the table, heavy metals does not need to be added as they will figure under **[General Leachate Substances]** which is substances set up in the chemical composition of the waste.
5. The amount of waste landfilled (in tonne of wet waste) can be defined in **[Amount]** and the methane potential in this amount can be specified in **[CH4 Potential]**. This

only works outside a scenario – inside a scenario these values are calculated by the program.

6. All the inputs to the landfill needed throughout the time horizon of the assessment are defined in **[Material and Energy Inputs]**. They are specified in term of amount of input-material (mass or volume) per tonne of waste landfilled. Furthermore inputs for energy used for soil and clay movement can be selected **[General Input]**.
7. Time periods for gas generation are defined in term of duration (years) and characterized in term of percentage of the gas potential in landfill which is actually generated within each time period **[Gas Generation].**
8. Time periods for collection of the generated gas are defined **[Gas Collection]**. Duration of each time period and correlated percentages of generated gas collected are specified.
9. Each flow of collected gas is diverted to the available treatment technologies **[Treatment Technology for Collected Gas]**. The distribution of each flow to the treatment technologies is defined.
10. The **[Gas Specific Info]** buttom at the bottom of the screen is used to complete the definition of the gas quality and utilization. Information and data are divided into three categories, which are accessible from the icons **[Gas Composition & Oxidation]**, **[Gas Removal Efficiencies]** and **[Gas Treatment]**.
11. **[Gas Composition & Oxidation]** is used to define in detail the composition of the generated gas and the efficiencies of the oxidation of each component that the final soil cover provides. The time periods this information refers to are those defined in the gas generation table.
12. **[Gas Removal Efficiencies]** is used to specify the removal efficiencies of the gas constituents.
13. **[Gas Treatment]** is used to characterize the gas utilization technologies. In the upper table the efficiency of the energy recovery process is specified and the avoided energy production facility is selected. In the lower table the emissions to air which the gas treatment technologies lead to are specified in term of emitted mass of substance per unit-volume of methane processed.
14. Back to the main window the time periods for leachate generation are defined and the relative amount of leachate produced is specified **[Leachate Generation]**.
15. Time periods for leachate collection are defined and the collection efficiencies are specified for each time period **[Leachate Collection]**. The percentages of collected leachate diverted to the treatment plant or discharged to soil without treatment are specified **[Treatment and Discharge of Leachate]**
16. The **[Leachate Composition]** button at the bottom of the screen is used to define time periods for leachate concentration. Substance in leachate are categorized into two groups, accessible from the icons **[Input General Leachate Substances]** and **[Input Additional Leachate Substances]**. Emission of leachate occurring beyond the time frame of the assessment are distributed among surface water bodies and soil **[Stored Emission Distribution %]**.
17. Back to the main window, the button **[Leachate Attenuation]** at the bottom of the screen is used to specify attenuation efficiencies for components of uncollected leachate due to natural processes.

18. The button **[Leachate Treatment]** at the bottom of the main window is used to define the activity of the treatment plant in cleaning the processed leachate. Energy consumptions needed for the treatment is specified in term of electricity consumption per unit volume of leachate processed **[WWTP Energy Consumption]**. Removal efficiencies of substances in leachate and distribution of emission of treated leachate to fresh or marine water are defined for each substance **[WWTP Removal Efficiencies]**.

Data requirements

When collecting data for creating a new landfill technology for mixed waste there are a number of crucial parameters:

- **[CH4 Potential]** in the waste landfilled has a large impact on the overall evaluation of the technology. The model in fact calculates the overall amount of gas generated and show it as this number. It is therefore very important to obtain reliable data on methane potential in the waste. Chemical characterization of landfilled waste is the information needed to estimate the methane potential.
- **[% of Gas Generation Collected]** and **[% of Leachate Generation Collected]** are crucial parameters for the results of the assessment. They control the amount of fugitive gaseous and liquid emission to the environment, which are decisive to the impact assessment. A precise estimation of the efficiencies of gas and leachate collection systems is therefore needed.
- **[Gas Treatment – Energy recovery]** is also very important. Both in terms of the percent of energy recovered and in terms of the type of energy recovered. It has a large impact whether the substituted energy is based on coal, gas or an energy mix. The choice of a substitution process for the electricity production might often be based on regional consensus on which process is substituted, since electricity often is fed into a transnational grid. Selecting a substitution process for heat production delivered to a local district heating grid requires detailed information on the alternate production processes in the distribution net. In some cases a process representing the local heat substitution will not be present in the database and specific information must be gathered and a new process must be entered in the database for external processes.
- **[Inputs – Material and Energy Input]** might be important, if materials with a high environmental production load or long transportation distance are used.

Technical calculations

The main calculations performed in the mixed waste landfill module are shown below. Calculations that are necessary for generating data on the waste fed to the technology are not shown, as these calculations are identical to those specified for the output from the preceding technological modules.

Equation 1
Overall methane potential in the landfilled waste, based on the methane potentials of the single input fractions (m^3 of methane):

$$Tot\_CH4\_pot = Input\_mass \times \frac{\sum_{\substack{material\\fraction}} \left(\frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \frac{VS\_input\_frac}{100} \times CH4\_pot \right)}{\sum_{\substack{material\\fraction}} \frac{Input\_frac}{100}}$$

The summation includes all the fractions constituting the waste composition. The first bracket within the summation is the mass part of a fraction which is multiplied with the fraction of TS, the fraction of VS and with the methane potential of the fraction.

Equation 2
Overall amount of gas generated throughout the time horizon of the assessment (m^3 of landfill gas):

$$Tot\_gas\_gen = \frac{Tot\_CH4\_pot}{\frac{\sum_{i=1}^{i=4} \left(\frac{Gas\_gen\_tpi}{100} * \frac{CH4\_tpi}{100} \right)}{\sum_{i=1}^{i=4} \frac{Gas\_gen\_tp_i}{100}}}$$

The calculation of the total amount of gas generated is based on the overall amount of methane generated. The summation represents the relative importance of the overall emission of gas compared to the emission of methane.

Equation 3
Overall amount of methane generated throughout the time horizon of the assessment (m^3 of methane):

$$Tot\_CH4\_gen = Tot\_gas\_gen \times \sum_{i=1}^{i=4} \left(\frac{Gas\_gen\_tp_i}{100} \times \frac{CH4\_tp_i}{100} \right)$$

The summation refers to the overall assessment time horizon, which is divided into four time periods (tp_i, i=1, 2, 3, 4). The summation represents total fraction of the gas potential that is actually generated throughout the time horizon of the assessment.

Equation 4
Overall amount of gas collected throughout the time horizon of the assessment (m^3 of landfill gas):

$$Tot\_gas\_coll = Tot\_gas\_gen \times \sum_{i=1}^{i=4} \left(\frac{Gas\_gen\_tp_i}{100} \times \frac{Gas\_coll\_tp_i}{100} \right)$$

The total volume of gas collected is given by the total gas generation multiplied with the summation of the fractions of the generated gas that are actually collected for all time periods.

Equation 5

Overall amount of methane collected throughout the time horizon of the assessment (m^3 of methane):

$$Tot\_CH4\_coll = Tot\_CH4\_gen \times \sum_{i=1}^{i=4}\left(\frac{Gas\_gen\_tp_i}{100} \times \frac{Gas\_coll\_tp_i}{100}\right)$$

The total volume of methane collected is given by the total methane generation multiplied with the summation of the fractions of the generated gas that are actually collected for all time periods

Equation 6
Total amount of gas diverted to a treatment facility throughout the time horizon of the assessment (m^3 of gas). Flare is used as an example:

$$Tot\_gas\_flare = Tot\_gas\_gen \times \sum_{i=1}^{i=4}\left(\frac{Gas\_gen\_tp_i}{100} \times \frac{Gas\_coll\_tp_i}{100} \times \frac{Gas\_flare\_tp_i}{100}\right)$$

The total volume of gas diverted to treatment on flares is given by the total volume of gas generated multiplied with a coefficient that includes, for all time periods, specific gas generation, efficiency of the collection system of fraction of the collected gas diverted to flares facility.

Equation 7
Overall amount of methane emitted to the atmosphere throughout the time horizon of the assessment (m^3 of methane). As example, the collected gas is sent to treatment in flares:

$$Tot\_CH4\_air = Tot\_CH4\_gen \times \sum_{i=1}^{i=4}\left(\frac{Gas\_gen\_tp_i}{100} \times \left(\begin{array}{l}\frac{Gas\_coll\_tp_i}{100} \times \frac{Gas\_flare\_tp_i}{100} \times \left(1-\frac{CH4\_ox\_flare}{100}\right) + \\ + \left(1-\frac{Gas\_coll\_tp_i}{100}\right) \times \left(1-\frac{CH4\_ox}{100}\right)\end{array}\right)\right)$$

The total amount of methane emitted to the atmosphere is given by two main contributions: methane emitted from treatment facilities (flares in the example) due to incomplete oxidation and methane leaving the final cover surface not oxidized. The first contribution depends on the amount of gas collected and diverted to the treatment facility; the second contribution depends on the amount of uncollected gas, which is supposed to reach the final soil cover where it is partially oxidized.

Equation 8
Overall amount of carbon dioxide emitted to the atmosphere throughout the time horizon of the assessment (m^3 of carbon dioxide). As example, the collected gas is sent to treatment in flares:

$$Tot\_CO2\_air = Tot\_gas\_gen \times \sum_{i=1}^{i=4} \left(\frac{Gas\_gen\_tp_i}{100} \times \left(1 - \frac{Gas\_coll\_tp_i}{100}\right) \times \left(\frac{CO2\_gas\_tp_i}{100} + \frac{CH4\_gas\_tp_i}{100} \times \frac{CH4\_ox}{100} \right) \right) +$$
$$+ Tot\_CH4\_gen \times \sum_{i=1}^{i=4} \left(\frac{Gas\_gen\_tp_i}{100} \times \frac{Gas\_coll\_tp_i}{100} \times \frac{Gas\_flare\_tp_i}{100} \right) \times \frac{CH4\_ox\_flare}{100}$$

The total amount of carbon dioxide emitted to the atmosphere is given by two main contributions:. The first contribution is mathematically quantified with the first summation. It includes the carbon dioxide that leaves the final soil cover as it is and the methane that has been converted into carbon dioxide in the final cover. The second summation gives the second contribution to carbon dioxide emission and includes the emission originated in flares due to combustion of methane.

Equation 9
Overall amount of a gas substance that is emitted to the atmosphere throughout the time horizon of the assessment (g). As example, the collected gas is sent to treatment in flares:

$$Tot\_sub\_air = Tot\_gas\_gen \times \sum_{i=1}^{i=4} \left(\frac{Gas\_gen\_tp_i}{100} \times \left(1 - \frac{Gas\_coll\_tp_i}{100}\right) \times Sub\_gas\_tp_i \times \left(1 - \frac{Sub\_ox\_tp_i}{100}\right) \right) +$$
$$+ Tot\_CH4\_gen \times \sum_{i=1}^{i=4} \left(\frac{Gas\_gen\_tp_i}{100} \times \frac{Gas\_coll\_tp_i}{100} \times \frac{Gas\_flare\_tp_i}{100} \times Sub\_gas\_tp_i \right) \times \left(1 - \frac{Sub\_ox\_flare}{100}\right)$$

The total mass of a substance in the gas that is emitted to the atmosphere is given by two contributions that, in the equation, are represented by two summations. The first contribution expresses the mass of substance leaving the surface of the final soil cover not oxidized. It is therefore related to the amount of uncollected gas. The second contribution expresses the release of substance due to incomplete combustion in flares. It is therefore related to the amount of gas collected and diverted to flares facility.

Equation 10
Amount of energy produced from recovery of the energy content of landfill gas and substituting a given external process (MJ or kWh):

$$Energy\_process = Tot\_CH4\_gen \times \sum_{i=1}^{i=4} \left(\frac{Gas\_gen\_tp_i}{100} \times \frac{Gas\_coll\_tp_i}{100} \times \frac{Gas\_nrgplant\_tp_i}{100} \times \frac{Prod\_eff\_avoid}{100} \right)$$

The total amount of energy recovered from the landfill gas depends on the overall amount of methane diverted to a given plant (first three terms of the summation) and on the efficiency of the energy recovery process (last term of the summation).

Equation 11
Overall amount of leachate generated throughout the time horizon of the assessment (m^3):

$$Tot\_leach\_gen = Input\_mass \times \frac{\sum_{i=1}^{i=4} \left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \right)}{Landf\_height \times Waste\_wd}$$

The total volume of leachate generated is calculated as the mass of waste landfilled multiplied by the specific leachate generation per tonne of waste landfilled. The specific leachate generation in time periods, expressed in mm/year, is converted into m^3/year with a division by the factor 1000 (1000 mm in 1m). Landfill height and waste wet density are also involved in the calculation.

Equation 12
Overall amount of leachate collected throughout the time horizon of the assessment (m^3):

$$Tot\_leach\_coll = Input\_mass \times \frac{\sum_{i=1}^{i=4} \left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \times \frac{Leach\_coll\_tp_i}{100} \right)}{Landf\_height \times Waste\_wd}$$

The total volume of leachate collected is calculated as the mass of waste landfilled multiplied by the specific leachate collection per tonne of waste landfilled. Leachate collection efficiencies may vary in time periods and are therefore included in the summation.

Equation 13
Overall amount of leachate diverted to the treatment plant throughout the time horizon of the assessment (m^3):

$$Tot\_leach\_wwtp = Input\_mass \times \frac{\sum_{i=1}^{i=4} \left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \times \frac{Leach\_coll\_tp_i}{100} \times \frac{Leach\_wwtp\_tp_i}{100} \right)}{Landf\_height \times Waste\_wd}$$

The total volume of leachate diverted to the treatment plant is calculated as the mass of waste landfilled multiplied by the volume of collected leachate that is diverted to the plant, expressed per ton of waste landfilled. Fraction of leachate collected diverted to the plant may vary in time

Sub_atten	Percent of mass of substance in leachate that is removed due to natural attenuation processes (%)
Sub_remov_wwtp	Percent removal efficiency of a substance in leachate due to treatment in wwtp (%)
Sub_leach_tpi	Concentration of a substance in leachate in time period "i", i=1,2,3,4 (g /m3 leachate)

periods and are therefore included in the summation.

Equation 14
Overall amount of leachate reaching groundwater (untreated) throughout the time horizon of the assessment (m^3):

$$Tot\_leach\_gw = Input\_mass \times \frac{\sum_{i=1}^{i=4}\left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \times \left(1 - \frac{Leach\_coll\_tp_i}{100}\right)\right)}{Landf\_height \times Waste\_wd}$$

The model considers uncollected leachate as entirely reaching groundwater. Therefore, in the equation, the amount of leachate generated is multiplied by the fraction of leachate that is not collected.

Equation 15
Overall amount of a substance in leachate reaching groundwater through emission of uncollected leachate, throughout the time horizon of the assessment (g of substance):

$$Tot\_sub\_gw = Input\_mass \times \frac{\sum_{i=1}^{i=4}\left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \times \times \left(1 - \frac{Leach\_coll\_tp_i}{100}\right) \times Sub\_leach\_tp_i\right)}{Landf\_height \times Waste\_wd} \times \left(1 - \frac{Sub\_atten}{100}\right)$$

The equation calculates the mass of a generic substance in leachate that reaches groundwater through leachate percolation. The last term in the summation is the concentration of the substance in leachate. Natural attenuation processes of leachate constituents might take place. The cleaning effects of these processes are mathematically considered in the last term of the equation.

Equation 16
Overall amount of a substance in leachate that reaches surface water bodies through emission of treated leachate (after treatment in wwtp) throughout the time horizon of the assessment (g of substance):

$$Tot\_sub\_swb = Input\_mass \times \frac{\sum_{i=1}^{i=4} \left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \times \frac{Leach\_coll\_tp_i}{100} \times Sub\_leach\_tp_i \right)}{Landf\_height \times Waste\_wd} \times \left(1 - \frac{Sub\_remov\_wwtp}{100} \right)$$

Treatment plants receiving leachate from landfills do emit treated leachate to surface water bodies. The equation calculates the amount of a given substance in the leachate diverted to the plants and reduces its concentration according to the removal efficiency achieved in the plant for that substance, which is expressed in the last term of the equation.

Equation 17
Overall amount of a substance in sludge from leachate treatment assumed to end in soil throughout the time horizon of the assessment (g of substance):

$$Tot\_sub\_soil = Input\_mass \times \frac{\sum_{i=1}^{i=4} \left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \times \frac{Leach\_coll\_tp_i}{100} \times Sub\_leach\_tp_i \right)}{Landf\_height \times Waste\_wd} \times \left(\frac{Sub\_remov\_wwtp}{100} \right)$$

Treatment plants receiving leachate from landfills do emit treated leachate to surface water bodies. The equation calculates the amount of a given substance in the leachate diverted to the plants and reduces its concentration according to the removal efficiency achieved in the plant for that substance, which is expressed in the last term of the equation.

Equation 18
Overall amount of a substance in leachate reaching the surface water compartment through direct discharge of collected leachate, throughout the time horizon of the assessment (g of substance):

$$Tot\_sub\_soil = Input\_mass \times \frac{\sum_{i=1}^{i=4} \left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \times \frac{Leach\_coll\_tp_i}{100} \times \frac{Leach\_soil\_tp_i}{100} \times Sub\_leach\_tp_i \right)}{Landf\_height \times Waste\_wd}$$

A certain fraction of the collected leachate might be discharged directly to soil. The equation calculates the mass of substance reaching the soil. The fourth term in the summation expresses the fraction of collected leachate that is directly discharged to soil.

Equation 19

LCI calculation for a substance is the sum of process specific and input specific emissions, LCI of external processes and substitution of external processes and the overall equation looks like this:

$$LCI=\left(Input\_mass\times\sum_{Emissions}\overline{Specific\_emiss}\right)+\left(Input\_mass\times\sum_{Processes}\left(Process\_amount\times\overline{Ext\_LCI}\right)\right)-\sum_{Processes}\left(Proces\_avoid\times\overline{Ext\_LCI}\right)-\left(Avoid\_mass\times\sum_{Emissions}\overline{Specific\_emis}\right)$$

The LCI for landfill of mixed waste includes emissions to air, soil or water related to the waste input (like CO emissions to air) described in the first bracket in the LCI equation. The use of materials or energy (like $CaCO_3$ or Electricity) is added to the LCI with the emissions related in the second bracket. Any products that substitute a process (like heat and power production) is subtracted the LCI with regards to the avoided emissions in the third bracket. For further description of the equation see the document on LCI.

Equation 20

Overall amount of a substance left in the landfilled waste after the time horizon of the assessment (g of substance):

$$Tot\_sub\_stored=\left(Input\_mass\times\frac{Input\_frac}{100}\times\frac{TS\_input\_frac}{100}\times Toxsub\_waste\right)+$$
$$-\left(Tot\_sub\_air+Tot\_sub\_gw+Tot\_sub\_swb\ +Tot\_sub\_soil\right)$$

The equation accounts for the mass of a given toxic substance that is left in the landfilled waste after the time horizon of the assessment. This mass is calculated as subtraction of the mass of substance emitted to the various compartments throughout the time horizon of the assessment from the mass of substance in the waste landfilled. The latter is based on the mass and on the composition of waste landfill. Processes contributing to emission of the substance are emission of landfill gas (uncontrolled or controlled), leachate percolation toward groundwater, emission of treated leachate to surface water bodies and direct discharge of leachate to soil.

Equation 21

Overall amount of a carbon which is assumed to be permanently sequestered in the landfill:

$$C\_sequested=\left(C\_bio\_in-\frac{Tot\_CH4\_air*12}{16}*716.1-\frac{Tot\_CO2\_air*12}{44}*1964.7-\frac{\sum(Leach\_gen\_tpi*COD\_tpi*18*12)}{32*17.5}\right)$$

The equation accounts for the biological carbon that is assumed to be sequestered and which will not leave the landfill. This is calculated based on the input of biological carbon in the waste to the landfill, from which the individual amounts of carbon leaving the landfill through the generated gas and leachate are subtracted. These are are: amount of carbon in the overall methane generated (where 716.1 is the mass (g) of $1m^3$ of methane at STP), amount of carbon in the overall biological CO2 generated (where 1964.7 is the mass (g) of 1m^3 of Carbon Dioxide) and lastly the amount of carbon in the leachate generated represented by the COD (Chemical Oxygen Demand).

