GUIDEBOOK

# The Co-benefits Evaluation Tool for Municipal Solid Waste


UNITED NATIONS UNIVERSITY
UNU-IAS

# GUIDEBOOK
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# Contents

# 1. Introduction

Different waste management technologies have the potential to reduce the amount of Municipal Solid Waste (MSW) disposed in landfills while also providing electricity or electricity and heat that reduces GHG emissions.

This co-benefits evaluation tool in the municipal solid waste sector evaluates the climate co-benefits of the municipal waste management technologies by using a life cycle assessment (LCA) approach. This approach is used in the tool to consider coordination of a number of actions to recover material and energy and to reduce environmental impact through Integrated Waste Management System (IWMS). This tool quantify the environmental impacts including GHG emissions and air pollutants accompanied by energy implications and cost-benefit analysis of the various waste management technologies including incineration, landfilling, composting, anaerobic digestion and recycling.

This guidebook provides a manual for the waste tool which is developed by the sustainable urban future program in the United Nation University, Institute of Advanced Studies (UNU-IAS), to estimate GHG emissions, energy potentials and economic evaluation of different municipal solid waste management technologies. This chapter provides brief information for understanding the concept of solid waste management and climate change. Also, the scope of this assessment and structure of this manual is explained.

## 1.1. Solid Waste Management and Climate Change

The concentration of Greenhouse Gases (GHG) is increasing in the atmosphere through human activity. This is expected to result in a significant warming of the earth's surface and other associated changes in climate within the next few decades. The greenhouse gases that are making the largest contribution to global warming are carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$). All three are produced during the management and disposal of waste.

Under the United Nations Framework Convention on Climate Change (UNFCCC) through the Kyoto Protocol, the developed countries have agreed to reduce emissions of greenhouse gases. In this context, waste management policy has an important role in achieving this objective.

The disposal of solid waste produces greenhouse gas emissions in a number of ways. First, the anaerobic decomposition of waste in landfills produces methane, a greenhouse gas with 21 times the warming potential of carbon dioxide. Second, the incineration of waste produces carbon dioxide as a by-product. Greenhouse gases are also emitted due to the combustion of fossil fuels in transporting waste section for waste disposal. Additionally, providing electrical and heat energy for operation of machinery can produce GHG emissions. Finally, fossil fuels are required for extracting and processing the raw materials necessary to replace those materials that are being disposed with new products in recycling technology.

In general, different waste management technologies such as incineration, landfilling, composting, anaerobic digestion and recycling are effective and considerable approaches to better manage the solid waste as follows:

- Reduces methane emissions from landfills
- Reduces GHG emissions from incineration, open-burning, composting, anaerobic digestion and recycling
- Reduces emissions from energy consumption
- Increases storage of carbon in trees (carbon sequestration)

## 1.2. The Scope of the tool

The aim of the tool is to quantify the local and global impacts of different options for managing Municipal Solid Waste (MSW). Waste management has an extensive variety of environmental impacts.

The tool considers those environmental impacts associated with climate change, air pollution and wastewater. It quantifies the emissions including GHG emissions and air pollutants into the environment resulting from the technologies being considered. The discharge of water to the land as wastewater also considered. The analysis is also accompanied by energy recovery implications of the various scenarios by running the Integrated Waste Management System (IWMS) method in the base of policy intervention. A cost-Benefit Analysis (CBA) assessment capability is also included.

## 1.3. Structure of the Manual

This manual divided to four major chapters, introduction, background and methodology, technical calculations and tool description. It aims to accommodate the needs of users with different levels of available resources and skills to facilitate usage of the tool. This manual has three further chapters.

*Chapter 2*, *Background and Methodology,* describes waste management technologies and the methodology which has been used for estimating emissions from different technologies. A brief description of different waste management technologies is addressed in the section 2-2. In the section of methodology and approach, sub-sections 2.3.1 to 2.3.3, the LCA concept as applicable approach for analyzing, assumptions for modeling and also, the emissions inventory are discussed. Section 2.4 presents the policy indicators in the three different categories as emission indicators, energy indicators and economic indicators and, the concept of policy intervention has presented in section 2.5.

*Chapter 3*, *Technical Calculations*, the calculation of GHG emissions and air pollution from different waste management technologies and sections is addressed in section 3.1. The technologies and sections include waste transportation, operational activities, incineration, open-burning, landfilling, composting, anaerobic digestion, recycling, wastewater generation. Also, air pollutant, GHG emissions avoidance from energy recovery and compost production and, leachate production are explained in sub-sections 3.1.10 and 3.1.11. Section 3.2 describes the policy intervention and discussed three major factors can affect the indicators.

*Chapter 4, Tool Description*, describes structure of the tool and explains procedure for the sequential steps which should be done by the user to enter input data, run and get results. In this content, the baseline scenario, policy intervention and economical analysis are three different sections that will be discussed in this chapter.

Finally, conclusions and future works is presented for further developing tools in the waste sector.

## 1.4. Access to the download link

The toolkit is is freely available for download and use to the users through the UNU-IAS online website: http://tools.ias.unu.edu

At first, the users need to register in order to create their own account. Then, the users must register their baseline scenario (input data described in this guide) by filling out the input data forms. These forms provide the initial data which will be required to set up the database of the toolkit. After submitting the input forms, the download link will be accessible. Users can then download the tool on their personal computer. Upon opening the tool, the user enters their username/password and their data will be downloaded into the tool. Over time, users will be able to compare results with those of other users. Full details are to be found in the “How to Use” tab at the website.

# 2. Methodology and Background

This chapter describes waste management technologies and the methodology which has been used for estimating emissions from different technologies. The LCA concept as applicable approach for analyzing, assumptions for modeling and also, the emissions inventory are discussed. Also, the policy indicators in the three different categories as emission indicators, energy indicators and economic indicators and, the concept of policy intervention are presented in this chapter.

## 2.1. Background

### 2.1.1. Type of Waste

The materials in municipal solid waste represent what is left over after primary consumption. The various type of solid waste have different amount of degradable organic carbon (DOC) and fossil carbon. Therefore, one of the major factors which affects on the solid waste environmental emissions is waste composition. The definition of MSW used for the tool is that given by the IPCC definition which includes food, paper and cardboard, wood, textiles, rubber and leather, plastics, metal, glass, garden and park wastes, nappies and other (e.g., ash, dirt, dust, soil, electronic waste).

### 2.1.2. Waste Management Technologies

For the purpose of the tool, the Waste Management System (WMS) includes waste transportation, incineration, open burning, landfilling, composting, anaerobic digestion and, recycling. A brief description of waste management technologies and variations on each of the major technologies which evaluated in the tool are listed in Table 1.

#### 2.1.2.1. Waste Transportation

The GHG emissions from transport of waste to the treatment/disposal facilities are also considered in the tool. For all waste management technologies, collection, sorting and transport of waste from the source to the treatment / disposal facilities and end markets for recovered materials are needed. All of these steps have greenhouse gas impacts, mostly through the use of fossil fuels (gasoline, diesel and, Compressed Natural Gas (CNG)) and associated emission of $CO_2$.

Table 1. Waste management technologies and their variations assessed in the tool

| Waste management technology | Variables assessed in the tool |
|---|---|
| **Landfilling** | • Landfill gas recovered and used for electricity production<br>• Landfill gas recovered and used for electricity and heat (CHP) production<br>• No Recovery of landfill gas |
| **Incineration** | Incineration with no energy recovery<br>Incineration with energy recovered as electricity<br>Incineration with energy recovered as heat and power (CHP) |
| **Composting** | Compost recovered for beneficial use in agriculture |
| **Anaerobic Digestion** | Compost recovered for beneficial use in agriculture<br>Anaerobic digestion with energy recovered as electricity in biogas power plants<br>Anaerobic digestion with energy recovered as fuel<br>Anaerobic digestion without energy recovery |
| **Recycling** | Metal<br>Glass<br>Plastics<br>Paper and cardboard<br>Wood<br>Rubber and Leather |

#### *2.1.2.2. Incineration*

The most widely practiced alternative to landfilling is incineration. In incinerators, bulk MSW is burnt with little or no pre-treatment in a furnace. The main concerns are energy recovery and control of air pollution from incinerators. The recovery of the energy released by the combustion process is as electricity or electricity and heat which can be replaces the need for providing energy from other sources, especially from fossil fuels. Then, there is a potential for avoiding GHG production is caused by combustion of fossil fuels for providing electricity and/or heat.

The main residue from incineration is a volume-reduced inorganic ash which is finally disposed at landfills and so, incineration may therefore be considered as a landfill pretreatment. The disposal fees charged are supported by revenue from energy sales.

In addition of MSW, Refuse-Derived Fuel (RDF) which is a fuel produced by shredding and dehydrating solid waste with using mechanical heat treatment, mechanical biological treatment or waste autoclaves can be used as incinerators feed. RDF consists largely of combustible components of municipal waste such as plastics and biodegradable waste.

#### *2.1.2.3. Open Burning*

Open burning is defined as the burning of the waste that combustion products are emitted directly into the ambient air without any control. This technology uses instead of, or in addition to, disposal to landfills or incineration. The simplicity, convenience, or low cost of this technology is the main reasons for waste open burning. The main problem of this strategy is scattering of combustion products and GHG emissions which distribute in the atmosphere with no control.

#### *2.1.2.4. Landfilling*

Landfilling involves the managed disposal of waste on land with little or no pre-treatment. As such, it is distinguished from dumping, which is characterized by the absence of control of the disposal operations and lack of management of the dump site. In fact, a landfill site is a place where waste is dumped, flattened, covered with sand, and left to decompose or break down and decays. It can be a large hole in the ground or it can be where waste is piled up above the ground. Landfilling of biodegradable wastes results in the formation of landfill gas (LFG). In a modern landfill site, decaying wastes use up the oxygen entrained within the waste mass, creating anaerobic conditions. The depths of wastes typically employed means that oxygen is used up faster than it can diffuse in from the air. Under anaerobic conditions, the waste continues to degrade to produce landfill gas, which contains roughly 50% methane and 50% carbon dioxide. The carbon dioxide component is generally considered as being biogenic in origin and is thus not considered as greenhouse gas. Then, the methane emitted in landfill gas is thought to represent the main greenhouse gas impact of MSW management. All components of MSW are currently acceptable for landfilling, including residual fractions left over after the separation of materials for recycling and the residues from pre-treatment processes such as incineration, composting and anaerobic digestion.

#### *2.1.2.5. Composting*

Composting is a specific waste management process by which organic waste is aerobically converted to a stabilized solid product called compost, which can then be used as fertilizer or soil amendment. There are three common methods of composting: windrow composting, aerated static pile composting and in-vessel composting. As a small fraction of carbon in the waste may be converted to $CH_4$ in anaerobic sections within composting piles, most of the generated $CH_4$ is oxidized in the aerobic sections of the compost. Therefore, most of the carbon degraded within the compost pile will be converted to $CO_2$ which have biogenic origin.

#### *2.1.2.6.Anaerobic Digestion*

Anaerobic Digestion, as one of the main options for processing the biodegradable organic materials in MSW, consists of the degradation of organic material in the absence of oxygen and the presence of anaerobic microorganisms. It produces biogas as a source of renewable energy which contains mainly 60-70% methane 30-40 % carbon dioxide gas, tracer amount of nitrogen, oxygen, hydrogen and hydrogen sulfide as well as nutrients in the form of compost product as a fertilizer and soil conditioner. The biogas which is produced in anaerobic digestion process can be used directly as fuel or as electricity provider in a biogas power plant. By recovering energy, the fossil fuel usage for providing energy can be avoided and so, there is a potential for GHG emissions avoidance.

#### *2.1.2.7. Recycling*

Recycling means collecting materials from waste stream to reusable them in place of virgin inputs in the manufacturing process, rather than being disposed of and managed as waste. Recycling of materials from the municipal solid waste stream generally involves the following steps:

1. Collecting the separated materials from individual households and transporting to a place for further treatment
2. Sorting, baling and bulking for onward transfer to re-processors (e.g. at a Materials Recycling Facility (MRF))
3. Reprocessing to produce marketable materials and products (Re- manufacturing)

There are two types of recycling cycle including closed loop and open loop. In a closed loop cycle, materials are recycled into same materials, such as aluminum can is recycled into new aluminum can. Open loop means that the secondary product is different than the primary product and often occurs when a material is degraded or changed by the recycling process. In general, recycling credit is based on closed- and open-loop recycling depending on the materials.

## 2.2. Methodology and Approach

### 2.2.1. LCA Concept

The steps which are attributed in the waste management system include (1) collection of the waste, (2) transportation of the waste, (3) processing of the wastes, and (4) disposal of the waste to the landfills. In the case of recycling treatment technology, the extraction and processing of raw materials is also considered. Every step along with municipal solid waste management as “Life Cycle” contributes in GHG emissions production. So, the Life Cycle Assessment (LCA) accounts for all possible environmental impacts along the whole steps required to recover energy and/or material from the waste. The LCA method is applied in the tool for estimating the environmental impacts from waste which is including GHG emissions, air pollutions as well as energy recovery potentials. Note that different waste management options have different implications for GHG emissions, energy consumption and energy recovery potentials. This LCA assessment includes the four basic steps according to Standards ISO 14040:

1- Definition of the scope of the system, the technologies and MSW system boundaries (Scope Definition)
2- Energy and mass balance in every technology (Life Cycle Inventory (LCI))
3- Estimation of environmental impact of the technology through policy indicators calculation (Life Cycle Impact Assessment (LCIA))
4- Evaluation of possible potential for reducing of environmental impacts by applying an Integrated Waste Management System (IWMS) approach as different scenarios (Life Cycle Interpretation)

Figure 1 illustrates the MSW technologies considered for LCA approach. In the tool, the WMS includes incineration, open burning, landfilling, composting, anaerobic digestion and, recycling.

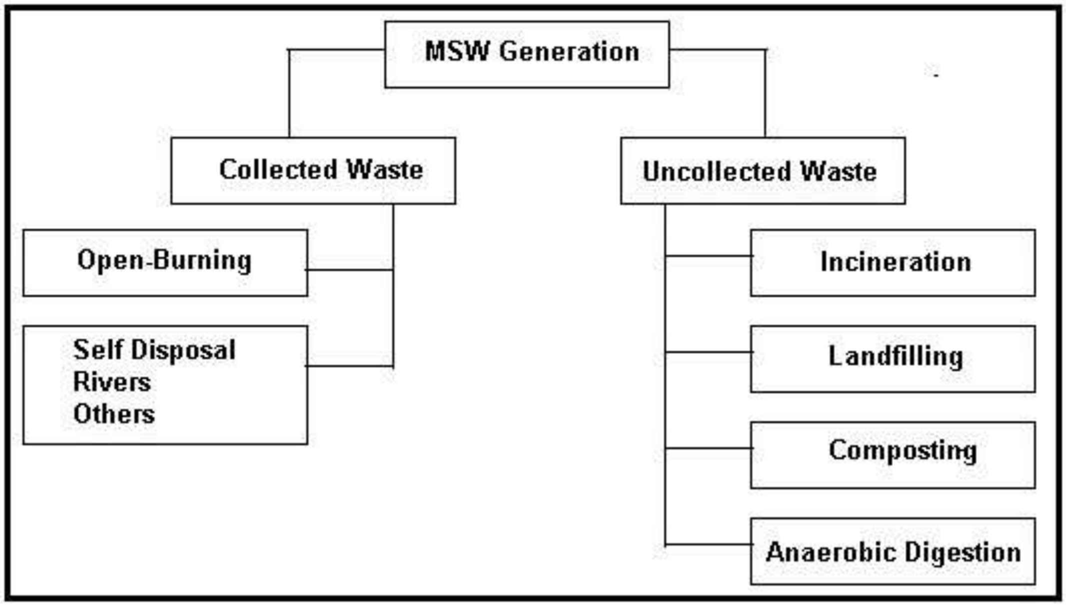



Figure 1. The overall structure for waste management technologies in the tool

Generally, two main types of waste management system can be considered, depending on whether bulk MSW or source-separation of various waste components is offered. The landfilling, open-burning and incineration are used for the bulk MSW and composting, anaerobic digestion and recycling deal with source-separated waste. On the basis of current approach, it is assumed that the waste going to incineration, landfilling, composting, anaerobic digestion and, recycling techniques as will result in a specified fraction of the total gross MSW production collected waste. Then, the residue of materials as uncollected waste is going to different scenarios including open-burning, self disposal, dispose to rivers and others (Figure 1). In this analysis, the total MSW production can be calculated according to population and waste rate production (kg/(person.day)) which are considered as input in the tool.

