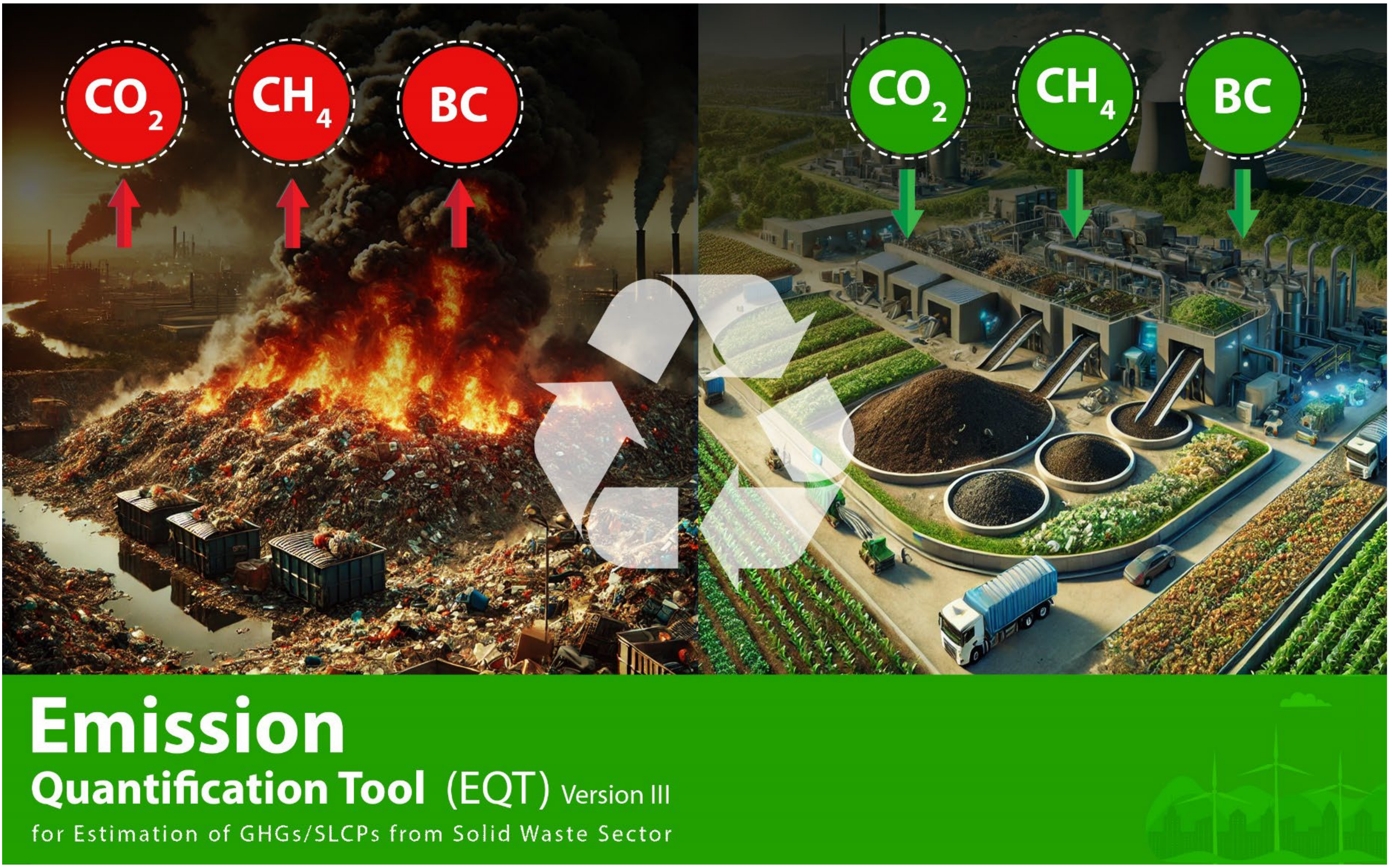
# User's Manual

# Emission Quantification Tool (EQT) for Estimating Short Lived Climate Pollutants (SLCPs) and Other Greenhouse Gases (GHGs) from Waste Sector




**Version III -January 2025**

CLIMATE & CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

UN environment programme

IGES Institute for Global Environmental Strategies

## Executive Summary

With increasing population, urbanization, and development, the waste sector has become a significant contributor to climate change at the national level in both developed and developing countries. Emission Quantification Tool (EQT) has been designed to support a rapid assessment of greenhouse gases (GHGs) and short-lived climate pollutants (SLCPs) (i.e., black carbon) associated with solid waste management. Specifically intended for policymakers and practitioners engaged in the municipal solid waste sector, the tool enables users to conduct a baseline estimation of selected emissions that can be measured against several proposed scenarios aimed at guiding the identification of climate friendly waste management options and alternatives for acity/country

This is version III of the EQT, which follows a life cycle assessment (LCA) approach to account for both actual and projected waste related emissions. As such the tool is customized for estimating direct and indirect GHG and SLCP emissions, including potential emissions avoidance/savings (for example through resource recovery from waste) and net emissions considering all the phases of life cycle of waste management. The tool is both practical and user-friendly: presented in a spreadsheet format, it provides step-by-step instructions on how to enter data and obtain results, utilising either country/regional specific data or indicated default values. Moreover, the EQT is equipped to cover the full range of waste treatment approaches employed in both developed and developing countries, including those related to waste collection and transportation, biological treatment methods such as composting, anaerobic digestion (AD), recycling and material recovery, incineration (with and without energy recovery), and mechanical biological treatment (MBT), through to different final disposal methods, RDF production from waste and use for energy production, open burning and landfill fires.

The basic functional unit for the estimation of emissions is "kg of emissions per tonne of waste". Data results associated with business-as-usual and alternative scenarios are also disaggregated for each pollutant ($CH_4$, BC, $CO_2$, $N_2O$) and presented per gas with respect to the specific treatment method being examined. Net climate impact displayed in terms of $CO_2$ equivalent values per tonne of waste. It is important to note that because the global warming potential (GWP) of BC has yet to be officially determined, net BC emissions are estimated and presented separately. In the summary sheet, net GHG and SLCP emissions are summarized both with respect to individual treatment methods and various analyzed scenarios. The tool also provides the choice of modifying the basic functional unit and estimating the emissions according to the user's preferred criteria. Lastly, BC and other GHGs emissions from BAU practice and alternative scenarios have been displayed graphically for easy comparison.

**Note to Users:**

For further information or any feedback, please contact:

Dr. Nirmala Menikpura (nirmala.menikpura@mx.iges.or.jp; samanthinir@yahoo.co.in) or

Dr. Dickella Gamaralalage Jagath Premakumara (premakumara@iges.or.jp).

Sustainable Consumption and Production (SCP) Area
Institute for Global Environmental Strategies (IGES),
Kamiyamaguchi, Hayama, Kanagwa, Japan

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Glossary of Terms

| Term | Meaning |
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| Greenhouse gas (GHG) | Gas in an atmosphere absorbs and emits radiation within the thermal infrared range. Major GHGs from waste management are carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous dioxide ($N_2O$). |
| Short Lived Climate Pollutants (SLCP) | Short-lived climate pollutants (SLCPs) are agents that have relatively short lifetime in the atmosphere - a few days to a few decades - and a warming influence on climate. The main SLCPs emissions from waste management are black carbon (BC), methane ($CH_4$). |
| Business-as-Usual (BAU) | The normal performance of standard functional operations. |
| Refuse Derived Fuel (RDF) | A solid fuel derived from waste, which can be used as a fuel product either in an on-site combustion facility or by a third-party user such as cement kilns or power stations. |
| Black Carbon (BC) | Black carbon (BC) is a major component of soot and is produced by incomplete combustion of fossil fuel and biomass |
| Global Warming Potential (GWP) | The global warming potential (GWP) of a gas refers to the total contribution to global warming resulting from the emission of one unit of that gas relative to one unit of the reference gas, $CO_2$ which is assigned a value of 1. |
| Life Cycle Assessment (LCA) | Life Cycle Assessment (LCA) is a tool/method for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle. |
| Intended scenarios | Planned or meant options for future |
| Composting | Composting is the breakdown of organic material such as food or garden waste in a controlled aerobic environment. Compost can be used in agriculture as a soil conditioner and as a source of nutrients. |
| Anaerobic Digestion (AD) | Anaerobic digestion (AD) is a collection of processes by which microorganisms break down biodegradable material in the absence of oxygen and produce biogas and bio fertilizer |
| Digestate | Material resulting from an anaerobic digestion process that has not undergone post-digestion separation. |
| Combined Heat and Power (CHP) plant | Combined heat and power (CHP) integrate the production of usable heat and power (electricity), in one single, highly efficient process. |
| Recycling | Recycling is the reprocessing of old materials into new products, with the aims of preventing the waste of potentially useful materials, reducing the consumption of fresh raw materials, and reducing energy usage. |
| Recyclability | Ability of a material to be recovered from a waste stream for conversion or reuse. |
| Recovery | Recovery of materials and energy from waste through either recycling the material or using incineration, anaerobic digestion or other end-treatment technologies to allow some of the energy value to be retrieved from the material through the generation of heat and power. |

| | |
|---|---|
| Mechanical Biological Treatment (MBT) | A mechanical biological treatment system is a type of waste processing facility that combines a sorting facility with a form of biological treatment. |
| Residual Derived Fuel (RDF) | Solid recovered fuel which is produced by shredding and dehydrating solid waste |
| Incineration | Incineration is a method where bulk waste can break down and disperse into the environment through air, water and ash emissions. |
| Efficiency of electricity recovery | Potential for recovery of energy in the form of electricity relative to the gross energy content of waste. |
| Managed landfill | A managed landfill is defined as having controlled placement of waste as well as having cover material, mechanical compacting, or leveling of waste. |
| Open dumping | Land disposal site at which solid wastes are disposed of in a manner that does not protect the environment, are susceptible to open burning, and are exposed to the elements, disease vectors, and scavengers |
| Landfill gas (LFG) | Landfill gas (LFG) is created when organic is degraded in the landfill. This gas consists of about 60 % of $CH_4$ and about 40% of $CO_2$, and a small amount of non-methane organic compounds (NMOCs). |
| Landfill Gas (LFG) Recovery | The fraction of the LFG generation that is or can be captured by a landfill gas collection and control system. LFG recovery is calculated by multiplying the LFG generation rate by the collection system efficiency. |
| Degradable Organic Carbon(DOC) | Degradable organic carbon (DOC) is one of the main parameters affecting the $CH_4$ emissions from solid waste disposal |
| Methane generation rate constant (k) | Model constant that determines the estimated rate at which waste decays and generates LFG |
| Methane Correction Factor (MCF) | Adjustment to model estimates of LFG generation that accounts for the degree to which waste decays anaerobically |

## 1.0 Introduction

Greenhouse gas (GHGs) emissions from waste management activities and their contribution to climate change are a matter of critical environmental concern. Methane ($CH_4$) is the major GHG emitted from the waste sector, and open dumping and landfilling has been reported as the third highest anthropogenic $CH_4$ emission source. Short Lived Climate Pollutants (SLCPs) such as black carbon (BC) emissions from open burning of waste which is practiced in many cities in developing countries, present another urgent issue. In addition, other GHGs emissions (e.g. $CO_2$, $N_2O$) from waste handling, transportation and operation of machinery are also significant, especially due to the utilisation of fossil-fuel based energy. Unfortunately, local authorities responsible for waste management often do not have a clear understanding about the significance on climate change of climate pollutants resulting from their current waste management.

Cities need to undertake a rapid assessment of their present waste management situation and identify suitable alternative solutions from a climate perspective. However, quantification of GHGs and SLCPs emissions from waste management is quite difficult for personnel in local authorities since they are not familiar with the complex computations that are required to quantify climate impact from waste management. This emission quantification tool was developed in order to quantify the Short-Lived Climate Pollutants (SLCP), and other greenhouse gases, from waste management treatment methods in cities. This is version III of emission quantification tool, which has more technology coverage and has enhanced the user friendliness.

## 1.1 Objectives

The aim of this tool is to develop decision-making guide towards undertaking a rapid assessment of current emissions resulting (business-as-usual-BAU) from waste management and identify suitable alternative solutions(s) from an emissions reduction perspective. By using this tool, cities will be able to compare emissions from their BAU scenario with alternative solutions to better understand appropriate sets of waste management practices, which align with their local context, in terms of reducing GHGs and SLCPs.

Once local authorities have selected and implemented the most suitable climate-friendly waste management scenario for a city, ongoing monitoring should be conducted regularly (e.g., monthly or annually) to track reductions in Short-Lived Climate Pollutants (SLCPs) and greenhouse gas (GHG) emissions. This tool allows for the annual measurement of GHG emissions progress, enabling local authorities to compare reductions in net GHG and SLCP emissions each year relative to a baseline. This comparison provides insights into the effectiveness of the chosen waste management strategy and facilitates continuous improvement in the city's climate action efforts.

## 1.2 Basic guidelines to the users

### 1.2.1 Selection of number of scenario

This tool can be used to compare up to five waste management scenarios. Users should decide the number of scenarios that they would like to compare with BAU practice. Data entry should be limited only to the number of scenarios chosen and entries should be left blank in other scenarios.

If city is interested in pursuing more climate friendly options, instead of primary disposal methods currently being practiced, alternative waste management options can be selected in line with specific waste characteristics, financial and technical capacity of the city. In this regard, the total amount of waste utilised in each scenario (e.g. total amount of collected waste from the city) should be the same. As an example, Figure 1 shows how to allocate the collected waste among different technologies in BAU and Scenario 1. Similarly, users can compare up to 4 intended scenarios with BAU practice.