Economic calculations

Not yet available.

Variables and Constants

$CH4\_gas\_tp_i$	Percent of CH4 in the generated gas in time period "i", i=1,2,3,4 (%)
CH4_ox	Percent of CH4 oxidized to CO2 in soil top cover (%)
CH4_ox_flare	Percent of CH4 oxidized to CO2 by treatment of the gas in flares (%)
$CH4\_tp_i$	Percent of methane in the generated gas in time period "i", i=1,2,3,4 (%)
$CO2\_gas\_tp_i$	Percent of CO2 in the generated gas in time period "i", i=1,2,3,4 (%)
$COD\_\ tp_i$	Amount of COD generated per m3 leachate in time period "i", i=1,2,3,4 (%)
Dur_tp_i	Duration of time period "i", i=1,2,3,4 (year)
$Gas\_coll\_tp_i$	Percent of gas generated collected in time period "i", i=1,2,3,4 (%)
$Gas\_flare\_tp_i$	Percent of gas collected diverted to flare treatment in time period "i", i=1,2,3,4 (%)
$Gas\_gen\_tp_i$	Percent of gas potential generated in time period "i", i=1,2,3,4 (%)
$Gas\_nrgplant\_tp_i$	Percent of gas diverted to a facility for energy recovery in time period "i", i=1, 2, 3, 4 (%)
$Leach\_gen\_tp_i$	Amount of leachate generated per year in time period "i", i=1,2,3,4 (mm/year)
Landf_height	Height of the landfill (m)
Leach_coll_tpi	Percent of leachate collected in time period "i", i=1,2,3,4 (%)
$Leach\_wwtp\_tp_i$	Percent of leachate diverted to waste water treatment plant in time period "i", i=1,2,3,4 (%)
Prod_eff_avoid	Percent efficiency of energy recovery (%)

Tot_CH4_air	Overall amount of CH4 emitted to the atmosphere throughout the time horizon of the assessment (in m3 CH4)
Tot_CH4_gen	Overall amount of gas generated throughout the time horizon of the assessment (m3 CH4)
Tot_CH4_pot	Total methane potential in landfilled waste (m3 CH4)
Tot_CO2_air	Overall amount of CO2 emitted to the atmosphere throughout the time horizon of the assessment (in m3 CO2)
Tot_gas_flare	Overall amount of gas diverted to flare treatment throughout the time horizon of the assessment, in m3
Tot_gas_gen	Overall amount of gas generated throughout the time horizon of the assessment (m3)
Tot_leach_coll	Overall amount of leachate collected throughout the time horizon of the assessment, in m3
Tot_leach_gen	Overall amount of leachate generated throughout the time horizon of the assessment (m3)
Tot_leach_gw	Overall amount of leachate reaching groundwater throughout the time horizon of the assessment (m3)
Tot_leach_wwtp	Overall amount of leachate diverted to the treatment plant throughout the time horizon of the assessment (m3)
Tot_sub_gw	Overall amount of a substance in leachate reaching groundwater through emission of treated leachate, throughout the time horizon of the assessment (g)
Tot_sub_soil	Overall amount of a substance in leachate reaching soil compartment through emission of leachate either directly or via sludge from leachate treatment, throughout the time horizon of the assessment (g)
Tot_sub_stored	Overall mass of substance left in the landfilled waste after the time horizon of the assessment (g)
Toxsub_waste	Concentration of a toxic element in the input of waste landfilled (g /tonne wet waste)
Sub_gas_tpi	Concentration of a substance in the gas in time period “i”, i=1,2,3,4 (g/m3)
Sub_ox_flare	Percent of oxidation of a substance in the gas due to combustion in flares (%)

$Sub\_ox\_tp_i$	Percent of oxidation of a substance in the gas in time period "i", i=1,2,3,4 (%)
Waste_wd	Wet density of waste landfilled, in tonne wet waste/m3

11 Landfill: Mineral waste

Document updated February 10, 2007 by AND. Original document prepared by SIM and THC and controlled by AND.

The module represents landfilling of mineral waste containing no organic matter in a conventional landfill. The absence of organic matter leads to negligible methane potential in the waste landfilled. No technical measures for gas handling are therefore taken. The module may also account for any use of soil or flexible membranes for lining and energy used for earth works, operation etc. The amount and composition of leachate as well as the efficiencies of technical measures (liners, leachate collection, etc.) can be set for four time periods defined individually for each factor. The sum of periods in years represents the full life time of the landfill considered in the inventory and thus the time horizon of the life-cycle-impact-assessment. All emissions are counted equally, regardless of the moment they occur within the defined time period. A mass balance calculates the amount of toxic elements in terms of heavy metals left in the landfill at the end of the considered time horizon. The module accounts for leachate generation, leachate entering into treatment plant as well as leachate migrating into surface water and groundwater.

Approach

Each landfill dataset represents a full plant, including the technology of the plant and the operation of the plant. If supplementary technologies, e.g. additional leachate treatment are needed, this can only be modeled by establishing a new dataset where the considered add-on-technology is an integral part of the dataset.

The landfill module is based on two key assumptions:

- mineral wastes are assumed to contain no organic matter and therefore they have a negligible methane potential. Technical measures for the gas handling (collection, utilization, etc.) are therefore not implemented. As a consequence, there is no potential for energy recovery.
- the amount of leachate generated is set as typical values (mm/year) representing the hydrological conditions (precipitation, evapotranspiration, runoff, etc.) at the site and the composition of leachate (main constituents as well as trace components) is set as typical values within each period. This means that the leachate composition is not directly related to the waste composition

The module employs process-specific (mass or energy per ton of waste landfilled) material and energy use as well as process-specific emissions. Process-specific emissions are categorized according to the receiving compartment (air, surface/marine/ground-water, soil). Input-specific emissions are not employed since emissions to the various environmental compartments depend principally on the way the landfill is designed and operated rather than the quality of waste landfilled.

Handling of landfill leachate is structured in three sets of independent time periods. These address leachate generation, leachate composition and leachate collection, respectively. The amount of leachate generated in time periods has to be specified by the user and does not only depend on the annual precipitation. In fact, amongst the various technical and environmental factors influencing leachate generation, the user should also consider the effect of the final soil cover in limiting the actual rain-water infiltration to the waste body. The composition of the generated leachate, defined by the user, should reflect the evolution of the waste degradation process. Leachate composition can be specified not only in terms of for instance BOD, COD, ammonia, salts, etc, but also in terms of heavy metal, organic and trace organic contents. The subdivision in time periods for leachate collection should reflect the operational and post-closure stages of the considered landfill. Leachate collection efficiencies in time periods should reflect the technical measures adopted in each stage. Uncollected leachate is considered to reach the groundwater as-it-is or, eventually, somewhat purified because natural attenuation processes have occurred. Cleaning efficiencies of leachate constituents due to natural attenuation are user-defined. Collected leachate can either be discharged to soil, or sent to a plant for treatment, or any combination of the two options. Cleaning efficiencies achieved in the treatment plant have to be specified by the user for all constituents considered in the leachate composition. Emissions of treated leachate can be diverted to both surface water and marine water bodies in a proportion that is user defined.

In the impact category stored ecotoxicity, the model keeps account of how much is left of each toxic substance in the waste at the end of the time horizon and ascribes each substance the characterization factor for ecotoxicity to water and to soil, 50% to each. This inherently assumes that, in the long run, half of the toxic substances end up in the water compartment and the other half in the soil compartment. This is a somewhat arbitrary choice, but the intention of the stored toxicity is to represent the potential ecotoxicity of what is left in the landfill after the time horizon, were it to be released, perhaps abruptly due to later geological events or as slow leaching.

An overview of the flows of landfill leachate in the specified time period is provided in the model by pressing the **[Gas & Leachate]** button. This brings the user to a table that gives the flows throughout the defined LCA time horizon. The first icon of the table **[Leachate Generation & Collection]** quantifies the volumetric flows of leachate; the second icon **[Gas, Leachate Composition & Treatment]** estimates the mass flows of each compound in the landfill leachate.

Literature

Kirkeby, J.T., Birgisdóttir, H., Bhander, G.S., Hauschild, M.Z. & Christensen, T.H. (2007): Modeling of environmental impacts of solid waste landfilling in a life cycle perspective (EASEWASTE). *Waste Management*, (Accepted).

Hansen, E., Olsen, S.I., Schmidt, A., Hauschild, M., Hjelmar, O., Bendtsen, N., Poulsen, T.S., Hansen, H.H., Christensen, K. (2004); Life cycle assessment of landfilled waste (in Danish). Environmental project no. 971, Danish Environmental Protection Agency, Copenhagen, Denmark

User instructions

A new dataset is established by:

1. Select **[Waste Management]** → **[Technologies]** → **[Landfill Mineral Waste]** in the left window pane of the screen.
2. **[Leachate Substance]** in the bottom right pane of the screen is used to select the substances present in the landfill leachate and the compartments (fresh water, marine water and groundwater) receiving the emission of each substance.
3. Give the technology a **[name]**. In the EASEWASTE database Mixed Waste Landfills are named according to: Type, name of the landfill (if any), geographical area,

country and year. The year refers to when the main data behind the technology were collected, e.g. “Conventional landfill, Faxe, DK, 2006”. Save the technology before entering further data.

4. Once the **[Landfill Mineral Waste]** has been selected under “waste management-technologies”, the button **[Leachate Substance]** appears in the bottom of the screen. It allows entering a table listing all the leachate constituents. From the table, the water-compartments that leachate constituents are potentially allowed to reach are selected. Additional leachate constituents can be included in the table.
5. The amount of waste landfilled (in tonne of wet waste) can be defined in **[Amount]**. This only works outside a scenario – inside a scenario this value is calculated by the program.
6. All the inputs to the landfill needed throughout the time horizon of the assessment are defined **[Inputs]**. They are specified in term of amount of input-material (mass or volume) per tonne of waste landfilled. Besides inputs of materials and energy needed to keep the site operational **[Material and Energy Input]**, inputs of general nature can be selected **[General Input]**.
7. Time periods for leachate generation are defined and the relative amount of leachate produced is specified **[Leachate Generation]**.
8. Time periods for leachate collection are defined and the collection efficiencies are specified for each time period **[Leachate Collection]**. The percentages of collected leachate diverted to the treatment plant or discharged to soil without treatment are specified **[Treatment and Discharge of Leachate]**
9. The **[Leachate Composition]** button at the bottom of the screen is used to define time periods for leachate concentration. Substance in leachate are categorized into two groups, accessible from the icons **[Input General Leachate Substances]** and **[Input Additional Leachate Substances]**. Emission of leachate occurring beyond the time frame of the assessment are distributed among surface water bodies and soil **[Stored Emission Distribution %]**.
10. Back to the main window, the button **[Leachate Attenuation]** at the bottom of the screen is used to specify attenuation efficiencies for components of uncollected leachate due to natural processes.
11. The button **[Leachate Treatment]** at the bottom of the main window is used to define the activity of the treatment plant in cleaning the processed leachate. Energy consumptions needed for the treatment is specified in term of electricity consumption per unit volume of leachate processed **[WWTP Energy Consumption]**. Removal efficiencies of substances in leachate and distribution of emission of treated leachate to fresh or marine water are defined for each substance **[WWTP Removal Efficiencies]**.

Data requirements

When collecting data for creating a new landfill technology for mixed waste there are a number of crucial parameters:

- **[% of Leachate Generation Collected]** is a crucial parameter for the results of the assessment. In fact, it decides the amount of uncontrolled liquid emission to groundwater, which is decisive to the impact assessment. A precise estimation of the efficiencies of the leachate collection systems is therefore needed.
- **[Leachate Composition]**, especially in terms of heavy metals and toxic organics concentrations, is crucial in a mineral waste landfill, where the leachate generated has very low levels of BOD and COD.
- **[Inputs – Material and Energy Input]** might be important, if materials with a high environmental production load or long transportation distance are used.

Technical calculations

The main calculations performed in the mixed waste landfill module are shown below. Calculations that are necessary for generating data on the waste fed to the technology are not shown, as these calculations are identical to those specified for the output from the preceding technological modules.

Equation 1
Overall amount of leachate generated throughout the time horizon of the assessment (m^3):

$$Tot\_leach\_gen = Input\_mass \times \frac{\sum_{i=1}^{i=4}\left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i\right)}{Landf\_height \times Waste\_wd}$$

The total volume of leachate generated is calculated as the mass of waste landfilled multiplied by the specific leachate generation per tonne of waste landfilled. The specific leachate generation in time periods, expressed in mm/year, is converted into m^3/year with a division by the factor 1000 (1000 mm in 1m). Landfill height and waste wet density are also involved in the calculation.

Equation 2
Overall amount of leachate collected throughout the time horizon of the assessment ($m^{3):}$

$$Tot\_leach\_coll = Input\_mass \times \frac{\sum_{i=1}^{i=4}\left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \times \frac{Leach\_coll\_tp_i}{100}\right)}{Landf\_height \times Waste\_wd}$$

The total volume of leachate collected is calculated as the mass of waste landfilled multiplied by the specific leachate collection per tonne of waste landfilled. Leachate collection efficiencies may vary in time periods and are therefore included in the summation.

Equation 3
Overall amount of leachate diverted to the treatment plant throughout the time horizon of the assessment (m^3):

$$Tot\_leach\_wwtp = Input\_mass \times \frac{\sum_{i=1}^{i=4}\left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \times \frac{Leach\_coll\_tp_i}{100} \times \frac{Leach\_wwtp\_tp_i}{100}\right)}{Landf\_height \times Waste\_wd}$$

The total volume of leachate diverted to the treatment plant is calculated as the mass of waste landfilled multiplied by the volume of collected leachate that is diverted to the plant, expressed per ton of waste landfilled. Fraction of leachate collected diverted to the plant may vary in time periods and are therefore included in the summation.

Equation 4
Overall amount of leachate reaching groundwater (untreated) throughout the time horizon of the assessment (m^3):

$$Tot\_leach\_gw = Input\_mass \times \frac{\sum_{i=1}^{i=4}\left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \times \left(1 - \frac{Leach\_coll\_tp_i}{100}\right)\right)}{Landf\_height \times Waste\_wd}$$

The model considers uncollected leachate as entirely reaching groundwater. Therefore, in the equation, the amount of leachate generated is multiplied by the fraction of leachate that is not collected.

Equation 5
Overall amount of a substance in leachate reaching groundwater through emission of uncollected leachate, throughout the time horizon of the assessment (g of substance):

$$Tot\_sub\_gw = Input\_mass \times \frac{\sum_{i=1}^{i=4}\left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \times \left(1 - \frac{Leach\_coll\_tp_i}{100}\right) \times Sub\_leach\_tp_i\right)}{Landf\_height \times Waste\_wd} \times \left(1 - \frac{Sub\_atten}{100}\right)$$

The equation calculates the mass of a generic substance in leachate that reaches groundwater through leachate percolation. The last term in the summation is the concentration of the substance in leachate. Natural attenuation processes of leachate constituents might take place. The cleaning effects of these processes are mathematically considered in the last term of the equation.

Equation 6
Overall amount of a substance in leachate that reaches surface water bodies through emission of treated leachate (after treatment in wwtp) throughout the time horizon of the assessment (g of substance):

$$Tot\_sub\_swb = Input\_mass \times \frac{\sum_{i=1}^{i=4} \left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \times \frac{Leach\_coll\_tp_i}{100} \times Sub\_leach\_tp_i \right)}{Landf\_height \times Waste\_wd} \times \left(1 - \frac{Sub\_remov\_wwtp}{100} \right)$$

Treatment plants receiving leachate from landfills do emit treated leachate to surface water bodies. The equation calculates the amount of a given substance in the leachate diverted to the plants and reduces its concentration according to the removal efficiency achieved in the plant for that substance, which is expressed in the last term of the equation.

Equation 7
Overall amount of a substance in leachate reaching the soil compartment through direct discharge of collected leachate, throughout the time horizon of the assessment (g of substance):

$$Tot\_sub\_soil = Input\_mass \times \frac{\sum_{i=1}^{i=4} \left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \times \frac{Leach\_coll\_tp_i}{100} \times \frac{Leach\_soil\_tp_i}{100} \times Sub\_leach\_tp_i \right)}{Landf\_height \times Waste\_wd}$$

A certain fraction of the collected leachate might be discharged directly to soil. The equation calculates the mass of substance reaching the soil. The fourth term in the summation expresses the fraction of collected leachate that is directly discharged to soil.

Equation 8
Overall amount of a substance in sludge from leachate treatment assumed to end in soil throughout the time horizon of the assessment (g of substance):

$$Tot\_sub\_soil = Input\_mass \times \frac{\sum_{i=1}^{i=4} \left(\frac{Leach\_gen\_tp_i}{1000} \times Dur\_tp_i \times \frac{Leach\_coll\_tp_i}{100} \times Sub\_leach\_tp_i \right)}{Landf\_height \times Waste\_wd} \times \left(\frac{Sub\_remov\_wwtp}{100} \right)$$

Treatment plants receiving leachate from landfills do emit treated leachate to surface water bodies. The equation calculates the amount of a given substance in the leachate diverted to the plants and reduces its concentration according to the removal efficiency achieved in the plant for that substance, which is expressed in the last term of the equation.

Equation 9
LCI calculation for a substance is the sum of process specific and input specific emissions, LCI of external processes and substitution of external processes and the overall equation looks like this:

$$LCI = \left(Input\_mass \times \sum_{Emissions} \overline{Specific\_emiss} \right) + \left(Input\_mass \times \sum_{Processes} \left(Process\_amount \times \overline{Ext\_LCI} \right) \right) - \sum_{Processes} \left(Proces\_avoid \times \overline{Ext\_LCI} \right) - \left(Avoid\_mass \times \sum_{Emissions} \overline{Specific\_emis} \right)$$

The LCI for landfill of mixed waste includes emissions to air, soil or water related to the waste input (like CO emissions to air) described in the first bracket in the LCI equation. The use of materials or energy (like $CaCO_3$ or Electricity) is added to the LCI with the emissions related in the second bracket. Any products that substitute a process (like heat and power production) is subtracted the LCI with regards to the avoided emissions in the third bracket. For incinerators no specific emissions can be substituted why the last bracket is zero. For further description of the equation see the document on LCI.

Equation 10
Overall amount of a substance left in the landfilled waste after the time horizon of the assessment (g of substance):

$$Tot\_sub\_stored = \left(Input\_mass \times \frac{Input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times Toxsub\_waste \right) + -\left(Tot\_sub\_gw + Tot\_sub\_swb + Tot\_sub\_soil \right)$$

The equation accounts for the mass of a given toxic substance that is left in the landfilled waste after the time horizon of the assessment. This mass is calculated as subtraction of the mass of substance emitted to the various compartments throughout the time horizon of the assessment from the mass of substance in the waste landfilled. The latter is based on the mass and on the composition of waste landfill. Processes contributing to emission of the substance are leachate percolation toward groundwater, emission of treated leachate to surface water bodies and direct discharge of leachate to soil.

Economic calculations

Not yet available.