### 2.2.2. Assumptions

The general assumptions that have been made to use for developing the waste tool are as follows:

- In every technology, estimated emissions were developed in units of mass emitted per mass of input waste rather than unit mass of final product. For example, in anaerobic digestion technology, the GHG emissions is expressed as “$CO_2$eq./tonne waste” instead of “$CO_2$eq./tonne compost”.
- The input waste is considered on a wet basis.

- The sequence of each MSW management strategy starts when the waste transported to the technology and then, leaves system as materials, disposals, environmental impacts and/or energy carriers (electricity and/or heat).
- The six different MSW technologies considered in IWMS are incineration, open-burning, composting, anaerobic digestion, landfilling and recycling.
- Estimation of emissions from landfills depends on the year whose emissions are of interest.
- When fossil fuels are used for the technology, consumption of this fuel is considered under both GHG estimation, air pollutants and energy sector.
- Recovered energy is considered as electricity and/or heat production. In the case of heat production, the heat potential is estimated heat production (MJoule heat/year) from diesel combustion.
- Different types of energy recovery systems are considered where the energy can be recovered from the process as electricity and/or heat. These systems available in the tool include gas turbines, steam turbines, Internal Combustion Engines (ICE) and Combined Heat and Power (CHP) systems.
- The default concentration for specific GHG emissions and air pollutants compounds have gathered by survey of different references. However, should the user have their own, more appropriate or site-specific emission factors, these can be changed by the user themselves.
- Because specific air pollutants concentrations in the combustion products of incinerator are slightly different for different types, there is a possibility for the user to choose different types of incinerator in the tool.
- The tool does not consider carbon sequestration for calculating the GHG emissions.

### 2.2.3. Emissions Inventory

The default concentration for specific GHG emissions and air pollutants which are used for different technologies have been gathered through a literature review. The emission factors of selected atmospheric pollutants which used in the tool has presented in the "Default Emissions Factor" excel sheet for each waste management technology. But, there is a possibility in the tool to change the emissions factor to the actual site-specific test data by the user.

For calculating the GHG emissions and air pollutants, the following environmental emissions are taken into account:

- GHG emissions from the transport of solid waste to the technologies due to combustion of fossil fuels (gasoline, diesel and CNG)

- GHG emissions from operational activities
- GHG emissions from waste management process
- Avoided GHG emissions from fertilizer production in compost and anaerobic digestion technologies
- Avoided GHG emissions from reduced production of original materials when the original materials replaced by recycling.
- Avoided GHG emissions from electricity and/or heat production (energy recovery). These emissions are calculated when electricity and heat are provided by fossil power plants and diesel fuel combustion, respectively.
- Avoided GHG emissions from 100% landfilling in incineration, composting, anaerobic digestion and, open-burning techniques
- Air pollutants from the transport of solid waste to the technologies as typical combustion products like CO, $SO_X$, $NO_X$ $PM_{10}$, $PM_{2.5}$,VOCs and, UHC.
- Air pollutants released from incineration and open burning which are included typical combustion products and heavy metals
- Air pollutants released from landfilled disposal site
- Heavy metals released from incineration
- Leachate production from landfilled disposal site
- Wastewater generation from landfilled disposal site

## 2.3. Policy Indicators

For analyzing and monitoring sustainability towards climate change in terms of the environmental impacts of waste management technologies, indicators are needed. These indicators should provide an integrated view on the links between waste generation, transportation, waste management technologies and environmental impacts. As mentioned before, one of the approaches that facilitate such integrated view is life cycle approach. The indicators used in the life-cycle approach cover the entire waste management chain and account for the benefits or impacts associated with material or energy recovery. The indicators are therefore valuable for evaluating and comparing waste management technologies and scenarios. Different policy indicators which have been used in the tool are emission indicators, energy indicators and economic indicators.

### 2.3.1. Emission Indicators

The emission indicators associated with the waste management technologies are mainly driven by the accounting of greenhouse gases and air pollutants compounds concentration which transmitted to the atmosphere. In this context, the GHG emission and air pollutant indicators are defined as follows:

$$GHG\ Emissions\ Indicator = \frac{GHG\ Emission\ (gr\ of\ CO2-equivalent)}{waste\ treated\ in\ each\ technology\ (tonne)} \quad \textbf{Eq.(1)}$$

$$Air\ pollutant\ Indicator = \frac{air\ pollution\ \ (gr\ of\ air\ pollutant)}{waste\ treated\ in\ each\ technology\ (tonne)} \quad \textbf{Eq.(2)}$$

### 2.3.2. Energy Indicator

The recovery of secondary products or energy from waste substitutes primary production, and can thus contribute to the reduction of resource/fuel consumption and emission releases. Then, one of the important indicators which present energy recovery potential is an energy indicator. The energy indicator is defined as:

$$Enrgy\ Indicator = \frac{\text{Energy recovery production as heat}\frac{\text{(MJ)and}}{\text{or}}\text{electricity ( kWh)}}{waste\ treated\ in\ each\ technology\ (tonne)} \quad \textbf{Eq.(3)}$$

### 2.3.3. Economic Indicators

Cost-benefit analysis is a simple and useful way to help decision-makers choosing the proper scenario among the alternative scenarios economically. As the focus of the tool is to quantify greenhouse gas fluxes, it is not needed to undertake a detailed cost-effectiveness analysis of the waste management options which would require a much more detailed analysis of economic costs.

The costs-benefit analysis reported here is provided to give an indication of the likely costs of waste treatments. According to this approach, two different economic indicators are considered in the tool. One of the indicators is "Benefit-Cost Ratio (BCR)" which is presents amount of monetary gain realized by performing a project versus the amount it costs to execute the project. The higher BCR which results in the higher benefits rather than costs defines as follows:

$$BCR = \frac{Total\ Benefits}{Total\ Costs} \quad \textbf{Eq.(4)}$$

BCR should be greater than 1 for a good investment. Another indicator is "Payback Period (PBP)" which refers to the period of time required for the return on an investment. This indicator which is considered as a proxy for repay time of the sum of the original investment defines as follows:

$$Payback\ Period = \frac{Capital\ Investment}{Periodic\ Cash\ Flow} \qquad \textbf{Eq.(5)}$$

For calculation of total costs and benefits, following items should be considered as cost and benefit items:

<u>Cost Items:</u>

a) Fixed Costs
    - Land Acquisition Cost
    - Equipment and Technology Acquisition Cost
    - Construction and Installation Cost
b) Running Costs
    - Transportation Cost
    - Operational Cost
    - Maintenance Cost

<u>Benefit Items</u>

- Revenue from heat production (energy recovery)
- Revenue from electricity production (energy recovery)
- Revenue from tipping fee
- Revenue from sale of recovered/recycled materials (recycling)
- Revenue from sale of produced materials (compost)
- Benefit from avoided landfilling

Some benefit items are not considered depend on technology type. Table 2 summarizes the benefit items for different technologies included in the tool.

Table 2. Benefit items for different technologies in the tool

| Technology | Incineration | Landfilling | Composting | Anaerobic Digestion | Recycling |
|---|---|---|---|---|---|
| Revenue from heat production | Yes | Yes | NO | Yes | NO |
| Revenue from electricity production | Yes | Yes | NO | Yes | NO |
| Revenue from tipping fee | Yes | Yes | Yes | Yes | Yes |
| Revenue from sale of recovered/recycled materials | NO | NO | NO | NO | Yes |
| Revenue from sale of produced materials | Yes | NO | Yes | Yes | NO |
| Benefit from avoided landfilling | Yes | NO | Yes | Yes | Yes |

## 2.4. Policy Intervention

The environmental indicators depend on the waste composition and, the share of each strategy in the WMS highly as well as on the technology efficiency less. The policy intervention deals with the effect of impressive parameters on the (policy) indicators resulting in the decision of policy makers in the WMS. In this work, three different interventions are examined as:

- the total waste volume and composition
- the waste composition in each waste management technologies
- the technology specifications

Different scenarios which can be run by changing the mentioned interventions examine the effect of several variables on the GHG emissions, air pollution and energy recovery potentials. The comparison between the results of different scenarios can direct the user to choose the best scenario/technology in the WMS.

# 3. Technical Calculations

This chapter describes the calculation of GHG emissions from different waste management technologies and sections The technologies and sections include waste transportation, operational activities, incineration, open-burning, landfilling, composting, anaerobic digestion, recycling, wastewater generation. Also, air pollutant, GHG emissions avoidance from energy recovery and compost production and, leachate production are explained. Then, the policy intervention and discussed three major factors which can affect the indicators are presented.

## 3.1. Calculation of GHG Emissions in Different Sections

### 3.1.1. Waste Transportation

Waste transportation system consumes fossil fuels (gasoline, diesel and CNG) to transport of waste from the source to the treatment / disposal facilities. By considering the fossil fuel consumption, GHG emissions of waste transportation are calculated as follows:

**Eq. (6)**

$$Emission\ \left(\frac{1000\ Tonne\ Pollutants}{Year}\right) = MSW\ \left(\frac{Tonne\ Waste}{Year}\right) \times\ Fuel\ Consumption\ \left(\frac{Lit}{Tonne\ Waste}\right) \times\ EF_{Fuel}\ \left(\frac{gr\ Pollutants}{Lit}\right) \times 10^{-9}$$

If the fuel millage data is available, following equation should be used instead of equation (6):

**Eq. (7)**

$$Emission\ \left(\frac{1000\ Tonne\ Pollutants}{Year}\right) = MSW\ \left(\frac{Tonne\ Waste}{Year}\right) \times\ Fuel\ Millage\ \left(\frac{100\ km}{Tonne\ Waste}\right) \times\ Fuel\ Efficiency\ \left(\frac{Lit}{100\ km}\right) \times\ EF_{Fuel}\ \left(\frac{gr\ Pollutants}{Lit}\right) \times 10^{-9}$$

where MSW and EF indicate annual municipal solid waste volume and emission factor, respectively. In Eq.(6) and Eq.(7), the pollutants include $CO_2$, $CH_4$ and $N_2O$ species (greenhouse gases). The emission factors and fuel efficiencies are considered as default values which are defined in the “default emissions factors” and “default technical data” sheets in the tool. For example, the amount of fuel efficiency of gasoline, diesel and CNG which are considered for light truck vehicles are assumed 14.7, 12.5 and 8.3 Lit/100km, respectively. If a user would like to use specific data, there is the possibility to change the emissions factors in the tool.

### 3.1.2. Operational Activities

In some process such as landfilling, composting and, anaerobic digestion, pre-treatment processes such as mechanical biological pre-treatment (for landfill) mechanical pre-treatment, fermentation and maturing (for composting and anaerobic digestion) consume electricity and/or heat for operation of machineries (operational activities). Therefore, there is required to estimate GHG emissions due to providing of these energy carriers. As the combustion of fossil fuels is considered as a source for providing heat, the tool consider only $CO_2$ as GHG emission gas and the $CH_4$ and $N_2O$ emissions assumed to be negligible for fossil fuel combustion. The following equations (8) and (9) are used to calculate $CO_2$ emission from operational activities with respect to energy source:

**Eq.(8)**

$$Fuel\ Emission\ \left(\frac{1000\ Tonne\ CO_2}{Year}\right) = MSW\ \left(\frac{Tonne\ Waste}{Year}\right) \times\ Fuel\ Consumption\ \left(\frac{Lit}{Tonne\ Waste}\right) \times\ EF_{Fuel}\ \left(\frac{gr\ CO_2}{Lit}\right) \times 10^{-9}$$

**Eq.(9)**

$$Electricity\ Emission\ \left(\frac{1000\ Tonne\ CO_2\ eq.}{Year}\right) = MSW\ \left(\frac{Tonne\ Waste}{Year}\right) \times\ Electricity\ Consumption\ \left(\frac{kWh}{Tonne\ Waste}\right) \times\ EF_{Elec.}\ \left(\frac{gr\ CO_2\ eq.}{MJ}\right) \times 10^{-9}$$

Note that the emission factor for providing the heat is obtained by assuming diesel combustion. Also, the emission factor of oil products power plants are used as a default data for calculation of GHG emission of electricity supply for operational activities. The emissions factor of different energy sources are reported in Table (7) in "Default Emissions Factor" excel sheet in the tool.

### 3.1.3. Incineration

Equations (10)-(12) are applied for calculation of GHG emissions in incineration process according to IPCC 2006:

**Eq.(10)**

$$CO_2\ Emission\ \left(\frac{1000\ Tonne\ CO_2}{Year}\right) = IW\ \left(\frac{Tonne\ Waste}{Year}\right) \times\ DMCof\ Waste \times CF\ \ of\ Dry\ Waste \times FCF\ of\ Waste\ \times OX \times \frac{44}{12} \times 10^{-3}$$

which IW, DMC, CF, FCF and OX indicate incinerated waste, dry matter content, fraction of carbon content, fraction of fossil carbon content and oxidation factor, respectively.

**Eq.(11)**

$$CH_4\ Emission\left(\frac{1000\ Tonne\ CH_4}{Year}\right) = IW\ \left(\frac{Tonne\ Waste}{Year}\right)\ \times\ EF_{CH_4}\ \left(\frac{gr\ CH_4}{Tonne\ Waste}\right) \times 10^{-9}$$

**Eq.(12)**

$$N_2O\ Emission\left(\frac{1000\ Tonne\ N_2O}{Year}\right) = IW\ \left(\frac{Tonne\ Waste}{Year}\right)\ \times\ EF_{N_2O}\ \left(\frac{gr\ N_2O}{Tonne\ Waste}\right) \times 10^{-9}$$

The oxidation factor of incineration is generally assumed to be unit in the tool. Dry matter content, total carbon content and the fraction of fossil carbon in total carbon content are calculated as follows:

$$DMC = \sum_i WF_i \times dmc_i$$ **Eq.(13)**

$$CF = \sum_i WF_i \times CF_i$$ **Eq.(14)**

$$FCF = \sum_i WF_i \times FCF_i$$ **Eq.(15)**

which $WF_i$, $dmc_i$, $CF_i$ and $FCF_i$ present fraction of component *i* in waste, dry matter of component *i* in the waste (fraction), carbon content of component *i* in the waste (fraction) and fossil carbon content of component *i* in the waste (fraction), respectively. In the tool, food, paper and cardboard, wood, textiles, rubber and leather, plastics, metal, glass, garden and park wastes, nappies and other (e.g., ash, dirt, dust, soil, electronic waste) are the components which form the MSW.

### 3.1.4. Open Burning

According to IPCC 2006, the GHG emissions of open burning can be calculated the same manner for incineration. In fact, the open burning is an uncontrolled combustion of the waste. Therefore, the emission factor and oxidation factor of open burning is different from incineration process. The oxidation factor of open burning process used is 0.58.