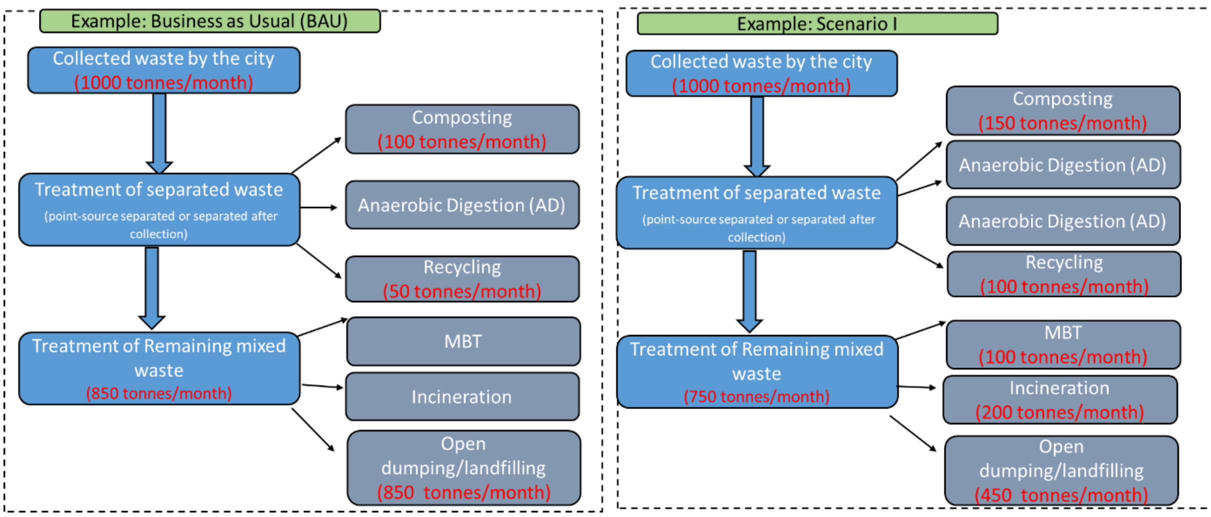


Figure 1: How to allocate amount of collected waste among technologies

In order to compare potential improvements brought by specific management practices (e.g. higher waste collection rate) in terms of GHGs/SLCPs emissions reductions, the user can enter a higher rate of waste collection in the intended scenario and allocate the corresponding waste amount among the selected technologies. The generated results will demonstrate the degree to which an improved rate of waste collection would contribute to climate change mitigation.

### 1.2.2 Direction of data entry

The tool consists of a number of worksheets and users are asked to enter the required data in every sheet. User must enter the data in every cell that is coloured in green in every sheet and should not try to enter any data in the cells which are coloured in blue and black. The tool has the ability to estimate GHGs/SLCPs emissions from integrated waste management systems in which several technologies may exist. Therefore, users should follow the direction of data entry with respect to different technologies as shown in Figure 2 (left to right). It should be noted that the flow of data entry would play an important role in accurate estimation of the emissions from BAU practice and other intended scenarios. In the absence of one or several technologies in the preferred scenarios, data entry should not be done on those sheets and should move to the next available technology. Soon after completing technology-specific data entry for individual sheets, a results table will appear on the same page. Once the user enters all the required data with respect to different technologies in BAU and intended scenarios, the overall results will be displayed in the summary sheet.

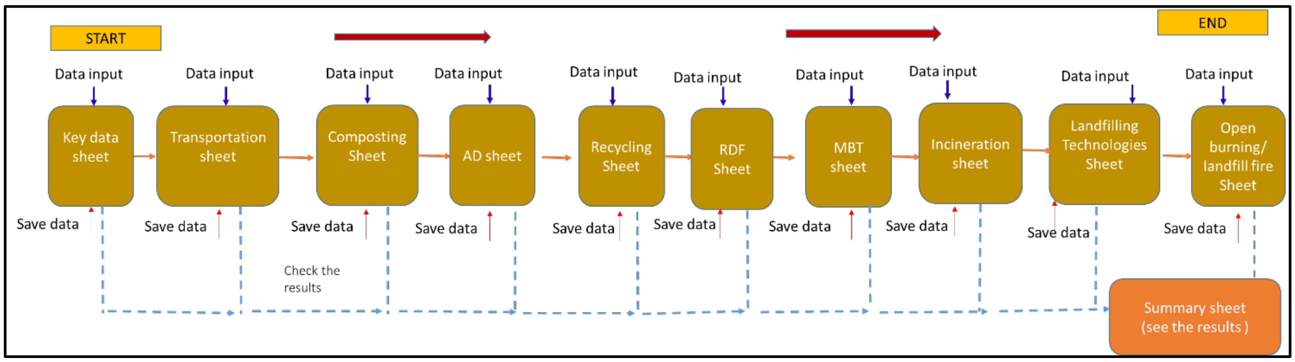


Figure 2: Direction of data entry of the EQT

### 1.2.3 Importance of the accuracy of data

In order to perform a more accurate estimation, users should have a general understanding of the importance of the different type of data which is required for estimating emissions from their waste management systems. Users should pay specific attention to collecting important data such as composition of generated and collected waste as accurately as possible. Waste composition data would be the main factor that significantly influences the accuracy of the final estimated emissions from BAU and intended scenarios. Therefore, it is desirable to use location-specific composition data whenever possible rather than using the default composition data provided in the tool.

The amount of different fractions of waste utilised for the treatment options would significantly change the final results. For instance, if a city plans to use the organic fraction of waste for composting or Anaerobic Digestion (AD), emissions reduction would be more significant than if the same amount of waste was disposed in a landfill.

Furthermore, users are encouraged to collect accurate data on resource recovery with respect to the different treatment options. From an LCA perspective, possible avoidance of emissions depend entirely on the accuracy of resource recovery data. Users are thus encouraged to collect country/location specific resource recovery data from the chosen technologies rather than using the default values provided by the developer.

Impact from waste transportation has the lowest impact on overall results. Transportation emissions only contribute 5-6% of the total emissions from waste management due to combustion of fossil fuel. The illustration below (see Figure 3) shows the importance of accuracy with regard to different types of data.

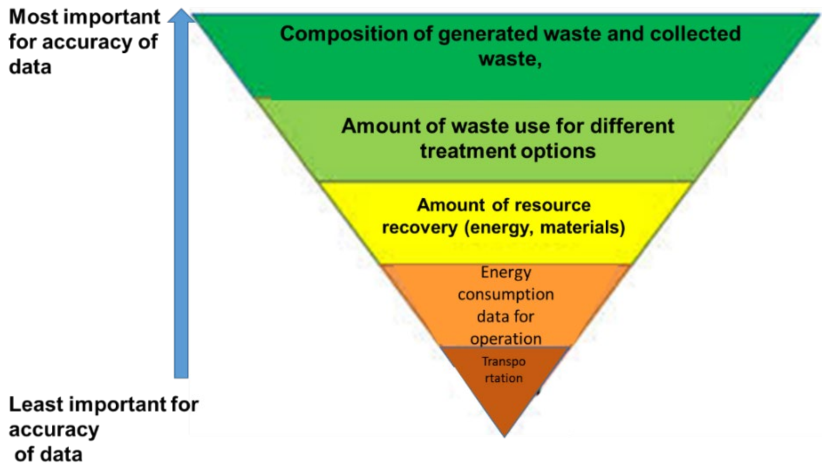


Figure 3: Hierarchical importance regarding accuracy of the data

### 1.2.4 Unit of measurement of BC and other GHGs in individual sheets and the summary sheet.

Users should pay careful attention to the 'unit of measurement' in terms of BC and other GHGs in the tool for optimal understanding of the results and to make appropriate decisions on selecting climate friendly waste management systems for the city in question. In the results table of the individual technology, SLCPs (e.g. BC, $CH_4$) and other GHGs ($CO_2$ and $N_2O$) emissions have been estimated as "kg per tonne of waste". The unit 'kg' has been used in order to show the magnitude of small amount of emissions over different phases of the life cycle. In the same table, aggregated net impact has been presented as "net BC emissions (kg/tonne of waste)" and "net GHG emissions (kg of $CO_2$-eq/tonne of waste)". Except BC, all emissions have been shown as $CO_2$-eq in order to understand the aggregated effect of GHGs on climate. The user can see the graphical comparison by clicking the "Show Graph" button in each sheet. IPCC recommended global Warming Potential (GWP) 100 years values have been utilised aggregating net climate impact from different GHGs (e.g. methane biogenic $CH_4$-28; fossil methane $CH_4$-30; nitrous oxide $N_2O$-265). GWP value of BC has not yet been finalised by the recognized body (e.g. IPCC) and therefore, net BC emissions have been shown in a separate line.

In the summary worksheet, net emissions of BC, $CH_4$, $CO_2$ and $N_2O$ are shown as kg of emissions per tonne of treated waste under different technologies and for the uncollected waste. To measure the accumulated emissions from each scenario, an option has given to the user to change the unit of measurements based on their preferences. Therefore, the tool facilitate to measure the climate impact of each scenario for four types of functional units given below.

1. Emissions per tonne of generate waste
2. Emissions per tonne of collected waste
3. Emissions from yearly generated waste
4. Emissions from yearly collected waste

User can change the functional unit in the dropdown list and estimate the emissions for any of the unit listed above based on their interest and effectiveness for policy making process.

If estimated net GHGs or net BC emissions retain a positive value (indicating that the scenario is still contributing to climate impact), this suggests that further improvements are needed for mitigating GHGs/SLCPs emissions. If the result is a net negative emission value, it indicates potential GHGs/ SLCPs savings from a particular scenario and the possibility to serve as a carbon sink. Further, net BC and GHGs emissions from individual treatment methods have been shown graphically for an easy comparison of different scenarios.

### 1.2.5 Application of the Concept of Life Cycle Assessment (LCA)

This tool has been developed based on the concept of Life Cycle Assessment (LCA) as its basis. LCA is a methodical approach for quantifying GHGs/SLCPs emissions with consideration all the phases of the life-cycle such as transportation, operation (pre-processing, treatment) and disposal. All waste treatment methods emit a considerable amount of direct GHGs/SLCPs from waste transportation, operational activities and during waste treatment, as seen in Figure 4. By adapting more appropriate treatment methods, a significant amount of materials and energy can be recovered from waste. These recovered resources can replace an equivalent amount of materials and energy that would otherwise need to be produced from virgin resources. Therefore GHGs/SLCPs emissions from those virgin production processes can be avoided (see Figure 4).

GHG/SLCP emissions from improved technologies can be considerably lower than savings potential via both materials and energy recovery. The overall climate impacts (net GHG/SLCP emissions) from particular technologies is estimated as shown below.

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| Net GHG/SLCP emissions | = | Total GHG/SLCP emissions from treatment technology | - | GHG/SLCP avoidance via resource recovery |

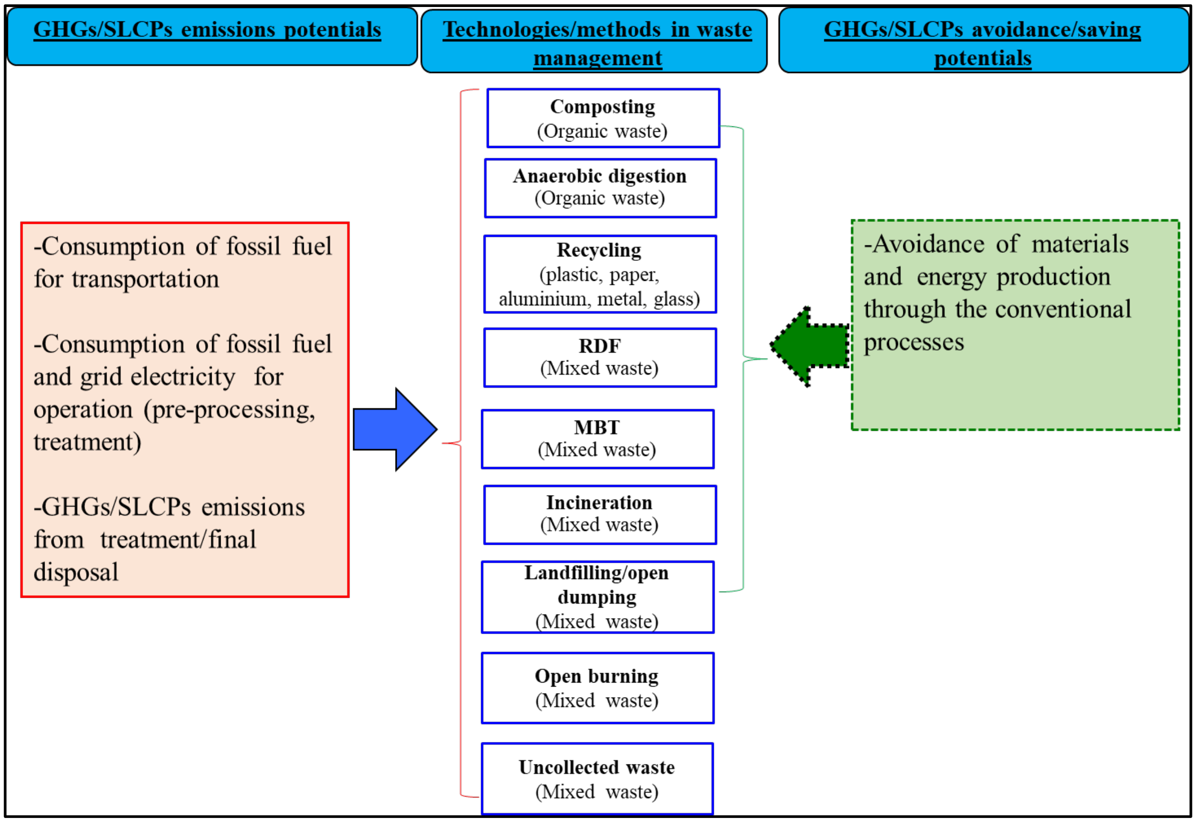


Figure 4: GHGs/SLCPs emissions and avoidance potential via LCA concept

### 1.2.6 Use of the default values

In using this tool, a considerable amount of data is required to quantify GHGs/SLCPs emissions. Users are always encouraged to gather location specific data for more accurate estimation. However, some cities may not have the detailed information required for such calculations. Therefore, default data has been provided by the developer based on available information in the literature. The types of default values provided in each sheet and the reference sources are provided in Table 1 below.