Variables and Constants

Dur_tp_i	Duration of time period "i", i=1,2,3,4 (year)
Landf_height	Height of the landfill (m)
Leach_coll_tpi	Percent of leachate collected in time period "i", i=1,2,3,4 (%)
$Leach\_gen\_tp_i$	Amount of leachate generated per year in time period "i", i=1,2,3,4 (mm/year)
$Leach\_wwtp\_tp_i$	Percent of leachate diverted to waste water treatment plant in time period "i", i=1,2,3,4 (%)
Tot_leach_coll	Overall amount of leachate collected throughout the time horizon of the assessment, in m3
Tot_leach_gen	Overall amount of leachate generated throughout the time horizon of the assessment (m3)
Tot_leach_gw	Overall amount of leachate reaching groundwater throughout the time horizon of the assessment (m3)
Tot_leach_wwtp	Overall amount of leachate diverted to the treatment plant throughout the time horizon of the assessment (m3)
Tot_sub_gw	Overall amount of a substance in leachate reaching groundwater through emission of treated leachate, throughout the time horizon of the assessment (g)
Tot_sub_soil	Overall amount of a substance in leachate reaching soil compartment through emission of leachate either directly or via sludge from leachate treatment, throughout the time horizon of the assessment (g)
Tot_sub_stored	Overall mass of substance left in the landfilled waste after the time horizon of the assessment (g)
Tot_sub_swb	Overall amount of a substance in leachate reaching surface water bodies through emission of treated leachate (after treatment in wwtp), throughout the time horizon (g)
Toxsub_waste	Concentration of a toxic element in the input of waste landfilled (g /tonne wet waste)
Sub_atten	Percent of mass of substance in leachate that is removed due to natural attenuation processes (%)
Sub_leach_tpi	Concentration of a substance in leachate in time period "i", i=1,2,3,4 (g /m3 leachate)
Sub_remov_wwtp	Percent removal efficiency of a substance in leachate due to treatment in wwtp (%)
Waste_wd	Wet density of waste landfilled, in tonne wet waste/m3

12 Material Recovery Facilities

Document updated November 29, 2007 by AWL. Original document prepared by AWL and HKL and controlled by THC.

The module represents mechanical treatment plants that separate the incoming waste into separate outputs. MRFs (Material Recovery Facilities) may include technologies as screens, shredders, magnets, air classifiers, etc. The module accounts for any use of energy and materials and process specific emissions (mass per tonne of wet waste) to air, water and soil. Transfer coefficients are used to route each material fraction to defined outputs. A residue waste output, included in all modules, accommodates all mass not routed to a specific output, thereby maintaining the mass balance. The transfer coefficients may also be instrumental in quantifying foreign items in the defined outputs. The transfer coefficients are based on wet waste and all characteristics of each material fraction are transferred proportionally to the mass transfer.

Approach

The MRF (Material Recovery Facility) is used for separating waste into multiple outputs and a residual output by transferring all characteristics of each material fraction in proportion to the wet weight. Typical technologies used in a MRF are screens, air classifiers, magnets, optical sorters and shredders. The non-organic MRF module assumes that all characteristics of a material fraction are transferred to the outputs proportional to the transfer of wet mass.

Each MRF dataset represents a full plant, including the technology of the plant and the operation of the plant. If supplementary technologies, e.g. adding magnetic separation to an existing plant, are needed, this can be modeled by establishing a new dataset where the considered add-on-technology is an integral part of the dataset.

The module employs process-specific (mass per tonne of waste) material and energy use as well as process-specific emissions. Process-specific emissions are categorized according to the receiving compartment (air, surface water, soil, etc.).

Transfer coefficients are used to route a material fraction or part of a material fraction to defined outputs. The number and types of outputs can be specified for each plant. The transfer coefficients are defined for each material fraction in the input. The transfer coefficients are mass conserving and, considering all outputs, add up to 100%. This is obtained by calculating the residual waste output as the mass not routed by the user to the defined outputs.

Literature

No specific literature

User instructions

A new dataset is established by:

1. Select **[Waste Management]** → **[Technologies]** → **[MRF]** in the left window pane of the screen.
2. Give the technology a **[name]**. In the EASEWASTE database MRF's are named according to: Type, name of the plant (if any), city, country and year. The year refers to when the main data behind the technology were collected, e.g. "Paper sorting facility, Copenhagen, DK, 2006". Save the technology before entering further data.
3. Data are entered per tonne of wet waste and the **[Amount]** "1 tonne", which is placed under the **[name],** cannot be changed.
4. One to ten outputs are defined in **[Number of Outputs]**. The residue also counts as an output.
5. User-defined names of the outputs are entered in the bottom of the screen: **[Output materials].** The output called Residue appears by default, but the name can be changed.
6. Press **[Transfer Coefficients]**, and a window containing a table with material fractions in rows and output names in columns appears. **[Transfer Coefficients]** are defined for all outputs and represent the percentage of the mass of each material fraction being transferred to the defined outputs. The transfer coefficients in the rightmost column are automatically calculated when data is entered in the other columns.
7. **[Input – material and energy]** is used to list materials and energy that are used in the operation of the plant. These inputs are chosen from the list of external processes, and new materials and energy processes must be created there. Resources and emissions associated with the extraction, production, manufacturing and use of these inputs contribute to the LCI of the plant.
8. **[Input – resources and raw materials]** is used to list materials that are used in the process but are not contributing to any significant emissions during their extraction, production, transport and consumption. These inputs are only accounted as resource use.
9. **[Output – Compartment]** is used to list the direct process specific emissions to various environmental compartments (kg/tonne of wet waste). The compartments are: **[Air Emissions]**, **[Fresh Water Emissions]**, **[Groundwater Emissions]**, **[Marine Water Emissions]**, **[Soil Emissions]** and **[Solid Emissions]**.

In a scenario, the user can route all **[Outputs]** to further downstream technological modules including a specification of the means of transport and transport distance. The routings available appear in a separate documentation file. It is not possible to change transfer coefficients from inside a scenario, but needs to be done in the technology itself. Be aware that changes in a technology will automatically update in all the scenario's the technology is used in.

Data requirements

The following issues must be considered when collecting data for creation of a new MRF technology:

- **[Transfer coefficients]** have a large impact on the overall performance of the technology. The transfer coefficients are related to the material fractions and should be defined for the material fractions intended for the defined outputs, but transfer coefficients can also be used to describe contamination of the defined outputs by other material fractions in the waste. Transfer coefficients are best estimated if detailed information with respect to material composition is available for all outputs including the residual waste. However, often less detailed information is available and the transfer coefficients must be estimated focusing on representing the overall mass balances.

- Data on inputs to the facility, like materials and energy, and outputs, like production of waste and emissions to air, water and soil, must be collected. All inputs and outputs are stated per tonne of wet waste. These are often available green accounts, emission monitoring, purchase accounts, and other statistics.

Technical calculations

The main calculation performed in the MRF module is shown in Equation 1. The incoming mass of wet waste is distributed to user-defined outputs for each material fractions and by transfer coefficients. The relative TS-content and substance content of each material fraction are not modified in the module. However, the substance compositions of the individual outputs can be different from the substance composition of the incoming waste, since the distribution of material fractions within each output is different. These new tables of substance composition are carried on to the successive modules. No mass is lost in the module, thus, the sum of outputs is equal to the input of wet waste (Equation 2).

Equation 1

$$Output\_mass = Input\_mass \times \sum_{frac} \frac{Input\_frac}{100} \times \frac{Mass\_output\_TFC\_frac}{100}$$

Equation 2

$$Input\_mass = \sum Output\_mass$$

LCI calculation for the substances is the sum of process specific emissions and LCI of external processes. Equation 3 shows the general form of the calculation:

Equation 3

$$\overline{LCI} = \left(Input\_mass \times \sum_{Emissions} \overline{Specific\_emis} \right) + \left(Input\_mass \times \sum_{Process} \left(Process\_amount \times \overline{Ext\_LCI} \right) \right)$$

The LCI for MRF's includes emissions to air, soil or water related to the waste input mass (like CO emissions to air) described in the first bracket in the LCI equation. The use of materials or energy (like electricity) is added to the LCI with the emissions related in the second bracket.

Economics

Not yet available

Variables and Constants

Input_frac	Percent of each material fraction in the incoming waste (%)

Input_mass	Input of wet waste to the technology (tonne)
Mass_output_TFC_frac	Transfer coefficients in percent to a given output for a material fraction (%)
Output_mass	Wet output mass from a collection fraction or a technology (tonne)

13 Material Recycling

Document updated November 28, 2007 by AND. Original document prepared by HKL, and controlled by JAM

The module represents material recycling of recyclable waste fractions (e.g. paper, glass, metals, plastics). The module accounts for any use of energy and materials and for process specific emissions to air, water and soil. The module includes the material loss, representing that some of the waste material is lost in the recycling process. Additionally, the module includes a quality loss in the recycling process as the materials can loose quality during the processing and therefore cannot be recycled eternally. The amount of output material is thus a percentage of the input waste amount. If the recycled material is a substitute for another product, a process representing the avoided production of the substituted material is chosen. The material recycling module thus calculates the both the environmental exchanges at the recycling plant and at the substituted production plant.

Approach

The material recycling module is used to model the recycling of a waste material into a new material/product. It is reasonably to assume that the recycled material is sold and can substitute for similar materials on the market. In this approach recycling leads to avoided production of other materials based on virgin resources which should be accounted for in the LCA of the waste management system.

Each material recycling dataset represents a full processing plant for the recycled material, including the operation of the plant, and a processing plant for the avoided material. The avoided process is chosen from the external processes and the materials produced in the two processes should be compatible with each other.

The module employs process-specific (amount per ton of waste applied) material and energy use. The module assumes that the materials chemical compositions do not influence the emissions from the process, and therefore only process specific data is employed. Process-specific emissions are categorized according to the receiving compartment (air, surface water, soil, etc.).

The dataset for this module requires a substituted amount to be entered, meaning that the amount of output is specified as a percentage of the amount of waste material input. This is required in order to take into account the material loss that occurs in the recycling process. When creating the dataset it is also necessary to specify a substitution percentage for the avoided production, because the recycled material not always can fully substitute a similar product on the market for several reasons: there might be a loss of quality (loss of material grade) during the reprocessing meaning that the material cannot be recycled forever; the properties of recycled material can be different from the properties of virgin material; and market elasticity, and thereby substitution ratio, might be different for recycled and virgin material.

If it is necessary to separate materials after collection in order to recycle these, the separation process should be modelled in the MRF module.

Literature

No specific literature

User instruction

A new dataset is established by:

1. Go to **[Waste Management]** → **[Technologies]** → **[Material Recycling]**. Right click in the main window and press **[New],** or choose the "blank page" button to create a new technology. A new technology window will open.
2. Give the technology a **[Name]**. Material recycling technologies in the EASEWASTE database are named according to: type of waste material, type of reprocessed material, city, country and year. The year refers to when the main data behind the technology were collected, e.g. "Paper waste to fine paper, Dalum, DK, 2001". Save the technology before entering further data.
3. Define an **[Amount]** in tonnes. This is as default set to 1 tonne as it will be multiplied with the incoming material in tonnes when used in a scenario.
4. Define a **[Substituted amount]** in the top right part of the window. This informs about how big a percentage of the input material processed into the material output. This says something about how much material is lost each time it is recycled, due to plant efficiency.
5. **[Input – Material and Energy]** is used to list materials and energy that are consumed in the processing of the material. These processes are chosen from the list of external processes, and if an existing external process does not cover the needed input, it is necessary to create a new external process. See the documentation on External Process feature for more information. The material included under **[Input – Material and Energy]** are all LCI's(Life Cycle Inventories) and therefore have an associated set of emissions which will be included in the LCI for the recycling process.
6. **[Input – Resources and Raw Materials]** is used to list materials that are used in the process but are not contributing to any significant emissions during their extraction, production, transport and consumption. These materials are only accounted as resource use in the LCI.
7. **[Output – *Compartment*]** is used to list the direct process specific emissions to various environmental compartments (kg/tonne of wet waste).
8. **[Substitution]** is used to define the substituted material including the processing of this material. This process is chosen from the list of external processes, and if an existing external process does not cover the needed profile, it is necessary to create a new external process. See the documentation on External Process feature for more information. The **[Avoided production (%)]** has to be defined. This represents the amount of product that can be avoided in relation to the amount produced in the recycling process. This says something about the quality of the product from the recycled material. If the recycled material has a lower quality than the substituted material the percentage will be lower than 100 %, and vice versa.

Data requirements

When collecting data for creating a new Material Recycling technology there are a number of important parameters:

- **[Substituted amount]** have a large impact on the overall evaluation of the technology, as this is a having a direct impact on the amount of material substituted and thereby the environmental profile of the overall technology.
- **[Input – material and energy]** might be important, if materials with a high environmental production load or long transportation distances are used.
- **[Output – *Compartment]*** can have a large impact if there are substances used in the in the processing of the material which have an important environmental impact.
- **[Substitution]** have a large impact on the overall evaluation of the recycling technology, as the substitution can be of high importance in relation to the environmental benefits.

Technical calculations

The main calculations performed in the Material Recycling module are shown below. Calculations that are necessary for generating data on the waste fed to the technology are not shown, as these are calculations that are identical to those specified for the output from the preceding technological modules.

Equation 1
The total mass that is produced from the recycled material (tonne):

$$Recycling\_mass\_output = Input\_mass \times \frac{Process\_eff}{100}$$

This amount is a multiplication of the input mass and the substituted amount percentage, which represents the process material utilization efficiency. The amount is used in the calculation of substitution.

Equation 2
The total mass that is substituted (tonne):

$$Process\_avoid = Recycling\_mass\_output \times \frac{Prod\_eff\_avoid}{100}$$

The substituted mass is linked to an external process including a number of inputs and outputs. This amount is a multiplication of the mass of material/product output from the recycling process and the substitution percentage.

Equation 3
LCI calculation for a substance is the sum of process specific and input specific emissions, LCI of external processes and substitution of external processes and the overall equation looks like this:

$$LCI = \left(Input\_mass \times \sum_{Emissions} \overline{Specific\_emis} \right)$$
$$+ \left(Input\_mass \times \sum_{processes} \left(Process\_amount \times \overline{Ext\_LCI} \right) \right)$$
$$- \sum_{Proceses} \left(Proces\_avoid \times \overline{Ext\_LCI} \right)$$

The LCI for material recycling includes emissions to air, soil or water related to the waste input (like CO emissions to air) described in the first bracket in the LCI equation. The use of materials or energy in the processing or addition to the material (like electricity or virgin material) is added to the LCI with the emissions related in the second bracket. Any products that substitute a process (like paper or glass produced from virgin material) is subtracted from the LCI with regards to the avoided emissions in the fourth bracket. The fifth bracket is used for the material specific emissions in the substituted material similar to the first bracket for the recycled material.

Variables

Avoid_mass	Mass that is avoided due to a substitution process (tonne)
Ext_LCI	LCI table of a external process (unit/tonne)
Input_mass	Input of wet mass to the technology (tonne ww)
Process_amount	Amount of a material, raw material or energy (tonne)
Process_avoid	The amount that substitutes a given external process (e.g. kWh or kg)
Process_eff	Percent of input mass that is left in the output material/product (%)
Prod_eff_avoid	Percent of input that substitutes a given external process or substitution profile (%)
Recycling_mass_output	The amount of material produced in the process from the amount of waste input (kg/tonne)
Specific_emis	Emission specified for the process related only to the waste amount (kg/tonne)

14 Material Utilization

Document updated November 28 by ALB 2007. Original document prepared by AND and controlled by HKL and THF.

The module represents material utilization of waste resulting in emissions to air, water, soil; and substitution of avoided products. The module can be used, for example, for utilization of compost (e.g. peat substitution) and incineration bottom ash (e.g. gravel substitution). The module contains a profile of the leaching from the use of the utilized material as well as a profile for the substituted material. Based on the chemical composition and water content of the material fractions present in the input waste and the leaching profile, the module calculates the potential stored toxicity. Process specific emissions allow the model to calculate emissions to air, soil, water and solid outputs (the solid outputs cannot be routed any further).

Approach

Each material utilization dataset represents a full utilization of the input waste, encompassing the application of the material as well as the emissions related to this use. Processes that are identical for both the material utilized as well as the substituted material can be left out by choice as these will out-balance each other.

The module employs process-specific (amount per tonne of waste applied) material and energy use as well as leaching-specific emissions (kg per tonne of waste applied). Process-specific emissions are categorized according to the receiving compartment (air, surface water, soil, etc.). Stored emissions are calculated by subtracting each leaching substance from the same substance inherent in the input waste.

The user must specify the substitution value (based on wet weight of the utilized waste material) in order to obtain credits for the materials substituted.

Literature

Boldrin, A., Hartling, K.R., Smidt, M.M. & Christensen, T.H. Use of compost and peat in growth media preparation: An environmental comparison using LCA-modeling (EASEWASTE) (in preparation).

User instructions

A new dataset is established by:

1. Choose [**Waste Management] → [Technologies]** → [**Material Utilization]**. Right click in the main window and press **[New],** or choose the "blank page" button to create a new technology. A new technology window will open.
2. Define an **[Amount]** in tonnes. This is as default set to 1 tonne as it will be multiplied with the incoming material in tonnes when used in a scenario.
3. Define a **[Substitution %]** in the top part of the screen. This informs about how big a percentage of the original material that is substituted. This says something about how

well the utilized material works. If the utilized material is less efficient than the substituted material the percentage will be lower than 100 %, and higher than 100% if it is more efficient. This represents how much is saved expressed in percentage of substituted material relative to waste material (wet weight)

4. **[Input – material and energy]** is used to list materials and energy that are consumed in the processing and the utilization of the material. These processes are chosen from the list of external processes, and if an existing external process does not cover the needed input, it is necessary to create a new external process. See the External Process feature for more information. The materials included under **[Input – material and energy]** are all LCI's and therefore have an associated set of emissions which will be included in the LCI for the utilization process.
5. **[Input – resources and raw materials]** is used to list materials that are used in the process but are not contributing to any significant emissions during their extraction, production, transport and consummation. These materials are only accounted as resource use.
6. **[Output – *Compartment*]** is used to list the direct process specific emissions to various environmental compartments (kg/tonne of wet waste).
7. **[Leaching profile]** is used to define the leaching from the utilized material. In the table can be added substances which are defined in the "Documentation: Waste Composition". The leaching can be set to go to **[Fresh Water]**, **[Marine Water]** and **[Groundwater]**. Finally it is necessary to define a **[Soil]** and **[Stored Soil and water Emissions Distribution %]** which is used to set the distribution between soil and water of the substances left in the utilized material. If the material utilization module is placed after a thermal treatment module, the remaining none-leached substances will be considered as an impact as Stored Soil or Stored water, as the material will most likely be bottom-ash locked as a sub-base in road construction. If the material utilization module is placed after a biotech module the none-leached substances will be considered to be left as impact to soil or Stored water emissions, as the material here most likely will be biogenic material mixed into soil. The model will show which type it is when opened inside a scenario.
8. **[Substitution profile]** is used to define the substituted material including the processing of this material. The profile is defined for 1 tonne of substituted material and it is necessary to define the similar field as in the bullets 4-7 above. Leaching from the substituted material will be defined in the **[Output – *Compartment*]** fields.

Data requirements

When collecting data for creating a new Material Utilization technology there are a number of important parameters:

- **[Substitution %]** have a large impact on the overall evaluation of the technology, as this is having a direct impact on the environmental profile of the overall technology.
- **[Input – material and energy]** might be important, if materials with a high environmental production load or long transportation distance are used. This is relevant for both the utilized material and the substituted product.

- **[Output – *Compartment]* and [Leaching profile]** can have a large impact if there are substances with a critical environmental impact used in the utilized material or in the processing of the material.

Technical calculations

The main calculations performed in the Material Utilization module are shown below. Calculations that are necessary for generating data on the waste fed to the technology are not shown, as these are calculations that are identical to those specified for the output from the preceding technological modules.

Equation 1
The total mass that is substituted is calculated from:

$$Process\_avoid = Input\_mass \times \frac{Prod\_eff\_avoid}{100}$$

The substituted mass is linked to a whole profile including a number of specific emissions and external processes. This amount is input mass times the substitution percentage.

Equation 2
The amount that is considered as stored toxicity (kg):

$$Stored\_tox\_emis = Input\_mass \times \sum \left(\frac{Input\_frac}{100} \times \frac{Subs\_input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times 1000 - Leach\_subs \right)$$

The stored toxicity gives an indication of unresolved issues from the utilization of a material where a substance might have an impact at a later time; especially heavy metals are very persistent and will stay in the environment for thousands of years. The emission amount is a found by multiplying the following variables: the input fraction for each material, the substance input fraction, the TS in the input fraction and with 1000 (to get the answer in kg/tonne). This is then subtracted the amount of substance leached. Finally this is multiplied with the input mass.