### 3.1.5. Landfilling

Methane ($CH_4$) and carbon dioxide ($CO_2$) are the primary constituents of Landfill Gas (LFG), and are produced by microorganisms within the landfill under anaerobic conditions. Landfill disposal sites manage waste on a long-term basis, so there is a need to track the quantity of waste managed over historic years. The first-order biological delay model which is adapted from IPCC 2006 and EPA 2008 is used for calculation of $CH_4$ generation as follows:

$$CH_4\ Emission\ \left(\frac{Tonne}{Year}\right) = \sum_{x=S}^{T-1} LW_x\ L'_x\ (e^{-k(T-x-1)} - e^{-k(T-x)})$$ **Eq. (16)**

where

A = $CH_4$ generation (Tonne/Year)

x = Year in which waste was disposed

S = Start year of inventory calculation

T = Inventory year for which emissions are calculated

$LW_x$ = the quantity of waste disposed at the landfill site (Tonne/Year)

$L'_x$ = $CH_4$ generation potential (Tonne $CH_4$/Tonne waste)

= MCF × DOC × DOCF × F × 16 / 12

where

MCF = Methane Correction Factor (fraction)

DOC = Degradable Organic Carbon [fraction (Tonne C in waste/Tonne waste)]

DOCF = Fraction of DOC which decomposes (fraction), generally assumed to be 0.5

F = Fraction by volume of $CH_4$ in landfill gas, generally assumed to be 0.5

k = Decay rate constant (1/Year)

Amount of MCF is classified according to the type of landfill site according to IPCC 2006. Also, the following equations estimate DOC and k:

$$DOC = \sum_i WL_i \times DOC_i$$ **Eq.(17)**

$$k = \sum_i WL_i \times k_i$$ **Eq.(18)**

where $DOC_i$ and $k_i$ indicate the fraction of degradable organic carbon fraction and the decay rate constant of component *i* in waste, respectively. The default parameters for DOC and k with respect to waste component are reported in Table (1) in "Default Technical Data" excel sheet in the tool. The values of $k_i$ are depend on climate type that classified to dry, wet, dry tropical and wet & most tropical climates. $CO_2$ emission can be estimated by the following equation:

$$CO_2\ Emission(kg/Year) = Q_{CO_2} \times \frac{MW_{CO_2} \times 1\ atm}{8.205\times10^{-5}\ (m^3\ .atm/gmole.K)\times1000(gr/kg)\times(273+T)}$$ **Eq.(19)**

where

MWP = Molecular weight of $CO_2$ which is 44 g/gmol

$Q_{CO2}$ = Emission rate of $CO_2$, $m^3$/Year; and

T = Temperature of LFG, $^oC$

Eq.(19) assumes that the operating pressure of the system is approximately 1 atmosphere. If the temperature of the LFG is not known, a temperature of $25^{0C}$ is recommended. To estimate $Q_{CO2}$, the following equation has been used:

$$Q_{CO_2} = \frac{Q_{CH_4} \times \frac{C_{CO_2}}{C_{CO_2} + C_{CH_4}}}{0.5} \qquad \textbf{Eq.(20)}$$

Where:

$Q_{CH4}$ = $CH_4$ generation rate, $m^3$/Year (according to Eq.(17))

$C_{CO2}$ = Concentration of $CO_2$ in LFG, ppmv; and

$C_{CH4}$ = Concentration of $CH_4$ in the LFG, ppmv

The value of 0.5 in denominator presents the volume concentration of methane in LFG. The concentration of $CO_2$ and $CH_4$ in ppmv (parts per million by volume) can be obtained by considering 50% methane and 50% carbon dioxide in LFG (Typically, LFG also contains non-methane organic compounds (NMOC) and volatile organic compounds (VOC), but in a very low concentration rather than methane and carbon monoxide).

### 3.1.6. Composting

As mentioned before, most of the carbon degraded within the compost pile will be converted to biogenic $CO_2$ through aerobic degradation. While $CO_2$ emissions from biogenic sources are not considered in the tool, the major components of GHG emissions are $CH_4$ and $N_2O$. The annual equivalent $CO_2$ emission from composting can be estimated by using the Global Warming Potentials (GWP) as:

**Eq.(21)**

$$GHG\ Emissions\ \left(\frac{kg\ CO_{2e}}{Year}\right) = OW\ \left(\frac{Tonne\ Waste}{Year}\right) \times [CH_4\ Emission\ Factor\ \left(\frac{kg\ CH_4}{Tonne\ Waste}\right) \times GWP_{CH_4}\left(\frac{kg\ CO_2}{kg\ CH_4}\right) + N_2O\ Emission\ Factor\ \left(\frac{kg\ N_2O}{Tonne\ Waste}\right) \times\ GWP_{N_2O}(\frac{kg\ CO_2}{kg\ N_2O})]\ ]$$

Where OW indicates organic waste treated by composting treatment.

According to IPCC 2006, the emission factors of $CH_4$ and $N_2O$ in compost facilities are 4 (kg $CH_4$/tonne waste) and 0.3 (kg $N_2O$/tonne waste), respectively. Also, the $GWP_{CH4}$ and $GWP_{N2O}$ are assumed 21 and 310, respectively.

### 3.1.7. Anaerobic Digestion

Similar to composting, $CO_2$ emissions of Anaerobic Digestion (AD) are of biogenic origin, and are not considered in the tool [IPCC 2006, Chapter 4]. According to IPCC, 2006, $N_2O$ emission factor of AD is assumed to be negligible and $CH_4$ emission can be calculated as follows:

**Eq.(22)**

$$CH_4\,Emission\,\left(\frac{kg\,CH_4}{Year}\right) = OW\,\left(\frac{Tonne\,Waste}{Year}\right) \times CH_4\,Emission\,Factor\left(\frac{kg\,CH_4}{Tonne\,Waste}\right) - R\,\left(\frac{kg\,CH_4}{Year}\right)$$

where OW indicates organic waste treated by anaerobic digestion treatment and R represent total amount of $CH_4$ recovered as biogas for energy recovery. Also, the amount of $CH_4$ emission can be converted to equivalent $CO_2$ emission by using the GWP of $CH_4$ as:

**Eq.(23)**

$$GHG\,Emissions\,\left(\frac{kg\,CO_{2e}}{Year}\right) = CH_4\,Emission\,\left(\frac{kg\,CH_4}{Year}\right) \times\;\; GWP_{CH_4}\left(\frac{kg\,CO_2}{kg\,CH_4}\right)$$

### 3.1.8 Recycling

No GHG emissions occur at the MSW management stage because the recycled material is diverted from waste management facilities. In recycling, net GHG emissions which is associated with remanufacture of recycled inputs reduce. The avoided GHG emissions are calculated by the difference between (1) the GHG emissions from manufacturing the marketable materials and products from 100% recycled materials and (2) the GHG emissions from manufacturing the marketable and products from 100% virgin materials by accounting loss rates in between recovery and manufacturing. The GHG emissions from making materials from recycled inputs are typically less rather than virgin inputs.

When any material is recovered for recycling, some portion of the recovered material is unsuitable for use as a recycled input. This portion is discarded either in the recovery stage or in the remanufacturing stage. Consequently, less than 1 ton of recyclable material generally is made from 1 ton of recovered material. Material losses are quantified and translated into loss rates. Figure 2 shows the loss rates concept schematically.

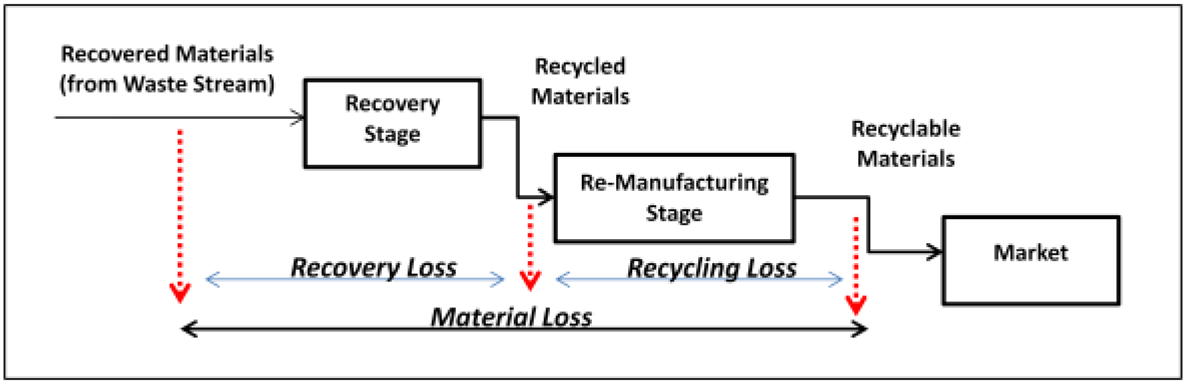



Figure 2. The loss rates concept in the recycling strategy

By considering loss rates, recycling can be evaluated in terms of tonnes of recyclable materials or tonnes of recovered materials. According to EPA, the avoided GHG emissions factor of recycling which is associated with remanufacturing divided to two different categories: energy related GHG emissions factor including processes and technology and; non-energy related GHG emissions factor including processes. The GHG emissions factor regarding of recovered material reported in Table (6) in "Default Emissions Factor" excel sheet in the tool. In this table, the GHG emissions can be converted to MTCE/Tonne (MTCE: Metric Tonne Carbon Equivalent) of recyclable material by using the loss rate of recovery stage. In the tool, user can choose the units of material as recyclable or recovered according to input data which are available.

By considering the GHG emission factors and the tones of material recycled reported by EPA, the total GHG emissions of recycling can be estimated regarding GHG emissions of each material as follows:

**Eq.(24)**

$$Total\ GHG\ Emissions\ \left(\frac{Tonne\ CO_{2e}}{Year}\right) =$$
$$\sum_i GHG\ Emissions\ Factor_i\ \left(\frac{Tonne\ CO_{2e}}{Tonne\ of\ Recycled\ Materials}\right) \times\ RW_i\left(\frac{Tonne\ of\ Recycled\ Materials}{Year}\right)$$

where index *i* presents components of recycled material and RW indicates the recycled Waste.

### 3.1.9. Wastewater Generation

Wastewater is a term applied to any type of water that has been utilized in some capacity that negatively impacts the quality of the water. Common examples of wastewater include water that is discharged from households, office and retail buildings, and manufacturing plants. Municipal wastewater is usually conveyed in a combined sewer or sanitary sewer, and treated at a wastewater treatment (WWT) plant or septic tank. WWT plants are industrial structure designed to remove biological or chemical waste products from water, thereby permitting the treated water to be used for other purposes.

The wastewater generation rate represents average wastewater generation within the area and is used to characterize the wastewater in terms of typical pollutant concentrations and characteristics. According to IPCC 2006, wastewater can be a source of carbon dioxide, methane and nitrous oxide when treated or disposed anaerobically. But, the origin of carbon dioxide emission is biogenic and it should not be therefore included in national total emissions. Domestic wastewater generation rate is developed from an assessment of the IPCC 2006 as follows:

$$CH_4\,Emission\,(\frac{kg\,CH_4}{Year}) = \left[TOW\,\left(\frac{kg\,BOD}{Year}\right) - S\,\left(\frac{kg\,BOD}{Year}\right)\right] \times EF_{CH_4}\left(\frac{kg\,CH_4}{kg\,BOD}\right)\; - \;R\,(\frac{kg\,CH_4}{Year})$$

**Eq. (25)**

where:

TOW = Total Organic material in the Wastewater in inventory year

EF $_{CH4}$ = Emission factor of methane

S = Organic component removed as sludge in inventory year, and

R = Amount of $CH_4$ recovered in inventory year

TOW as total BOD in wastewater in inventory year and $EF_{CH4}$ are calculated by using the following equations:

$$TOW\,\left(\frac{gr\,BOD}{Year}\right) = P\,(Person) \times BOD\,\left(\frac{gr\,BOD}{Person.Day}\right) \times\; SBF\;\; \times 365\,\left(\frac{Day}{Year}\right)$$

**Eq.(26)**

where:

P = Country population in inventory year

BOD = Country-specific per capita BOD in inventory year (gr BOD/(person.day))

SBF= Fraction of BOD that settles, assumed to be 0.5

$$EF_{CH_4}\,\left(\frac{gr\,CH_4}{gr\,BOD}\right) = B_0\,\left(\frac{gr\,CH_4}{gr\,BOD}\right) \times Weighted\;average\;MCF$$

**Eq.(27)**

where:

$B_0$ = Maximum $CH_4$ producing capacity, 0.6 $\frac{gr\,CH_4}{gr\,BOD}$

Weighted average MCF = Weighted average OF Methane Correction Factor, assumed to be 0.8

Table (1) in the “Default Technical Data” excel sheet reported the BOD default values for different countries.

Nitrous oxide emissions from wastewater ($N_2O$) come from two different resources: direct emission from WWT plants and indirect emission from wastewater after disposal of drainage into waterways, lakes or the sea. Direct emissions need to be estimated only for countries that have predominantly advanced centralized wastewater treatment plants with nitrification and de-nitrification steps. Direct emissions can be estimated by using the following equation developed by IPCC 2006:

$$N_2O_{Direct}(\frac{kg\ N_2O}{Year}) = P\ (person) \times T_{WWT\ Plant}(\%) \times F_{Ind.-Comm.} \times EF_{WWT\ Plant}(\frac{gr\ N_2O}{Person.Year}) \quad \textbf{Eq.(28)}$$

Where:

P = Country population

$T_{WWT\ Plant}$ = Degree of utilization of modern, centralized WWT plants, assumed to be 90%

$F_{Ind.-Comm.}$ = Fraction of industrial and commercial co-discharged protein, assumed to be 1.25

$EF_{WWT\ Plant}$ = Emission factor of WWT plant, assumed to be 3.2 (gr $N_2O$/(person.year))

$$N_2O_{Indirect}\left(\frac{kg\ N_2O}{Year}\right) = N_{Effluent}\left(\frac{kg\ N}{Year}\right) \times EF_{Effluent}\left(\frac{kg\ N_2O-N}{kg\ N}\right) \times \frac{44}{28} \quad \textbf{Eq.(29)}$$

Where:

$N_{Effluent}$ = Nitrogen in the effluent discharged to aquatic environments

$EF_{Effluent}$ = Emission factor for $N_2O$ emissions from discharged to wastewater

The N Effluent expressed as follows:

$$N_{Effluent}\left(\frac{kg\ N}{Year}\right) = P\ (person) \times Protein\ \left(\frac{kg}{(Person.Year)}\right) \times F_{NPR}\ (\frac{kg\ N}{kg\ Protein}) \times\ F_{non-con} \times F_{Ind.-Comm.} -\ N_{Sludge}\ (\frac{kg\ N}{Year}) \quad \textbf{Eq.(30)}$$

Where:

P = Country population

Protein = Annual per capita protein consumption (kg Protein/Person.Year)

$F_{NPR}$ = Fraction of nitrogen in protein, assumed to be 0.16 (kg N/kg Protein)

$F_{non-con}$ = Factor for non-consumed protein added to the wastewater, assumed to be 1.4 for developed country and 1.1 for developing country (This factor can differ for developed and developing nations)

$F_{Ind.-Comm.}$ = Factor for industrial and commercial co-discharged protein into the sewer system, assumed to be 1.25

$N_{Sludge}$ = Nitrogen removed with sludge, assumed to be zero (kg N/ Year)

Note that if wastewater emissions include $N_2O$ direct emissions from plants, the equal amount of nitrogen associated with these emissions (which can be calculated by multiplying $N_2O$ directly by 28/44, using the molecular weights) must be back calculated and subtracted from the $N_{Effluent}$.

### 3.1.10. Energy Recovery

Energy recovery is the process of generating energy in the form of electricity and, electricity and heat from the waste management technologies. In the tool, incineration, landfilling and anaerobic digestion are three common waste management technologies with possibility of energy recovery using energy recovery devices. The combustion of fossil fuels is considered as a source for providing heat and, gas turbine, steam turbine, ICE engine and, CHP systems are considered as devices for electricity production. Regarding energy recovery of the waste, the GHG emissions which are caused by fossil fuel combustion for energy production can be avoided. As operational activities in section 3.1.2., the required equations for calculating the GHG emissions of energy recovery (fuel, heat or electricity) are the same as Eq.(8) and (9), with the difference that the calculated emissions should be considered negative (avoided GHG emissions).

### 3.1.11. Compost Production as Fertilizer

As mentioned before, the compost which is produced through aerobic degradation of organic waste in composting facility can be used as fertilizer or soil amendment in agriculture. Therefore, by replacing the fertilizer by compost, the GHG emissions which are yielded through fertilizer production can be avoided. The avoided GHG emissions from fertilizer replacement can be calculated by using the GWP as follows:

**Eq.(31)**

$$GHG\ Emissions\left(\frac{kg\ CO_{2e}}{Year}\right) = M_C\left(\frac{Tonne\ Compost}{Year}\right) \times \left[EF_{CO_2}\left(\frac{kg\ CO_2}{Tonne\ Compost}\right) + EF_{CH_4}\left(\frac{kg\ CH_4}{Tonne\ Compost}\right) \times GWP_{CH_4}\left(\frac{kg\ CO_2}{kg\ CH_4}\right) + EF_{N_2O}\left(\frac{kg\ N_2O}{Tonne\ Compost}\right) \times GWP_{N_2O}\left(\frac{kg\ CO_2}{kg\ N_2O}\right)\right]$$

where $M_c$ is the amount of compost production.