Table 1: Default values and emission factors used in the tool

| Name of the sheet | Description of the default value | Reference source |
|---|---|---|
| | Climatic zones of the countries are defined based on IPCC waste model,<br>(1) Moist and Wet Tropical = Mean Annual Precipitation (MAP) ⩾ 1000 mm , Mean Annual Temperature (MAT) >20 °C<br>(ii) Dry Tropical = Mean Annual Precipitation (MAP) < 1000 mm, Mean Annual Temperature (MAT) >20 ºC | IPCC, 2014 |

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| Key data sheet | (iii) Dry Temperate = Mean Annual Precipitation (MAP)/Potential Evapotranspiration (PET) <1 , Mean Annual Temperature (MAT) 0-20 ºC<br>(iv) Wet Temperate = Mean Annual Precipitation (MAP)/Potential Evapotranspiration (PET) >1 , Mean Annual Temperature (MAT) 0-20 ºC | |
| | Economic level of the countries<br>(1) Lower-income -Gross National Income (GNI) per capita- $1,045 or less,<br>(2) Lower-middle-income GNI per capita $1,045-$4,125<br>(3) Lower-middle-income GNI per capita $4,125-$12,746<br>(4) High income- GNI per capita $12,746 or more | The World Bank, 2013 |
| | Per capita waste generation rate for different economic level<br>Lower income -0.43; Lower middle income -0.61; Upper middle income-0.69; High income-1.57 (kg/capita/day) | The World Bank, 2018 |
| | Waste collection rate based on the development level of the country<br>Low income countries < 50%; Middle income countries 50-80%; High income countries > 90% | The World Bank, 2012 |
| | Waste composition data based on the region | IPCC, 2006 c World Bank, 2018 |
| | Emission Factors for grid electricity production (The values cannot be presented here as it is a long list) | IGES, 2024; Carbon Footprint, 2024 |
| | Calorific values of fossil fuel | IPCC,2006 d Staffell, 2011 |
| Transportation | Fuel efficiency in waste collection vehicles varies by type. Diesel-powered compactor trucks achieve 2.5-4.5 km/L, rear loaders 3-4 km/L, and side loaders 3-5 km/L. Small dump trucks cover 5-7 km/L, while larger ones manage 3-5 km/L. Electric trucks consume about 1-2 kWh per kilometer, offering a sustainable alternative to diesel vehicles | Use difference sources for different type of trucks. Original references are linked in the tool. |
| | Fossil fuel and grid electricity consumption rate at transfer station<br>Electricity consumption – 2.5 kWh/tonne<br>Diesel fuel consumption -0.125 L/tonne | Diaz,R. and Warith,M. 2006 |
| | Black Carbon (BC) emission factor from different type of vehicles<br>Both modern and older trucks-1.43 g/kg of fuel; Modern trucks -0.47 g/kg of fuel; Older trucks - 2.39 g/kg of fuel | Bond et al. 2013 |
| | Global Warming Potential (GWP) of 100 years values have been used throughout the tool to aggregate the | IPCC, 2013. |

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| | climate impact from different GHGs; Methane ($CH_4$)-28; Fossil methane ($CH_4$) – 30; Nitrous Oxide ($N_2O$)-265 | |
| Composting | Black Carbon emissions from operational activities due to fossil fuel burning | EMEP/EEA,2016 |
| | Emission factors from waste degradation (4 kg of $CH_4$/tonne of wet organic waste; 0.3 kg of $N_2O$/tonne of wet organic waste ) | IPCC, 2006 a |
| | Amount of compost production potential from organic waste (0.2-0.3 tonnes/tonne of organic waste) | Rx3 rethink recycle remake, 2012 |
| | Potential replacement of chemical fertilizer from compost (N fertilizer-7.1; $P_2O_5$-4.1; $K_2O$-5.4 kg/tonne of compost) | Bovea, et al., 2010; Patyk, 1996 |
| | Emissions factors of chemical fertilizer production | Kool et al., 2012 |
| AD | Average fuel consumption for handling of waste (operational activities) at AD facility (1.6L of diesel/tonne of organic waste) | Møller et al., 2009 |
| | Emission factors from waste degradation (1 kg of $CH_4$/tonne of wet organic waste) | IPCC, 2006 a |
| | Theoretical electricity recovery (35% efficiency) and heat recovery (50%) potentials from AD | WRAP, 2009 |
| | Theoretical biogas production potential (140 $m^3$/tonne of organic waste) from AD. | WRAP, 2009 |
| | Calorific value of methane (37MJ/$m^3$) and methane content of the biogas from AD (60%) | UNFCCC, 2006. |
| | Recovery of solid digested (compost) from AD process (0.2 tonnes/tonne of organic waste) | Ostrem, 2004 |
| Recycling | Fossil energy requirement for paper and cardboard recycling and related emissions | EMEP/EEA, 2016 |
| | Grid electricity consumption for plastic recycling and fossil fuel requirement for virgin plastic production. | UNFCCC, 2012 |
| | Fossil energy requirement and related emissions from recycling of aluminium scraps | European Aluminium Industry, 2013. |
| | Fossil fuel consumption and related emissions from virgin aluminium ingot production | World Aluminium Industry, 2010 |
| | Fossil fuel and grid electricity requirement for recycling of metal/steel scraps and virgin production of metals. | World Steel Association, 2011 |
| | Total thermal energy requirement for glass recycling and virgin production and related emissions | EMEP/EEA, 2016 |
| | Recyclability of different type of materials (Actual amount of materials that can recovered per tonne of recyclables) Paper-90%; Plastic-90%; Aluminium-75%; Steel-90%; Glasss-95% | Menikpura et al., 2012 |
| | Emission factor from waste degradation in MBT piles | IPCC, 2006 a |

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| MBT | (4 kg of $CH_4$/tonne of wet organic waste; 0.3 kg of $N_2O$/tonne of wet organic waste ) | |
| | Energy consumption for operational activities at MBT plant (Diesel-3.5L/tonne of waste, Electricity- 0.2 kWh/tonne of waste) | Phitsanulok Municipality, 2012 |
| | Energy requirement for RDF production (Diesel-0.64 L/tonne of RDF; Electricity- 207.5 kWh/tonne of RDF) | Arena et al., 2003 |
| | Crude oil production potential from waste plastic (600L/tonne of waste plastic) | Warinchamrap Municipality, 2012 |
| Incineration | Energy consumption for operation activities (grid electricity 66.8 kWh/tonne), fossil fuel consumption for initial combustion (0.01Ldiesel/tonne) | Cherubini et al., 2008 |
| | Efficiencies of electricity and heat recovery from incineration plants (i) For electricity: Average efficiency 15-30% (Part of generated electricity is utilised for on-site activities, which amounts to 20-50%)<br>(ii) For heat: Average efficiency of heat recovery is 80-90% (for only heat recovery option).<br>(iii) For heat and power : Average electricity efficiency 15% and heat efficiency 50-60%<br>Note: In developing countries only electricity production can be assumed with an average electrical efficiency 20%. | DEFRA, 2013; Astrup et al., 2009 |
| | Default values for $CH_4$ and $N_2O$ emissions from different type of incinerators<br>$CH_4$ and $N_2O$ emissions from different type of incinerators in waste combustion: (i) Continuous-stoker 0.2 g $CH_4$ and 47 g $N_2O$; (ii) Continuous-fluidised bed 0 g $CH_4$ and 67 g $N_2O$; (iii) Semi-continuous-stoker 6g $CH_4$ and 41g $N_2O$; (iv) Semi-continuous-fluidised bed 188 g $CH_4$ and 68 g $N_2O$ per tonne of wet waste | IPCC, 2006 b |
| | BC emission factor from incineration is 0.322kg/tonne of waste | EMEP/EEA, 2016 |
| | Dry matter content, total carbon, fossil carbon and degradable organic carbon (DOC) in different fraction of waste, oxidation factor in percentage of carbon input | IPCC, 2006 b |
| | Calorific value (Low Heating Values) of different fractions of waste. Food waste 2 MJ/kg ; Garden waste 4 MJ/kg; Plastics 31.5 MJ/kg; Paper 11.5 MJ/kg; Textile 14.6 MJ/kg; Leather/rubber 14.6 MJ/kg; Glass 0 MJ/kg; Metal 0 MJ/kg; Nappies/Diapers 5 MJ/kg; Wood 15 MJ/kg.(the weight is in wet basis) | IFEU,2009 |
| | Total amount of fossil fuel used for the operation activities 3L/tonne of input waste | Based on field survey data in Indonesia, 2024 |

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| RDF | Electricity use per tonne of waste input for RDF production varies significantly. Large-scale, fully automated plants (100–1000 tonnes/day) use about 30–40 kWh per tonne, while medium-sized (50–100 tonnes/day) and small-scale plants (10–50 tonnes/day) require 40–50 kWh and 50–60 kWh per tonne, respectively. Partially automated, manual RDF plants are the most energy-efficient, consuming only 5–10 kWh per tonne. | Based on field survey data in Indonesia, 2024 |
| | The weight of RDF can be 30-33% of the fresh input waste | Based on field survey data in Indonesia, 2024 |
| | The moisture content of RDF varies based on its composition. RDF with 70% plastic and 30% garden waste typically has about 20% moisture, while RDF made up of 100% plastic has a lower moisture content, around 15% | Based on field survey data in Indonesia, 2024 |
| | The calorific value of Refuse-Derived Fuel (RDF) depends significantly on its composition and moisture content. For RDF composed of 100% plastic with approximately 15% moisture, the calorific value is around 7000-7500 kcal/kg. If the RDF contains 70% plastic and 30% garden waste with a higher moisture content of about 20%, its calorific value drops to around 3400-3500 kcal/kg. For RDF made entirely from organic waste residue, with a moisture content between 7-10%, the calorific value is further reduced, typically around 2200-2300 kcal/kg. | Based on data gathered during the field survey in Indonesia, 2024 |
| | Efficiencies of RDF combustion/co-combustion | Rigamonti et al., 2012 |
| | Fuel consumption for trucks transporting RDF varies based on truck type and load. For small dump trucks (10m³ capacity), fuel efficiency is about 7 km per liter of diesel, while larger dump trucks (18m³) consume approximately 1 liter of diesel every 5 km. Container trucks, when empty or lightly loaded, have a fuel efficiency of around 3-4 km per liter, but when fully loaded, they consume more fuel, averaging only 2-3 km per liter. | Based on data gathered during the field survey in Indonesia, 2024 |
| Landfilling | Fossil fuel consumption for operational activities (e.g. for operation of machineries (bulldozers, backhoes etc.) (0.8L per tonne of landfilled waste).<br>Grid electricity consumption for operational activities (e.g. for running engines for leachate management) ( 0.1 kWh per tonne of sanitary landfilled waste) | Mendes et al., 2004 |
| | Default values required to use IPCC waste model: Degradable Organic Carbon (DOC), Fraction of DOC | IPCC, 2006 a |

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| | decomposing under Anaerobic condition (DOCf), Methane generation rate constant (k), Methane Oxidation on Landfill cover (OX), Methane Correction Factor (MCF) for the landfill/open dumpsite | |
| | Density of $CH_4$ (0.716 kg/m$^3$); Percentage of $CH_4$ in LFG (60%); Energy content of $CH_4$ (37MJ/m$^3$), electricity production efficiency of IC engine (35%) | UNFCCC, 2006. IPCC, 2006 a |
| Uncollected waste | BC emissions from open burning of uncollected waste (0.65 kg BC/tonne of waste) | Bond et al. 2013 |
| | Emission factor for calculation fossil $CO_2$ from open burning (e.g. dry matter content, total carbon, fossil carbon and degradable organic carbon (DOC) in different fraction of waste, oxidation factor (58%) in percentage of carbon input) | IPCC, 2006 a |

## 2.0 Description of the tool

This tool consists of 12 major worksheets. The very first sheet of the tool is the "Home" page which has been designed to present brief background, objectives, key data requirement and contact information of the developer.

The second sheet is the key data sheet, in which user should apply the general data related to waste management. After that technology specific data should be entered in individual sheet related to each technology. Once user enter all the data related to chosen technological options, compiled results will appear in the summary sheet. Further, there is a sheet so called "user guide", in which background information and data has been shown which utilize for emissions estimations.

### 2.1 EQT History

As of December 2024, EQT has seen in three major public releases. Here's an overview of the evolution and key updates in each version:

EQT 1.0 (2013)

- Initial release of EQT in 2013: The first version of EQT was designed to cover a comprehensive range of waste management technologies, enabling the estimation of both greenhouse gases (GHG) and short-lived climate pollutants (SLCP) emissions. To improve user accessibility, a detailed user manual and built-in help buttons were added throughout the tool.
- Minor updates based on user feedback: Numerous minor updates have been implemented over time to address bugs identified through user feedback, as well as both internal and external reviews. These updates aimed to enhance stability and reliability in line with evolving user needs..

EQT Version 2.0 (December 2018)

The following modifications were done during the updates of version 2.

- Standardized emission basis: Emissions were quantified on a "per tonne of waste" basis across all sheets, rather than "per monthly disposed waste under each treatment method," enhancing user-friendliness and consistency in data reporting.
- Expanded landfill scenarios: The landfill sheet had been modified to include a user-friendly interface allowing for three types of landfills or open dumps in each scenario, as opposed to the single landfill model in the previous version.
- New sheet for emissions from open burning and landfill fires: A dedicated sheet added to account for emissions from both open burning and landfill fires, providing a more comprehensive emissions profile.
- Enhanced recycling sheet: The recycling sheet included emissions from virgin production processes, using literature-based emission factors, to capture the complete environmental impact of recycling.
- Black Carbon (BC) emissions in LCA context: BC emissions from recycling estimated from a life cycle assessment (LCA) perspective, incorporating available BC emission factors.
- Improved summary sheet for functional unit selection: The summary upgraded to allow users to select their preferred functional unit, facilitating decision-making. Users can calculate emissions for:

  Emissions per tonne of generated waste
  Emissions per tonne of collected waste
  Emissions from yearly generated waste
  Emissions from yearly collected waste
- References and source transparency: References for all emission factors were included in a dedicated reference sheet, providing transparency and ease of verification.
- User interface and excel programming enhancements: Modifications to the user interface and Excel programming improved tool usability and streamlined functionality throughout.
- Upgraded graphics: The visual display enhanced for clearer data presentation.
- Revised user manual: The user manual has been thoroughly updated to reflect all tool revisions, ensuring users can navigate and utilize the tool effectively.

EQT Version 3.0 (January 2025)

- Updated emission factors: Emission factors for grid electricity and thermal energy have been revised to ensure accurate and up-to-date calculations.
- Enhanced user interface and simplified input sheets: The user interface has been improved with simplified input sheets, allowing for easier data entry and navigation.

- New sheet for RDF production emissions: A dedicated sheet for emissions quantification from Refuse-Derived Fuel (RDF) production has been added, expanding the tool's functionality for a wider range of waste management processes.
- Bug fixes: Additional bug fixes from EQT 1.0 have been applied to enhance tool stability and performance.
- Improved visual images: Enhanced visuals have been added throughout the tool to capture user attention and improve data presentation.
- Improved user help guidance: New and improved user guidance has been included to make navigation simpler and more intuitive.
- Revised user manual: The user manual now includes the latest guidelines and emission factors, providing a comprehensive reference for users.

## 2.2 Key data sheet

Key data sheet has been designed to input three sets of data namely: general data, waste data and energy data. This data is necessary for estimation of GHG/SLCP from all technologies.

*General data*: This part of the sheet has been designed for user to input location/country-specific background data which are related to the waste management such as location of the country, climatic zone, and population of the city, economic level, and waste generation data, etc., as seen in Figure 5. User help buttons have been provided for users to understand the exact information required and then to input the most reliable and accurate data. For instance, for waste generation data, users can choose the options to either enter location-specific data or use the theoretical estimation provided (default value) by the developer based on per-capita waste generation rate and the population. If the user choose the option "default generation rate", calculation can be continued without entering actual waste generation data in cell G24. Waste generation data is the key figure which effects the total climate impact from the city and therefore accuracy of such data is crucial.