Note: when running the simulation an error message could pop up. A reason could that the define leaching profile contain an amount of a certain compound bigger than the input material. In the case no stored toxicity is calculated.

Equation 3
LCI calculation for a substance is the sum of process specific and input specific emissions, LCI of external processes and substitution of external processes and the overall equation looks like this:

$$LCI = \left(Input\_mass \times \sum_{Emissions} \overline{Specific\_emis} \right) + \left(Input\_mass \times \sum_{processes} \left(Process\_amount \times \overline{Ext\_LCI} \right) \right)$$
$$- \sum_{Proceses} \left(Proces\_avoid \times \overline{Ext\_LCI} \right) - \left(avoid\_mass \times \sum_{Emissions} \overline{Specific\_emis} \right)$$

The LCI for material utilization includes emissions to air, water or soil related to the waste input (like CO emissions to air) described in the first bracket in the LCI equation. The leaching emissions described in the leaching profile are included in the first bracket. The use of materials or energy in the processing or addition to the material (like fertilizer or electricity) is added to the LCI with the emissions related in the second bracket. Any product that substitute a process (like peat or bottom ash for gravel) is subtracted the LCI with regards to avoided emissions in the fourth bracket. The fifth bracket is used for the material specific emissions in the substituted material similar to the first bracket for the utilized material.

Economic calculations

Not yet available

Variables

Avoid_mass	Mass that is avoided due to a substitution process (tonne)
Ext_LCI	LCI table of an external process (unit/tonne)
Input_frac	Percent of each material fraction in incoming waste
Input_mass	Input of wet mass to the technology (tonne ww)
Leach_subs	Substance leaching from a technology (kg/tonne)
Process_amount	Amount of a material, raw material or energy (tonne)
Process_avoid	The amount that substitutes a given external process (e.g. kWh or kg)
Prod_eff_avoid	Percent of input that substitutes a given external process or substitution profile(%)
Specific_emis	Emission specified for the process related only to the waste amount (kg/tonne)
Stored_tox_emis	The amount of a substance left in the waste after the time period defined for the process (kg)
Subs_input_frac	Percent substance in TS in a material fraction (%)
TS_input_frac	Percent of total solids (TS) in wet material fraction (%)

15 Thermal Treatment

Document updated January 11, 2007 by THC. Original document prepared by CHR and controlled by AND.

The module represents thermal conversion of waste resulting in emissions to air, solid outputs and energy production. The module focuses on incineration of waste, but can also be used for pyrolysis and gasification as long as the gasses are combusted within the technical unit represented by the module. The thermal treatment technology may be extended in order to include additional management of solid outputs (e.g. bottom ash). This can also be modeled in a separate module following the thermal treatment module. Based on the chemical composition, water content and calorific value of the material fractions present in the input waste, the module calculates the energy recovery, emissions and solid outputs. The module also includes specific data on energy efficiency, use of auxiliary materials for air pollution control, process-specific emissions to air, transfer coefficients to air, wastewater and solid outputs, as well as the water content specified for the solid outputs. The type of energy production avoided as a consequence of the energy recovered by the thermal treatment must be specified to provide the appropriate credits of saved emissions and resource use.

Approach

The module represents thermal conversion of waste resulting in emissions to air, solid outputs and energy production. The module focuses on incineration of waste, but can also be used for pyrolysis and gasification as long as the gasses are combusted within the technical unit represented by the module.

Each thermal treatment dataset represents a full plant, defined by the type of technology and the operation of the plant. If supplementary technologies, e.g. additional flue gas cleaning, are needed, this can only be modeled by establishing a new dataset where the considered add-on-technology is an integral part of the dataset.

The module employs process-specific auxiliary material and energy use, based on the incoming quantity of waste related to the type of technology. The module also includes process-specific emissions originating specifically from the process, based on the waste input quantity and the technology type. In addition, transfer coefficients are used to link substances between the waste inputs and the outputs (input specific emissions).

Process-specific and input-specific emissions are categorized according to the receiving environmental compartments (air, surface water, soil) and/or material outputs. The number and types of outputs can be specified for each individual technology, but air emissions are always included. Process-specific and input-specific emissions can be used simultaneously to provide the flexibility to model plants as realistically as possible. This mix of emissions is particularly relevant where elemental inputs are closely monitored in the plant and the air pollution control system constantly adjusted to meet stack emission standards.

The transfer coefficients are defined for each input material fraction and are distributing outputs in different proportion for the air compartment or material output. All the transfer coefficients should add up to 100 %. This allows for distribution of heavy metals according to their origin. For example, chromium in leather is distributed differently than chromium in steel. Likewise, aluminum in cans is distributed differently between bottom ash and fly ash compared to aluminum foil in juice containers. Unfortunately, current data is usually too limited to make such fraction specific distribution coefficients, and in most datasets the distribution coefficients are the same for all fractions.

The bottom ash is often quenched (cooled down), drained and stored resulting in variable moisture content of the ash. Likewise APC-residues may be sprayed in order to reduce dust problems. Considering the transport of outputs away from the plant, the water content in the outputs must be specified, since all calculations of outputs are based on dry matter.

The module calculates the lower heating value of the waste input and through user-specified energy recovery factor (defined in percent of lower heating value) calculates the electricity and /or heat recovered. Following this stage, the user must specify the avoided energy production from a selected external process in order to obtain the credits for saving in resource use and emissions. The energy recovery is the gross energy production, since the plant's own use of energy is accounted for as an energy input.

Literature

Riber C., Christensen T.H., Bhander G.S. (2008), Environmental assessment of waste incineration in a life-cycle-perspective (EASEWASTE), Accepted by Waste Management & Research.

User instructions

A new dataset is established by:

10. Give the technology a **[name]**. In the EASEWASTE database thermal treatment plants are named according to: Type, name of the plant (if any), city, country and year. The year refers to when the main data behind the technology were collected, e.g. "Incinerator, Knudsmoseværket, Herning, DK, 2006". Save the technology before entering further data.
11. One to five outputs are defined **[Number of Outputs]** in the top part of the screen.
12. The type/name of the outputs is selected in the bottom of the screen **[Output materials].** If an output is not found in the drop-down list, it can be added by selecting **[Waste Management], [Technologies], [Thermal Treatment] and [Solid Output],** at the bottom of the screen.
13. The TS-content of each of the outputs must be specified (**[TS in % of wet weight]** of each output).
14. A lower heating value typical for the specific technology can be set in the **[LHV]** box. This parameter can only be entered/edited if the technology is used on its own, outside a scenario. For the modeling of a waste scenario, the LHV is always calculated and cannot be edited.
15. **[Transfer Coefficients]** are defined for each substance for all outputs and represent the percentage of the **[substance]** in each material fraction being transferred to the defined outputs. Air emissions are always found among the outputs and the transfer coefficients to air reflect emissions related to the content of the substance in the in-

put waste**.** The transfer coefficient for the ash content of the waste determines the mass of ash in the outputs. Note that the amount of output may also be affected by materials used as specified in **[Input – Material and Energy]** and **[Input – Resources and Raw Materials].**

16. **[Input – Material and Energy]** is used to list materials and energy that are consumed in the incineration process and the operation of the facility (process specific data). If any of these inputs contribute to outputs that must be routed further in the scenario, this can be defined in the same line as **[Output]** by specifying the corresponding contribution **[%/Unit]** (percent of input mass that is found in output). Note that only the mass and not the chemical composition is routed to the output. If fossil fuels are used in the thermal treatment in significant quantities, care should be taken not to double count the emissions (if the emissions from the fuel combustions already are included in the emissions measured and allocated to the waste, the chosen external process representing the fuel combusting should not include the emissions again). CO_2-fossil constitutes a special issue, because this emission is not based on emission measurements but estimated from the waste composition.
17. **[Output – Material and Energy]** is used to list the energy produced by the thermal process. **[Amount]** shows the percentage of the energy produced based on the lower heating value of the wet waste input (Energy efficiency factor). The sum of all **[Amounts]** corresponds to the total energy production efficiency of the plant. This percentage also includes the energy recovered from conversion of additional fuels, which suggests that the energy efficiency may be higher than what is directly recovered from the waste.
18. **[Input – Resources and Raw Materials]** is used to list materials that are used in the process but are not contributing to any significant emissions during their extraction, production, transport and consumption. These materials are only counted as resource use. For example, water extracted from its own well would be listed here. If any of these resources or raw materials contribute to outputs that must be routed further in the scenario this can be defined in the same line as **[Output]** by specifying the corresponding contribution **[%]** (percent of input mass that is found in output). Note that only the mass and not the chemical composition is routed to the output.
19. **[Output – "Compartment"]** is used to list the direct process specific emissions to various environmental compartments (kg/tonne of wet waste).
20. **In a scenario**, the user can route all **[outputs]** (except emissions to air) to further downstream technological modules including a specification of the means of transport and transport distance. The routings available appear in separate documentation file.

Data requirements

When collecting data for creating a new thermal treatment technology there are a number of important parameters:

- **[Transfer coefficients]** have a large impact on the overall evaluation of the technology, in particular the transfer coefficients controlling the amount of a substances being released to air. It is therefore very important to obtain reliable data on transfer coefficients. Chemical characterization of all outputs from the technology as well as precise mass balance is the information needed to estimate the transfer coefficients. The unit of transfer coefficients is a percentage of the input.

- **[Output – Material and Energy]** regarding the recovered energy is also very important. Both in terms of the percent of energy recovered and in terms of the type of energy recovered. The choice of substituted energy, based on coal, gas or an energy mix, has a large impact on the LCI and LCA results. The choice of a substitution process for the electricity production might often be based on regional consensus on which process is substituted, since electricity often is fed into a regional grid. Selecting a substitution process for heat production delivered to a local district heating grid requires detailed information on the alternative production processes for heat. In some cases, a process representing the local heat substitution will not be present in the database and specific information must be gathered and a new process entered in the database for external processes. The percent of energy recovered is calculated from the lower heating value of waste input and the substituted energy amount. The lower heating value of waste input is usually not known, but can be calculated by subtracting the energy from the added fossil fuel and the process loss. The process loss is often set at 5% as a first estimate.
- **[Input – material and energy]** might be important, if materials with a high environmental production load or long transportation distance are used. Required unit is related to the processes used, typically kg, kWh, l (liter) or MJ /tonne is used.
- **[Output – "Compartment"]** can be of great importance for the air compartment in the LCI/LCA result. Data is often present in form of continuous measurements or point samples in the stack. Required unit is kg/tonne.

Technical calculations

The main calculations performed in the thermal treatment module are shown below. Calculations that are necessary for generating data on the waste fed to the technology are not shown, as these calculations are identical to those specified for the output from the preceding technological modules.

Equation 1
Lower heating value (LHV) in wet waste input to the thermal treatment in GJ/tonne:

$$LHV = \frac{\sum_{frac}\left(\left(\frac{Input\_frac}{100}\right) \times \left(Heat\_input\_frac \times \frac{TS\_input\_frac}{100} - H2O\_constant \times \frac{H2O\_input\_frac}{100}\right)\right)}{\sum \frac{Input\_frac}{100}}$$

The first bracket within the summation is the wet mass of a fraction which is multiplied with the LHV of the wet fraction. The heating value is based on the wet waste and this is calculated in the second bracket. Multiplication of the heating value of TS in the fraction with the TS amount followed by subtracting the energy needed to evaporate the water content gives the available energy of the wet waste. The sum of the energy contributions of all fractions equals the LHV in the input waste, finally divided with the input fraction in order to make sure that it is per tonne.

Equation 2
The total energy amount produced and substituting a specific process in GJ:

$$Energy\_process = (input\_mass \times LHV \times \frac{Prod\_eff\_process}{100})$$

Substitution of an external process due to energy production is defined by a substitution process and a related efficiency percentage of the overall available energy amount. The overall available energy amount is a multiplication of the LHV and the input mass. The energy substitution is then calculated by multiplying the available energy with the substitution process related production efficiency.

Equation 3
Amount of a substance in an output (such as bottom ash or fly ash) is calculated. This equation also accounts for output to air (input specific emissions = Waste_emis). The word “output” in the equation might be exchanged with the name of any output and the word “substance” might be changed to any substance.

$$Subs\_output = Input\_mass \times \sum_{frac} \left(\frac{Input\_frac}{100} \times \frac{Subs\_input\_frac}{100} \times \frac{TS\_input\_frac}{100} \times \frac{Subs\_output\_TFC\_frac}{100} \right)$$

Within the summation the fraction part is multiplied with the fraction concentration to the output. This is summed up to be the overall concentration in the output and multiplied with the waste input to equal the output mass of the substance to the output. The fraction concentration to the output is the substance concentration (in % of TS) multiplied with the TS concentration of the wet waste and multiplied with the fraction of the waste concentration routed to the given output. For C to air output the emission is multiplied with $^{44}/_{12}$ to correct C to CO_2 emission.

Equation 4
Amount of a given output is calculated from routing of the waste ash content, TS % in the output defined in the technology window and any material input routed to the output:

$$Output\_mass = \frac{\left(Ash\_output + \sum_{Material}\left(Material\_amount \times \frac{Material\_output\%}{100}\right)\right)}{\frac{Output\_TS\%}{100}}$$

The mass of ash routed to an output is calculated as the "Subs_output" where Subs is exchanged with "Ash_output". The output is added to the mass of any inputs routed to the output and multiplied with the correction factor from dry to wet mass. This factor is calculated from the entered TS % in the technology window. The routed mass of an input is calculated from the consumed mass of the material and a user defined routed %.

Equation 5
LCI calculation for a substance is the sum of process specific and input specific emissions, LCI of external processes and substitution of external processes and the overall equation looks like this:

$$LCI = \left(Input\_mass \times \sum_{Emissions}\overline{Specific\_emis}\right) + \left(Input\_mass \times \sum_{processes}\left(Process\_amount \times \overline{Ext\_LCI}\right)\right)$$
$$+ \sum_{Substances}\left(\sum_{compartment}\left(\overline{Subs\_output\_comp}\right)\right) - \sum_{Proceses}\left(Proces\_avoid \times \overline{Ext\_LCI}\right)$$

The LCI for incineration includes emissions to air, soil or water related to the waste input (like CO emissions to air) described in the first bracket in the LCI equation. The use of materials or energy (like $CaCO_3$ or Electricity) is added to the LCI with the emissions related in the second bracket. If any waste specific emissions for air are present in form of a transfer coefficient to air (like 0.003% Hg to air) the related emission is added to the LCI in the third bracket. Any products that substitute a process (like heat and power production) is subtracted the LCI with regards to the avoided emissions in the fourth bracket. For further description of the equation see the document on LCI.

Equation 6
It should be noted that substance concentrations of the outputs are not part of a LCA method but are provided in EASEWASTE to facilitate the evaluation and comparison of results with monitoring data usually expressed in concentrations.

The output substance concentration is defined as the ratio between total mass of a material output and the quantity of a substance routed to this material output (e.g. grammes of mercury per tonne of ash). Note that the concentrations are not calculated for emissions but only for material outputs.

$$Output\_subs = \frac{Subs\_output}{Output\_mass}$$

Economics

Not yet available

Variables and Constants

Constants

H2O_constant	Evaporation heating constant for H_2O at 25^{o}C (2.435 MJ/kg)

Variables

Ext_LCI	LCI table of a external process (unit/tonne)
Energy_process	The energy amount that substitute an given external process (MJ or kWh)
H2O_input_frac	Percent of H_2O per wet material fraction (%)
Heat_input_frac	Lower heating value for the specific waste fraction (GJ / tonne TS)
Input_frac	Percent of each material fraction in incoming waste
Input_mass	Input of wet waste to the technology (tonne ww)
LCI	LCI table of an technology (kg/tonne)
Material_amount	Mass of a solid material input or raw material (tonne)
Material_output	Percent of the Material_amount routed to an output (%)
Output_mass	Wet output mass from a technology
Output_subs	Table of chemical composition of an output from a technology (g/tonne)
Output_TS	User defined TS in percent for an output (%)
Prod_eff_process	Percent of overall energy amount in incoming waste that substitute an given external process (%)
Specific_emis	Emission specified for the process related only to the waste amount (kg/tonne)
Sub_input_frac	Chemical substance as a percent of total solids (%)
Subs_input_frac	Percent substance in TS in a material fraction (%)
Subs_output	Substance amount in an output (tonne)

Subs_output_TFC_frac	Transfer coefficient in percent for a substance to a given output from technology for a material fraction (%)
Total_waste	The total amount of waste generated (tonne)
TS_input_frac	Percent of total solids (TS) in wet material fraction (%)
VS_input_frac	Volatile solids (VS) as a percent of total solids (%)

16 Use-on-land

Document updated November 29, 2007 by JAM. Original document prepared by JAM, ALB and THC and controlled by AND.

The module represents the use of compost and anaerobic digest in agriculture. The module calculates the additional release of ammonia and nitrous oxide as well as additional leaching of nitrogen as a consequence of using processed organic waste on land as a substitute for manure or mineral fertilizer. The module accounts for the long term consequences of a single application of organic waste, by quantifying the releases relative to the content of organic nitrogen and ammonia in the compost or digest. The releases may be negative if the use of compost or digest releases less nitrogen than the fertilizer that would have been used otherwise. The amount of nutrients utilized by the crops results in a similar saving in production of fertilizer. The heavy metal content in the organic waste is quantified and contributes directly to human toxicity and ecotoxicity according to the impact assessment. The module employs key parameters, e.g. for leaching, that eventually should be estimated by use of an agricultural nutrient management model.

Approach

Each use-on-land dataset represents one type of organic residue used on farmland with a specified agricultural profile. The module employs process-specific (mass per ton of waste processed) material and energy use as well as process-specific emissions. Process-specific emissions are categorized according to the receiving compartment (air, surface water, soil, etc.). The module calculates the impact of the mechanical application of the waste, the impact after the processed organic waste has been applied to the soil as well as the substitution value relative to the use of mineral fertilizers or manure.

Because an agricultural field is a complex system characterized by local conditions, soil type, nutrient content in the soil, yearly sequence of crops, crop management as well as fertilizer type the module includes a user-defined agricultural profile, where data should be entered to describe the specific conditions of the application in question. The agricultural profile contains – for each crop or crop rotation - data on soil type (clay, sand or loam), leaching, surface run-off, ammonia evaporation, nitrous oxide formation and carbon binding in the soil. The user also specifies the nitrogen content of the applied waste in terms of percentages of ammonia, nitrate and organic bound nitrogen.

In most cases, organic waste will be applied to a specific field occasionally, in respect of the existing crop rotation, and as a commodity together with commercial fertilizers or animal manure. Moreover, since mineralization of the processed organic waste extends beyond a single growth season the environmental impact calculation must consider the effects also in the following years until no more emissions occur originating from the applied waste. Thus, the emission coefficients supplied by the user should quantify the extra emission in an appropriate time frame that results from the use of processed organic waste in place of commercial inorganic fertilizers or manure.

The use-on-land module includes the following processes to account for nutrients lost to the environment: volatilization (NH_3), nitrous oxide formation (N_2O), run-off to surface waters (NO_3^-) and leaching to ground water (NO_3^-). These losses result from complicated biological and chemical processes in the soil and should preferable be based on simulations using an agricultural nutrient management model. The environmental impacts of fertilizer substitution are calculated separately for N, P and K fertilizers to allow adding new fertilizer types. Datasets for the production of commercial fertilizers are provided by the model. The amount of fertilizers contained in the processed waste is calculated automatically as an output from the Biotechnology module that precedes the Use-On-Land module in a scenario.

Temporary binding of carbon will not affect the global warming. In contrast, if the application is considered to contribute to an increase of the carbon level in the soil at the end of the considered time frame, it will represent an actual decrease in CO2-release thereby contributing (by a saving) to the global warming impact. In the use-on-land module it is possible to include this effect - carbon sequestration - as a percentage of the applied carbon in the waste being permanently bound in the soil.