### 3.1.12. Air Pollutants

The concentration of air pollutant is a factor determined by calculating the mount of air pollution in the region. The type of air pollutant depends on the waste technology, whereas CO, $SO_X$, $NO_X$ $PM_{10}$ and, $PM_{2.5}$ are the common air pollutants in the different technologies. Estimating the air pollutants concentration can be done according to air pollutants factor as follows:

**Eq.(32)**

$$Concentration\ of\ Air\ Pollutants\left(\frac{kg\ Air\ Pollutants}{Year}\right) = MSW\ \left(\frac{Tonne\ Waste}{Year}\right)\ \times\ EF_{Air\ Pollutant}\ \left(\frac{kg\ Air\ Pollutant}{Tonne\ Waste}\right)$$

where MSW presents the amount of waste.

### 3.1.13. Leachate Production

Leachate is any liquid that, in passing through matter, extracts solutes, suspended solids or any other component of the material through which it has passed. Leachate is most commonly used in the context of land-filling of decayable or industrial waste in terms of typical pollutant concentrations.

Landfill leachate is generated from liquids existing in the waste as it enters a landfill or from rainwater that passes through the waste. The leachate consists of different organic and inorganic compounds that may be either dissolved or suspended. High concentrations of Chemical Oxygen Demand (COD) associated, Biochemical Oxygen Demand (BOD), nitrogen, phenols, pesticides, solvents and heavy metals are common in these systems. The risks of leachate generation can be mitigated by properly designed and engineered landfill sites, such as sites that are constructed on geologically impermeable materials or sites that use impermeable liners made of geo-membranes or engineered clay to prevent pollution into surrounding ground and surface waters. Generally, a common leachate collection system includes liners, filters, pumps and sumps. The compositions of leachate from landfills include heavy metals which are As, Cd, Cr, Cu, Ni, Pb and Hg. The emissions of leachate are a function of the amount of waste generated and an emission factor that characterizes the extent to which this waste generate heavy metals as follows:

Eq.(33)

$$Leachate\ Emission_i\left(\frac{kg\ \ Pollutant\ i}{Year}\right) = MSW\ \left(\frac{Tonne\ Waste}{Year}\right)\ \times\ EF_i\ \left(\frac{kg\ Pollutant\ i}{Tonne\ Waste}\right)$$

where MSW presents the amount of waste and index *i* indicate to different heavy metal species including As, Cd, Cr, Cu, Ni, Pb and Hg.

## 4. Tool Description

This chapter describes the procedure for the user to input data into the tool, how to set policy interventions, get results and, perform an economic analysis.

### 4.1. “Home” sheet

The tool is run as an MS-Excel VBA (Visual Basic for Applications) spreadsheet, a windows-based application. Upon opening the spreadsheet, a dialogue box needs to be opened to enable macros. This is point [1] in Figure 3. Clicking it will open the dialogue box where ‘Enable this content’ needs to be selected and OK clicked in the box ([2] in Figure 3). When this has been done the green “Home” sheet will become fully operational. This is the first excel sheet of the tool to outline different available sections on the tool ([3] in Figure 3). The user can select an action between different options which are included input data, baseline results, policy intervention, summary results, detailed results, cost-benefit analysis, emissions factor and technical data. The “Input Data” action should be selected as the first action when user gets to work with the tool.

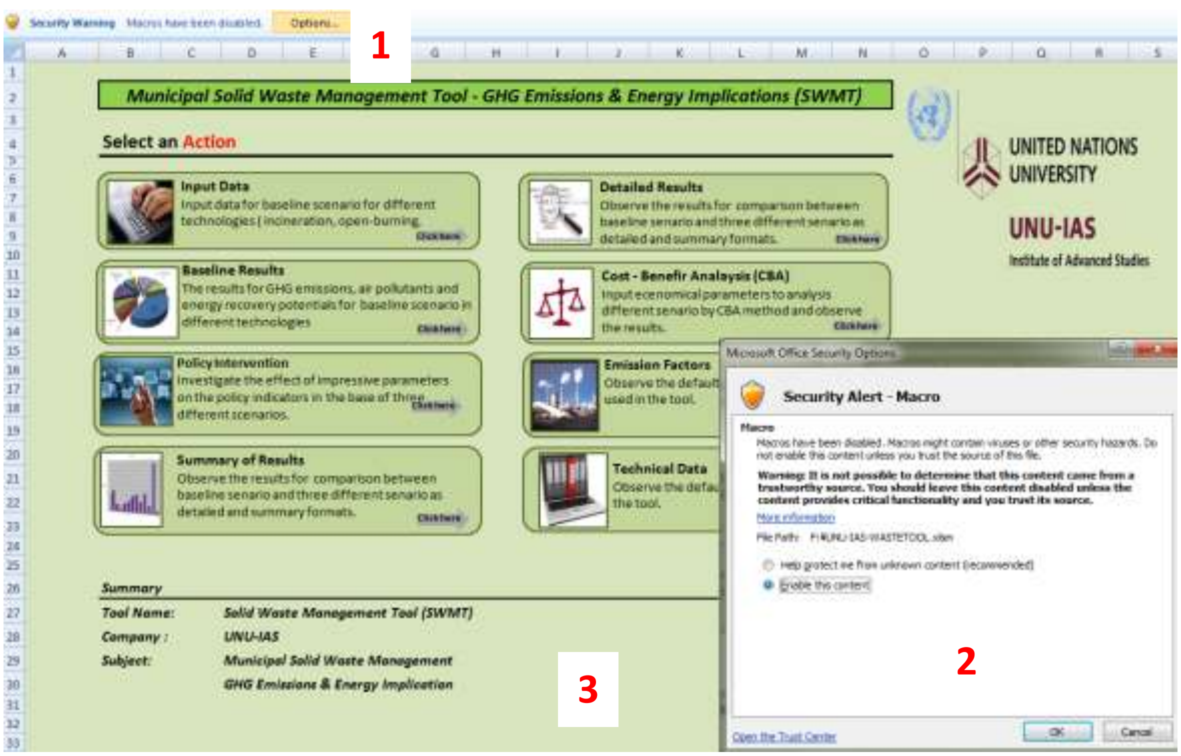



Figure 3. The opening sheet showing the option to enable macros [1], the dialogue box which enabling of the macros needs to be selected [2], and the first excel sheet (“Home” sheet) in the tool in the background [3]. Steps [1] and [2] need to be performed in order to use the tool.

Different parts of the tool can be accessed by clicking on the corresponding section by using a sequential steps menu running along the top of the screen in every sheet as shown in Figure 4.


Figure 4. The sequential steps configuration in the tool

All calculations in the all steps are based on equations were outlined in chapter 3. Also, as mentioned before, there is a possibility in the tool to change all of the default input data including emissions factor and technical data to the user's own the site-specific data which may be more accurate than the default values provided.

## 4.2. Steps in the Tool

### 4.2.1. Input Data (Baseline Scenario)

Figure 5 illustrates the input data excel sheet which is necessary to entered by the user as baseline scenario data.

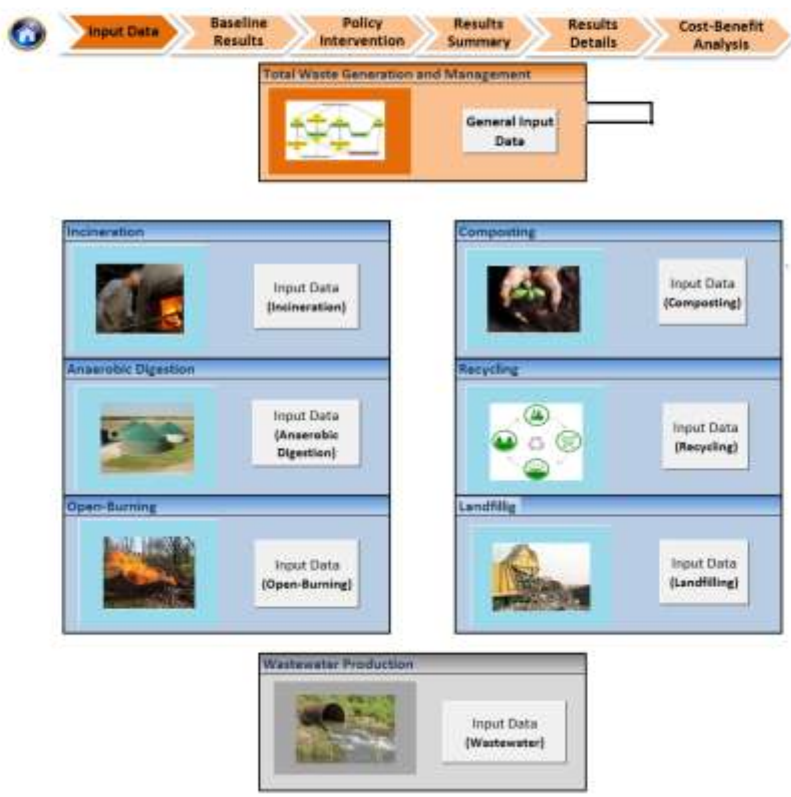



Figure 5. The Input Data excel sheet in the tool

A separate menu is available for each waste treatment technology. By clicking on each button, the corresponding input data form appears as shown in Figures (6) to (12) for different technologies. The technologies listed are intended to be exhaustive and therefore it may be the case that certain technologies are not relevant to the situation being modeled. In this case, users should enter a zero value for waste volume for the omitted waste processing streams.

#### *4.2.1.1 General Input Data*

Figure 6 shows the general input data which are initially required to generate the baseline scenario.


Figure 6. The general input data form in the tool

The general input data are categorized as follows:

-Waste generation as the amount of municipal solid waste which is generated per person per day. The tool provides a dataset including default value for this parameter per different regions

- Region population

- Waste distribution through the different treatment technologies
- Total waste composition

After entering the general data, the user needs to fill out the input data form for the other technologies as follows:

#### 4.2.1.2 Incineration

Figure 7 shows the input data form for incineration technology which is available by clicking on the incineration button in input excel sheet (Figure 5).

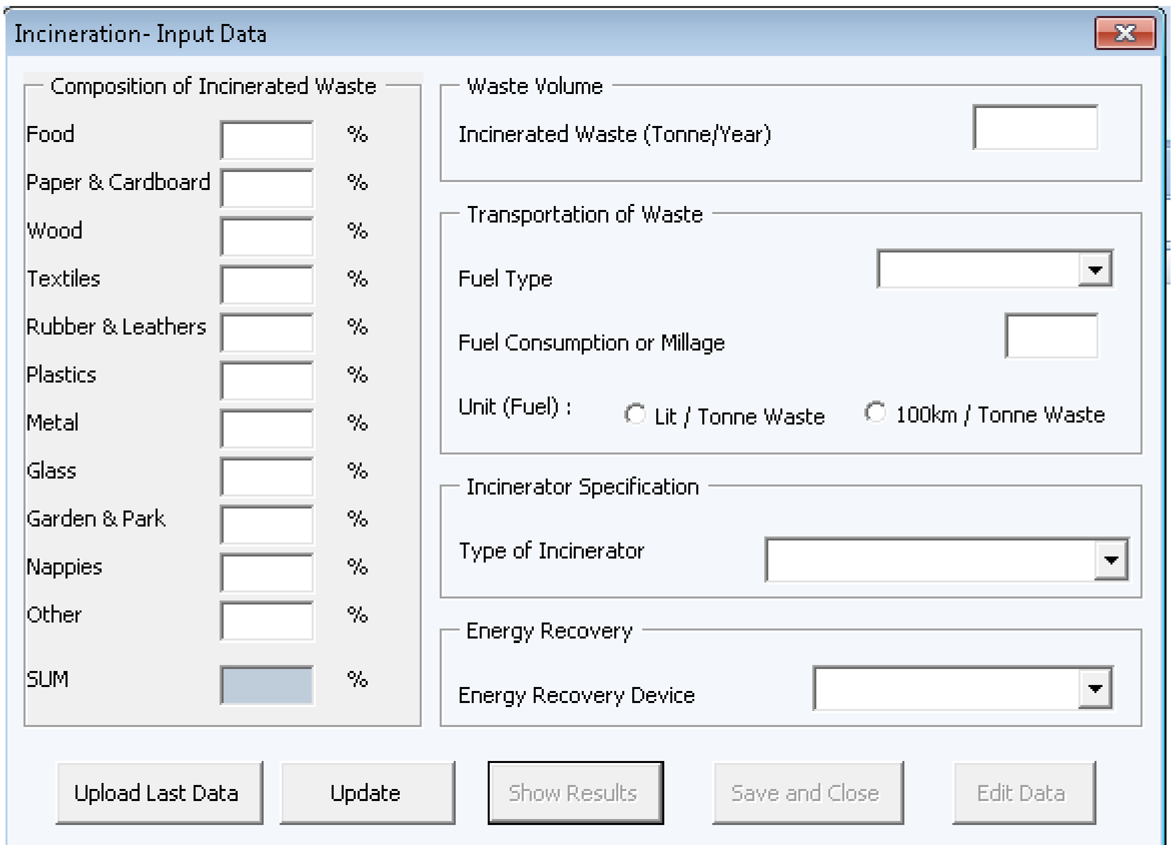



Figure 7. The incineration input data form in the tool

**>>Input Data:**

In the incineration form, the user is asked to enter the following input data:

- **Composition of incinerated waste,** as mass percentage of food, paper and cardboard, wood, textiles, rubber and leather, plastics, metal, glass, garden and park wastes, nappies and other
- **Amount of waste incinerated,** as 'Tonne/Year'

- **Fuel type and fuel amount for waste transportation,** as 'Lit/Tonne Waste' (fuel consumption) or '100km/Tonne Waste' (fuel millage)
- **Incinerator specification**, Three different incineration process type including continues type, semi-continue type and batch type were included in the tool. Every type includes the stoker type and fluidized bed type. The difference for incineration process, incineration technology and management practices of incinerators are caused difference between $CH_4$ emission factors highly and between $N_2O$ emission factors less.
- **Energy recovery device**, the tool includes different item as a energy recovery device, steam turbine, gas turbine, diesel engine and CHP (Combined Heat and Power) system for recovering energy from the heat produced in the incinerators. Also, the item 'NO Device' indicates no energy recovery.

**>>Default Data:**

The default data which is used in this section as follows:

- Dry matter content of different types of waste
- Carbon content of different types of waste
- Fossil carbon fraction of different types of waste
- Oxidation Factor of Incineration, assumed to be 100%
- The GHG emissions factor for incineration process
- The GHG emissions factor for different fuels (gasoline, diesel and CNG) in transportation section
- The GHG emissions factor for energy recovery (heat and/or electricity)
- The GHG emissions factor for 100% landfilling of the waste
- The emission factor of air pollutants for incineration process

The default emissions factor are provided in Table (1) in "Default Emissions Factor" excel sheet in the tool.

**>>Net GHG Emission:**

The calculation of net GHG emissions of incineration technology is released by considering the following items:

- Waste transportation to incineration facilities
- Incineration of waste
- Energy recovery
- 100% landfilling of incinerated waste

Therefore, total GHG emissions and air pollutants from incineration are calculated as follows:

**Net GHG emissions from incineration** = GHG emission from waste transportation + GHG emission from incineration – Avoided GHG emissions from energy recovery device – Avoided GHG emissions from 100% landfilling instead of incineration

In this tool, the GHG emissions avoidance potential from 100% landfilling of the waste (instead of incineration) are not included in the net GHG emissions value as default. If user would like to take into account the avoidance potential in the net value, user can add this item to the total value by clicking on the "Include avoided GHG emissions from 100% landfilling in Total Value" check box in the form. The net GHG emissions can be positive or negative. The positive value of the net GHG emissions is a proof of GHG emissions production by incineration and this technology is a source of carbon to climate impact. If the net GHG emissions value is negative, it shows that the technology contributes to mitigation of GHG as a carbon sink.

**>>Net Air Pollutants:**

The net air pollutants of incineration technology are calculation as follows:

**Net air pollutants from incineration** = Air pollutants from waste transportation + Air pollutants from incineration

#### *4.2.1.3. Open-Burning*

The input data form for open-burning technology which is available by clicking on the open-burning button in input data excel sheet (Figure 5) shown in Figure 8.