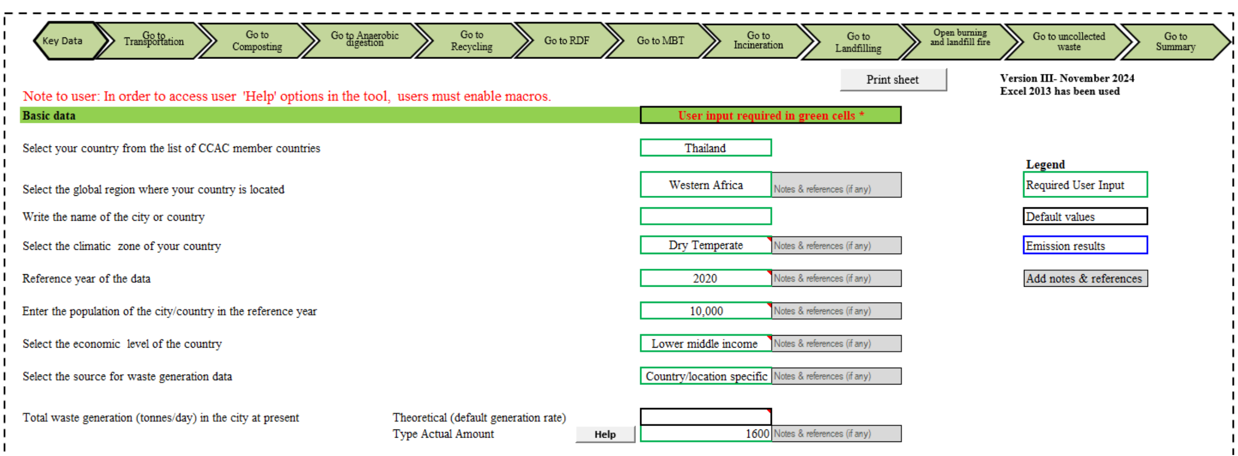



Figure 5: Key datasheet: Basic data section

*Waste data*: The basic data related to waste management is the waste collection rates (e.g. collection rate by the city, informal sector and uncollected waste). These figures should be provided as accurately as possible because the total amount of waste treated by the city, total amount of waste treated by informal sector and the total uncollected waste amount will be derived based on the input data in this table and rate of waste generation.

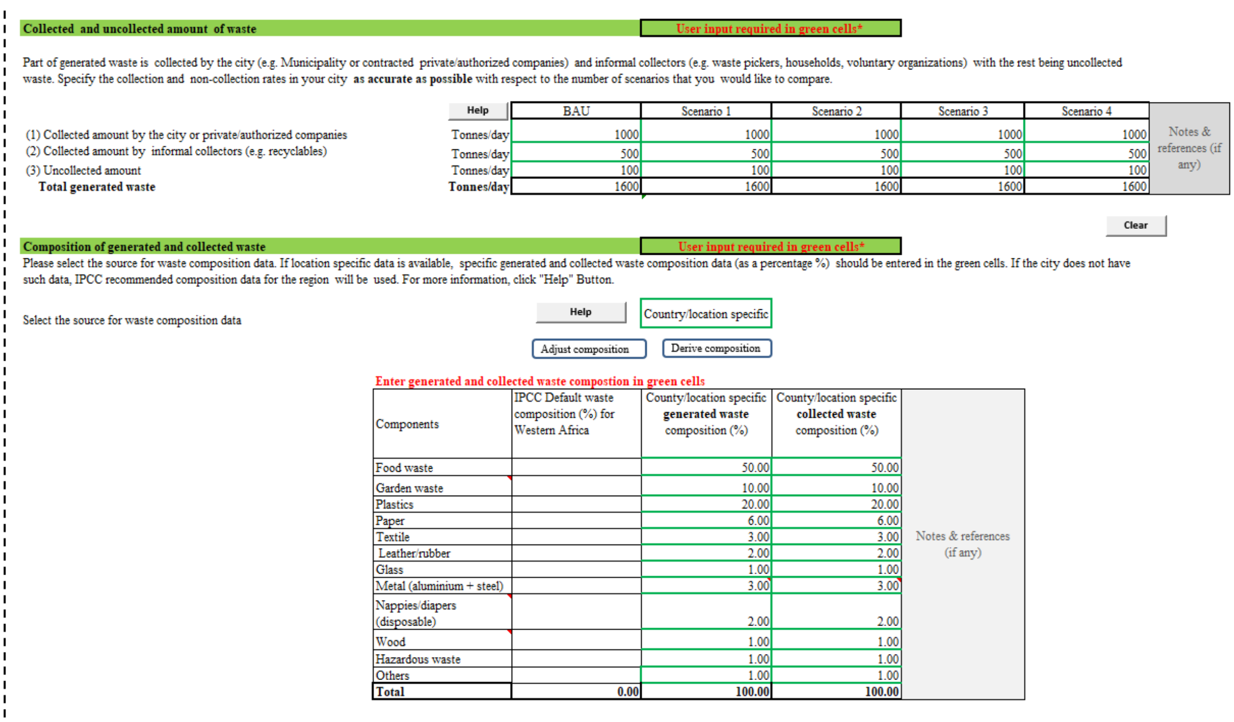
In addition, composition of the generated and collected waste should be provided as accurately as possible since this data is critically important for the accuracy of the final result. These are the options that users can follow to enter the compositions data.

Option I- Users are always encouraged to use country/location specific composition data for more accurate estimation. If location specific data is available, users are advised to enter specific generated and collected waste composition data (as a percentage %) in the green cell. If the city dispose all the collected waste at the landfill, and if the composition of waste at the landfill is known, then such composition data can be considered as the composition of collected waste. Further, if the city has similar generated and collected waste compositions, once data is entered in "generated waste composition", it can be copy and paste in collected waste composition column. See Figure 6.

Option II - In the absence of country/location specific data, the user select 'default value' and then IPCC default values will be considered as both generated and collected waste compositions. The percentage given may not add up to 100% due to partly incomplete composition data. When the total is not 100%, or somewhat deviated from the city composition data, user can adjust the composition by clicking 'Adjust composition' button in F42 cell. It will direct user to IPCC composition data table and user can change the percentages in corresponding region to bring the waste composition into more realistic figures.

Option III - If the user know the composition of collected waste and uncollected waste, tool will support to derive the composition of generated waste. Click 'derive composition' button and follow the instructions given in the "user guide page" see in Figure 6.  In order to derive the composition of generated waste, user much know the composition of collected waste, and uncollected waste. Then the derived 'generated composition' data can be copied and pasted back into 'generated waste composition' cells in key data sheet. Also user can copy and paste the "composition of collected waste" that has been entered in user guide page, back into the 'collected waste composition 'cells in key data sheet, without re-entering same data.

The next step is to enter the amount of waste aimed to be treated under different scenarios. Using this tool, users can compare BAU practice with four possible intended (future) scenarios. Users should decide the number of scenarios that they would like to compare with BAU practice. The amount of waste collection in each scenario will appear automatically based on the input data provided on the waste collection rate and total waste generation of the city. The user should enter the amount of the different fractions of waste (based on the available amount in the composition, technological and financial capacity of the city) that can be treated using different technologies in an individual scenario. For instance, the separated organic fractions of waste can be treated using composting and anaerobic digestion while separated recyclables can be treated with recycling. It should be noted that amount of organic waste user for composting and anaerobic digestion should not be higher that the available amount in collected waste. Therefore, the user should always “check available amount” prior to enter data in this table. Similarly, amount of recyclable used in each scenario should not be higher than available amount of recyclables (plastic + paper +glass+ metal). If the user enters a higher amount of organic or recyclables waste than the available amount in collected waste, an error message will be appeared. User should correct the error before moving into next cell data entry.



**Collected and uncollected amount of waste** — User input required in green cells*

Part of generated waste is collected by the city (e.g. Municipality or contracted private/authorized companies) and informal collectors (e.g. waste pickers, households, voluntary organizations) with the rest being uncollected waste. Specify the collection and non-collection rates in your city **as accurate as possible** with respect to the number of scenarios that you would like to compare.

| | Help | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Notes & references (if any) |
|---|---|---|---|---|---|---|---|
| (1) Collected amount by the city or private/authorized companies | Tonnes/day | 1000 | 1000 | 1000 | 1000 | 1000 | |
| (2) Collected amount by informal collectors (e.g. recyclables) | Tonnes/day | 500 | 500 | 500 | 500 | 500 | |
| (3) Uncollected amount | Tonnes/day | 100 | 100 | 100 | 100 | 100 | |
| **Total generated waste** | **Tonnes/day** | 1600 | 1600 | 1600 | 1600 | 1600 | |

Clear

**Composition of generated and collected waste** — User input required in green cells*

Please select the source for waste composition data. If location specific data is available, specific generated and collected waste composition data (as a percentage %) should be entered in the green cells. If the city does not have such data, IPCC recommended composition data for the region will be used. For more information, click "Help" Button.

Select the source for waste composition data — Help — Country/location specific

Adjust composition — Derive composition

Enter generated and collected waste compostion in green cells

| Components | IPCC Default waste composition (%) for Western Africa | County/location specific **generated waste** composition (%) | County/location specific **collected waste** composition (%) | Notes & references (if any) |
|---|---|---|---|---|
| Food waste | | 50.00 | 50.00 | |
| Garden waste | | 10.00 | 10.00 | |
| Plastics | | 20.00 | 20.00 | |
| Paper | | 6.00 | 6.00 | |
| Textile | | 3.00 | 3.00 | |
| Leather/rubber | | 2.00 | 2.00 | |
| Glass | | 1.00 | 1.00 | |
| Metal (aluminium + steel) | | 3.00 | 3.00 | |
| Nappies/diapers (disposable) | | 2.00 | 2.00 | |
| Wood | | 1.00 | 1.00 | |
| Hazardous waste | | 1.00 | 1.00 | |
| Others | | 1.00 | 1.00 | |
| **Total** | 0.00 | 100.00 | 100.00 | |

Figure 6: Key datasheet: waste collection rate and composition section

The remaining mix waste can be treated by using Mechanical Biological Treatment (MBT), incineration and landfilling/open dumping (landfilling includes all kind of landfills and legal open dumping operated by the city). The total amount of waste treated using different technologies in an individual scenario should be equal to the total amount of waste collected by the city (see Figure 7). A warning message will appeared whenever total amount of waste entered under different treatment options is lower or higher than the total collected waste amount. This will alert users so that they will understand the error and adjust the waste amount equal to the total amount of collected waste.

**Utilisation of waste ( collected by city or private/authorized companies ) for different treatment options** — User input required in green cells*

Note to User: Using this tool, Business as Usual (BAU) practice (BAU is the current situation) can be compared against possible 4 intended (future) scenarios. Decide the number of scenarios to compare against BAU. If only one intended scenario is to be compared against BAU, enter the data under BAU and Scenario 1, leaving other scenarios empty.

Amount of MSW collected will be shown based on the waste collection rate of the city or private/authorized companies . For the comparison purposes, the same amount of collected waste in each scenario can be used with different technological options in order to determine the best climate friendly technology. Decide the type of treatment method available in BAU and intended scenarios (e.g. type of treatment option chosen for intended scenarios may depend on the technical and financial capacity of the city). Enter the amount of waste that the city plans to use for each treatment type. The waste amount entered here under different treatment options will be displayed on the individual treatment sheet.

Help | Show example

| Utilization of MSW | Units | Note to User | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|---|
| Total collected waste by the formal collectors | Tonnes/day | Total collected waste by the city and formal collectors ( private/authorized companies) | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |
| **Step I: Type the amount of separated waste used for the below treatment options prior to disposal** | | Help | | | | | Check available amount |
| Composting | Tonnes/day | Total amount of organic waste (food waste and garden waste) used for composting | 30 | 30 | 30 | 30 | 30 |
| Anaerobic digestion | Tonnes/day | Total amount of organic waste (food waste and garden waste) used for anaerobic digestion | 40 | 40 | 40 | 40 | 40 |
| Recycling | Tonnes/day | Total amount of seperated recyclable collected by formal sector. (municipality/contracted private/ authorized companies only ) | 50 | 50 | 50 | 50 | 50 |
| RDF production | Tonnes/day | The amount of sorted waste used for RDF production | 300 | 300 | 300 | 300 | 300 |

Notes & references (if any)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total amount of remained mixed waste for final disposal | Tonnes/day | The remaining mix waste which can be treated using one or more disposal options shown below | 580 | 580 | 580 | 580 | 580 |
| **Step 2: Type the amount of remaining mix waste utilised among below disposal methods** | | Help | | | | | Check suitability of incineration for your |
| MBT | Tonnes/day | Mix waste use for MBT | 200 | 200 | 200 | 200 | 200 |
| Incineration | Tonnes/day | Mix waste use for incineration | 200 | 200 | 200 | 200 | 200 |
| Landfilling/Open dumping | Tonnes/day | Total mix waste dispose at landfills or open dumps | 180 | 180 | 180 | 180 | 180 |
| **Total treated waste collected by the city** | | | **1,000** | **1,000** | **1,000** | **1,000** | **1,000** |

Notes & references (if any)

Figure 7: Key datasheet: waste data section

*Energy data:* Different types of fossil fuel and grid electricity are utilized at various stages of waste management. In order to identify the emissions from fossil fuel and grid electricity consumption, users are requested to provide country/location specific energy content of the fossil fuel and emissions factor of grid electricity production (see Figure 8). In the absence of such data, default emission factors provided by the developer can be utilised. The energy values or the emission fraction that are chosen in this section will be utilised throughout the tool for emission calculations relevant to fossil fuel and grid electricity consumption. Once all the data is entered into the key data sheet, the user can move to the next sheet to enter the technology-specific data.

**Energy consumption data** — User input required in green cells*

Fossil fuel and grid electricity is utilized in various stages of waste management. If you know the country/location specific default values please enter in green cell. If you do not know, default emission factor will be utilized throughout the calculation.

**(1) Emission factors for grid electricity production**

| | | | |
|---|---|---|---|
| Default GHG emission factor from grid electricity production in Thailand | kg $CO_2$-eq/kWh | 0.548 | |
| Type country specific/location specific GHG emission factor for grid electricity production (if available) | kg $CO_2$-eq/kWh | | Notes & references (if any) |

**(2) Calorific values of fossil fuel**

Select the data source for heating values/calorific values of fossil fuel — Notes & references (if any)

| Type of fuel | IPCC default Net calorific value (MJ/L) | Country specific Net calorific value (MJ/L) | Notes & references (if any) |
|---|---|---|---|
| LPG | 25.07 | | |
| Gasoline | 35.44 | | |
| Kerosene | 35.28 | | |
| Diesel | 36.372 | | |
| Natural Gas | 0.0333 | | |

Figure 8: Key datasheet: Energy consumption data

### 2.3 Estimation of GHG/SLCP Emissions from Waste Collection and Transportation

MSW collection and transportation, and operational activities at transfer stations consume a significant amount of fossil fuel and grid electricity which lead to GHGs and BC emissions. The transportation sheet has been designed for quantifying emissions from the potential consumption of two types of fossil fuel as some cities may use more than one type of fossil fuel for transportation (e.g. diesel and/or natural gas). Users can choose the types of fossil fuel that are used from the drop-down list.