Processed organic waste has a certain heavy metal content, as does the commercial fertilizer substituted by the processed organic waste. The difference in input of heavy metals to soil from substitution of commercial fertilizers is included in the model. An increased level of heavy metals and organic pollutants in agricultural soil has a potential toxic impact on humans and ecosystems. Thus, the input of these substances to soil from use of compost influences the environmental impact as ecotoxicity and human toxicity as defined in the EDIP system.

The Use-On-Land module does not include all possible impacts of application of processed organic waste. Improved soil quality (including improved workability, drainage capacity, water retention capacity and biological activity, especially disease suppression) due to increased organic carbon content in the soil are at present not generally quantified with respect to the chosen output categories and are therefore not accounted for. The possibility of spreading of pathogens is not included in the model since the law-enforced (Danish/European law) heat treatment of composted or anaerobically digested waste is assumed to reduce the pathogens in the waste sufficiently.

Literature

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User instructions

A new complete dataset is established by creating a new technology and add a new agricultural profile.

A new technology is established by:

1. Select **[Waste Management] → [Technologies] → [Use-on-Land]** in the left window pane of the screen.
2. Give the technology a **[Name]**. Use-on-Land technologies in the EASEWASTE database are named according to: Type of processed organic waste, the use of the material, the type of land it is used on, country and the year of the measurements behind the data, e.g. "Composted household waste used as fertilizer on farm land [plant farming], DK, 2005".
3. **[Input – Material and Energy]** is used to list materials and energy that are used during application of the waste product on the farmland.
4. **[Input – Resources and Raw Materials]** is used to list materials that are used in the process but are not contributing to any significant emissions during their extraction or production, transport and consummation.
5. **[Output – Compartment]** is used to list the direct process specific emissions to various environmental compartments (kg/ton of wet waste).
6. **[Choose Agri. Profile]** is used for selecting the appropriate agricultural profile from a list. If a new agricultural profile has previously been established it will appear on the list.

A new agricultural profile is established by:

1. Give the profile a **[Name]**. Agricultural profiles in the EASEWASTE database are named according to: Geographical area, country and the year of the measurements behind the data, e.g. "Northern Zealand, DK, 2005".
2. **[Number of Crops]** is used to specify the number of different crops or crop rotation (one to five). For each crop a line named "crop" will appear to the left in the three tables described below under 3, 9 and 10.
3. The **[Agricultural Profile]**-table is used to specify the soil types of the agricultural profile. **[Soil Type 1 (Clayey Soil)]**, **[Soil Type 2 (Sandy Soil)]** and **[Soil Type 3 (Loam Soil)]** defines the percentage of total area (for all crops) covered by these soil types for the specified crop. The sum-total of the percentages of soil types for all crops must equal 100 as this represents the total land area on which the processed organic waste is distributed.
4. The **[Nitrogen distribution and carbon binding]**-table should be specified. **[Ammonia-N / % of Total N]**, **[Nitrate-N / % of Total N]**, **[Organic-N / % of Total N]** are used for defining the distribution of the total nitrogen contained in the processed organic waste (total nitrogen content is calculated as an output from the Biotechnology module). Only the **[Ammonia-N / % of Total N]** is used in further calculation – nitrate and organic N distribution do not have to be filled in.
5. **[Ammonia Evaporation / % of Ammonia]** is used to defining the percentage of the ammonia defined at point 4 which is evaporating to air.
6. **[Nitrous Oxide Formation / % of Total N]** is used for defining the formation and emission to air of nitrous oxide as a percentage of the total nitrogen content.
7. **[Carbon Binding / % of Carbon]** is used for defining the percentage of carbon originally contained in the material which is still in the soil after 100 years.

8. The **[Substitution of fertilizers]**-table should be specified. Right-click on [Fertilizer Name] to add a new line in the **[Substitution of fertilizers]**-table. Each line represents one substance which can be replaced by the processed organic waste. Double-click on the column named [New] and choose the appropriate fertilizer from the pop-up window. The list of substance is the same as defined in the waste composition. N, P and K are typically the fertilizers substituted. The **[Amount]** will be calculated inside a scenario and it is the output from the Biotechnology module. The utilization in percent of the substituting fertilizer should be specified in the **[Utilization-%]** column. To specify a fertilizer dataset double-click the **[Fertilizer dataset]**-column, choose **[Material Production]** followed by **[Fertilizer Production]** and choose the correct dataset.
9. The **[Surface Water Coefficients]**-table should be specified. For each **[Crop]** and **[Soil Type]** fill in a coefficient in percent of total nitrogen supplied with the waste product that describes the nitrate loss through run-off and drainage.
10. The **[Groundwater Coefficients]**-table should be specified. For each **[Crop]** and **[Soil Type]** fill in a coefficient in percent of total nitrogen supplied with the waste product that describes the nitrate loss through run-off and drainage.

Data requirements

When collecting data for creating a new dataset for the use-on-land module the user should consider the following points:

- Estimation of key processes, for example accumulated leaching of nitrate over a longer time period, is very complicated and ultimately requires the use of an agricultural nutrient management model. In Bruun et al. (2006) dataset representing different scenarios from Danish agriculture can be found, but these data should be used with discretion as they are applicable only under certain conditions specified in the paper.
- **[Nitrogen distribution]** among different forms depends in principle on how the biological treatment has been performed. This estimation, especially of ammonia content, is important as this may be an important emission to air.
- **[Ammonia Evaporation]** and **[Carbon Binding]** depend on agricultural procedures and weather conditions. The literature is only partly covering these issues on a local level. Moreover, **[Carbon Binding]** might have a significant influence on the final result of the assessment, especially considering the crediting on global warming that will result from just a few percents of carbon left in the soil at the end of the considered time period.
- All the mentioned parameters are calculated for a single application of the processed organic waste. In a system with repeated use of processed waste on the same area over several years environmental effects may not be directly proportional to a single application Repeated application of processed waste is, therefore, not consistent within the scope of the LCA, as performed in EASEWASTE.

Technical calculations

The main calculations performed in the Use-On-Land module are shown below. Calculations that are necessary for generating data on the waste fed to the technology are not shown, as these calculations are identical to those specified for the output from the preceding technological modules.

Equation 1
Amount of commercial fertilizer substituted by processed organic waste (kg):

$$Mass\_avoid = Input\_mass \times \frac{TS\_input}{100} \times \frac{Sub\_input\_frac}{100} \times \frac{Subs\_eff\_avoid}{100} \times 1000 \frac{kg}{tonne}$$

The equation is in general terms and a list of substances to be substituted is available. Most often, the substituted substances will be N, P, K. These nutrients contained in the processed organic waste will substitute commercially produced fertilizer. The utilization efficiency of the nutrients depends on different factors such as the mineralization rate of the processed organic waste after application to soil. The amount of nutrient (or other substance) carried by the input material (e.g. compost) is calculated by multiplying the first two terms (total mass and concentration). The last term is accounting for the utilization efficiency and is user defined. For some compounds such as P and K the efficiency can reach 100%, while the efficiency for nitrogen usually is much lower.

Equation 2
Amount of ammonia emitted to air (kg):

$$NH3\_output\_air = Input\_mass \times \frac{TS\_input}{100} \times \frac{N\_input}{100} \times \frac{NH3\_N}{100} \times \frac{NH3\_evap}{100} \times \frac{Molar\_NH3}{Molar\_N} \times 1000 \frac{kg}{tonne}$$

Processed organic waste contains nitrogen in different forms. Some of the nitrogen in the form of ammonia will evaporate to the atmosphere when applied to soil. The equation describes the amount of ammonia emitted to air. The first three terms calculate the total amount of nitrogen applied on land. The fourth and fifth terms are user defined and account for how much of the nitrogen is in ammonia form and how much of the ammonia is evaporating.

Equation 3
Amount of nitrous oxide emitted to air (kg):

$$N2O\_output\_air = Input\_mass \times \frac{TS\_input}{100} \times \frac{N\_input}{100} \times \frac{N2O\_N}{100} \times \frac{Molar\_N2O}{Molar\_N2} \times 1000 \frac{kg}{tonne}$$

Some of the nitrogen applied with the waste is emitted to the atmosphere as N_2O. The equation describes the amount of N_2O emitted to air. The first three terms calculate the total amount of nitrogen spread on land. The fourth term is user defined and account for how much of the total nitrogen in the input to the process is emitted in N_2O form.

Equation 4
Amount of nitrate in run-off to surface water after application of processed organic waste to soil (kg):

$$NO3\_runoff = Input\_mass \times \frac{TS\_input}{100} \times \frac{N\_input}{100} \times \frac{NO3\_N}{100}$$
$$\times \left(\sum_{i=1}^{i=3} \sum_{m=1}^{i=n} \left(Soil\_frac_{i,m} \times NO3\_runoff\_frac_{i,m} \right) \right) \times$$
$$\times \frac{Molar\_NO3}{Molar\_N} \times 1000 \frac{kg}{tonne}$$

Some of the nitrate in the applied waste will be lost as run-off to surface water bodies. The soil/crop table is user defined. The table has three columns for the three types of soil (i=1,2,3 for clay, sand, loam). The number and type of crops is user defined to a maximum of five (max n=5). The sum of all the coefficients in the table must equal 100. The run-off coefficients table has the same number of lines and columns as the soil/crop table.

The equation describes the amount of NO_3 reaching surface water. The first three terms calculate the total amount of nitrogen applied on land. The fourth term is user defined and accounts for how much of the total nitrogen applied on the field is in NO_3 form. The double summation is calculating the weighed run-off coefficient. This is done by multiplying each single run-off coefficient with the respective area percentage covered by that specific soil/crop combination.

Equation 5
Amount of nitrate leaching to groundwater after application of processed organic waste to soil (kg):

$$NO3\_leach = Input\_mass \times \frac{TS\_input}{100} \times \frac{N\_input}{100} \times \frac{NO3\_N}{100}$$
$$\times \left(\sum_{i=1}^{i=3} \sum_{m=1}^{i=n} \left(Soil\_frac_{i,m} \times NO3\_leach\_frac_{i,m} \right) \right)$$
$$\times \frac{Molar\_NO3}{Molar\_N} \times 1000 \frac{kg}{tonne}$$

Some of the nitrate in the applied waste will leach to groundwater. The equation describes the amount of NO_3 reaching groundwater. The calculation is the same as in Equation 4 with “run-off” substituted by “leach”.

Equation 6
Avoided emissions of CO_2 to the atmosphere due to carbon binding to soil (kg):

$$CO2\_bind\_soil = Input\_mass \times \frac{TS\_input}{100} \times \frac{C\_input}{100} \times \frac{C\_bind\_frac}{100} \times \frac{Molar\_CO2}{Molar\_C} \times 1000 \frac{kg}{tonne}$$

When processed organic waste is used on land, the carbon content will slowly degrade and be released to the atmosphere as CO_2. Within the time horizon of the assessment not all the carbon will be converted and a fraction of it will remain in the soil after 100 years. This represents a carbon sink and (saved) CO_2-eq emissions will be credited to the system. The equation is calculating the avoided emissions of CO_2 due to carbon binding to soil. The first three terms calculate the amount of carbon contained in the output from the Biotechnology module. The forth term is user defined and accounts for the percentage of carbon bounded to soil.

Equation 7
Amount of biological CO_2 emitted to the atmosphere (kg):

$$CO2\_output\_air = Input\_mass \times \frac{TS\_input}{100} \times \frac{C\_input}{100} \times \frac{(100\text{-}C\_bind\_frac)}{100} \times \frac{Molar\_CO2}{Molar\_C} \times 1000\frac{kg}{tonne}$$

When processed organic waste is applied on land, the carbon contained will slowly degrade and be released to the atmosphere as CO_2. The equation is calculated these emissions of CO2. The first three terms calculate the amount of carbon contained in the output from the Biotechnology module and used on land. The forth term accounts for the fact (explained in equation 6) that part of the carbon is bound to soil and not released as CO_2. A very small amount of the carbon emitted as CO_2 will originate from degradation of material fractions in the processed waste containing fossilized carbon, this is included in the formula.

Economic calculations

Not yet available.

Variables and Constants

Constants

Molar_N	Molar weight of nitrogen (14.01 g/mole)
Molar_N2O	Molar weight of nitrous oxide (44.02 g/mole)
Molar_NH3	Molar weight of ammonia (17.03 g/mole)
Molar_NO3	Molar weight of nitrate (62.00 g/mole)

Variables

CO2_bind_soil	Amount of CO_2 emission avoided by carbon binding to soil (%)
CO2_output_air	Amount of CO_2 emitted to air (kg)
C_bind_frac	Percent of C bounded to soil after 100 years (%)
Input_mass	Input of wet mass to the technology (tonne)
Mass_avoid	Mass that is avoided due to a substitution process (tonne)
N_input	Nitrogen as a percent of TS (%)
N2O_N	Percent of N in N2O form (%)
N2O_output_air	Amount of nitrous oxide emitted to air (kg)
NH3_evap	Percent of NH3 evaporated (%)
NH3_N	Percent of N in NH3 form (%)
NH3_output_air	Amount of ammonia emitted to air (kg)
NO3_N	Percent of N in NO3 form (%)
NO3_leach	Amount of nitrate leaching to groundwater after application of processed organic waste to land (kg)
$NO3\_leach\_frac_{i,m}$	Percent of applied NO3 in run-off for a soil with composition –i and used for crop rotation –m (%)
NO3_runoff	Amount of nitrate in run-off to surface water after application of processed organic waste to land (kg)
$NO3\_runoff\_frac_{i,m}$	Percent of applied NO3 in run-off for a soil with composition –i and used for crop rotation –m (%)
Prod_eff_avoid	Percent of input that substitutes a given external process (%)
$Soil\_frac_{i,m}$	Percent of area with soil composition -i and used for crop rotation –m (%)
Subs_input_frac	Percent substance in TS in a material fraction (%)
TS_input	Percent of total solids (TS) in wet input (%)

17 Flow

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Flow comprises approximately 1000 different substances constituting the environmental exchanges of an LCA. It consists of ten compartments, e.g. air, water and soil. Resources and raw materials, and solid emissions are part of the flow as well. The majority of substances are linked to an assessment category. All assessment categories from EDIP97 (Wenzel *et al.*, 1997) are available; the same applies for all substances with an EDIP characterization factor.

Approach

Flow is the overall term for the substances included in EASEWASTE. The term is chosen as the substances constitute the environmental exchanges (flowing in and out) from the waste technologies and external processes. It is divided into nine compartments five of which can be considered as true recipients: Air, Fresh Surface Water, Groundwater, Marine water and Soil. Additional, *Flow* contains Resources and Raw Materials constituting the pool of resources used in the program. Solid Emissions are different waste fractions generated. Stored Emissions to Soil and Water, respectively, are emissions with long-time leaching properties.

The substance list is comprised of substances from different sources. All substances used in the waste technologies and external processes are included, but also all the substances included in the EDIP97 method (Wenzel *et al.*, 1997). It differs which substances the compartments contain and likewise does the number of substances. 17 substances are included in the compartments comprising the stored emissions to soil and water, whereas the compartment comprising air emissions contains more than 400.

The substance list includes four columns: Substance, Unit, Reference and Link. The unit of the substances is “kg” with a few exceptions for resources and raw materials. A few substances in this compartment have “m^2” or “MJ” as unit. The reference column provides information about the source of characterization factor for the specific substance (except for Resources and Raw Materials as the substances of this compartment do not need to be characterized).

When EDIP is the reference the characterization factors used are the ones used for the EDIP97 method. This applies to air emissions (except for benzene and vinyl chloride – the characterization factors of these substances have been reduced with a factor 100 for human toxicity via soil), emissions to fresh water and marine water, and soil emissions. The newest and most updated version of the factors is used (LCA Center, 2004). The factors were updated last time in 2002 (Frees *et al.*, 2002). When no reference is given it means that no characterization factor exists for the substance. This does not necessarily mean that the environmental load of the substance is zero; just that it will not be included in the LCIA. Groundwater emissions have three different references: EDIP, ROAD-RES and BEK nr. 871 (Miljøstyrelsen, 2005).

Emissions to marine water are special in the sense that the characterization factors for this compartment are identical to the ones used for fresh surface water. EDIP97 only provides characterization factors for fresh water and in most cases they will be sufficient for modeling environmental impacts for marine water as well. However, e.g. salts released to a marine environment do not cause as much damage as to fresh water. New factors for marine water emissions have not yet been developed, but they should substitute the current ones, when they are established.

The reference for solid emissions is stated as EDIP. This should be understood as the emissions are contributing to one of the four waste categories contained in EDIP97 (Bulky waste, Hazardous waste, Slag and ashes, and Radioactive waste). To make the correct categorization requires knowledge about what kind of treatment the waste fraction will receive. This can be a difficult task, since this kind of information is often unavailable, or the name of the waste fraction makes it difficult to categorize the waste fraction. The latter has been the case for the majority of the solid emissions as they stem from external processes and thus have not been established by the developers of EASEWASTE. Consequently, not all solid emissions are linked to a waste category.

Stored emissions to soil and water also have EDIP as reference. This is true in the sense that the characterization factors for these compartments are identical to the ones for fresh water and soil (ecotoxicity). The assessment categories for stored emissions are, however, not part of the original EDIP97 method, but were developed by Hansen *et al.* (2004).

The last compartment, resources and raw materials, has EDIP, GaBi and ROAD-RES as reference. When the reference is EDIP it means that a normalization reference and weighting factor are provided by EDIP97. The opposite is the case for resources with GaBi as reference; they cannot be accounted for environmentally in an LCA using the EDIP method as they do not have a normalization reference and weighting factor. Substances with ROAD-RES as reference stem from the development of ROAD-RES (Birgisdóttir *et al.*, 2007). Normalization references and weighting factors are not provided for these substances.

The last column, Link, is used for indicating whether a substance is linked to an impact category or not. The only exception is resources and raw materials as the substances in this compartment linked to ROAD-RES only are accounted for in an LCI.

Literature

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User instruction

A new dataset is established through:

1. Choose **[Basic In & Outputs] → [Flow].**
2. Choose the wanted **[Compartment]** (click on it so it is marked), click in the area under **[Substance List]** and choose **[New]**.
3. Fill in **[Name]**, **[CAS Number]**, chemical formula **[Ch. Formula]** and a reference.
4. To fill in the standard unit **[Std. Unit]** click the icon with the red arrow (next to **[Description]**). A new window shows up. Choose **[Technical Units]** and **[Mass]**. Double-click on **[Mass]**.
5. To link the substance to an impact category, click **[New Entry]** and it turns green. Double-click and it says **[New]**. Double-click again and a new window shows up. Click on the wanted category and pick the right impact category by double-clicking. The **[Unit]** related to the chosen category is automatically generated and cannot be changed. Key in the characterization factor.

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18 External Processes

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This feature comprises more than 100 processes constituting background data for modelling waste scenarios. The processes represent data for numerous production (materials and energy) and recovery processes, disposal processes and transportation. The processes employ data for consumption of resources and raw materials, emissions to air, water and soil emissions. A common unit is kg emission per kg or kWh. The majority of the processes originate from EDIP (2002), but other data sources have been used as well. The user has the possibility of establishing new processes; instructions for this are presented in the end of this chapter.

Approach

The external processes constitute background information necessary for modelling of most waste scenarios. These processes are not waste specific nor necessarily site-specific, instead they provide information about the production of, e.g. 1 kWh of electricity or 1 kg of steel. Essential for modelling of the processes is especially knowledge about the energy use, the resource consumption and emissions to air, water and soil.

Type and origin

Six main categories exist for the external processes: Construction Processes, Disposal Processes, Energy Production, Material Production, Material Recovery and Transportation. Each category consists of 1 to 8 sub-categories which may contain more than twenty processes. Most processes originate from the Danish EDIP database (EDIP, 2002). Other processes have been customized for EASEWASTE. Currently, EASEWASTE contains more than 100 processes which can function as default data. The source for each process is stated in the documentation field (inside the program) for every single process.