**>>Input Data:**

In the open-burning form, the user is asked to enter the following input data:

- **Composition of open-burned waste,** as mass percentage of food, paper and cardboard, wood, textiles, rubber and leather, plastics, metal, glass, garden and park wastes, nappies and other
- **Amount of waste open-burned,** as 'Tonne/Year'
- **Fuel type and fuel amount for waste transportation,** as 'Lit/Tonne Waste' (fuel consumption) or '100km/Tonne Waste' (fuel millage)

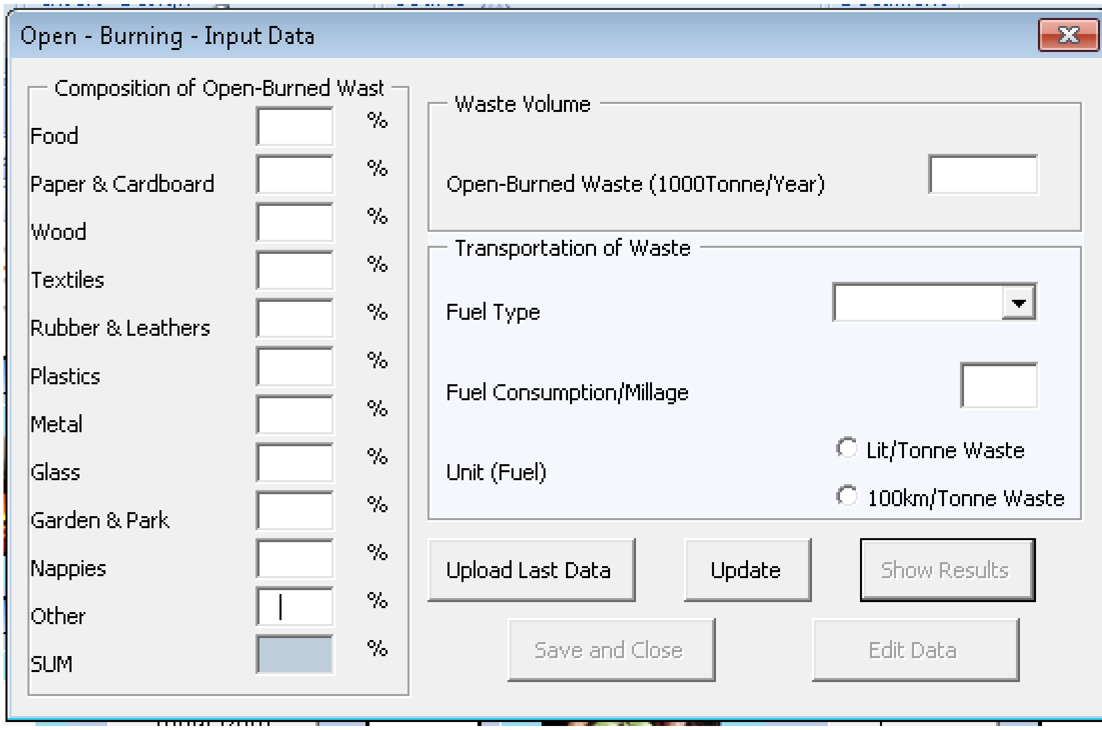



Figure 8. The open-burning input data form in the tool

**>>Default Data:**

The default data which is used in this section as follows:

- Dry matter content of different types of waste
- Carbon content of different types of waste
- Fossil carbon fraction of different types of waste
- Oxidation facto for uncontrolled combustion, assumed to be 58%
- The GHG emissions factor for uncontrolled combustion process
- The GHG emissions factor for different fuels (gasoline, diesel and CNG) in transportation section
- The emission factor of air pollutants for uncontrolled combustion process

The default emissions factor of open-burning are reported in Table (2) in “Default Emissions Factor” excel sheet in the tool.

**>>Net GHG Emission:**

The net GHG emissions of open-burning strategy are calculated by considering the following items:

- Waste transportation to incineration facilities
- Open burning of waste

Therefore, total GHG emissions from open-burning are calculated as follows:

**Net GHG emissions from incineration** = GHG emission from waste transportation + GHG emission from uncontrolled combustion (open-burning process)

The net GHG emissions are positive and open-burning is a source of carbon to climate impact, as expected.

**>>Net Air Pollutants:**

The net air pollutants of open-burning technology are calculation as follows:

**Net air pollutants from open-burning** = Air pollutants from waste transportation + Air pollutants from open-burning

#### *4.2.1.4. Landfilling*

The input data form for landfilling technology which is available by clicking on the landfilling button in input sheet (Figure 5) is shown in Figure 9.

**>>Input Data:**

The following items are required as input data for landfilling technology:

- **Composition of landfilled waste,** as mass percentage of food, paper and cardboard, wood, textiles, rubber and leather, plastics, metal, glass, garden and park wastes, nappies and other
- **Energy consumption for operation of machineries,** as 'Lit/Tonne Waste' of fuel consumption and 'kWh/Tonne Waste' of electricity consumption for operational activities
- **Amount of waste landfilled,** as 'Tonne/Year'
- **Fuel type and fuel amount for waste transportation,** as 'Lit/Tonne Waste' (fuel consumption) or '100km/Tonne Waste' (fuel millage);
- **Landfilll site type,** Three different landfill sites include managed landfill, unmanaged landfill or open dump (two type: deep and shallow) and uncategorized landfill. Managed landfill produces more methane emission

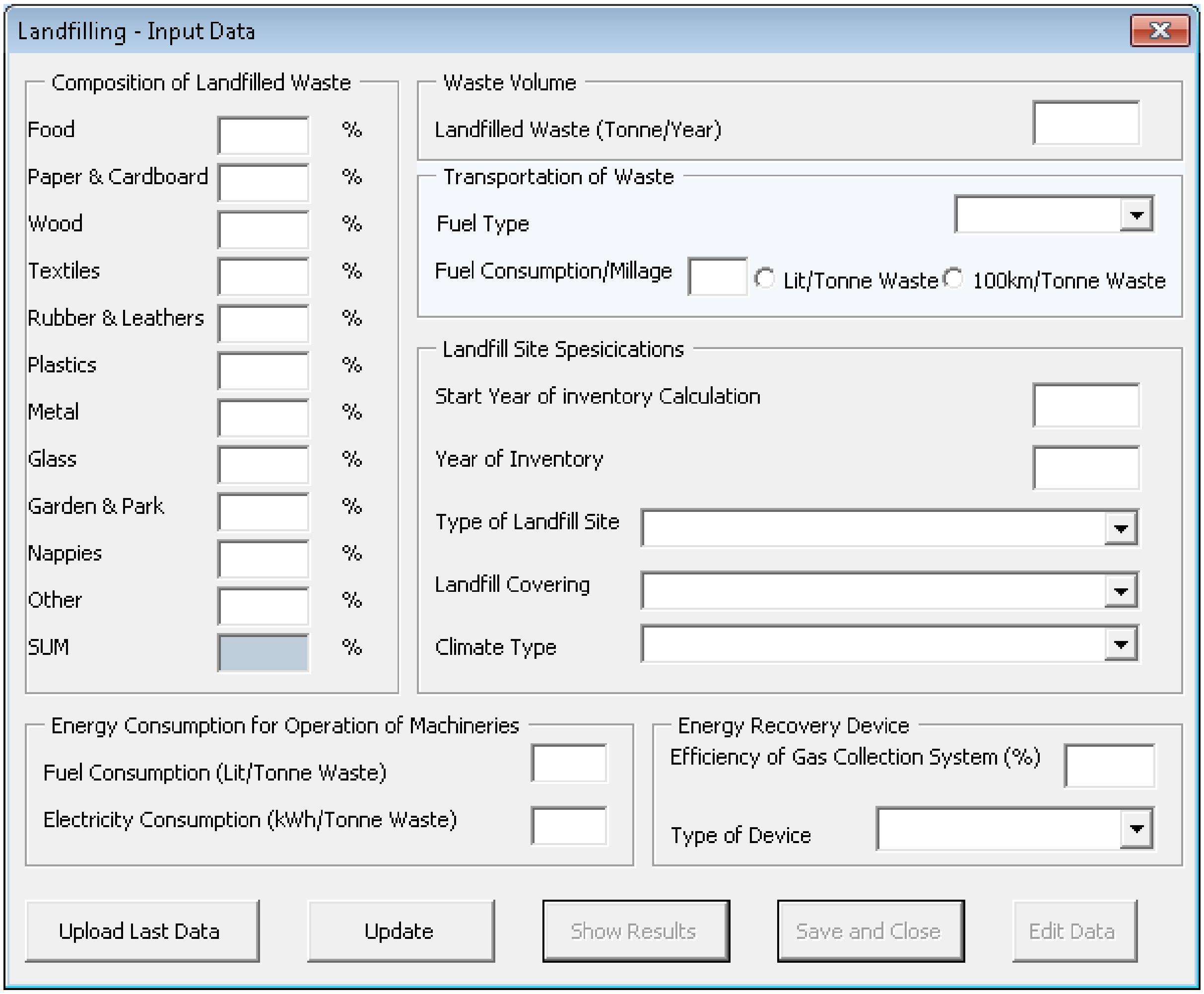



Figure 9. The landfilling input data form in the tool

rather than that of unmanaged landfill where waste can rot away aerobically in the top layers. Also, greater methane emission is emitted from deeper unmanaged sites rather than that of unmanaged sites.

- **Landfilll covering**, The landfill sites can be covered or uncovered with clay, plastic liners, and composites to enhance methane oxidation. The purpose of covering a landfill site are minimizing leachate generation, resisting erosion due to wind/runoff and preventing exposure of waste to animals, insects and rodents and, improve aesthetics.
- **Climate type**, The tool includes four different climates type for calculating CH4 oxidation rate (dry temperate climate, wet temperate climate, dry tropical climate and mist & wet tropical climate). Note that decay rate values for the landfills can be changed according to the climate type.

- **Efficiency of gas collection system**, as percentage of the gas collection system efficiency. If the user selects 'No Device' item as energy recovery device, the efficiency is equaled to zero automatically.
- **Energy recovery device**, the tool includes different item as a energy recovery device, steam turbine, gas turbine, diesel engine and CHP (Combined Heat and Power) system for recovering energy from the heat produced in the incinerators. Also, the item 'No Device' indicates no energy recovery.

**>>Default Data:**

The default data which is used in this section as follows:

- Methane Correction Factor (MCF)
- Fraction of DOC (DOCF) which decomposes, generally assumed to be 0.5
- Degradable Organic Carbon (DOC) of different types of waste
- Fraction by volume of $CH_4$ in landfill gas, generally assumed to be 0.5
- Fraction by volume of $CO_2$ in landfill gas, generally assumed to be 0.5
- Decay rate constant of different types of waste for various climate types
- The GHG emissions factor for waste landfilling
- The GHG emission factor for operation of machineries (diesel and electricity)
- The GHG emissions factor for different fuels (gasoline, diesel and CNG) in transportation section
- The GHG emissions factor for energy recovery (heat and/or electricity)
- The emission factor of air pollutants for operation of machineries (diesel and electricity).
- The emission factor of air pollutants for landfilling

These default emissions factor are provided in Table (3) in "Default Emissions Factor" excel sheet in the tool.

**>>Net GHG Emission:**

The calculation of net GHG emissions of landfilling technology is released by considering the following items:

- Waste transportation to landfill site
- Landfilling of waste
- Usage of fuel and electricity for operational activities
- Energy recovery

Therefore, total GHG emissions from landfilling are calculated as follows:

**Net GHG emissions from landfill sites** = GHG emission from waste transportation + GHG emission from Landfill sites + GHG emission from operation of machineries - Avoided emissions from energy recovery device

The positive value of the net GHG emissions is a reason that the landfilling is a source of carbon production to climate impact and negative net GHG emissions value indicates the mitigation of GHG emissions (carbon sink).

**>>Net Air Pollutants:**

The net air pollutants of landfilling technology are calculation as follows:

**Net air pollutants from landfill sites** = Air pollutants from waste transportation + Air pollutants from landfill sites + Air pollutants from operation of machineries

#### *4.2.1.5. Composting*

The input data form for composting technology has illustrated in Figure 10.

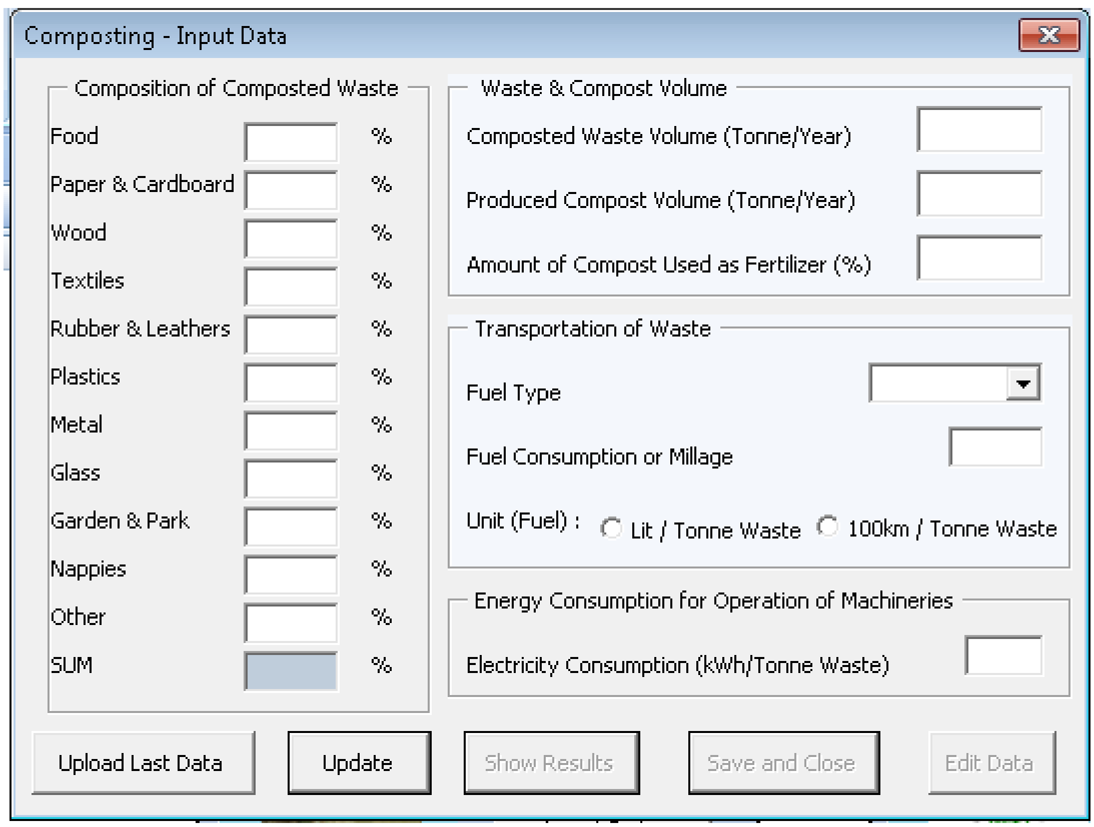



Figure 10. The composting input data form in the tool

**>>Input Data:**

The following items are required as input data for composting technology:

- **Composition of composted waste,** as mass percentage of food, paper and cardboard, wood, textiles, rubber and leather, plastics, metal, glass, garden and park wastes, nappies and other
- **Amount of waste composted,** as 'Tonne/Year'
- **Amount of compost prodution,** as 'Tonne/Year'
- **Amount of compost used as fertilizer,** as '%'
- **Fuel type and fuel amount for waste transportation,** as 'Lit/Tonne Waste' (fuel consumption) or '100km/Tonne Waste' (fuel millage);
- **Energy Consumption for operation of machineries,** as 'kWh/Tonne Waste' of electricity consumption for operational activities

**>>Default Data:**

The default data which is used in this section as follows:

- Global Warming Potentials of CH4 and N2O
- The GHG emissions factor for waste composting
- The GHG emission factor for operation of machineries (electricity)
- The GHG emissions factor for different fuels (gasoline, diesel and CNG) in transportation section
- The GHG emissions factor for 100% landfilling of the waste
- The emission factor of air pollutants for operation of machineries (electricity).
- The emission factor of air pollutants for composting

The default emissions factor are provided in Table (4) in "Default Emissions Factor" excel sheet in the tool.

**>>Net GHG Emission:**

The calculation of net GHG emissions of composting strategy is released by considering the following items:

- Waste transportation to composting facilities
- Composting of waste
- Usage of electricity for operational activities
- 100% landifilling of composted waste

Therefore, total GHG emissions from composting are calculated as follows:

**Net GHG emissions from composting** = GHG emission from waste transportation + GHG emission from composting + GHG emission from operation of machineries - Avoided emissions from 100% landfilling instead of composting

The positive value of the net GHG emissions shows that carbon is released to the atmosphere by composting technology, while the negative value expresses that composting is a carbon sink by mitigation of GHG emissions.