In version 3, EQT has expanded its functionality to incorporate a comprehensive range of vehicle types commonly used for waste collection and transportation in both developed and developing countries. This includes tractors, compactor trucks, rear loader trucks, side loader trucks, small and large dump trucks, and electric waste trucks. By including these diverse vehicle types, the tool offers users more accurate emissions estimation options that reflect real-world practices across different regions. Users are asked to choose the most common type of vehicle in the city. The user must then enter the data on average daily fossil fuel consumption with respect to BAU and intended scenarios.

Box 1: Method of estimating GHG/SLCP from transportation

(i)Total fuel consumption for waste collection and transportation;

*Fuel (units/day) = Number of vehicles × Number of total trips per day per vehicle × Average fuel efficiency (Units L or kg/trip)*

(ii)GHG emissions from waste transportation and operational activities;

$$Emissions_T = \frac{Fuel(units) \times NCV_{FF}(MJ/unit) \times EF(kg/MJ)}{AOW(tonnes/day)}$$

$Emissions_T$ – Emissions from transportation (kg GHG/tonne of waste)

Fuel (units) – Total amount of fossil fuel consumption per day, (Liters or kg (e.g. natural gas)

$NCV_{FF}$ – Net calorific value of the fossil fuel consumed (MJ/unit mass or volume) (e.g. Diesel 36.42 MJ/L, Natural gas 37.92 MJ/kg)

EF – $CO_2$, $CH_4$, $N_2O$ emission factor of fuel (e.g. diesel: 0.074 kg $CO_2$/MJ, Natural gas: 0.056 kg $CO_2$/MJ)

AOW- Amount of Waste Transport (tonnes/day)

(iii)BC emissions from waste transportation and operational activities at transfer station;

$$Emissions_T = \frac{Fuel(units/day) \times Density(kg/unit) \times EF(g/kg)/1000}{AOW(tonnes/day)}$$

EF – EF of black carbon has given in g/kg (divided by 1000 to convert into kg)

(iv) GHG emissions from grid electricity consumption:

$$Emissions_E = \frac{EC \times EF_{el}}{AOW}$$

EC – Electricity consumption for operation activities at transfer station (kWh/day)

$EF_{el}$ –Emission factor of grid electricity production (kg $CO_2$-eq/kWh)

AOW- Amount of Waste (tonnes/day)

(iv)-Total GHG emissions are estimated as follows:

$$NetGHG_{(CO2-eq/tonne)} = (CO_{2(net)} \times 1 + CH_4(biogenic)_{(net)} \times 28 + CH_4(fossil)_{(net)} \times 30 + N_2O_{(net)} \times 265)/1000$$

Net GHG emissions – Estimated as kg of $CO_2$-eq/tonne

Some cities may not have daily fossil fuel consumption data for waste collection and transportation. In such situation daily fuel consumption can be approximately estimated as shown in Box I.

Some cities may have transfer stations for proper handling, sorting and management of collected waste. This sheet would thus support the quantification of emissions from the transfer stations. Users are asked to provide the total amount of waste handled at the transfer station (note that not all the waste collected by the city may reach the transfer station). In addition, data should provide on utilisation fossil fuel and grid electricity for operational activities. In the absence of such data, default values provided by the developer can be utilised. Once the data entry is done, net climate impact from BC and other GHGs will be shown in the bottom of the table. IPCC recommended GWP-100 years values have been utilised aggregating net climate impact from different GHGs (e.g. methane biogenic $CH_4$-28; Fossil methane $CH_4$– 30; Nitrous Oxide $N_2O$-265). The estimation method of emissions is presented in Box 1. The results will be displayed in the same sheet in which emissions have been calculated per gas, taking into account life cycle phases. All default values and emission factors used in this calculation are listed in Table 1. The structure of the page is shown in Figure 9.

Key Data | Transportation | Go to Composting | Go to Anaerobic digestion | Go to Recycling | Go to RDF | Go to MBT | Go to Incineration | Go to Landfilling | Open burning and landfill fire | Go to uncollected waste | Go to Summary

**GHG and SLCP emissions from waste collection and transportation**

User input is required in green cells *

| Data Input | Unit | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| Amount of collected waste by the city | Tonnes /day | 1000 | 1000 | 1000 | 1000 | 1000 |
| **(I) Fossil fuel consumption for collection and transportation** | | | | | | |
| Type of trucks used for waste collection and transportation | Type | Side Loader Truck | Side Loader Truck | Side Loader Truck | Side Loader Truck | Side Loader Truck |
| Type of fuel (type I) used for collection and transportation | Type I | Diesel | Diesel | Diesel | Diesel | Diesel |
| Total amount of fossil fuel (type 1) used | L/day | 100 | 100 | 100 | 100 | 100 |
| Type of fuel (type II - if city uses more than one fuel type) used for collection and transportation | Type II | Natural Gas | Natural Gas | Natural Gas | Natural Gas | Natural Gas |
| Total amount of fossil fuel (type II) used | L/day | 400 | 400 | 400 | 400 | 400 |
| **(II) Energy consumption at transfer station (only if available)** | | | | | | |
| Amount of waste handled at the transfer station | Tonnes/day | 500 | 500 | 500 | 500 | 500 |
| Type of fossil fuel used at the transfer station | Type | Diesel | Diesel | Diesel | Diesel | Diesel |
| Amount of fossil fuel used for operation at transfer station | L/day | 500 | 500 | 500 | 500 | 500 |
| Amount of electricity used for operation at transfer station | kWh/day | 200 | 200 | 200 | 200 | 200 |

Help | Help | Help | Clear

**Results: Summary of the emissions**

Show Graph | Print sheet

| Category | Type of emissions | Emissions | Emissions from waste transportation (kg/tonne) | | | | |
|---|---|---|---|---|---|---|---|
| | | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
| SLCPs | $CH_4$ | Direct (Type I fuel ) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Direct (Type II fuel) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Direct (fuel at transfer Station) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Net emissions** | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| | BC | Direct (Type I fuel ) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Direct (Type II fuel) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Direct (fuel at transfer Station) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Net emissions** | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| Other GHGs | $CO_2$ | Direct (Type I fuel ) | 3.36 | 3.03 | 3.03 | 2.69 | 0.00 |
| | | Direct (Type II fuel) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Direct (fuel at transfer Station) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Indirect (electricity at transfer Station) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Net emissions** | | **3.36** | **3.03** | **3.03** | **2.69** | **0.00** |
| | $N_2O$ | Direct (Type I fuel ) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Direct (Type II fuel) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Direct (fuel at transfer Station) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Net emissions** | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| **Net BC emissions (kg of BC/tonne)** | | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| **Net climate impact of GHGs (kg/tonne)** | | | **3.41** | **3.07** | **3.07** | **2.73** | **0.00** |

Figure 9: Print screen view of transportation sheet

### 2.4 Selection of technologies for treating separated waste fractions

Part of organic waste and/or recyclables are separated at the household level or at material recovery facilities. The separated organic waste can be treated using composting and AD technologies while the separated recyclables can be recycled for recovery of materials. In this tool, separate sheets have been designed for the above technologies to quantify the emissions from separated organic waste and recyclables. Users should provide technology-specific data in those individual sheets if they have chosen any of those technologies in BAU or intended scenarios. The detailed specifications of composting, AD and recycling sheets are described in the sections below.

#### 2.4.1 Estimation of GHG/SLCP from Composting

The separated organic waste (at the household level or at the resource recovery facility in the city) can be utilised for composting. Amongst organic waste utilisation technologies, most cities have shown an interest in composting technologies as they are simple, easy to manage and comprise a low-cost option for waste management.

There are two major ways that composting can emit GHG/SLCP: i) GHG and BC emissions from utilisation of fossil energy (e.g. grid electricity and diesel) for various operational activities at composting facility; and ii) GHG emissions from organic waste degradation during the composting process.

As far as GHG emissions from organic waste degradation is concerned, a large fraction of the degradable organic carbon in the waste material is converted into $CO_2$. These $CO_2$ emissions have biogenic origin and would not be taken into account for GHG calculations. $CH_4$ can be formed due to anaerobic degradation of waste in deep layers of composting piles. However, such $CH_4$ is oxidised to a large extent in the aerobic sections of the compost piles. Composting can also produce $N_2O$ in minor concentrations. In this study, average default emission factors recommended by IPCC (e.g. 4 kg $CH_4$/tonne of organic waste in wet basis and 0.3 kg $N_2O$/tonne of organic waste in wet basis) were used to quantify the GHG emissions from composting (IPCC, 2006 a).

At the end of the composting process, there is a potential for producing a significant amount of marketable compost (200-300 kg/tonne of organic waste) (Rx3 rethink recycle remake, 2012). The produced compost can be used for agricultural purposes as a substitute for conventional fertilizer. Utilisation of compost has been credited for avoiding emissions from production of chemical fertilizer. However, in practice, this co-benefit should not be included in the calculation if farmers do not decrease the use of chemical fertilizer after application of compost.

Box 2: Method of estimating GHG/SLCP from composting

(i) GHG/SLCP emissions from operational activities

$$Emissions_{GHG(i)-Operation} = \frac{Fuel(unit/day) \times NCV(MJ/unit) \times EF(kg/MJ) + EC \times EF_{el}}{AOW(tonnes/day)}$$

$Emissions_{GHG(i)-operation}$ – Emissions $i^{th}$ GHG (e.g. $CO_2$, $CH_4$, $N_2O$) from operational activities
Fuel (unit/day) – Total amount of fossil fuel units (kg or L) consumption per day
$NCV_{FF}$ – Net calorific value of the fossil fuel consumed
EF – $CO_2$, $CH_4$, $N_2O$ emission factor of the fuel (e.g. diesel: 0.074 kg $CO_2$/MJ)
EC- Electricity consumption for operation activities (kWh/day)
$EF_{el}$ –Emission factor of grid electricity production (kg $CO_2$-eq/kWh)
AOW-Amount of Waste use for composting (tonnes/day)

(ii) SLCP (e.g. BC) emissions from operational activities

$$Emissions_{BC-Operation} = \frac{Fuel(unit/day) \times NCV(MJ/unit) \times EF(g/MJ)/1000}{AOW(tonnes/day)}$$

EF – EF of black carbon has given in g/MJ (divided by 1000 to convert into kg)

(iii) GHG emission from waste degradation
GHG emissions from waste degradation are calculated as follows:

$$Emission_{GHG(i)-Degradation} = EF(kg/tonne)$$

EF – Emissions of $CH_4$ and $N_2O$ from organic waste degradation (kg/tonne of organic waste)
(iv) Total $i^{th}$ GHG emissions from composting is calculated as follows:

$$TotalGHG_{(i)} = Emissions_{Operation} + Emission_{Degradation}$$

(v) Avoided GHG emissions by replacing chemical fertilizer are calculated as follows:

$$AvoidedGHG_{(i)} = AC \times PC_{Agriculture} \times A_{GHG}$$

$AvoidedGHG_{(i)}$ – Avoided $i^{th}$GHG from composting due to avoidance of chemical fertilizer production (kg/tonne)
AC – Amount of Compost produced (tonne of compost/tonne of waste)
$PC_{Agriculture}$ – Percentage of Compost use for agricultural and gardening purpose (%)
$A_{GHG(i)}$ – $i^{th}$ GHG Avoidance potential from chemical fertilizer production which is equivalent to one tonne of compost (kg/tonne of compost)

(vi) Net $i^{th}$ GHG emissions and net BC emissions can be calculated as follows:

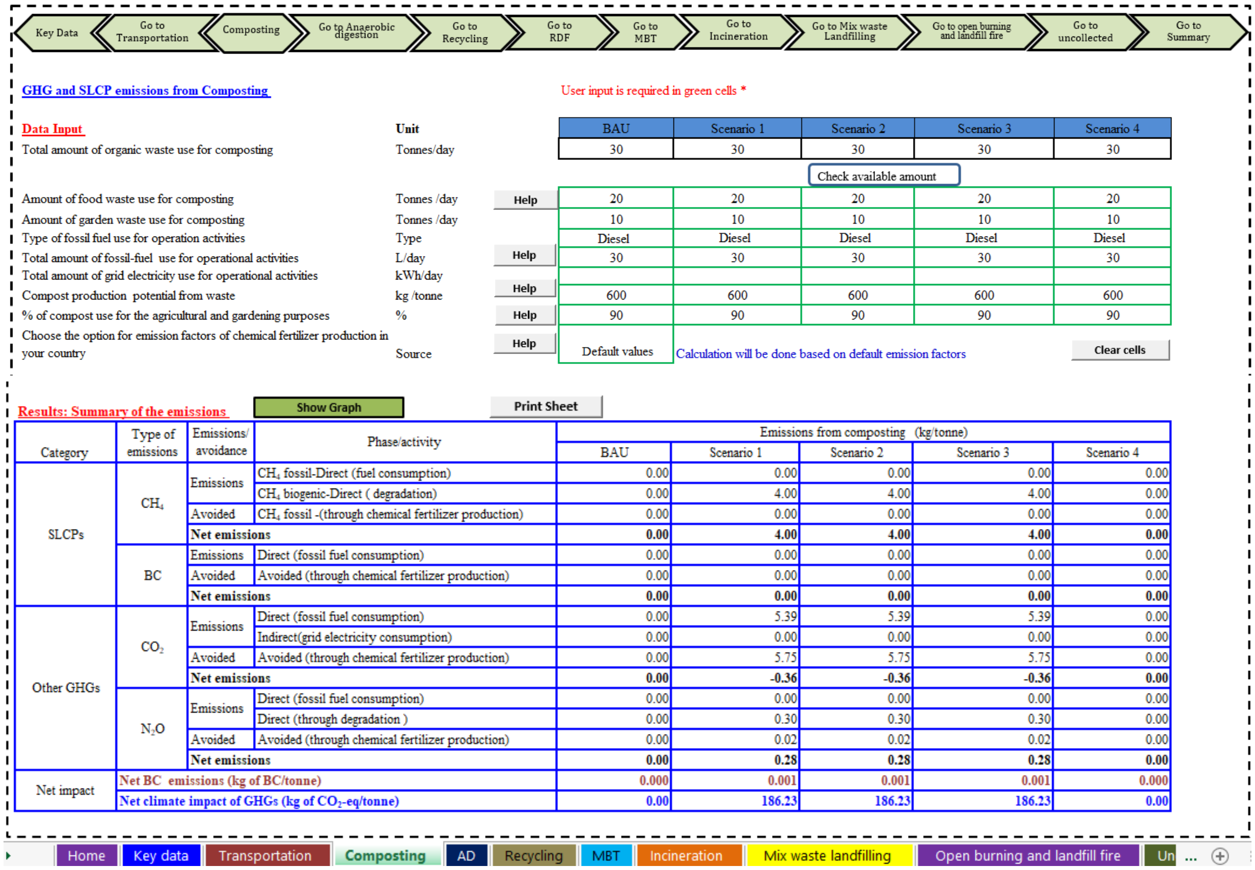
$$Net(GHG)_{(i)} = Total(GHG)_{(i)} - Avoided(GHG)_{(i)};\; Net(BC) = Total(BC) - Avoided(BC)$$

(vii)Net climate impact from all GHG is estimated as follow;

$$NetGHG_{(CO2-eq/tonne)} = CO_{2(net)} \times 1 + CH_4(biogenic)_{(net)} \times 28 + CH_4(fossil)_{(net)} \times 30 + N_2O_{(net)} \times 265$$

Net GHG emissions – Estimated as kg $CO_2$-eq/tonne

In order to calculate GHG/SLCP emissions and avoidance potentials, users are asked to enter the daily average data such as amount of food waste and garden waste used for composting, fossil-fuel/grid electricity utilisation for operational activities, the total amount of compost production and percentage of produced compost utilisation for agricultural purpose. In the absence of energy consumption data or compost production potential etc. at the city level, the default values provided by the developer can be used. All the default values and emission factors used in this technology have been listed in Table 1 with the references. Box 2 shows the step-by-step procedure to calculate GHG/SLCP emissions from composting. The print screen view of the composting sheet is shown in Figure 10 in which data has been entered in some scenarios to show the procedure of data entry.