The first category, Construction Processes, contains 6 sub-categories all developed for the LCA model, ROAD-RES, a tool for assessing the environmental impacts of road constructions and use/disposal of residues from waste incineration (Birgisdóttir *et al.*, 2007). The category provides data for, e.g. soil movement, cement production, extraction of gravel and upgrading of MSWI residues. The data should be used, however, with reservation as the data have not been checked after the import to EASEWASTE 2008.

The second category, Disposal, contains more than twenty processes for incineration of different materials, especially plastic and paper. All processes originate from the Danish EDIP database (EDIP, 2002). This category could as well contain data for landfilling of different materials.

The third category, Energy Production, contains 5 sub-categories. The first sub-category, Electricity Production – Grid, contains information of electricity production to the grid in different countries. The Danish processes are further divided between electricity production/electricity consumption and energy content/energy quality. Electricity production comprises data for electricity produced at Danish plants (the amount of electricity which leaves the plant) whereas electricity consumption comprises data delivered to the consumer (a mixture of Danish and foreign electricity). Energy content/energy quality are two extreme allocation points used for allocating resource consumption and emissions to heat and power (electricity), respectively, when production takes place at combined heat and power plants. Energy content holds heat and power together in energy units (1 kWh heat = 1 kWh electricity), whereas energy quality takes the quality of electricity (exergy) into account (1 kWh heat = 0.15 kWh electricity). Using energy content as basis of allocation ascribes the benefits of co-production to electricity, whereas energy quality ascribes the benefits to heat (Energi E2 *et al.*, 2000). All processes but the German originate from EDIP (2002). More information about the Danish processes from 2001 can be found in Energi E2 *et al.* (2003).

The second sub-category, Electricity Production – Single Technology, contains data for electricity based on only one energy source, e.g. natural gas, coal or biomass. They all holds data for electricity production and most of them are divided between energy content and energy quality. More information about the processes covering Danish Electricity production 2001 can be found in Energi E2 *et al*. (2000) and Energi E2 *et al.* (2003). The majority of the processes originate from EDIP (2002).

The third and fourth sub-category, Fuel Combustion and Fuel Production, employ data for combustion and production of different fuels, respectively. Note that Fuel Combustion also includes production/extraction of the fuel (except the two processes for paper combustion), unlike Fuel Production which only covers production/extraction. The majority of the processes originate from EDIP (2002).

The last sub-category is Thermal Energy Production, i.e. heat production. More information about the processes covering Danish District Heating 2001 can be found in Energi E2 *et al.* (2000) and Energi E2 *et al.* (2003). The majority of the processes originate from EDIP (2002).

The fourth category, Material Production, contains 6 sub-categories e.g. production of plastic, paper, and steel and metal. The majority of the processes employ data for production based on virgin materials, some of the metal production, however, is partly based on recycled materials. The processes for fertilizer production are based on Audsley *et al.* (1997), Davis & Haglund (1999) and Patyk & Reinhardt (1997). Glass production, steel and metal production, and most processes for plastic production and mixed materials originate from EDIP (2002). Most of the processes for paper production have been customized for EASEWASTE. Note that some of the processes for mixed materials have been marked with an asterisk (*) meaning they do not contain any data. The reason for having these processes in the database is that they are used in some of the waste technologies modeled by the EASEWASTE developers. For example is “TMT 15” used in some of the thermal treatment technologies for precipitation of heavy metals in the waste water from the flue gas cleaning. No data was available for the production of TMT 15, but instead of leaving the product out of the LCA the amount of TMT 15 used is accounted for and will be part of the LCI.

The fifth category, Material Recovery, contains 5 sub-categories for recovery of materials, e.g. recovery of plastic, paper, and steel and metal. All processes but the 5 for tire disposal originate from EDIP (2002). The latter are based on Spriensma *et al.* (2001). Note that the processes for tire disposal also comprise the production of the avoided product, e.g. vinyl for sports surfaces.

The sixth and last category, Transportation, contains 3 sub-categories: railway transportation, road transportation and waterway. It is possible to choose among different loads of the vehicles and different traffic situations.

Units

The unit of the external processes differs depending on the type of process. The most common unit is per kWh (all energy processes) and per kg (disposal, material production, material recovery). The unit of the transportation processes is per liter fuel or per kgkm. Resource consumption and emissions are all in kg. The unit of energy consumption is kWh. This will be further described under User instruction.

Terminated processes

The external processes can either be terminated or non-terminated. A terminated process is a process where all exchanges have been quantified directly to the environment, i.e. all inputs directly from nature (resource consumption) and all outputs directly to the recipient (air, water, soil) (Wenzel *et al.*, 1997). The final unit, in EASEWASTE, it is kg, since all energy consumption, resources and emissions have been quantified. In the framework of LCA it is important to keep in mind that production of a product in principle comprises all steps in the life-cycle of the product. For production of 1 kWh of electricity this means that the process comprises all steps from extraction of energy resources (e.g. coal), transportation of the energy resource, combustion in a power plant and maybe distribution and transmission of the produced electricity. In reality the product system is infinite and it is thus not possible to include all processes or to terminate all exchanges. One has to decide how many levels of the product system to include and be aware that the magnitude of exchanges will decrease the more levels one goes back. A non-terminated process in EASEWASTE can be terminated by pushing the icon looking like √ or in File choosing Terminate Dataset.

Literature

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User instruction

A new dataset is established by:

1. Choose [**External Processes] → [Process List]**
2. If you want to establish a new category, right-click in the area under **[Category]** and choose **[New].** Name the category by stating the type of material/energy produced/recovered/handled and the year of the data.
3. If you want to establish a new sub-category, click on the associated **[Category]** so it is marked, right-click in the area under **[Sub-Category]** and choose **[Add Folder]**. Name the new sub-category.
4. To establish a new process, click on the associated **[Category]** so it is marked, right-click in the area under **[Sub-Category]** and choose **[New Process].** A new window shows up. To name the new process, click twice (necessary almost everywhere in the program) in **[Name]** and write the name. In the area under **[Amount]** press 1, as the unit of an external process always is 1 kg, 1 kWh, etc. Choose the proper unit by clicking twice in the area under **[Unit]**. An arrow shows up and by clicking it you can scroll down and pick the wanted unit. Note that not all units should be chosen. The same is repeated for **[Category]**; a list of sub-categories shows up depending on the chosen category. If Material Production is chosen, the list will contain Plastic Production, Steel and Metal Production, Paper Production, Fertilizer Production, Glass Production and Mixed Materials. Choose the right one. The last field **[Comments]** can be used for e.g. providing a name for a reference.
5. The next to key in are environmental exchanges (inputs and outputs). Click **[Inputs]** and a new window shows up.
6. **[Input – Material and Energy]** is used to list materials and energy that are consumed (or produced) in the established process. Click **[New Entry]** and it turns blue. Double-click and it says **[New]**. Double-click again and a new window shows up. Click on the addition sign of the wanted category and the sub-categories will show. Choose a sub-category by clicking it and finally a process by double-clicking on the process. The **[Unit]** related to the chosen process will automatically be generated and cannot be changed. Key in the **[Amount]** consumed. If something is produced, key in a sign of subtraction first. The last four fields of the row can be left blank. Repeat this point if more processes are needed. Note that only terminated processes must be chosen, otherwise the program cannot perform the final calculations.
7. **[Input – Resources and Raw materials]** is used to list resources and raw materials consumed in the established process. Point 6 should be repeated, but it will be another window showing up. This window contains ten compartments with environmental exchanges. Click on **[Resources and Raw Materials]** and choose the wanted substance from the **[Substance List]** by double-clicking on the substance. Make sure the right compartment is chosen.
8. This step should be repeated for the outputs as well. For **[Water Emissions]** three different compartments exist (fresh water, marine water and groundwater). If it is not known to which compartment (recipient) the substance will be released, choose fresh water by default. **[Solid Emissions]** covers waste generated in the process. **[Stored Substances with Potential Emissions to Water/Soil]** covers substances stored in e.g. landfilled waste which will not be emitted within a timeframe of 100 years.

9. **[Documentation]** in the top of the window is used for writing documentation about the process, e.g. technology, location and data quality.

Data requirements

When collecting data for creating an external process no data are more important than others. However, the data easiest to get access to (e.g. from green accounts) are normally consumption of resources and raw materials, emissions to water and air, and solid emissions (waste). Emissions to soil are seldom measured or estimated (or may not exist). Stored emissions are especially relevant if a large part of a product is being landfilled, or if the external process is generating a large amount of waste. Normally, these data will not be available and will have to be estimated. If that is not possible, the waste fraction can be accounted for as a solid emission.

19 Evaluation

Updated 2008-01-07 (THC). Original document prepared by THC and AWL. Controlled by AND.

The evaluation database contains three files: Assessment Categories (containing existing and potential assessment categories), LCA Methods (containing available impact assessment methods and their associated normalization and weighting references) and Cost Methods (containing the available cost assessment methods and their associated unit costs). These are briefly explained.

The four potential steps in evaluating a scenario are described: Life cycle inventory (LCI), life cycle impact assessment (LCIA), normalization, and weighting. Graphical facilities are presented and Sensitivity Analysis and Sensitivity Ratios are explained as well.

Approach

Evaluation: Assessment Categories: This file lists active as well as potential assessment categories. The active assessment categories are:

- Environmental assessment
- Resource consumption
- Waste quantities

Not yet active assessment categories are Economic Assessment (expected by summer 2008), Energy Assessment and Working Environment Assessment.

Environmental Assessment contains all environmental impact categories included in any of the LCA methods available in EASEWASTE: They are given by name and LCA method. By double-clicking, a list appears showing all the substances and their characterizations factors contributing to the environmental impact category. Substances can be added or removed, and characterization factors can be edited. When adding new substances to a category, the Flow list is opened automatically and the substances must be selected from this list and linked to the actual environmental assessment category.

Resource Consumption contains all resource consumption categories included in any of the LCA methods available in EASEWASTE: They are given by name. By double-clicking, a list appears showing all the substances and their characterizations factors contributing to the resource consumption category. Substances can be added or removed, and characterization factors can be edited. When adding new substances to a category, the Flow list is opened automatically and the substances must be selected from this list and linked to the actual environmental assessment category.

Waste Quantities contain all secondary waste streams included in any of the LCA methods available in EASEWASTE: They are given by name (Bulky Waste, Hazardous Waste, Ash and Slag, Radioactive Waste). By double-clicking, a list appears showing all the flows and substances and their characterizations factors contributing to the waste quantities. Substances can be added or removed, and characterization factors can be edited. When adding new substances to a category, the Flow list is opened and the substances must be selected from this list and linked to the actual environmental assessment category. The Waste Quantities assessment is needed because several upstream as well as down-stream processes may contain such quantifications as part of their environmental profile.

LCA-methods: EASEWASTE uses as default a mid-point impact assessment method. The EDIP method *(Wenzel, H., Hauschild, M. Alting, L. (1997) Environmental assessment of products, vol. 1: Methodology, tools and case studies in product development, London, Chapman & Hall)*. Other impacts assessment methods can also be used, e.g. Eco-indicator and IPCC, but these are currently not supported although available.

The impact assessment method aggregates all the inventory data into relatively few impact categories representing environmental burdens as well as resource consumption.

The environmental impacts are described as potential environmental impacts to all relevant emissions no matter where and when they take place. Positive potential impacts are burdens to the environment, while negative potential impacts are savings to the environment. The potential environmental impacts according to EDIP are:

- Global Warming: aggregates all greenhouse gas emissions into CO_2-equivalences (kg CO_2).
- Nutrient Enrichment: aggregates all nutrient enriching emissions into NO_3-equivalences (kg NO_3)
- Acidification: aggregates all emissions leading to acidification into SO_2-equivalences (kg SO_2)
- Ecotoxicity in Soil and Water: aggregates all toxic emissions potentially impacting the environment into m^3 soil or water (m^3)
- Human Toxicity via Soil, Air and Water: aggregates all toxic emissions potentially impacting the human health into m^3 soil, air or water (m^3)
- Stratospheric Ozone Depletion: aggregates all emissions leading to stratospheric ozone depletion into CFC11-equivalences (kg CFC11)
- Photochemical Ozone Formation: aggregates all emissions leading to photochemical ozone formation into C_2H_4-equivalences (kg C_2H_4).

Resource Consumption covers consumption of resources such as fossil fuels, metals and renewable resources. Geological construction materials like gravel, sand, clay and limestone are not included in the impact assessment. Resources are used as input for production of energy and materials or as auxiliary materials. Recycling and utilization of materials and energy may cause savings of resources which are also considered in the calculation of resource consumption. The inventory of resources is calculated as the mass of pure resources used, not the mass of ore materials. Characterization factors for pure resources as well as ore materials are available in the EDIP method.

Additional Impacts: In order to represent the environmental concerns and features of waste management, two additional impact categories have been introduced:

- Spoiled Groundwater Resources: leaching from landfills, from bottom ashes used in road construction, and from compost spread on land are important environmental concerns. The majority of technical measures and cost of landfilling are introduced in order to limit the migration of leachate into groundwater. However groundwater pollution is traditionally not included in LCA impact assessment because no exposure and hence toxicity are related to leachate entering groundwater. The exposure and potential toxicity depend on how the groundwater is used and where it discharges into surface water. In addition many substances in leachate that potential could spoil groundwater are not as such toxic.

The Spoiled Groundwater Resource is quantifying the leaching into groundwater by the amount of groundwater that is needed to dilute the leachate so that it meets drinking water standards. The impact is the sum of each substance assuming that the diluting groundwater does not contain the substance. The approach is similar to the approach used for quantifying Human Toxicity and Ecotoxicity.

- Stored Ecotoxicty: ashes used in road construction and waste in landfills contain even after 100 years, which often is used as a the cut-of time frame value in EASEWASTE, significant amounts of substances, e.g heavy metals, that should not be forgotten. In order to quantify this stock of material and keep it in the assessment we ascribe it a potential of Stored Toxicity to Water and Stored Toxicity to Soil. The categorization factors are similar to those for Ecotoxicity to Water and Ecotoxicty to Soil. The amounts of substances stored are as default assigned 50% to Stored Toxicity to Water and 50% to Stored Toxicity to Soil. These values represent what might impact the soil and water after the considered time period in the study. The time frame can be set by the user.

***Person equivalents*:** The categories of environmental impact and resource consumption are normalized to show the relative magnitude of each category. Normalization gives an impression of which impact categories are large or small by comparing them to a reference common for all categories. The normalization references in the EDIP method are the annual environmental impact or resource consumption of one person in each of the categories. The environmental load of the waste management system is thereby set in relation to the total environmental load of the society. The impact potential or resource consumption of a given category is divided by the corresponding normalization reference, and the unit of the normalized results is Person Equivalents (PE). All categories of environmental impact and resource consumption are assigned the same unit and thereby made comparable.

The normalization references are for the normal impacts taken from Stranddorf et al. (2005). For the Stored Toxicity the values are based on a study from the Danish EPA (Hansen, E., 2004). The impact for spoiled groundwater is normalized with regards to the amount of contaminated groundwater per person per year in Denmark (2900 m³/person/year (DMU & DJF, 2003)). This is therefore a very local normalization reference and should be kept in mind.

Weighting: Furthermore, the user can choose to assign a weight to each category if they are of unequal importance. The weighting method is as default the EDIP method. Environmental impacts are weighted by political reduction targets, and resources are weighted by their supply horizon. The weighing factors were updated in 2004 based on LCA-center (2004), the factor for phosphorous were based on Hauschild (2009).

Normalization references and weighting factors are found by double-clicking on the actual method under **[LCA method → Group]**

Cost methods: Will be available in a later version

Literature

Danmarks Miljøundersøgelser & Dansk Jordbrugsforskning, DMU & DJF, 2003. Vandmiljøplan II: Slutevaluering (In Danish). Danmarks Miljøundersøgelser. Miljøstyrelsen, Copenhagen. Denmark

Hansen, E. (2004). Livscyklusvurdering af deponeret affald. (Life cycle assessment of landfilled waste, in Danish). Miljøministeriet, Miljøstyrelsen, Copenhagen, Denmark. (Miljøprojekt 971).
LCA-center: UMIP97-faktorer. Link: http://www.lca-center.dk/cms/site.aspx?p=1595 (last accessed on Dec 29th 2010).

Hauschild, M. (2009). Personal Communication.

Stranddorf, H.K., L. Hoffmann & A. Schmidt (2005a) Update on Impact Categories, Normalisation and Weighting in LCA. Selected EDIP97-data. Environmental Project Nr. 995 2005. Miljøprojekt. Danish Ministry of the Environment. Environmental Protection Agency. Copenhagen, Denmark.

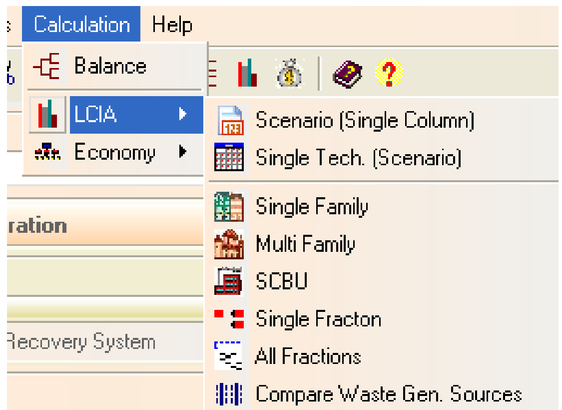
Stranddorf, H.K., L. Hoffmann & A. Schmidt (2005b) Impact categories, normalisation and weighting in LCA. Updated on selected EDIP97-data. Environmental news No. 78. Danish Ministry of the Environment. Environmental Protection Agency. Copenhagen, Denmark.

Wenzel, H., Hauschild & M. Alting, L. (1997) Environmental assessment of products, vol. 1: Methodology, tools and case studies in product development, London, Chapman & Hall.

User instruction

Running an Evaluation

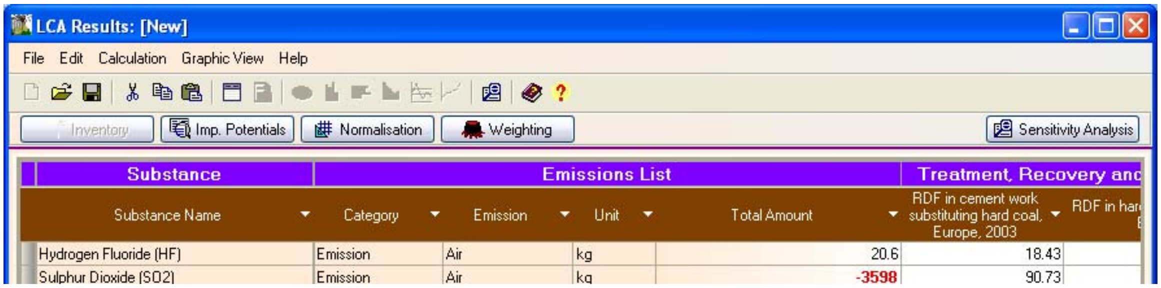
In order to evaluate a single technology or a scenario you either click the button, or you choose **[Calculation]** in the top bar of the window. A calculation can be run for either a single technology, a full scenario, or an individual technology under a scenario with the waste routed to it. The **[Calculation]** button open up for a number of options depending on the type of scenario or technology that is chosen. The figure below shows all the possible options.



1. The [**Balance]** button gives a mass balance overview of the scenario, where the flow of the mass of the waste through different technologies can be seen
2. **[LCIA]** is used for the Life Cycle Impact Assessment of the scenario or individual technology.
    1. **[Scenario (Single Column)]** is the standard assessment and is also what is found by pressing the button. This aggregates all the emissions from all the technologies into one column with totals for each emissions. This includes all data from Single- and Multi family as well as SCBU
    2. **[Single Tech. (Scenario)]** will give a table where each technology is listed as an independent column.
    3. **[Single Family]**, **[Multi Family]** and **[SCBU]** will give only that part of the scenario. Data will be given similar to **[Single Tech. (Scenario)]** as individual columns.
    4. **[Single Fraction]** allows the user to choose one source separated waste fraction, and calculate the LCIA for that one.
    5. **[All Fractions]** will give an overview similar to **[Single Tech. (Scenario)]** but where each technology is listed together with other technologies of their kind.**[Compare Waste Gen. Sources]** will show **[Single Family]**, **[Multi Family]** and **[SCBU]** in each their results table and they can then be compared

[Economy] will be available from summer 2008.