**>>Net Air Pollutants:**

The net air pollutants of composting technology are calculation as follows:

**Net air pollutants from composting** = Air pollutants from waste transportation + Air pollutants from composting + Air pollutants from operation of machineries

### *4.2.1.6. Anaerobic Digestion*

Figure 10 shows the input data form for anaerobic digestion technology which is available by clicking on the anaerobic digestion button in input sheet (Figure 5).

**>>Input Data:**

Following items are needed to enter in the input form by the user:

- **Composition of digested waste,** as mass percentage of food, paper and cardboard, wood, textiles, rubber and leather, plastics, metal, glass, garden and park wastes, nappies and other
- **Amount of waste digested,** as 'Tonne/Year'
- **Amount of compost production,** as 'Tonne/Year'
- **Amount of compost used as fertilizer,** as '%'
- **Fuel type and fuel amount for waste transportation,** as 'Lit/Tonne Waste' (fuel consumption) or '100km/Tonne Waste' (fuel millage)
- **Energy consumption for operation of machineries,** as 'kWh/Tonne Waste' of electricity consumption for operational activities
- **Energy recovery options**, the tool includes two different items for using of bio-gas as energy recovery resource which is produced in the anaerobic digestion process as fuel or as electricity producer in the bio-gas power plant Also, user can choose 'Without energy recovery' option for ignorance of energy recovery in the process.

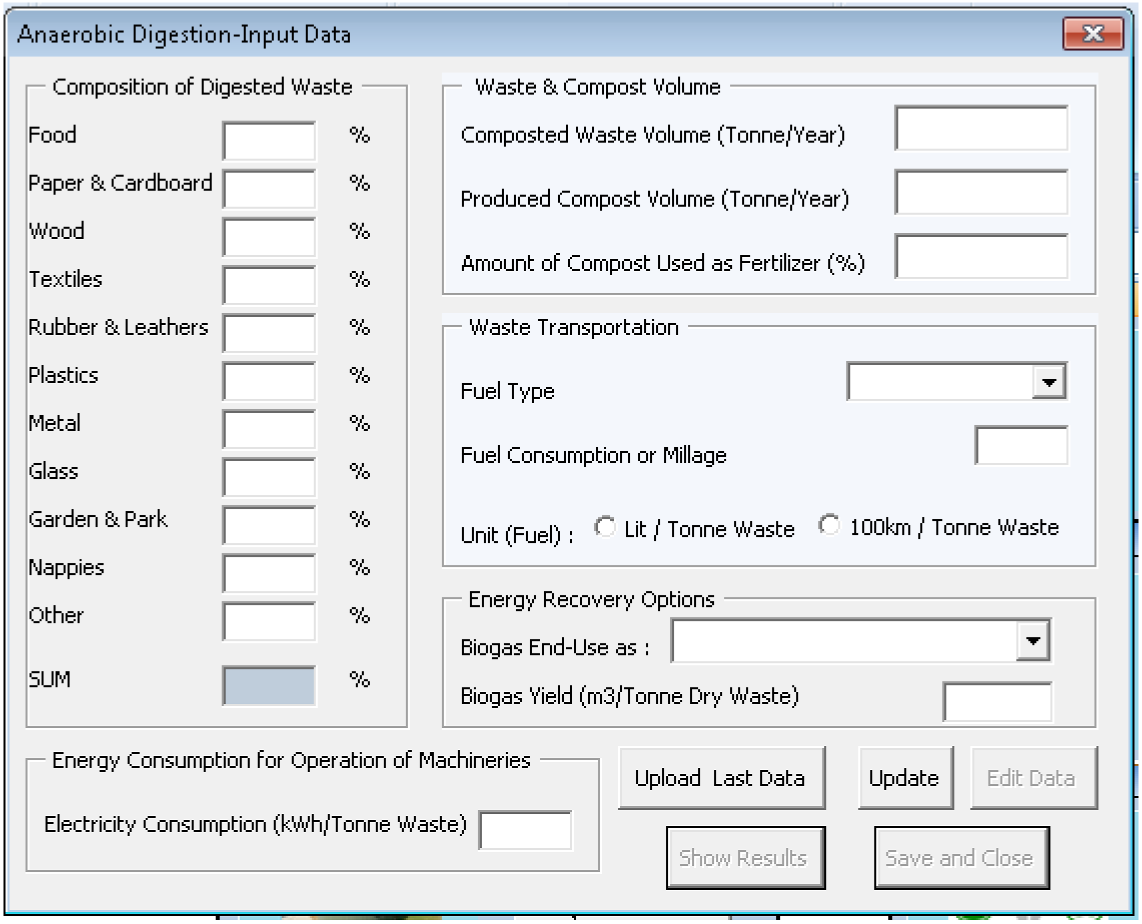


Figure 11. The anaerobic digestion input data form in the tool

**>>Default Data:**

The default data which is used in this section as follows:

- Global Warming Potentials of $CH_4$ and $N_2O$
- The GHG emissions factor for waste digestion anaerobically
- The GHG emission factor for operation of machineries (electricity)
- The GHG emissions factor for different fuels (gasoline, diesel and CNG) in transportation section
- The emission factor of air pollutants for operation of machineries (diesel and electricity).
- The GHG emissions factor for energy recovery (heat and/or electricity)
- The GHG emissions factor for 100% landfilling of the waste
- The emission factor of air pollutants for operation of machineries (electricity).
- The emission factor of air pollutants for anaerobic digestion

The default emissions factor are reported in Table (5) in “Default Emissions Factor” excel sheet in the tool.

**>>Net GHG Emission:**

Net GHG emissions of anaerobic digestion strategy are estimated by considering the following items:

- Waste transportation to digesting facilities
- Digestion of waste
- Usage of electricity for operational activities
- Energy recovery
- 100% landfilling of digested waste

Total GHG emissions from digestion are computed as follows:

**Net GHG emissions from digestion** = GHG emission from waste transportation + GHG emission from digestion + GHG emission from operation of machineries -Avoided emissions from energy recovery device -Avoided emissions from 100% landfilling instead of digestion

The positive value of the net GHG emissions shows that carbon is released to the atmosphere by anaerobic digestion technology, while the negative value gives evidence of mitigation of GHG emissions (carbon sink) by this technology.

**>>Net Air Pollutants:**

The net air pollutants of anaerobic digestion technology are calculation as follows:

**Net air pollutants from digestion** = Air pollutants from waste transportation + Air pollutants from digestion + Air pollutants from operation of machineries

#### *4.2.1.7. Recycling*

Figure 12 presents the input data form for recycling technology which is available by clicking on the recycling button in input sheet Figure 5).

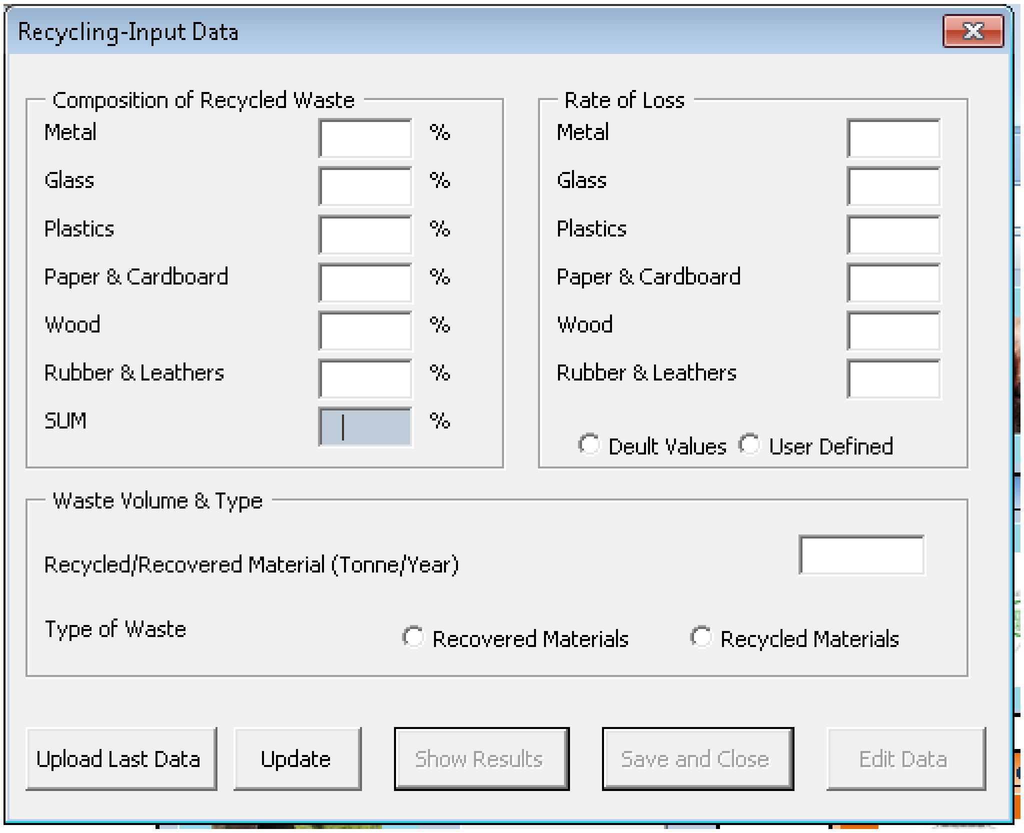


Figure 12. The recycling input data form in the tool

**>>Input Data:**

Following items are needed to enter in the input form by the user:

- **Composition of materials as waste,** as mass percentage of metal, glass, plastics, paper and cardboard, wood, rubber and leather
- **Amount and type of materials as recycled or recovered,** as 'Tonne/Year'
- **Rate of loss**, dimensionless. User can choose default data or enter own specified data for rate of loss.
-

**>>Default Data:**

The default data which is used in this section as follows:

- The GHG emissions factor for waste transportation
- The GHG emissions factor for recycling processes (including energy processes and non-energy processes)

The default emissions factor are provided in Table (6) in "Default Emissions Factor" excel sheet in the tool.

**>>Net GHG Emission:**

Net GHG emissions of recycling strategy are estimated by considering the following items:

- Waste transportation to recycling facilities
- Recycling of waste

Total GHG emissions from recycling are computed as follows:

**Net GHG emissions from recycling** = GHG emission from waste transportation + GHG emission from recycling process -Avoided emissions by recycling of the materials

The net GHG emissions of recycling are negative. It is associated with obtaining of considerable amount of recovered materials from the recycling process replacing them by the equivalent amount of virgin materials.

#### *4.2.1.8. Wastewater Generation*

Figure 13 presents the input data form for wastewater generation which is available by clicking on the wastewater generation button in input sheet Figure 5).

**>>Input Data:**

Three groups of data are needed to enter in the input form by the user: Country specifications, Coefficients for $CH_4$ emission calculations, Coefficients for total $N_2O$ emission (direct and indirect) calculations. For all data, user can choose default data or enter own specified data.

- **Country Specifications**
    - Name of country
    - Type of country (Developed or developing)
    - Population, as '1000 persons'
    - Daily Biochemical Oxygen Demand (BOD) per capita, as 'gr BOD/(Person.Day)'
    - Daily protein intake per capita, as 'gr Protein/(Person.Dday)
- **Coefficients for CH4 emission calculations**
    - Fraction of settled BOD, dimensionless
    - Average Methane Correction Factor (MCF), dimensionless
    - Amount of CH4 Recovered, as 'kg $CH_4$/Year'
    - Organic Component Removed as Sludge, as 'kg BOD/Year'

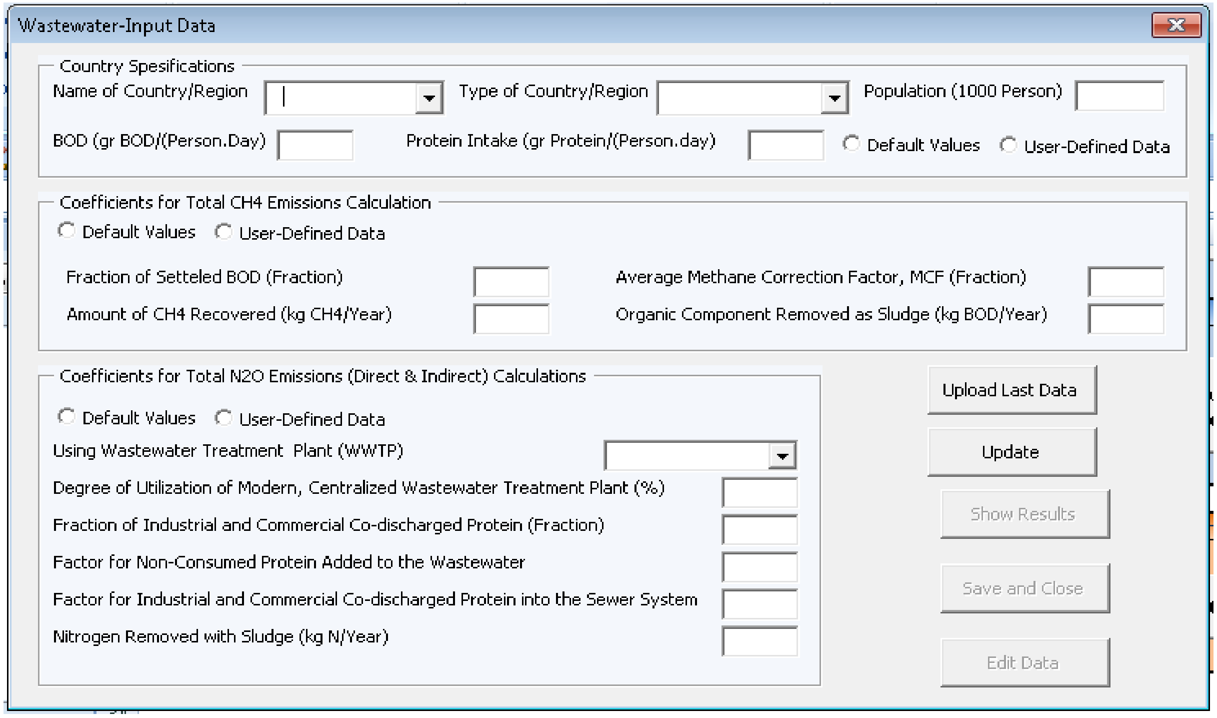



Figure 13. The wastewater input data form in the tool

- **Coefficients for total N2O emission (direct and indirect)**
  - Using Wastewater Treatment Plant (WWTP), as ‘Yes’ or ‘NO’
  - Degree of Utilization of Modern, Centralized Wastewater Treatment Plant, as ‘%’
  - Fraction of Industrial and Commercial Co-discharged Protein, dimensionless
  - Factor for Non-Consumed Protein Added to the Wastewater, dimensionless
  - Factor for Industrial and Commercial Co-discharged Protein into the Sewer System, dimensionless
  - Nitrogen Removed with Sludge, as ‘kg N/Year’

**>>Default Data:**

The default data which is used in this section as follows:

- Emission factor of CH4
- Country population
- Country-specific per capita BOD in inventory year (BOD) (gr BOD/(person.day))
- Fraction of BOD that settles (SBF), assumed to be 0.5

- Maximum $CH_4$ producing capacity ($B_0$), 0.6( $\frac{gr\ CH_4}{gr\ BOD}$)
- Weighted average OF Methane Correction Factor (MCF), assumed to be 0.8
- Degree of utilization of modern, centralized WWT plants, assumed to be 90%
- Emission factor of WWT plant, assumed to be 3.2 (gr $N_2O$/(person.year))
- Fraction of nitrogen in protein, assumed to be 0.16 (kg N/kg Protein)
- Factor for non-consumed protein added to the wastewater, assumed to be 1.4 for developed country and 1.1 for developing country
- Factor for industrial and commercial co-discharged protein into the sewer system, assumed to be 1.25
- Nitrogen removed with sludge, assumed to be zero (kg N/ Year)

These default emissions factor are presented in Table (8) in "Default Emissions Factor" excel sheet in the tool.

**>>Net GHG Emission:**

Total GHG emissions of wastewater generation are estimated by using the Global Warming Potentials (GWP) as:

**Eq.(22)**

$$GHG\ Emissions\ \left(\frac{kg\ CO_{2e}}{Year}\right) = CH_4\ Emission\ \left(\frac{kg\ CH_4}{Year}\right) \times\ GWP_{CH_4}\left(\frac{kg\ CO_2}{kg\ CH_4}\right) + [N_2O\ Direct\ Emission\ \left(\frac{kg\ N_2O}{Year}\right) + N_2O\ Indirect\ Emission\ \left(\frac{kg\ N_2O}{Year}\right)] \times\ GWP_{N_2O}(\frac{kg\ CO_2}{kg\ N_2O})]$$

where the $GWP_{CH4}$ and $GWP_{N2O}$ are assumed 21 and 310, respectively.