Key Data | Go to Transportation | Composting | Go to Anaerobic digestion | Go to Recycling | Go to RDF | Go to MBT | Go to Incineration | Go to Mix waste Landfilling | Go to open burning and landfill fire | Go to uncollected | Go to Summary

GHG and SLCP emissions from Composting

User input is required in green cells *

| Data Input | Unit | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|---|
| Total amount of organic waste use for composting | Tonnes/day | | 30 | 30 | 30 | 30 | 30 |
| | | | | | Check available amount | | |
| Amount of food waste use for composting | Tonnes /day | Help | 20 | 20 | 20 | 20 | 20 |
| Amount of garden waste use for composting | Tonnes /day | | 10 | 10 | 10 | 10 | 10 |
| Type of fossil fuel use for operation activities | Type | | Diesel | Diesel | Diesel | Diesel | Diesel |
| Total amount of fossil-fuel use for operational activities | L/day | Help | 30 | 30 | 30 | 30 | 30 |
| Total amount of grid electricity use for operational activities | kWh/day | | | | | | |
| Compost production potential from waste | kg /tonne | Help | 600 | 600 | 600 | 600 | 600 |
| % of compost use for the agricultural and gardening purposes | % | Help | 90 | 90 | 90 | 90 | 90 |
| Choose the option for emission factors of chemical fertilizer production in your country | Source | Help | Default values | Calculation will be done based on default emission factors | | | Clear cells |

Results: Summary of the emissions | Show Graph | Print Sheet

| Category | Type of emissions | Emissions/ avoidance | Phase/activity | Emissions from composting (kg/tonne) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
| SLCPs | $CH_4$ | Emissions | $CH_4$ fossil-Direct (fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | $CH_4$ biogenic-Direct ( degradation) | 0.00 | 4.00 | 4.00 | 4.00 | 0.00 |
| | | Avoided | $CH_4$ fossil -(through chemical fertilizer production) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | **Net emissions** | | **0.00** | **4.00** | **4.00** | **4.00** | **0.00** |
| | BC | Emissions | Direct (fossil fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Avoided (through chemical fertilizer production) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | **Net emissions** | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| Other GHGs | $CO_2$ | Emissions | Direct (fossil fuel consumption) | 0.00 | 5.39 | 5.39 | 5.39 | 0.00 |
| | | | Indirect(grid electricity consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Avoided (through chemical fertilizer production) | 0.00 | 5.75 | 5.75 | 5.75 | 0.00 |
| | | **Net emissions** | | **0.00** | **-0.36** | **-0.36** | **-0.36** | **0.00** |
| | $N_2O$ | Emissions | Direct (fossil fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Direct (through degradation ) | 0.00 | 0.30 | 0.30 | 0.30 | 0.00 |
| | | Avoided | Avoided (through chemical fertilizer production) | 0.00 | 0.02 | 0.02 | 0.02 | 0.00 |
| | | **Net emissions** | | **0.00** | **0.28** | **0.28** | **0.28** | **0.00** |
| Net impact | **Net BC emissions (kg of BC/tonne)** | | | **0.000** | **0.001** | **0.001** | **0.001** | **0.000** |
| | **Net climate impact of GHGs (kg of $CO_2$-eq/tonne)** | | | **0.00** | **186.23** | **186.23** | **186.23** | **0.00** |

Home | Key data | Transportation | Composting | AD | Recycling | MBT | Incineration | Mix waste landfilling | Open burning and landfill fire | Un ...

Figure 10: Print screen view of composting sheet

### 2.4.2 Estimation of GHG/SLCP Emissions from Anaerobic Digestion (AD)

AD has been recognised as one of the most effective approaches for treating the separated organic fraction of waste. Among the biological treatment methods, AD is the most cost effective, due to the potential of high-energy recovery linked to the process as well as its low environmental impact. In order to calculate potential emissions and avoidance from a particular AD facility, users are asked to enter the daily average data such as the amount of food waste, garden waste use for AD, fossil-fuel and electricity utilisation for operational activities, as well as the type and amount of recovery potential from AD (electricity, thermal energy, biogas)

There are two major ways that AD could emit GHGs/SLCPs: i) GHGs and BC emissions from fossil fuel burning and grid electricity consumption for operation; and ii) GHGs emissions from the reactor due to unavoidable leakages. According to IPCC, unavoidable $CH_4$ emissions from reactors is 1 kg of $CH_4$/tonne of wet organic waste and $N_2O$ emission can be considered as negligible (IPCC, 2006a).

The biogas can be utilised to produce electricity or in combined heat and power (CHP) plants to both produce electricity and recover heat. In addition, biogas can be directly used as a thermal energy source. Users are encouraged to enter the location-specific energy recovery data for a more precise estimation. In the tool, default energy production values have been given which can be used if the city does not have the data. All the defaults values and emission factors used in AD sheet are listed in Table 1. The produced electricity or the thermal energy could be used to replace fossil-fuel-based conventional electricity and thermal energy production, thereby reducing the GHG/SLCP emissions from those conventional processes. Therefore, avoidance of emissions due to energy recovery has been weighted in the emissions calculation. Similarly, solid digestate can be recovered at the end of the AD process. If the user chooses the option of 'solid digestate is utilised as a compost', the tool will estimate the potential GHG/SLCP avoidance potential due to avoidance of conventional fertilizer application.

In order to understand the net emissions of GHG/SLCP, total avoidance potential should be subtracted from total emissions potential. If the estimated net GHG/SLCP emissions remain as a positive value, it means that the AD technology is still contributing to climate impacts and therefore efficiency resource recovery (e.g. energy, fertilizer) should be further improved. If the result is a net negative GHG/SLCP emissions value, it indicates the potential savings from AD and the possibility to be a carbon sink. The step-by-step procedure of estimating GHG/SLCP emissions from AD is shown in Box 3. The print screen view of the AD sheet is shown in Figure 11.

Box 3: Method of estimating GHG/SLCP emissions from AD

(i) GHG/SLCP emissions from operational activities of AD

$$Emissions_{GHG(i)-Operation} = \frac{Fuel(unit/day) \times NCV(MJ/unit) \times EF(kg/MJ) + EC \times EF_{el}}{AOW(tonnes/day)}$$

$Emissions_{GHG(i)\text{-}operation}$ – Emissions i^th^ GHG (different type of GHG e.g. $CO_2$, $CH_4$, $N_2O$)
Fuel (unit) – Total amount of fossil fuel units (kg or L) consumption per day
$NCV_{FF}$ – Net calorific value of fossil fuel consumed
EF – $CO_2$, $CH_4$, $N_2O$ emission factor of fuel (e.g. diesel: 0.074 kg $CO_2$/MJ)
EC- Electricity consumption for operation activities (kWh/day)
$EF_{el}$ –Emission factor of grid electricity production (kg CO2-eq/kWh)
AOW- Amount of Waste use for AD (tonnes/day)

(ii) SLCP (e.g. BC) emissions from operational activities of AD

$$Emissions_{BC-Operation} = \frac{Fuel(unit/day) \times NCV(MJ/unit) \times EF(g/MJ)/1000}{AOW(tonnes/day)}$$

EF – EF of black carbon has given in g/MJ (divided by 1000 to convert into kg)

(iii) GHG emissions from AD process
GHG emissions from digestion process are calculated as follows:

$$Emission_{GHG(i)-Leakage} = EF(kg/tonne)$$

EF – Emissions of $CH_4$ due to unavoidable leakages (kg/tonne of organic waste)

(iv) Total $i^{th}$ GHGs emissions from AD are calculated as follows:

$$TotalGHG_{(i)} = Emissions_{Operation} + Emission_{Degradation}$$

(v) Avoided GHG emissions by recovering electricity

$$AvoidanceGHG_{(i)} = A_{Biogas} \times P_{CH4} \times E_{CH4} \times \frac{1}{CF_{Energy}} \times E_{Powerplant} \times EF_{el}$$

Avoidance $GHG_{(i)}$ – $i^{th}$ GHG avoidance due to electricity production (kg/tonne)
$A_{Biogas}$ –Amount of Biogas produced ($m^3$/tonne); $P_{CH4}$ – Percentage of $CH_4$ in biogas (%)
$E_{CH4}$ – Energy content of $CH_4$ ($MJ/m^3$); $CF_{Energy}$ – Conversion Factor of Energy (3.6 MJ/kWh)
$E_{Powerplant}$ – Efficiency of the Power plant (%) ; $EF_{el}$ - Emission factor of country grid electricity production (kg $CO_2$-eq/kWh)

(vi) Avoided GHG/SLCP emissions by utilising biogas as thermal energy source for replacing fossil energy

$$AvoidanceGHG/SLCP_{(i)} = C_{Biogas} \times P_{CH4} \times E_{CH4} \times EF_{(i)}$$

Avoidance $GHG_i$–$i^{th}$ GHG avoidance due to thermal energy production (kg /tonne)
$C_{Biogas}$ – Collected amount of biogas ($m^3$/tonne)
$P_{CH4}$ –Percentage of $CH_4$ in biogas (%)
$E_{CH4}$ –Energy content of $CH_4$ ($MJ/m^3$)
$EF_{(i)}$- Emission factor of $i^{th}$ GHG/SLCP by avoided fossil fuel combustion (kg/MJ)

(vii) Avoided GHG emissions by utilising digestate as compost and thereby replacement of chemical fertilizer is calculated as follows:

$$AvoidedGHG/SLCP_{(i)} = AC \times PC_{Agriculture} \times A_{GHG}$$

AvoidedGHG$_{(i)}$ – Avoided i$^{th}$GHG from AD due to avoidance of chemical fertilizer production (kg/tonne)
AC – Amount of digestate/Compost produced (tonne of compost/tonne of waste)
PC$_{Agriculture}$ – Percentage of digestate/compost use for agricultural and gardening purpose (%)
A$_{GHG(i)}$ – i$^{th}$ GHG Avoidance potential from chemical fertilizer production which is equivalent to one tonne of compost (kg/tonne of compost)

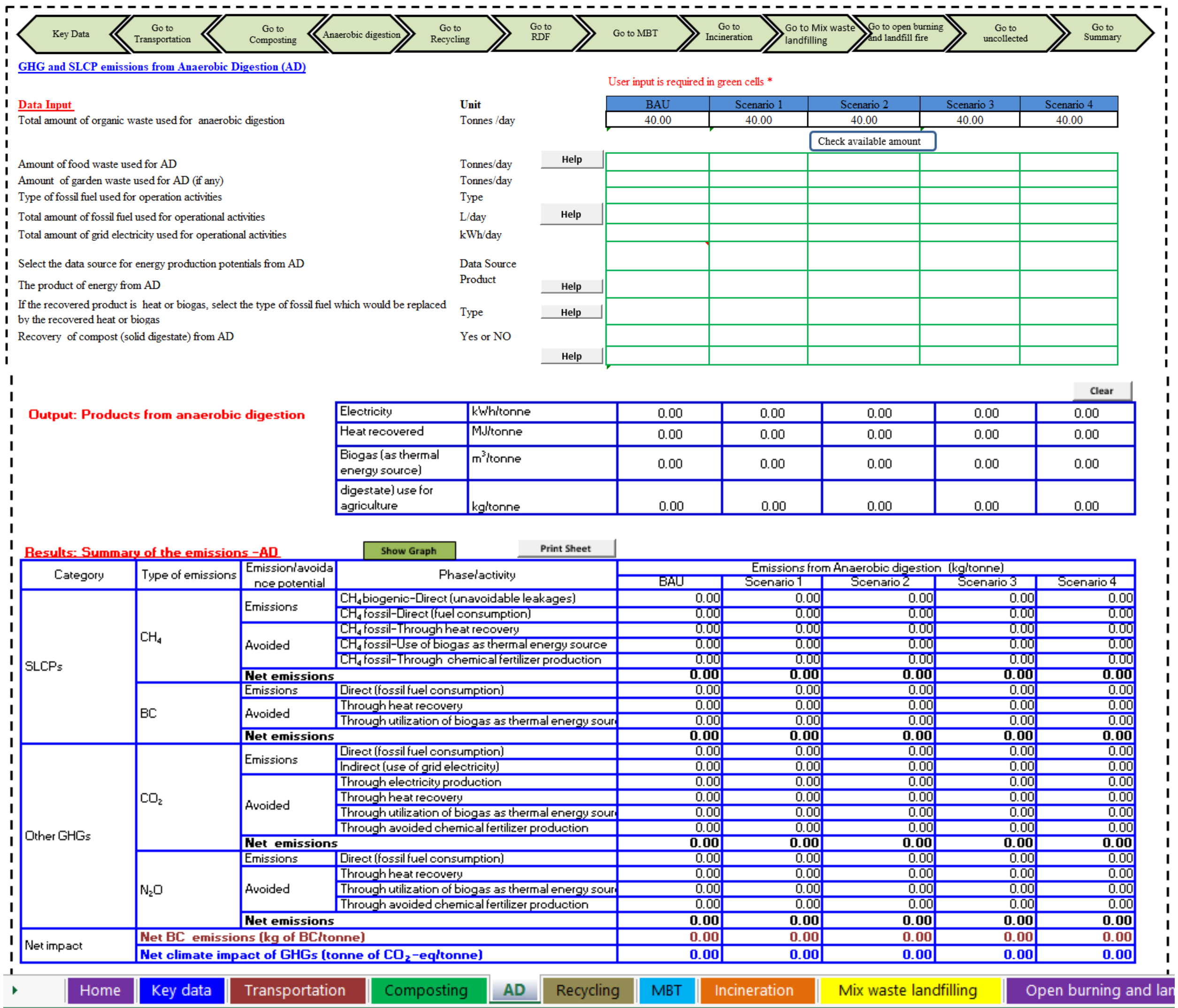
(viii) Net i$^{th}$ GHG emissions and net BC emissions can be calculated as follows:

$$Net(GHG)_{(i)} = Total(GHG)_{(i)} - Avoided(GHG)_{(i)}; \; Net(BC) = Total(BC) - Avoided(BC)$$