After having chosen one of the above options under **[Calculation]** a screen like the one below will appear.



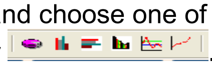
On this screen is seen four buttons to the left and the **[Sensitivity Analysis]** to the right, the following is a short description of each button.

1. **[Inventory]** is the default calculation first shown by the program. This is the life cycle inventory (LCI) list of all emissions that are included in the chosen technologies. Each emission is also given a category, emission type and unit so it is possible to get a quick overview. If interested in getting a more detailed overview of a process or technology this is possible by selecting a column and right clicking it. By choosing **[Calculate Selected**] the user will then be given a new table with a detailed overview of the chosen column representing a technology.
2. Based on the LCI the impact potentials can be calculated by pressing **[Imp. Potentials]**. Afterwards it is necessary to select a method (default is EDIP97) and a category group (default is all EDIP 97 environmental impacts). By default the potential impacts are chosen per emission, but by clicking **[Processes]** it is possible to get the impacts per process technology. The user can get back to an emission overview by selecting **[Sub. Style]**. Furthermore it is possible to get an overview of the sensitivity as explained later, by clicking **[Sensitivity Ratio].**
3. **[Normalization]** shows the impacts normalized with regards to the normalization references set for the category group chosen under **[Imp. Potentials]**. They can also be shown as both **[Processes]** and **[Sub. Style]**.
4. Similarly by pressing **[Weighting]** it is possible to get the weighted result, which uses the weighting factors chosen for the category set under **[Imp. Potentials]**.
5. **[Sensitivity Analysis]** allows the user to run an analysis of the sensitivity of the different processes which is a part of the calculated scenario.

In each of the abovementioned tables it is possible to move columns and to sort within a column according numerical importance

Graphical output and export

There are a number of graphical outputs, and export options available for the calculated results. They are shown here below.

1. It is possible to get a graphical overview of the results found in **[Imp. Potentials]**, **[Normalization]** and **[Weighting].** These options can be accessed by clicking **[Graphical View]** in the top bar, and choose one of the graph options or choosing one of the Graph icons below the top bar .

2. All the values shown can be exported to Excel for easier access to other graphical settings, or if only some numbers are to be used. This is done by either right clicking the table and choosing **[Export File]** or if a number of columns or rows are selected by choosing **[Export Selection]**.

Sensitivity Analysis

The sensitivity analysis is used to assess how sensitive the overall LCI is to specified changes in a single process or changes in selected processes. The user defines the changes as percentage improvement in the LCI of the selected processes

1. In a scenario, the LCI table holds the tab **[Sensitivity Analysis]**. It may be useful to extend the LCI table to the full scenario having each contributing process appear as a column before the sensitivity analysis is shown. Activate **[Sensitivity Analysis]**. A table appears having all the individual processes as rows. The column **Analysis** allows for dining an improvement percentage for each process. A 100% improvement is equal to removing the process. The user can specify any percentage for each process. Using **[Calculate]** allows for calculating the LCI for the improved scenario and using **[Compare]** allows both the improved and the original scenario to appear.
2. In the window containing the two LCIs (**Compare**), it is now possible to activate **[Imp.Potentials]** or **[Normalization]** and the LCIA of the two scenarios will appear side by side for comparison.

Sensitivity Ratios

Within the tables of **Imp.Potentials** and **Normalization** it is possible to run the sensitivity analysis directly in terms of sensitivity ratios. The sensitivity ratio expresses the relation between the relative change in the over all impacts and the relative change in the process LCIs, using the same relative changes in the LCI for all processes involved in the scenario. This illustrated by the equation below.

$$SR = \frac{\dfrac{\Delta \mathrm{Impact}_{\mathrm{i\ scenario}}}{\mathrm{Impact}_{\mathrm{i\ scenario}}}}{\dfrac{\Delta \mathrm{LCI}_{\mathrm{process\ k}}}{\mathrm{LCI}_{\mathrm{process\ k}}}}$$

1. In a scenario, the LCIA tables hold the tab **[Sensitivity Ratio]**. It may be useful to extend the LCIA table to the full scenario having each contributing process appear as a column before the sensitivity ratios are calculated. Activate **[Sensitivity Ratio]**. A table appears having all the individual processes as rows and columns of sensitivity ratios for each impact potential.
2. Within each column the sum of ratios is one since the impacts by definition are linear with the LCIs. The individual numbers show which process has the greatest influence on the impact or, in other words, which process is the impact most sensitive to. The results should not be interpreted horizontally since the relative numbers in the column are relative only within the column. This is also seen from the fact that the sum horizontally may differ from one. Note that this analysis deals with relative values and does not distinguish between large and small impact potentials.

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20 Administration

Updated 2008-01-07 (AND). Original document prepared by AND. Controlled by THC .

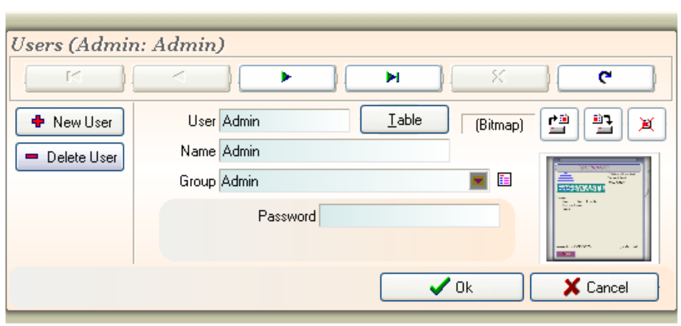
The Administration module contains two tabs. Create User and Create Administrator. Under here people can add, remove and edit the current users having access to the different parts of the software. Main administrative parts which are not needed in the daily use are only enabled under the main Admin.

Approach

The administration module controls which modules can be accessed by which user. As default the user can access all modules and technologies. But if the administrator wants to make sure that other users can not use parts or all of the modules this can be changed here. It should be noted that only a user that has created a process can change it. All the default processes coming with EASEWASTE is made by “admin” and a user should therefore not use the “admin” as a user unless this is fully intentional.

When clicking on either **[Create User]** or **[Create Administrator]** under the **[Administration]** button the following screen will pop up.

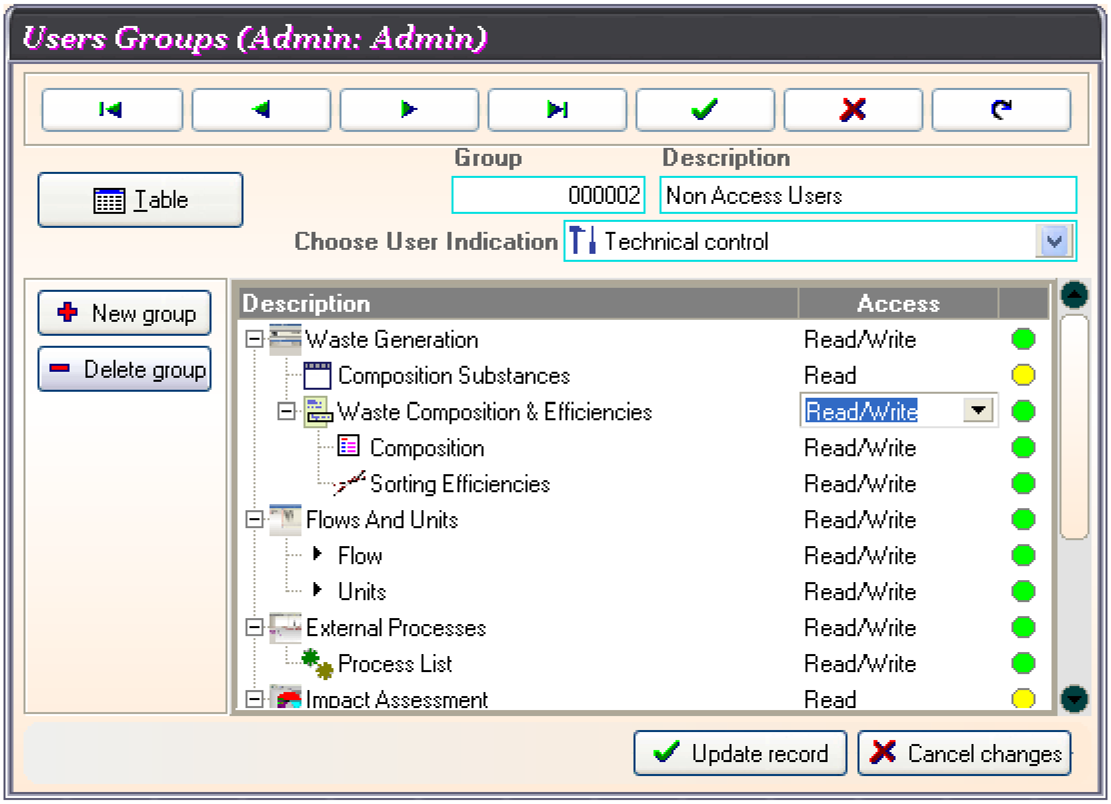
By double left clicking on the “admin” user and entering the admin password you will get access to the admin module seen below.



This is where new users are made, the **[Create administrator]** main window looks similar. The arrow buttons are used to browse between the different user. In order to make a new user the following steps need to be taken

1. Press **[New User]**. And fill in a short abbreviation for the user in the **[User]** box (max 6 letters), and fill in the full **[Name].**

2. Choose a **[Group]**, the **[Group]** is a list of access rights to all parts of the model, allowing the same user rights to be given to a number of different users. In order to edit a **[Group]** click the little letter icon after the **[Group]** box. This will open up the screen below.



The user group can be browsed with the arrows, or a new group can be made by choosing [New Group]. There are 3 access options which can be seen in the table below.

None	The user can not access the information
Read	The user can see all the information but can not change them and can not enter new information
Read / Write	The user can see all information, and can change all information entered by the user. Furthermore the user can make copies of processes made by other users and also make new processes

It is suggested that the categories below are not accessible for the average user as they are only for advanced user and administrative purposes, such as adding new chemical substances in the waste composition, new impact categories etc.

- Waste generation→ Composition substances
- Basic in and outputs → Units
- Basic in and outputs → Constants

21 Features

Updated 2012-04-12 (AND). Original document prepared by AND. Controlled by THC

EASEWASTE has a number of common features. This includes option such as: “Save As”; importing technologies and external processes from other EASEWASTE databases; Documentation and Data Quality Indicators.

The following covers a number of common features found in EASEWASTE.

Data

Save As

In order to make it easy to make new processes you can make a copy of an existing technology. This is done by opening the process you wish to copy and under **[File]** choose **[Save as].** You will then be asked to provide a new name and you then have a copy of the process. When copying an external process you will also have to specify which sub category it is to be placed under.
Currently **[Save as]** does not work for scenario’s but we expect to send out a fix that solves this problem by the spring 2008.

Import

In order to make it easy to share data between different databases if more people are using EASEWASTE data can be imported from one EASEWASTE database to another. Currently the following types of data can be imported: All technologies, all external processes, Waste Compositions. Importing is done by doing the following:

1. Go to Technologies or External processes depending on what you wish to import. You can then either right click and choose **[Import File]** or click the  icon(upper right corner).
2. You will get a window where you click on  and then find the database you wish to import from. In this database you choose the file called “Import_Link_File.wps” and click open.
3. A new window will pop up where all the processes from the database you wish to import from can be seen. A moving green bar will show the link is active(don’t wait for it to stop moving). You then navigate to the process you wish to import and select it and choose **[Import file]**.
4. You will be prompted to enter a new name, and click **[OK]** and the process is imported.
5. If you are importing a technology that links to external processes you will have a new window popping up with the message “Listed processes/flow are not available in imported database”. You will therefore also have to import these processes. You do this by clicking on **[Import listed Processes/Substances].**
6. After this is done you can import another process by clicking on **[Import Another]** or double-click on another process you wish to import, and go back and repeat from step 3.
7. When you have imported all the processes you want, you **[Close]** the window.

With EASEWASTE2012 we made it possible to import from the previous database version. For an explanation how to do this please see the end of section 22 Installation.

Export

It is not possible to export data from EASEWASTE to other programs LCA models. The reason for this is that all LCA programs operate with ID's for each emission and process and these can not be imported to other software until they support EASEWASTE. All results that are generated can be exported to Excel. Furthermore graphical figures made in the results part can be exported in a number of picture formats.

Documentation

Most data in EASEWASTE have documentation. The documentation for a process can be found by clicking on the icon placed after the name of the dataset. All data includes a date for the data entry of the process, the "owner" which is the user that entered the process and a DQI (Data Quality Indicator. The DQI can be used for getting a quick overview of a number of processes and see which are the most trusted datasets.

The colour coding for the DQI are as follows:

Dark green: Very good
Light green: Good
Yellow: Fair
Orange: Limited
Red: Bad
Brown: Unknown

22 Installation

Updated 2012-04-12 (AND). Original document prepared by AND.

This section covers installation of EASEWASTE2012. Please be aware you need to have filled out a user agreement and taken a course in the use of EASEWASTE to have access to the software.

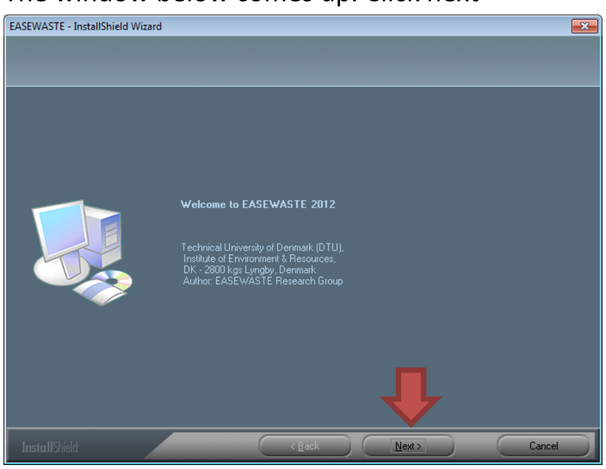
How to Install EASEWASTE 2012

(Hint: You can keep your existing EASEWASTE 2008 version and have both on the computer at the same time if you wish to be able to rerun old scenarios. Both versions can just not be active at the same time. Just make sure to install to another folder if so, see more about this later)

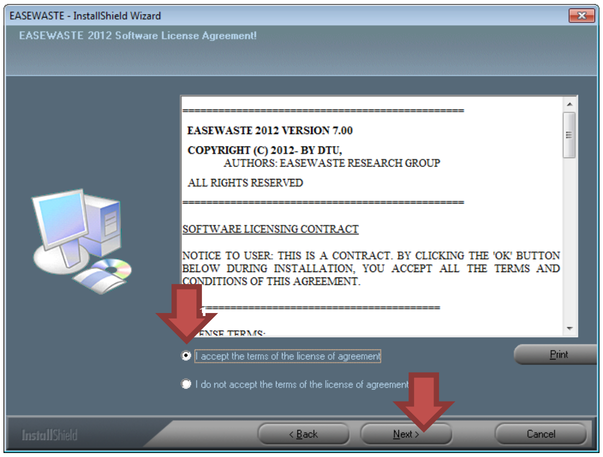
1. EASEWASTE has been developed using an English database system. This system can only recognize a decimal divider if this is set to a dot (.). So if your language options are set to use a comma (,) as the Danish as default is you will need to change this to a dot. This is done by going to the **[Control Panel]** in Windows and opening **[Regional and Language Options]**. You then choose **[Customize]** and set the decimal divider to dot, and can then change the thousand separator to a comma or leave it out. If not doing this you will get errors when running the calculation part of EASEWASTE.

2. Double-click the Setup.exe file

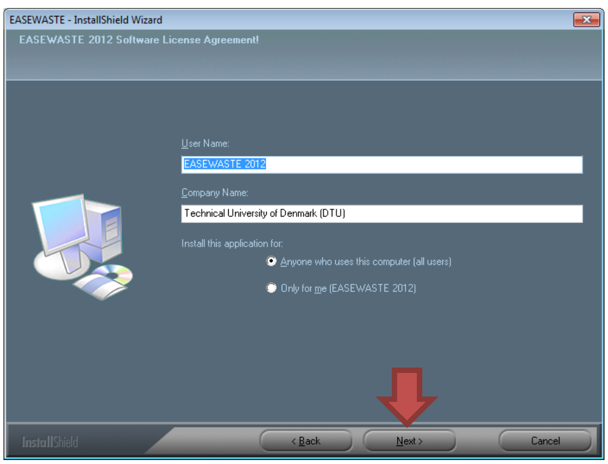
3. The window below comes up. Click next



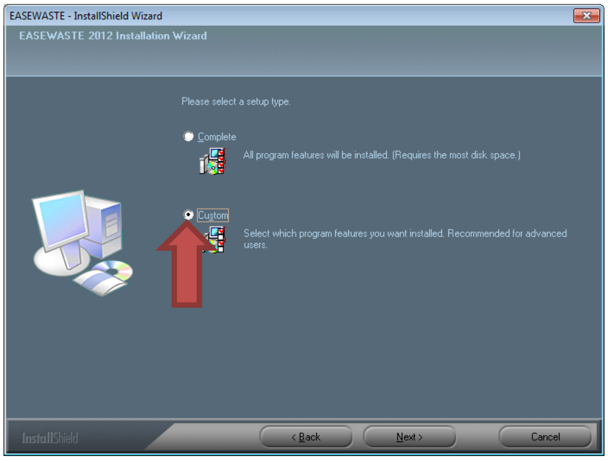
4. The next window shows the End-User-License-Agreement. You have to click the little box by the "I accept the Terms of the license agreement" message:



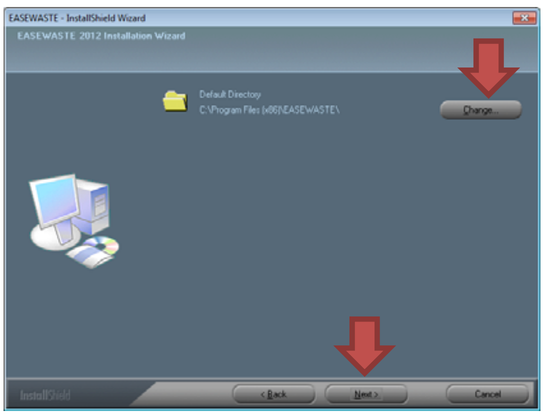
5. In the next window you choose whom to register the program for. You can either fill in your company credentials or just leave it as it is and click on next



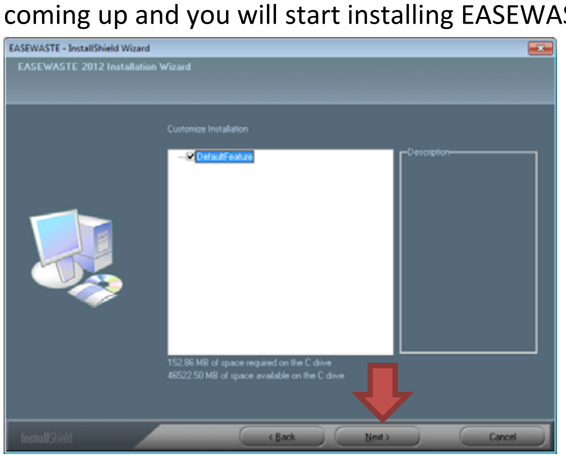
6. In the next window you choose where to install EASEWASTE 2012. Previous versions of EASEWASTE had to be installed at C:\EASEWASTE this is not the case anymore. If you choose Complete it will go to the normal programs folder (e.i. C:\Program Files (x86)\EASEWASTE for 64 bit based operating systems and C:\Program Files)\EASEWASTE for 32 bit based system). If you click Custom you are allowed to choose where you want to install EASEWASTE to. Databases can be placed separate places from where the program is installed which is also a new feature (more about this later). If unsure we recommend choosing custom and placing it where you would like it.