The total GHG emissions of wastewater are positive (source of carbon).

#### *4.2.1.9. Common Buttons in Input Data Forms*

As seen in Figures 7-13, there are four common different buttons for various technologies in input data form as follows:

**Upload Last Data**

This button has been considered for recovery and upload the last data which entered by the user in the last run.

**Update**

This button is designed to transfer the input data to database of tool for make calculation.

**Show Results**

By clicking on this button, the user can see the results for GHG emissions, air pollutants and energy section for corresponding technology as specific value (per tonnage) and as total value (per year). In Figure 14, the results form is shown as a sample for incineration technology.

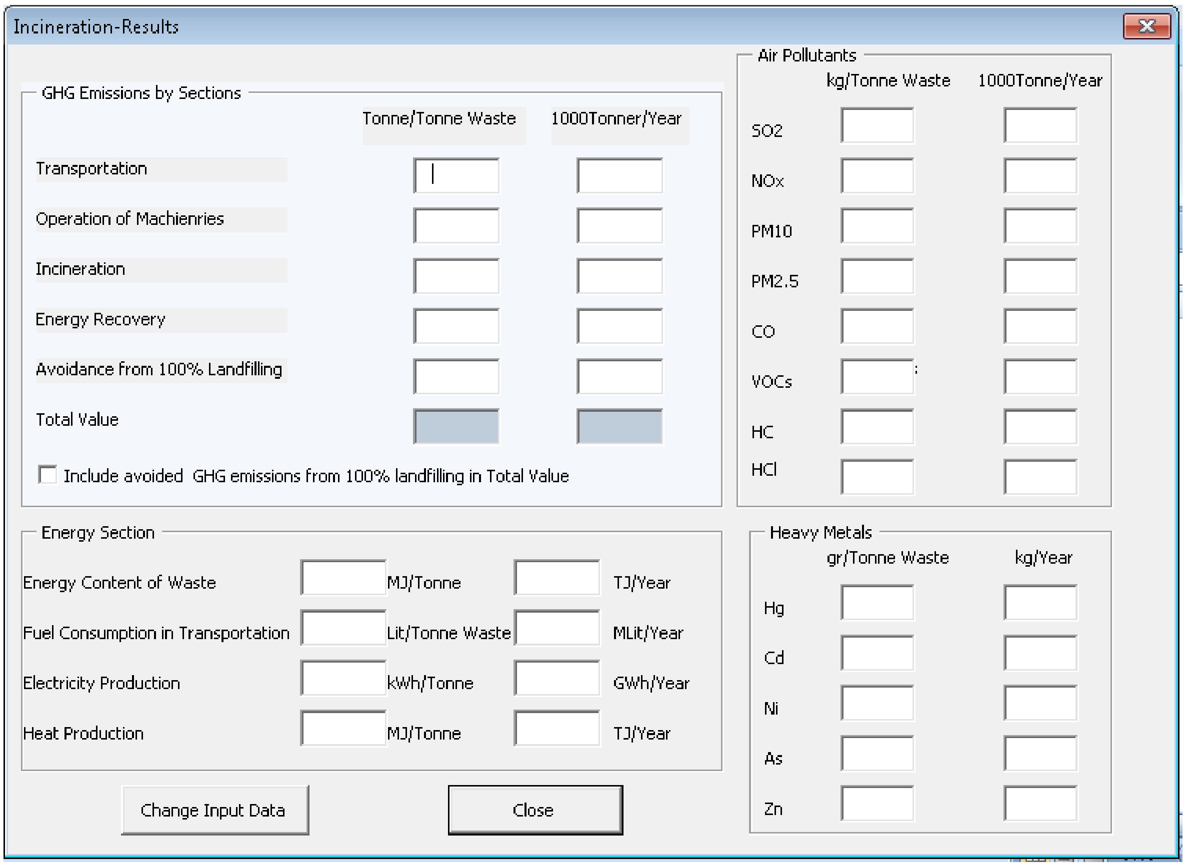



Figure 14. The incineration results form in the tool

In the tool, the results forms have similar format for all waste management technologies. As seen from Figure 14, there are two different buttons, "Change Input Data" and "Close" in the results form. By clicking on "Close" button, the form will be closed. Also, there is a possibility for user to change input data after observing the results. If user would like to comeback to input data form to know the results for another input data, it will be achievable by clicking on the "Change Input Data" button.

**Save and Close**

This button makes allowance for the possibility of saving input data and closing the form without seeing the results. In fact, this button helps to user to save the entered data and see the results whenever the user wants.

**Edit Data**

By clicking on this button, all input data fields are deleted for entering the new ones.

#### *4.2.1.10. Run the Baseline Scenario*

The sequential steps which should be done for run baseline scenario (all waste management technologies) as follows:

1. In the input data form, the user is asked to enter the required input data which has described for each waste management technology in the previous sections.
   Note that that waste volume is not necessary to enter by the user because it has been calculated according to input data in "Waste Generation" form in the tool. Also, there is possibility to use the last data which entered in the last run as input data in the baseline scenario. For this purpose, user should click on "Upload Last Data" button to observe the last input data in the input fields.
2. After entering required input data, **user should click on "Update" button** to transfer entered input data to the database of the tool. Then, the "Show Results", "Save and Close" and "Edit Data" buttons will be changed from disable state to enabled state.
3. In the next step, user can select one of the following buttons:
   - **"Show Results" button,** to observe results as GHG emissions, air pollutants, heavy metals and energy items
   - **"Save and Close" button,** to save entered input data and close the form without observing results
   - **"Edit Data",** to enable all input data fields to edit the entered data

### 4.2.2. Policy Intervention

As mentioned previously, three different interventions are examined in this work as three different scenarios:

- Scenario 1: Changing the waste volume and composition
- Scenario 2: Shifting waste processing
- Scenario 3: Changing technology specifications

By clicking on 'Policy Intervention', the scenarios can be available (Figure 15).


Figure 15. The policy intervention form in the tool

Figures 16-18 show the designed forms to run scenarios 1, 2 and 3 three different scenarios, respectively.

#### *4.2.2.1. Scenario1: Changing Total Waste Composition*

In this scenario, user can change waste volume through changing total waste composition. As the scenario1 form opens, the values of waste composition and waste volume of baseline scenario are appeared in the left column/field. User can enter the corresponding changing percent of volume for each waste type (food, paper & cardboard, wood, etc) and then by clicking on the 'Update' button, the new tonnage of waste are calculated accordance with the entered changing values and then shown in the right column/field. If the change fields keep blank, it is assumed that the changing percent is zero. After updating the waste volume and composition, the user should save and close the form by clicking on 'Save and Close' button.

Also, there is possibility to use the last data which entered in the last run as changing percent. User can click on "Upload Last Data" button to observe the changing percent in the corresponding column.

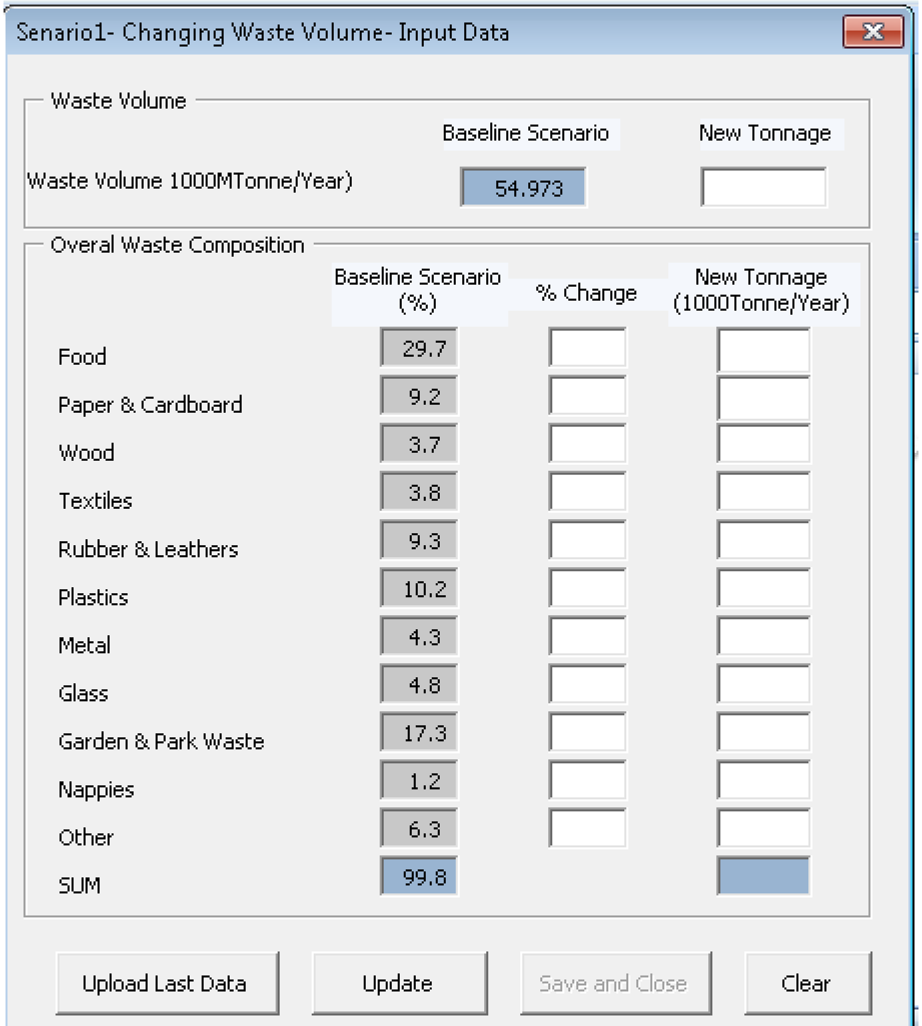
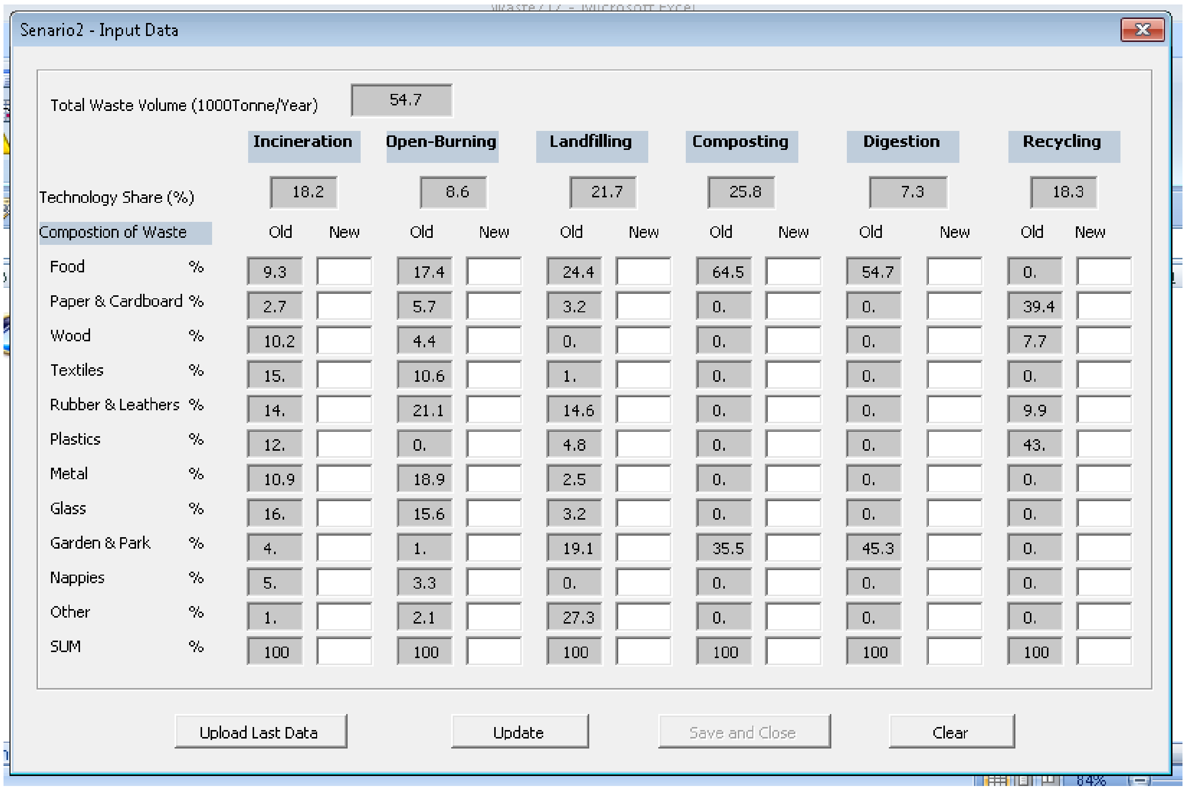



Figure 16. The scenario1 input data form in the tool

### *4.2.2.2. Scenario2: Shifting Waste Processing*

Shifting between different waste processing can be done in the scenario2 which is shown in Figure 17. Total After clicking on scenario 2 button in Figure 15, total waste volume, share of different waste management technologies and waste composition in each technology are appeared. These values which have titled 'Old' are accordance with last scenario has been run in the model (baseline scenario or scenario 1) and so, they cannot be changed by the user. User can shift the waste volume between different wastes processing methods (incineration, open-burning, landfilling, etc) by entering the new values of waste composition in the 'New' field. If the change fields keep blank, it is assumed that the changing percent is zero and the values are the same as old ones. By clicking on the 'Update' button, the new composition of waste are considered for every process. After updating, the user should save and close the form by clicking on 'Save and Close' button. By clicking on this button, the tool calculates the results according to the new composition, saves results and then, closes the form.

If user would like to see/consider the last “New” values which entered in the last run as input data, she/he should click on “Upload Last Data” button to observe the last values.



Senario2 - Input Data

Total Waste Volume (1000Tonne/Year) 54.7

| | Incineration | | Open-Burning | | Landfilling | | Composting | | Digestion | | Recycling | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technology Share (%) | 18.2 | | 8.6 | | 21.7 | | 25.8 | | 7.3 | | 18.3 | |
| Compostion of Waste | Old | New | Old | New | Old | New | Old | New | Old | New | Old | New |
| Food % | 9.3 | | 17.4 | | 24.4 | | 64.5 | | 54.7 | | 0. | |
| Paper & Cardboard % | 2.7 | | 5.7 | | 3.2 | | 0. | | 0. | | 39.4 | |
| Wood % | 10.2 | | 4.4 | | 0. | | 0. | | 0. | | 7.7 | |
| Textiles % | 15. | | 10.6 | | 1. | | 0. | | 0. | | 0. | |
| Rubber & Leathers % | 14. | | 21.1 | | 14.6 | | 0. | | 0. | | 9.9 | |
| Plastics % | 12. | | 0. | | 4.8 | | 0. | | 0. | | 43. | |
| Metal % | 10.9 | | 18.9 | | 2.5 | | 0. | | 0. | | 0. | |
| Glass % | 16. | | 15.6 | | 3.2 | | 0. | | 0. | | 0. | |
| Garden & Park % | 4. | | 1. | | 19.1 | | 35.5 | | 45.3 | | 0. | |
| Nappies % | 5. | | 3.3 | | 0. | | 0. | | 0. | | 0. | |
| Other % | 1. | | 2.1 | | 27.3 | | 0. | | 0. | | 0. | |
| SUM % | 100 | | 100 | | 100 | | 100 | | 100 | | 100 | |

Upload Last Data | Update | Save and Close | Clear

Figure 17. The input data form for changing shares of waste processing in the tool

### *4.2.2.3. Scenario3: Changing Technology Specifications*

In this scenario, the effects of technology specifications on GHG emissions and air pollutants as well as energy recovery potentials can be investigated (Figure 18). The parameters which can be changed include: type and amount of fuel using for waste transporting, required energy for operational activities, type of technology in each waste processing method and, energy recovery devices.