(ix) Net climate impact from all GHGs (except BC) is estimated as follows:

$$NetGHG_{(CO2-eq/tonne)} = (CO_{2(net)} \times 1 + CH_4(biogenic)_{(net)} \times 28 + CH_4(fossil)_{(net)} \times 30 + N_2O_{(net)} \times 265$$

Net GHG emissions – Estimated as kg of $CO_2$-eq/tonne



Key Data | Go to Transportation | Go to Composting | Anaerobic digestion | Go to Recycling | Go to RDF | Go to MBT | Go to Incineration | Go to Mix waste landfilling | Go to open burning and landfill fire | Go to uncollected | Go to Summary

**GHG and SLCP emissions from Anaerobic Digestion (AD)**

User input is required in green cells *

| Data Input | Unit | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|---|
| Total amount of organic waste used for anaerobic digestion | Tonnes /day | | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 |
| | | | | | Check available amount | | |
| Amount of food waste used for AD | Tonnes/day | Help | | | | | |
| Amount of garden waste used for AD (if any) | Tonnes/day | | | | | | |
| Type of fossil fuel used for operation activities | Type | | | | | | |
| Total amount of fossil fuel used for operational activities | L/day | Help | | | | | |
| Total amount of grid electricity used for operational activities | kWh/day | | | | | | |
| Select the data source for energy production potentials from AD | Data Source | | | | | | |
| The product of energy from AD | Product | Help | | | | | |
| If the recovered product is heat or biogas, select the type of fossil fuel which would be replaced by the recovered heat or biogas | Type | Help | | | | | |
| Recovery of compost (solid digestate) from AD | Yes or NO | | | | | | |
| | | Help | | | | | |

Clear

**Output: Products from anaerobic digestion**

| | | | | | | |
|---|---|---|---|---|---|---|
| Electricity | kWh/tonne | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Heat recovered | MJ/tonne | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Biogas (as thermal energy source) | $m^3$/tonne | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| digestate) use for agriculture | kg/tonne | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Results: Summary of the emissions -AD** | Show Graph | Print Sheet

| Category | Type of emissions | Emission/avoidance potential | Phase/activity | Emissions from Anaerobic digestion (kg/tonne) BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|---|---|
| SLCPs | $CH_4$ | Emissions | $CH_4$ biogenic-Direct (unavoidable leakages) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | $CH_4$ fossil-Direct (fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | $CH_4$ fossil-Through heat recovery | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | $CH_4$ fossil-Use of biogas as thermal energy source | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | $CH_4$ fossil-Through chemical fertilizer production | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | **Net emissions** | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| | BC | Emissions | Direct (fossil fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Through heat recovery | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Through utilization of biogas as thermal energy sour | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | **Net emissions** | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| Other GHGs | $CO_2$ | Emissions | Direct (fossil fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Indirect (use of grid electricity) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Through electricity production | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Through heat recovery | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Through utilization of biogas as thermal energy sour | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Through avoided chemical fertilizer production | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | **Net emissions** | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| | $N_2O$ | Emissions | Direct (fossil fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Through heat recovery | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Through utilization of biogas as thermal energy sour | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Through avoided chemical fertilizer production | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | **Net emissions** | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| Net impact | **Net BC emissions (kg of BC/tonne)** | | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| | **Net climate impact of GHGs (tonne of $CO_2$-eq/tonne)** | | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |

Home | Key data | Transportation | Composting | AD | Recycling | MBT | Incineration | Mix waste landfilling | Open burning and lar

Figure 11: Print screen view of AD sheet

### 2.4.3 Estimation of GHG/SLCP Emissions from Recycling

Recycling has long been recognised as an environmentally friendly waste management option. A significant amount of valuable materials can be recovered from waste recycling, with positive outcomes for the environment, economy and greater society. Incorporating recycling into integrated waste management would be the most valuable action to drive the entire system towards sustainability. Therefore at present, many cities are interested in moving towards material recycling and resource recovery.

Recycling is not a simple process, and it includes different activities such as cleaning, baling, sorting, smelting etc. The entire process requires a significant amount of fossil energy and grid electricity. Thus, all these activities may emit a considerable amount of GHG/SLCP. On the other hand, material recovered from the recycling processes can be used to replace the virgin production of an equivalent amount of materials, thereby avoiding a massive amount of GHG/SLCP emissions that would otherwise occur through the production of the virgin resources. Therefore, estimation of net GHG/SLCP emissions from a recycling scheme is very important to inform decisions on addressing overall climate impacts.

In order to carry out an assessment on GHG/SLCP emissions from recycling activities in a particular city, data related to the composition of major type of recyclables (% paper and cardboard, % plastic, % Aluminium, %Metal/steel and % Glass), total fossil fuel and electricity requirement for the entire recycling process (cleaning, particle size reduction, baling, smelting etc.) and the recyclability (how much material can actually be recovered) of different type of materials is required. It should be noted that this data should be provided with respect to two aspects of recycling: (i) recyclables collected by the city, and (ii) recyclables collected by the informal sector. Finding data on recycling process flow of informal sector may prove difficult for the city. In reality, recyclables collected by informal sector join up with the formal route after pre-processing. Therefore, energy consumption and material recovery potential can be assumed to be similar to the formal unit weight values of material recycling.

In some cities, pre-process recyclables might be transported to another province for final smelting/recycling. However, finding data on these logistical processes may be difficult at the city level. Therefore, energy consumption for transportation of recyclables for further smelting/recycling is considered equivalent to the corresponding fuel consumption for transportation of the virgin materials and therefore ignores the emissions from long-distance transportation of recyclables.

Recycling entails more than a one-stage process and the various stakeholders involved with this process. Obtaining site-specific data related to recycling of different types of recyclables presents a challenge for the municipal policy makers. Cooperation from all stakeholders who are connected with the recycling flow would be necessary to gather sound data. Therefore, in the recycling sheet, the users have two options: either to enter the location-specific data (if available), or to choose the default values.

Option I estimates emissions based on location/country-specific data; cities may cooperate with relevant recycling/smelting companies to collect this data. Usually recycling companies keep records of monthly data (e.g. operational capacity, total energy consumption). Once the location-specific data has been entered in the given table, GHG/SLCP emissions can be calculated with respect to data on waste composition provided by the user.

Option II: Estimate the emissions based on default values: “The developer has provided average energy consumption data and related emissions which are available in literature. The emissions will be calculated based on the default energy consumption data."

Recycled material can be used in finished or intermediary products and therefore the equivalent quantity of material made from virgin inputs can be replaced. According to the literature, the potential recyclability of major recyclables such as paper, plastic, aluminium, metal and glass is as high as 90-95%. The amount of recovered materials from recycling would be equal to the amount of potential avoidance of virgin resources. The developer has been provided default energy consumption data and related GHG/SLCP emissions from virgin production. In the absence of location specific data, GHG/SLCP emissions from virgin production process chains can be calculated based on the default values. If users are aware of country-specific emissions from virgin production of materials, it is desirable to enter such data into the tool for precise estimation. Emission factors and default values used in the recycling sheet have been summarised in Table 1. The calculation procedure for estimating emissions has been show in Box4.

Similar to any other technology, if the estimated net GHG/SLCP emissions remain as a positive value, it implies that the recycling process is still contributing to climate impact. In most cases, a net negative GHG/SLCP emission value may be expected due to the avoidance of a massive amount of emissions that would occur from virgin resource production chains. If the result is a net negative emission value, it indicates the potential GHG/SLCP saving potential from the recycling process chain and the possibility to be a carbon sink.

It is important to highlight that, when compared to other waste management technologies, GHG/SLCP mitigation potential from appropriate recycling schemes is highly significant. In this regard, more accurate data collection is very important when taking into account the location-specific data.

Box 4: Method of estimating GHG/SLCP emissions from recycling

(i) GHG/SLCP emissions from operational activities of one type of recyclables (e.g. paper) recycling

$$Emissions_{GHG(i)-Operation} = \frac{Fuel(unit/day) \times NCV(MJ/unit) \times EF(kg/MJ) + EC \times EF_{el}}{AOR(tonnes/day)}$$

$Emissions_{GHG(i)-operation}$ – Emissions i[th] GHG (e.g. $CO_2$, $CH_4$, $N_2O$) from operational activities
Fuel (unit) – Total amount of fossil fuel units (kg or L) consumption per day (for all the operations)
$NCV_{FF}$ – Net calorific value of fossil fuel consumed
EF – $CO_2$, $CH_4$, $N_2O$ emission factor of fuel (e.g. diesel: 0.074 kg $CO_2$/MJ)
EC - Electricity consumption for operation activities (kWh/day)
$EF_{el}$ –Emission factor of grid electricity production (kg $CO_2$-eq/kWh)
AOR - Amount of Recyclables (tonnes/day)

(ii) SLCP (e.g. BC) emissions from operational activities of one type of recyclables (e.g.paper)

$$Emissions_{BC-Operation} = \frac{Fuel(unit/day) \times NCV(MJ/unit) \times EF(g/MJ)/1000}{AOR(tonnes/day)}$$

EF – EF of black carbon has given in g/MJ (divided by 1000 to convert into kg)

(iii) GHG/SLCP emissions from recyclable mix (mixture of recyclables collected from the city) =

$Emissions_{GHGs/SLCPs\ (i)} = Total_{recyclables} \times PC_{Paper} \times E_{Paper\ (i)} + Total_{recyclables} \times PC_{Plastic} \times E_{Plastic\ (i)} + Total_{recyclables} \times PC_{Aluminium} \times E_{Aluminium\ (i)} + Total_{recyclables} \times PC_{Metal} \times E_{Metal\ (i)} + Total_{recyclables} \times PC_{Glass} \times E_{Glass(i)}$

$Emissions_{GHGs/SLCPs\ (i)}$ –Emissions from i[th] GHG/SLCP from the recyclable mix (kg/tonne)

$Total_{recyclables}$-Total amount of recyclables collected (tonnes/day)
PC-Percentage of different types in the composition (e.g. paper, plastic, aluminium)
$E_{paper(i)}$-Amount of i[th] emissions per tonne of paper recycling (kg/tonne)

(iv) Avoided GHG/SLCP emissions from recyclable mix through material recovery =

$Avoided_{GHGs/SLCPs\ (i)} = Total_{recyclables} \times PC_{Paper} \times RE_{Paper} \times EV_{Paper\ (i)} + Total_{recyclables} \times PC_{Plastic} \times RE_{Plastic} \times EV_{Plastic\ (i)} + Total_{recyclables} \times PC_{Aluminium} \times RE_{Aluminium} \times EV_{Aluminium\ (i)} + Total_{recyclables} \times PC_{Metal} \times RE_{Metal} \times EV_{Metal\ (i)} + Total_{recyclables} \times PC_{Glass} \times RE_{Glass} \times EV_{Glass(i)}$

$Avoided_{GHG/SLCP\ (i)}$ - Avoided i[th] GHG/SLCP emissions from recovery of material (kg/tonne)
$Total_{recyclables}$-Total amount of recyclables collected (tonnes/day)
PC - Percentage of different types in the composition (e.g. paper, plastic, aluminium)
RE – Recyclability of materials (actual amount of materials recovery per tonne of waste (%))
$EV_{(i)}$-Amount of i[th] Emissions per tonne Virgin material production. (kg/tonne)

(v) Net i[th] GHG emissions and net BC emissions from recycling;

$$Net(GHG)_{(i)} = Total(GHG)_{(i)} - Avoided(GHG)_{(i)}; \ Net(BC) = Total(BC) - Avoided(BC)$$

(vi)Net climate impact from all GHGs (except BC) is estimated as follow;

$$NetGHG_{(CO2-eq/tonne)} = (CO_{2(net)} \times 1 + CH_4(biogenic)_{(net)} \times 28 + CH_4(fossil)_{(net)} \times 30 + N_2O_{(net)} \times 265)$$

Net GHG emissions – Estimated as kg of $CO_2$-eq/tonne

Key Data | Go to Transportation | Go to Composting | Go to Anaerobic digestion | Recycling | Go to RDF | Go to MBT | Go to Incineration | Go to Mix waste landfilling | Go to open burning and landfill fire | Go to uncollected waste | Go to Summary

**GHG and SLCP emissions from Recycling**

**Data Input** — User input is required in green cells *

**(1) Recyclables collected by the city (e.g. Municipality or contracted/authorized private companies)**

Help

| | Unit | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| Total amount of recyclables collected by the city | Tonnes/day | 50 | 50 | 50 | 50 | 50 |

Composition (percentage %) of recyclables collected by the city — Check available amount

| | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| Paper and cardboard | Percentage (%) | | | | | |
| Plastic | | | | | | |
| Aluminium | | | | | | |
| Metal/Steel | | | | | | |
| Glass | | | | | | |
| **Total** | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**2) Recyclables collected by the informal sector (e.g. waste pickers, households, any voluntary organizations)**

Help

| | Unit | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| Total amount of recyclables collected by the informal collectors | Tonnes/day | 500 | 500 | 500 | 500 | 500 |

Composition (percentage %) of recyclables collected by the informal sector

| | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| Paper and cardboard | Percentage (%) | | | | | |
| Plastic | | | | | | |
| Aluminium | | | | | | |
| Metal/Steel | | | | | | |
| Glass | | | | | | |
| **Total** | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**3) Energy consumption data**

Clear

**(i) Energy consumption for transportation:** Energy consumption for transportation of recyclables for further processing/ manufacturing is considered as equivalent to the corresponding fuel consumption for transportation of the virgin materials and therefore emissions from long distance transportation of recyclables are ignored.