7. You can here see where EASEWASTE 2012 will be installed. If ok just click next, else click change, and choose the new location you would like to install to, then click OK, then click next.

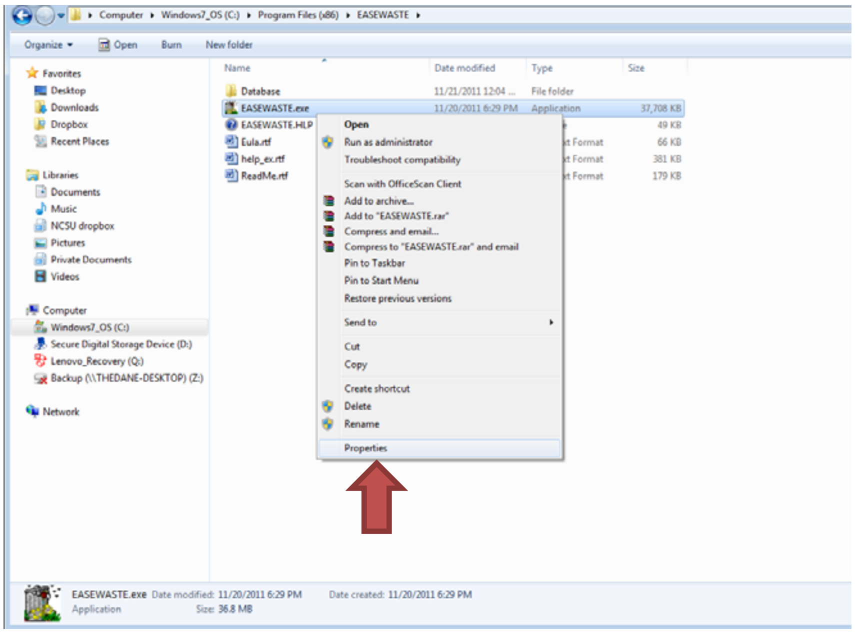


8. This window just shows which features will be installed. Just click next as EASEWASTE2012 only comes with one installable part. Click next, on the next window coming up and you will start installing EASEWASTE

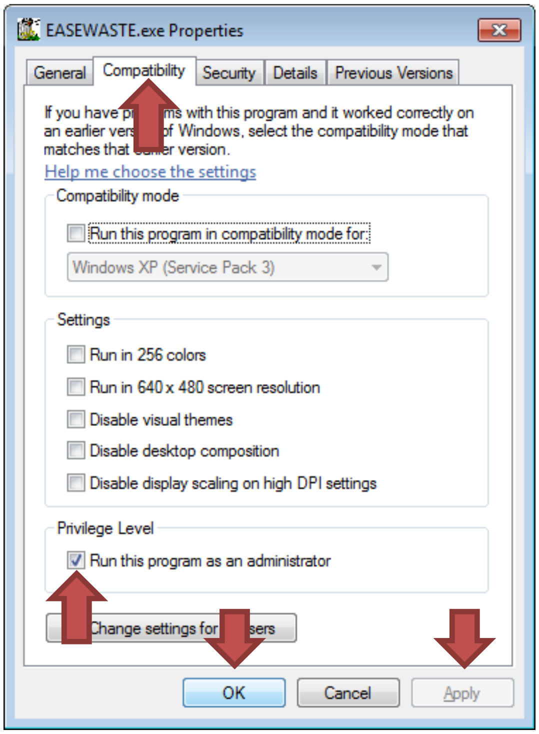


9. After the installer is finished click, finish. EASEWASTE is now installed, but we are not done yet.

10. Next step is **VERY IMPORTANT**. If you use Windows 7/VISTA you have to run EASEWASTE as administrator. Therefore go to the folder where you installed EASEWASTE. Right-click the EASEWASTE.exe file and choose properties.



11. Next you click Compatibility, then click the box by "Run as Administrator". Finally click Apply, then OK.

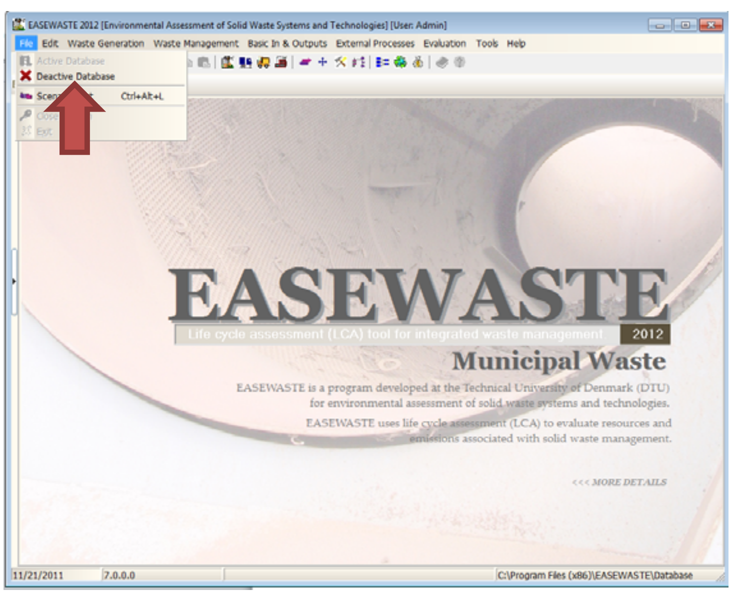


12. Now we are ready to start EASEWASTE. During installation a shortcut was placed on the desktop, but you can also just start it by right-clicking EASEWASTE.exe. A box will pop up, and you will need to choose Yes.

13. The normal EASEWASTE start window will now appear, but there is something different. You can now use different databases in EASEWASTE, and switch between those you use. First time you open EASEWASTE you will need to select which database to use, but from here on it will always open the last opened database.
(Hint: If you wish to have another different database location this is a good time to do this, to do it you must manually move the Database folder from the EASEWASTE main folder to wherever you like it placed).
To activate the database you click on Link. A new window pops up and you will need to navigate to wherever you installed EASEWASTE (or the location of the database folder). Go inside the database folder and you find a file called Database.dat. Choose that file and click Open.

This opens the normal user access window to EASEWASTE. You can choose between “Admin” and “Main”. There is no password needed for either user. All technologies are made as “Admin” so you can only change them directly if logged in as admin, if you log in as “Main” you will have to copy a process to change it (This is a good way to avoid deleting/changing a default process).

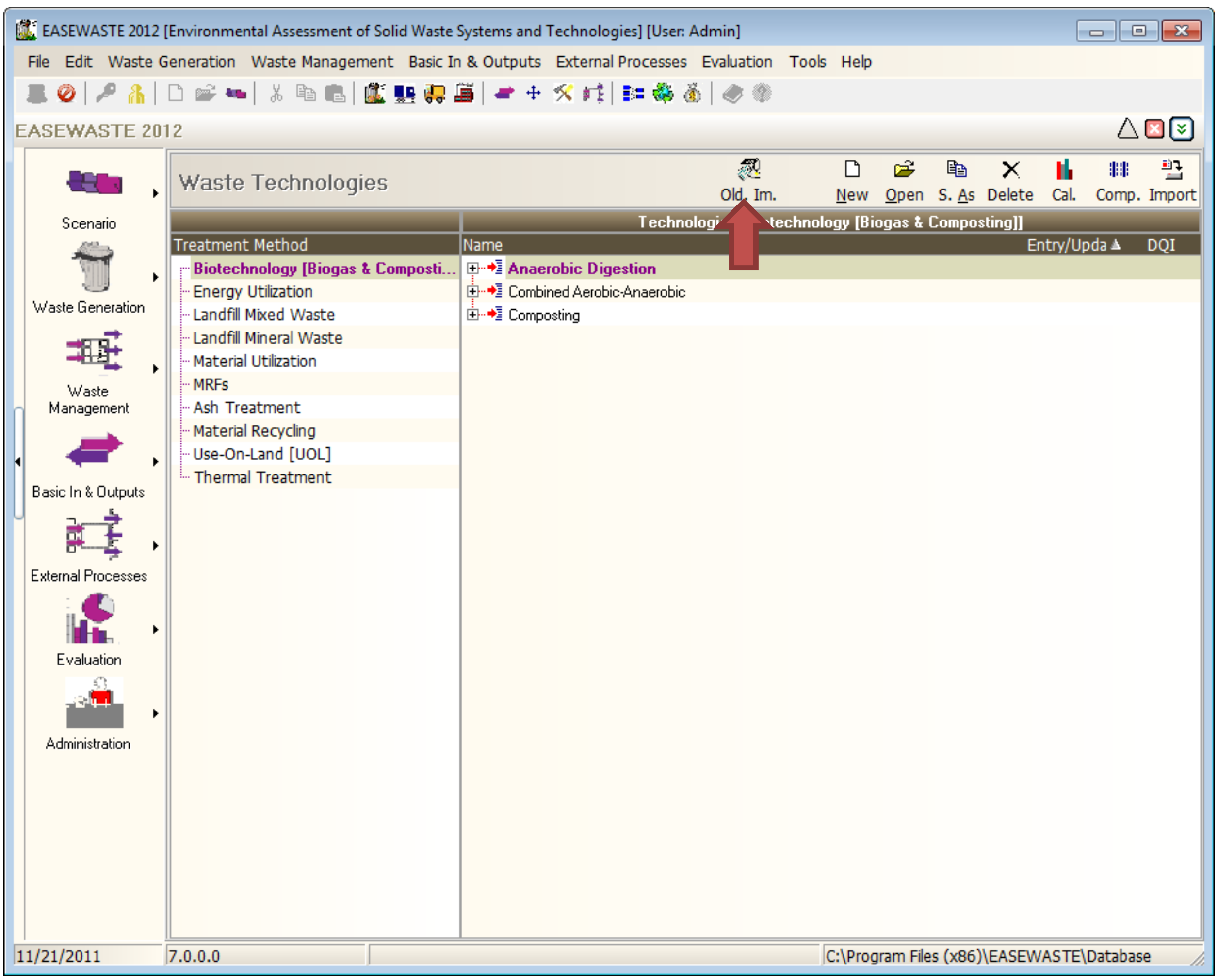
14. If you wish to change to another database you click on the X, or go to File→Deactivate Database. Then you repeat the process from bullet 13 above.



For old users – Import of Existing technologies.

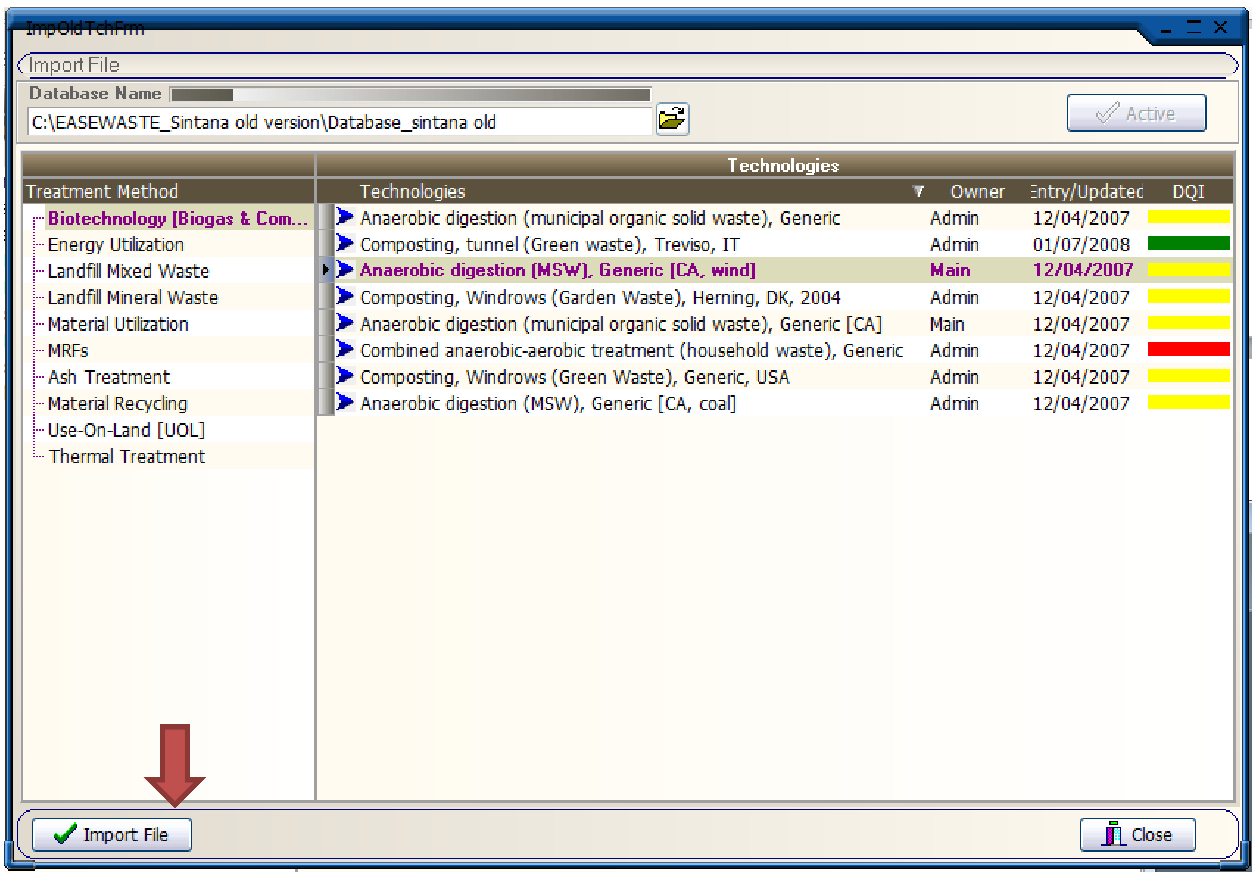
In the new version of EASEWASTE the structure of the view of treatment technologies have changed. We have therefore made a new import version that allows you to import technologies made in the old Database format into the new database structure. If your database is very old (pre 2010 where we released a beta of this new version) it might give errors as we have updated parts of the way we model technologies and the structure of the input boxes is therefore not identical to how we model them anymore. In order to import the technology into the new database do as follows

15. Go to Waste Management → Technologies
16. You then see the normal treatment technologies window, but will see that we have now made it so each treatment technology has a number of sub folders. To import your old technology you will then need to choose the button "Old Im." shown below. The normal Import is for importing technologies from databases with the same format as the one you just installed.

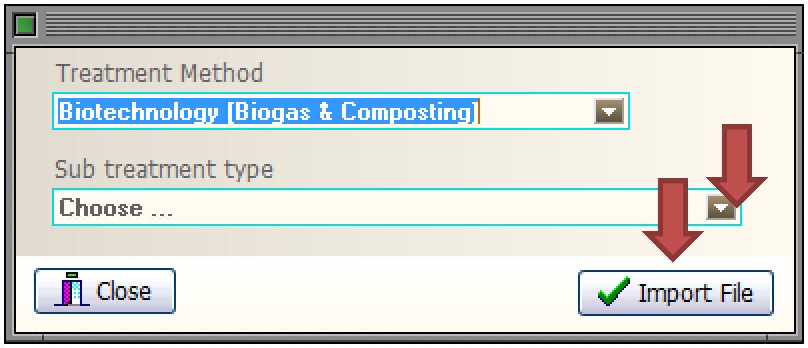


17. After you click the button a new window pops up and it asks you to find your old database. You navigate to this database and look for a file called “Import_Link_File.wps” if you have this file you choose it and click open (then go to next step). If your database is really old you will not have this file, but you might still be able to import your technology. In order to do so you need to change the file type you look for in the lower right corner to “All Files (*.*)”, after this you double-click a random file as this will tell the program in which folder to look for the technologies.

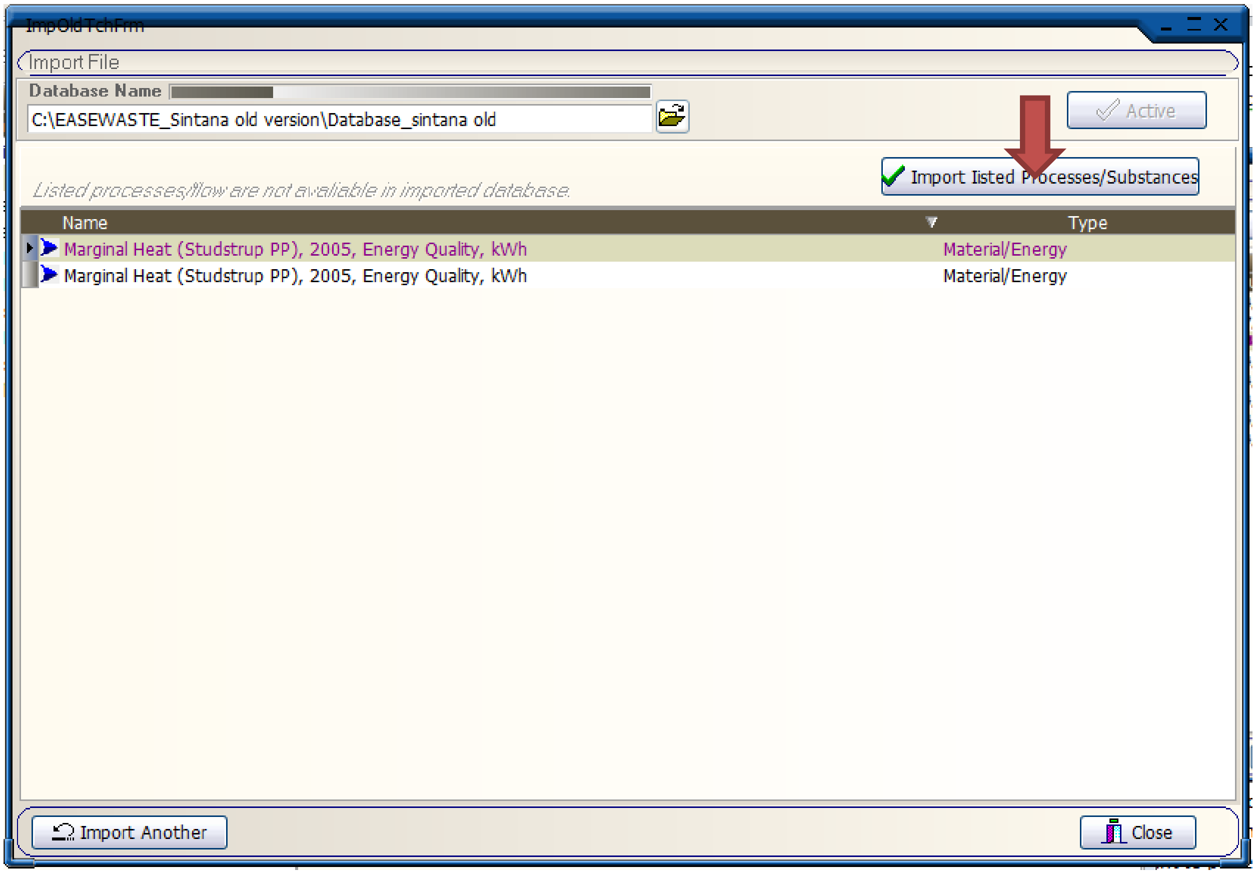
18. A new window will now open up which shows the structure of your old database. In the top a bar will be flashing, this does not mean it is loading, but just that there is an active link so do not wait for it to stop.



19. Navigate to the technology you wish to import, select it, and click Import File. A new window pops up, here you now need to select which Sub folder under the overall Treatment Technology you wish to place it under. After having chosen this click "Import File". If you want to place it in a new sub folder you have to create this subfolder before starting the import procedure.



20. If the technology being imported also has external processes or substances not in the new database already, a new window will pop up listing these external processes. You must then click the "Import listed Processes/Substances" After this you will return to the overview of your old technologies and you can click "Import Another" if you wish to import another process. For most selections in EASEWASTE you can also just double click a technology to start the import process.



21. You can now start making scenario's with your old EASEWASTE technologies in the new EASEWASTE 2012.