As the scenario3 form opens, user can input the corresponding values/items for different waste management technologies. If user would like to observe the last specifications which entered for the last run, he/she should click on the ‘Upload Last Data’ button. After entering the data, the button ‘Update’ should be clicked to take consideration the corresponding change in the model database. Then, the ‘Save and Close’ button should be clicked for calculation of results accordance with input changes, saving data and closing the form.

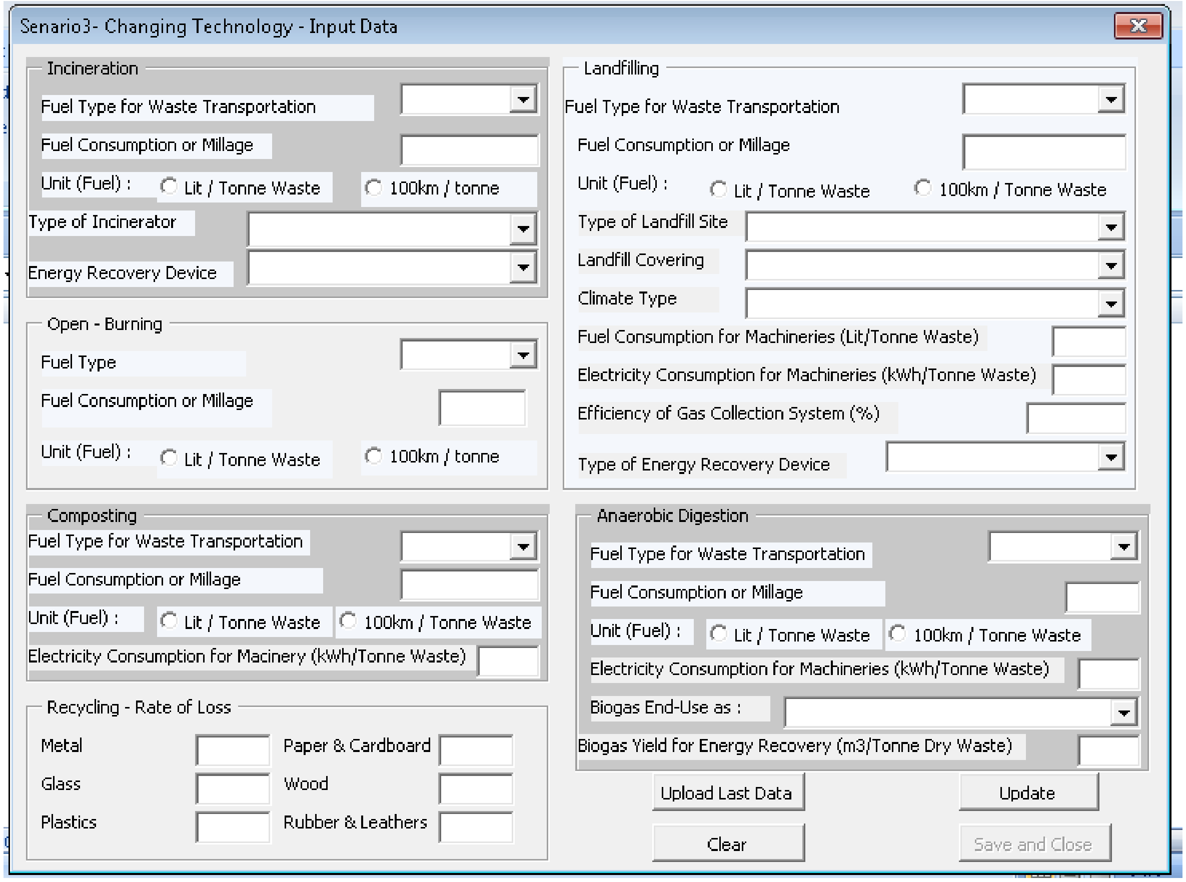



Figure 18. The data form for changing specific technologies and transport factors in the tool

### *4.2.2.4. Run the Policy Intervention*

The sequential steps which should be done for run a scenario in policy intervention as follows:

1. In the form, the user is asked to enter the required input data; changing percent of volume for each waste type in scenario 1, the new values of waste composition in the in different wastes processing methods in scenario 2 and technology specifications in scenario 3.

   Also, there is possibility to use the last data which entered in the last run as input data in the scenarios. In this context, user should click on "Upload Last Data" button to observe the last entered data in the related fields.
2. After entering required input data, **user should click on "Update" button** to transfer entered input data to the database of the tool. Then, the "Save and Close" and "Edit Data" buttons will be changed from disable state to enabled state.
3. In the next step, user can select one of the following buttons:

- **"Save and Close" button,** to save entered input data and close the form
- **"Edit Data",** to enable all input data fields to edit the entered data

### 4.2.3. Results

After entering input data, the results of the model can be seen as excel sheets in three formats. These can be accessed from the menu which runs along the top of the tool as shown in Figure 19.


Figure 19. Location of the results sheets in the tool

- **Baseline results:** This page shows the results for baseline scenario
- **Results Summary:** This page shows the summary of results after considering all interventions. In the other words, the results of last run can be seen in this page.
- **Results Details:** This page shows the results for each scenario individually.

If user would like to know the effect of changing all policy interventions on the results, the "Results Summary" excel sheet page should be selected. That is to say the "Results Summary" shows the final results after considering all interventions. This is the page where differences (co-benefits can be assessed as it shows the difference between the baseline and the interventions.

The results of each accomplished scenarios can be seen in proper if the "Results Details" selected. These can be accessed from the drop-down list shown in Figure 20.

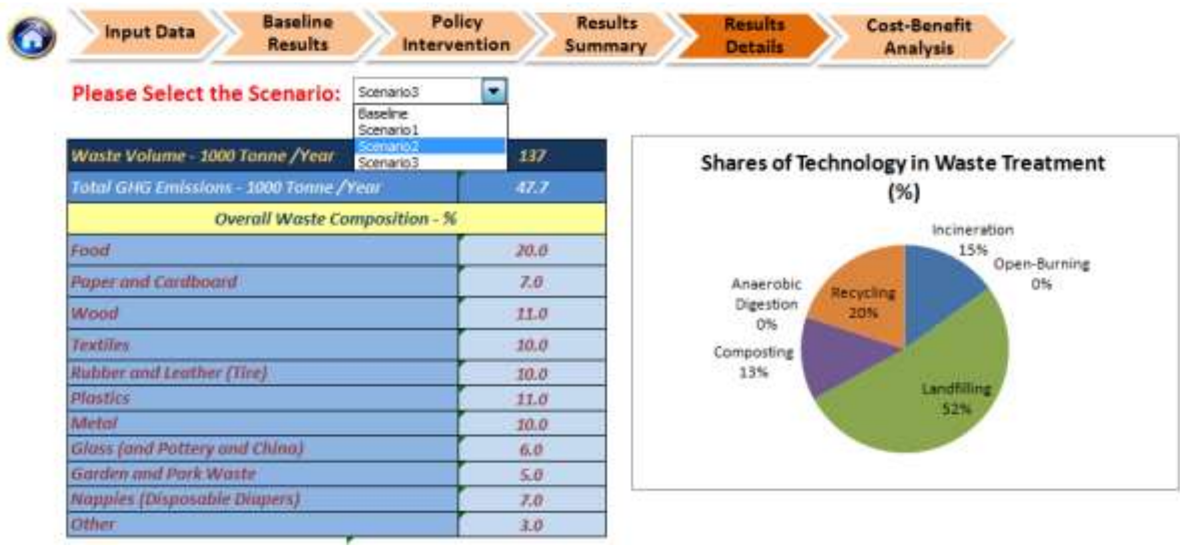



Figure 20. List where individual results can be analysed for each policy intervention

All excel sheets which show the results (baseline results, results summary or results details) are included following items:

**a) Results in the table format as:**

- Annual waste volume
- Annual total GHG emissions
- Overall waste composition
- Annual shares of sub-divisions (Transportation, Process, Energy Recovery and Avoided Potential) for each technology in GHG emissions production

**b) Results in the graphical format:**

- Annual total GHG emissions by technology
- Annual air pollutants by technologies including CO, $SO_2$, $NO_x$, $PM_{10}$ and $PM_{2.5}$
- Annual electricity production by technologies
- Annual heat production by technologies

Note that this tool is capable to estimate more pollutants with the exception CO, $SO_2$, $NO_x$, $PM_{10}$ and $PM_{2.5}$ (such as heavy metals composition in incineration, leachate composition in lanfilling and other air pollutants in different technologies). These pollutants can be seen by user in the results useform for each technology, in proper, if user clicks on the “Show Results” button in Figures 7-13.

### 4.2.4. Cost- Benefit Analysis (CBA)

The Cost-Benefit Analysis (CBA) is the last step in the tool. In this section, economic indicators including Benefit Cost Ratio (BCR) and Payback Period (PBP) are calculated for each technology. Figure 21 shows a sample of CBA analysis form which is available by clicking on the ‘Cost-Benefit Analysis’ in the first “Home” sheet in Figure (3) or sequential step configuration in Figure (4) . As all technologies have similar structure for CBA forms, it will suffice to mention ‘CBA-Incineration’ only as a sample.

In general, following items are required to enter in the cost-benefit analysis form by the user:

- **Input Data:**
    - Infiltration rate, as ‘%’
    - Price of Electricity, as ‘$/kWh1’
    - Price of Oil Barrel, as ‘$/BOE2’
    - Life Time, as ‘Year’
    - Waste Generation Rate for This Technology, as ‘%’

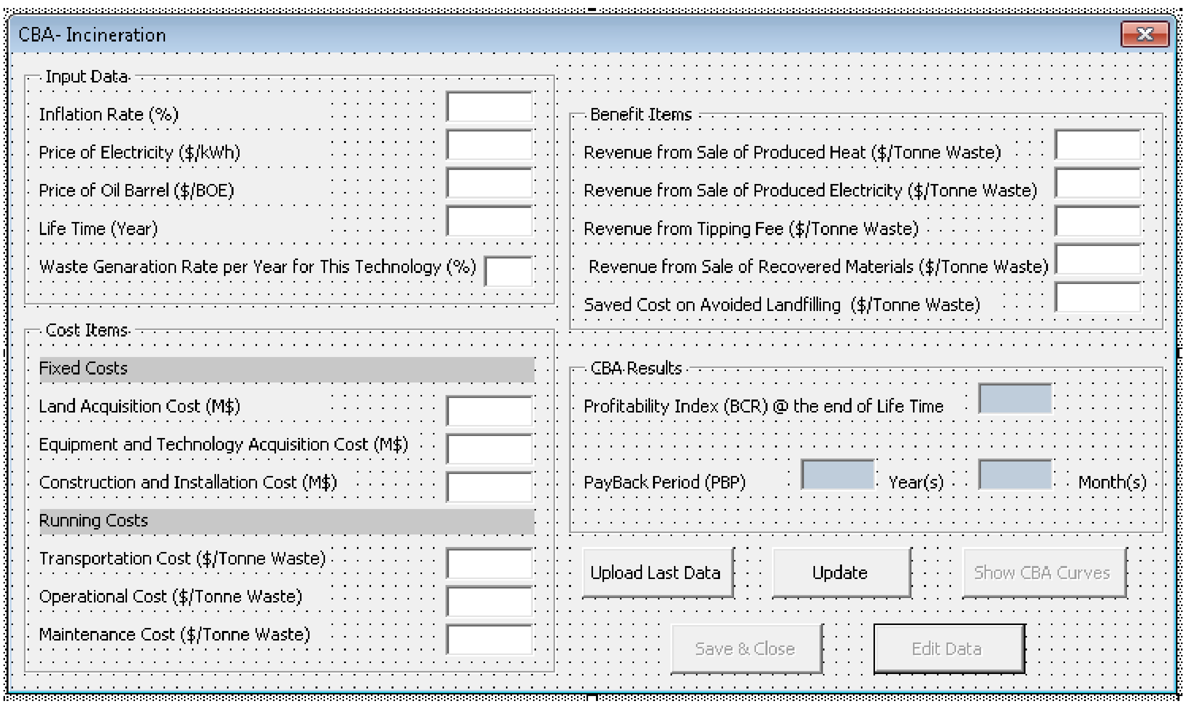



Figure 21. The CBA input data form in the tool

- **Cost Items**
    - Fixed Costs, as ‘M$’ (million dollar) including : Land Acquisition Cost, Equipment and Technology Acquisition Cost and, Construction and Installation Cost

[1] Barrel of Oil Equivalent (BOE)
[2] Barrel of Oil Equivalent (BOE)

    - Running Costs, as '$/Tonne Waste' including: Operational Cost and, Maintenance Cost
- **Benefit Items,** as '$/Tonne Waste' including:
    - Revenue from Sale of Produced Heat
    - Revenue from Sale of Produced Electricity
    - Revenue from Tipping Fee
    - Revenue from Sale of Recovered Materials
    - Revenue from Sale of Produced Materials
    - Saved Cost on Avoided Landfilling

It is important to note that, for all waste management technologies, cost of waste transportation (except recycling), revenue from sale of produced heat and, revenue from sale of produced electricity are not required to enter as input data by the user. In fact, the mentioned items are calculated by the tool according with the recorded data by user in the "Input Data" form. As a result, the corresponding fields are disabled in the CBA form and the calculated values will be appeared in the corresponding fields after clicking on update button.

In the CBA Results, the BCR and PBP are calculated as simple economical indicators to direct the user to get information about economic view. As expected, the BCR is increased when PPB is decreased. Note that the average life time of 20 year has been considered in the tool for all waste management technology.

#### *4.2.4. 1. Run the CBA for Each Technology*

The sequential steps which should be done for run CBA for a technology as follows:

1. In the CBA form, the user is asked to enter the required input data, cost items and benefit items (except waste transportation cost and revenue from sale of heat and electricity production).
   Also, there is possibility to use the last data which entered in the last run as input data in the corresponding CBA. In this context, user should click on "Upload Last Data" button to observe the last entered data in the related fields.
4. After entering required input data, **user should click on "Update" button** show BCR and PBP as CBA results. Then, the "Show CBA Curves", "Save and Close" and "Edit Data" buttons will be changed from disable state to enabled state.
5. In the next step, user can select one of the following buttons:

- **“Show CBA Curves” button,** to show cumulative cash flow and BCR as a function of year in a excel sheet
- **“Save and Close” button,** to save entered input data and close the form
- **“Edit Data”,** to enable all input data fields to edit the entered data

### 4.3. Default Input Data

In this tool, two different groups of default data has been used: emissions factor and technical data. Tables (1) to (9) in “Default Emissions Factor” excel sheet summarized the emissions factors for different waste management technologies which are used in the tool as default values. Also, the default technical data that are considered as default in this tool is addressed in the “Default Technical Data” excel sheet in Tables (1) to (10). Due to lack of country-specific data, this simulation uses an inventory data for emissions factor and technical data of different technologies which represents by EPA, IPCC2006 and literature to quantify GHG emissions, air pollutants and energy recovery implications.

## 5. Conclusions and Future Work

The excel VBA structure of the simulation in this tool results in simplicity and ease of the availability and understanding of different waste management practices including incineration, open-burning, landfilling, composting, anaerobic digestion and recycling. This tool can estimate the GHG emissions, air pollutants, energy recovery potentials as well as perform a cost-benefit analysis for these technologies. Moreover, the tool can evaluate possible reductions of environmental impacts by applying an Integrated Waste Management System approach. Through the consideration of different scenarios, it is possible to consider the impact of different policy interventions. The tool is flexible to the incorporation of region/country specific data on emission factors or other technical data that the user may have beyond what is provided in the existing database.

As such, there are some further improvements that can be made and will be investigated over time as hopefully more people use the tool. Two suggestions for improving this tool in the future work:

- Due to lack of region/country-specific data, baseline data in the tool uses an inventory data for emissions factor and some technical data which reported by EPA, IPCC2006 and literature to quantify GHG emissions, air pollutants and energy recovery implications. It is recommended that as much local data as possible is used for the most accurate results. These data (e.g. emissions factors and some technical data) can be added as necessary. Over time, though wider dissemination of the tool to many different users, we aim to develop a database of emissions factors and technical data which can help take into account country/region-specific data to overcome to some difficulties in gathering the input data which user is required to input in this tool.
- Develop a model to simulate recycling technology to estimate GHG emissions at the local authority level.

We welcome your feedback, suggestions and comments about this tool. Based on your feedback, you can help us highlight opportunities to improve the next version of the tool.

## 6. References: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Tools can be found online at: http://tools.ias.unu.edu

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