**(ii) Energy consumption for processing activities (cleaning, sorting, baling, processing)**

Data source for energy consumption data for recycling — Help — **Default values**

Location specific data requirement

| Description | Unit | Paper | Plastics | Aluminium | Steel | Glass |
|---|---|---|---|---|---|---|
| Type of fossil fuel use for recycling | Type | | | | | |
| Amount of fossil fuel used | L/tonne | | | | | |
| Amount of grid electricity used | kWh/tonne | | | | | |
| Recyclability of materials | % (Help) | | | | | |

Calculation will be done using the default values given in this Table

Default energy consumption data

| Description | Unit | Paper | Plastics | Aluminium | Steel | Glass |
|---|---|---|---|---|---|---|
| Type of fossil fuel use for recycling | Type (Help) | Coal | | | | Natural Gas |
| Amount of fossil energy | MJ/tonne | 13899.94 | | | | 6868.3 |
| Amount of grid electricity used | kWh/tonne (Help) | | 500 | 660 | 900 | |
| Recyclability of materials | % | 90 | 90 | 96 | 90 | 95 |

**(iv) Avoided emission quantification through material recovery**

Recycled material can be used in finished or intermediary products and therefore equivalent quantity of material made of virgin inputs can be replaced. Avoided emissions from birgin production process will be calculated based on default data in D184:O195

**(iv) Avoided emission quantification through material recovery**

Recycled material can be used in finished or intermediary products and therefore equivalent quantity of material made of virgin inputs can be replaced. Avoided emissions from birgin production process will be calculated based on default data in D184:O195

**Results: Summary of the emissions**

Show Graph | Print Sheet

| Type of emissions | | Emission/avoidance potential | Phase/activity | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|---|---|
| | | | | Emissions from recycling activities (kg/tonne of mixed recyclable waste) | | | | |
| SLCPs | $CH_4$ | Emissions | $CH_4$ fossil - Direct (fuel consumption) | 0.000 | 0.010 | 0.010 | 0.010 | 0.000 |
| | | Avoided | Through material recovery | 0.000 | 0.021 | 0.021 | 0.021 | 0.000 |
| | | **Net emissions** | | **0.000** | **-0.011** | **-0.011** | **-0.011** | **0.000** |
| | BC | Emissions | Direct (fossil fuel consumption) | 0.000 | 0.020 | 0.020 | 0.020 | 0.000 |
| | | Avoided | Through material recovery | 0.000 | 0.037 | 0.037 | 0.037 | 0.000 |
| | | **Net emissions** | | **0.000** | **-0.017** | **-0.017** | **-0.017** | **0.000** |
| Other GHGs | $CO_2$ | Emissions | Direct (fossil fuel consumption ) | 0.000 | 344.672 | 344.672 | 344.672 | 0.000 |
| | | | Indirect (Use of grid electricity) | 0.000 | 178.848 | 178.848 | 178.848 | 0.000 |
| | | Avoided | Through material recovery | 0.000 | 1,837.693 | 1,837.693 | 1,837.693 | 0.000 |
| | | **Net emissions** | | **0.000** | **-1,314.173** | **-1,314.173** | **-1,314.173** | **0.000** |
| | $N_2O$ | Emissions | Direct (fossil fuel consumption) | 0.000 | 0.003 | 0.003 | 0.003 | 0.000 |
| | | Avoided | Through material recovery | 0.000 | 0.006 | 0.006 | 0.006 | 0.000 |
| | | **Net emissions** | | **0.000** | **-0.003** | **-0.003** | **-0.003** | **0.000** |
| Net impact | **Net BC emissions (kg of BC/tonne of mixed recyclable waste)** | | | **0.000** | **-0.017** | **-0.017** | **-0.017** | **0.000** |
| | **Net climate impact of GHGs (kg of $CO_2$-eq/tonne of mixed recyclable waste)** | | | **0.00** | **-1,315.23** | **-1,315.23** | **-1,315.23** | **0.00** |

Home | Key data | Transportation | Composting | AD | Recycling | MBT | Incineration | Mix waste landfilling | Open burning and landfill fire | Un ...

Figure 12: Print screen view of Recycling sheet

### 2.4.4 Estimation of GHG/SLCP Emissions from RDF

Refuse-derived fuel (RDF) has gained attention as a viable alternative to address both global warming and municipal solid waste management challenges. RDF not only enhances global environmental quality but also reduces local economic losses associated with waste disposal. Various studies have explored the utilization of refuse fuels, with most focusing on direct combustion or thermal degradation processes such as gasification and pyrolysis, which offer considerable benefits in energy recovery and emission reductions compared to conventional landfilling. Promoting the use of biomass and waste for energy production can significantly reduce dependence on fossil fuels and enhance the sustainability of the energy system within a circular economy framework. In this context, RDF, a biofuel produced from the dry fractions of waste, emerges as an appealing energy option due to its generally higher quality compared to the original waste. RDF not only supports waste reduction but also serves as a valuable input for energy generation, aligning with sustainable resource management goals.

In version III of the EQT, energy recovery options from RDF (Refuse-Derived Fuel) produced from solid waste are included due to the high potential for cities to initiate RDF production. Estimating net GHG and SLCP emissions from RDF production is crucial to inform decisions that address overall climate impacts.

**Data Input**

To quantify these emissions, key data related to the RDF production process must be gathered. The first essential data set is the composition of sorted waste, measured on a wet basis, which serves as the initial input for RDF production. Generally, municipalities separate only combustible waste such as food, garden waste, plastic, paper, wood, textiles, and other combustibles like rubber for RDF manufacturing. Non-combustible fractions are sorted out and removed from the input waste used for RDF production. Users are then asked to enter the composition of input waste on a wet basis.

Next, users are prompted to enter the energy requirements for RDF (Refuse-Derived Fuel) production. This includes both the type and amount of fossil fuels and grid electricity used in the manufacturing process. If cities or users do not have access to this information, they can utilize default energy consumption data provided under the "User Help" section.

***Energy Requirement for the production for RDF***: Based on data collected from RDF plants in Indonesia, typical diesel consumption for machinery operations such as wheel loaders and rotary mixers is approximately 3 liters per tonne of input waste. Furthermore, electricity consumption varies depending on the plant's operational capacity and technology type, with estimated energy use for different RDF production systems as follows:

Fully automated large-scale RDF plant (100-1000 tonnes/day): 30-40 kWh/tonne

Fully automated medium-sized RDF plant (50-100 tonnes/day): 40-50 kWh/tonne

Fully automated small-sized RDF plant (10-50 tonnes/day): 50-60 kWh/tonne

Partially automated/manual RDF plant: 5-10 kWh/tonne

***Properties of RDF produced***: The next step involves providing data related to the properties and characteristics of the RDF produced. Key data points include:

- Amount of RDF produced per tonne of input waste
- Composition of produced RDF, including the percentage of food waste, garden waste, plastic, paper, wood, textile, etc.
- Moisture content of the RDF
- Calorific value of the RDF produced

These properties are crucial because the selling price of RDF depends on these parameters. It is ideal for users to input data on the properties of RDF produced at their facility. However, if location-specific data is unavailable, default values are provided based on a survey conducted in Indonesia.

In general, the weight of RDF produced is typically 30-33% of the fresh input waste. The moisture content of RDF is highly dependent on its composition. For instance:

- If the RDF is composed of 70% plastic and 30% garden waste, the approximate moisture content is around 20%.
- If the RDF consists of 100% plastic, the moisture content drops to approximately 15%.

The calorific value of RDF also varies based on its composition and moisture content based on the properties of the RDF produced, user can choose the most appropriate calorific value for the RDF produced:

- 100% plastic (15% moisture content): 7000-7500 kcal/kg
- 70% plastic and 30% garden waste (20% moisture content): 3400-3500 kcal/kg
- 100% organic waste residue (7-10% moisture content): 2200-2300 kcal/kg

**Data Input for Energy Recovery Options**: In the following stage, users are prompted to input data related to energy recovery from RDF. There are three main options for energy recovery from RDF:

1. Co-combustion in a cement kiln to replace coal
2. Co-combustion in a municipal solid waste (MSW) incinerator solely for electricity production

3. Co-combustion in an MSW incinerator for combined heat and power (CHP) to produce both electricity and heat

If users select option (1), they need to provide the approximate calorific value of the coal that RDF will replace. Calorific values for various types of coal are available in the "User Help" section as a reference. If option (2) is chosen, users should enter the efficiency of electricity recovery and the percentage of electricity used for onsite activities. For option (3), users are asked to input both electricity and heat recovery efficiencies, along with onsite energy consumption rates. Default efficiencies are provided, based on the study by Rigamonti et al. (2012):

- The efficiency of MSW incineration for electricity-only production is 27%.
- For CHP in an MSW incinerator, the electricity and heat recovery efficiencies are 24% and 18%, respectively.

Transport of produced RDF to cement/incineration plants: The final stage in RDF emissions calculation involves entering transportation data for the produced RDF. Since RDF may be transported over long distances to incineration or cement plants, different types of vehicles may be used for this process. Users are asked to enter:

- The type of truck used for RDF transport.
- The approximate loading capacity of RDF in the vehicle.
- The round-trip distance from the RDF production site to the cement or energy recovery plant.
- The type of fuel used for transportation, chosen from a dropdown list.
- The vehicle's fuel consumption efficiency.

For additional guidance, users can click on the “User Help” button to view approximate fuel consumption efficiencies for different vehicle types.

Once all data is entered in the designated cells, a summary of estimated GHG and SLCP emissions from RDF transport will be displayed. In order to enable decision making, a summary table has been incorporated, to show energy recovery potential per tonne of RDF production. Users should note that the estimations in the first table are per tonne of RDF produced, NOT per tonne of input waste used. In the emissions summary table, if the estimated net GHG/SLCP emissions from RDF retain a positive value, it implies that RDF continues to have climate impacts may be due to not recovering adequate amount of energy. Conversely, if the results are negative, these, net negative GHG/SLCP values may be attributed to an avoidance of a large percentage of emissions associated with conventional electricity and heat production processes. Therefore, increasing the calorific value of RDF and enhancing the efficiency of heat and electricity recovery processes are expected to positively contribute to achieving a GHG/SLCP mitigation target. Step-by-step procedures for calculating GHG/SLCP emissions from RDF production process is presented in Box 5. A print screen view of the RDF sheet is shown in Figure 13.

Box 5: Method of estimating GHG/SLCP emissions from RDF

(i) GHG/SLCP emissions from operational activities at RDF facility

$$Emissions_{GHG(i)-Operation} = \frac{Fuel(unit/day)\times NCV(MJ/unit)\times EF(kg/MJ)+EC\times EF_{el}}{AOW(tonnes/day)}$$

$Emissions_{GHG(i)-operation}$ – Emissions i[th] GHG (e.g. $CO_2$, $CH_4$, $N_2O$) from operational activities

Fuel (unit) – Total amount of fossil fuel units (kg or L) consumption per day

$NCV_{FF}$ – Net calorific value of fossil fuel consumed

EF – $CO_2$, $CH_4$, $N_2O$ emission factor of fuel (e.g. diesel: 0.074 kg $CO_2$/MJ)

EC- Grid electricity consumption for operation activities (kWh/day)

$EF_{el}$ –Emission factor of grid electricity production (kg $CO_2$-eq/kWh)

AOW- Amount of Waste used to produce RDF(tonnes/day)

(ii) SLCP (e.g. BC) emissions from operational activities at RDF plant

$$Emissions_{BC-Operation} = \frac{Fuel(unit/day)\times NCV(MJ/unit)\times EF(g/MJ)/1000}{AOW(tonnes/day)}$$

EF – EF of black carbon has given in g/MJ (divided by 1000 to convert into kg)

(iii) Quantify the GHG (e.g. fossil $CO_2$) emissions from combustion of RDF

$$CE = \sum_i (SW_i \times dm_i \times CF_i \times FCF_i \times OF_i) \times \frac{44}{12}$$

i - type of combustible waste used for RDF production such as food waste, garden waste, paper, plastic, textiles, rubber and leather

CE - Combustion Emissions (kg $CO_2$/tonne)

$SW_i$-total amount of i[th] type of waste (wet weight) used for RDF production (kg/tonne of waste)

dmi - dry matter content in the waste (partially wet weight) in the produced RDF

$CF_i$ -fraction of carbon in the dry matter (total carbon content), (fraction; 0.0-1.0)

$FCF_i$ - fraction of fossil carbon in the total carbon, (fraction; 0.0-1.0)

$OF_i$ - oxidation factor, (fraction; 0.0 – 100%)

44/12 - conversion factor from C to $CO_2$

(iv) Total fuel consumption transport of produced RDF;

GHG emissions from RDF transportation;

$$Emissions_T = \frac{Fuel(units)\times NCV_{FF}(MJ/unit)\times EF(kg/MJ)}{AOW(tonnes/trip)}$$

$Emissions_T$ – Emissions from transportation (kg GHG/tonne of waste)

Fuel (units) – Total amount of fossil fuel consumption per round, (Liters or kg (e.g. natural gas)

$NCV_{FF}$ – Net calorific value of the fossil fuel consumed (MJ/unit mass or volume) (e.g. Diesel 36.42 MJ/L, Natural gas 37.92 MJ/kg)

EF – $CO_2$, $CH_4$, $N_2O$ emission factor of fuel (e.g. diesel: 0.074 kg $CO_2$/MJ, Natural gas: 0.056 kg $CO_2$/MJ)

AOW- Amount of Waste Transport (tonnes/trip)

(V)BC emissions from waste transportation and operational activities at transfer station;

$$Emissions_T = \frac{Fuel(units/day)\times Density(kg/unit)\times EF(g/kg)/1000}{AOW(tonnes/trip)}$$

EF – EF of black carbon has given in g/kg (divided by 1000 to convert into kg)

(vi) Total i[th] GHG/SLCPs emissions from RDF production is calculated as follows;

$$TotalGHG/SLCP_{(i)} = Emissions_{Operation} + Emission_{Combustion} + Emission_{RDF\ transport}$$

vii -a) Avoided GHG/SLCP emissions via heat recovery

$$AvoidedGHG / SLCP_{(i)} = LHV_{waste} \times E_{HR} \times OC \times EF_i$$

(vii-b) Avoided GHG/SLCP emissions via electricity recovery

$$AvoidedGHG / SLCP_{(i)} = LHV_{waste} \times \frac{E_{ER}}{CF} \times OC \times EF_{el(i)}$$

Avoided GHG/SLCP$_{(i)}$– Avoided i$^{th}$ GHG or SLCP from heat recovery from incineration (MJ /tonne)
LHV$_{waste}$ – Low Heating Value of mixed waste (MJ/tonne)
$E_{HR}$–Efficiency of Heat Recovery (%); OC– Percentage of onsite Consumption (%)
$EF_i$-Emission Factor of i$^{th}$ GHGs/SLCPs from avoided fossil fuel combustion (kg/MJ) to provide equivalent amount of energy
$E_{ER}$-Efficiency of Electricity Recovery (%); CF- Conversion Factor (3.6 MJ/kWh)
$EF_{el}$ –Emission factor i$^{th}$ GHGs from grid electricity production (kg $CO_2$-eq/kWh)

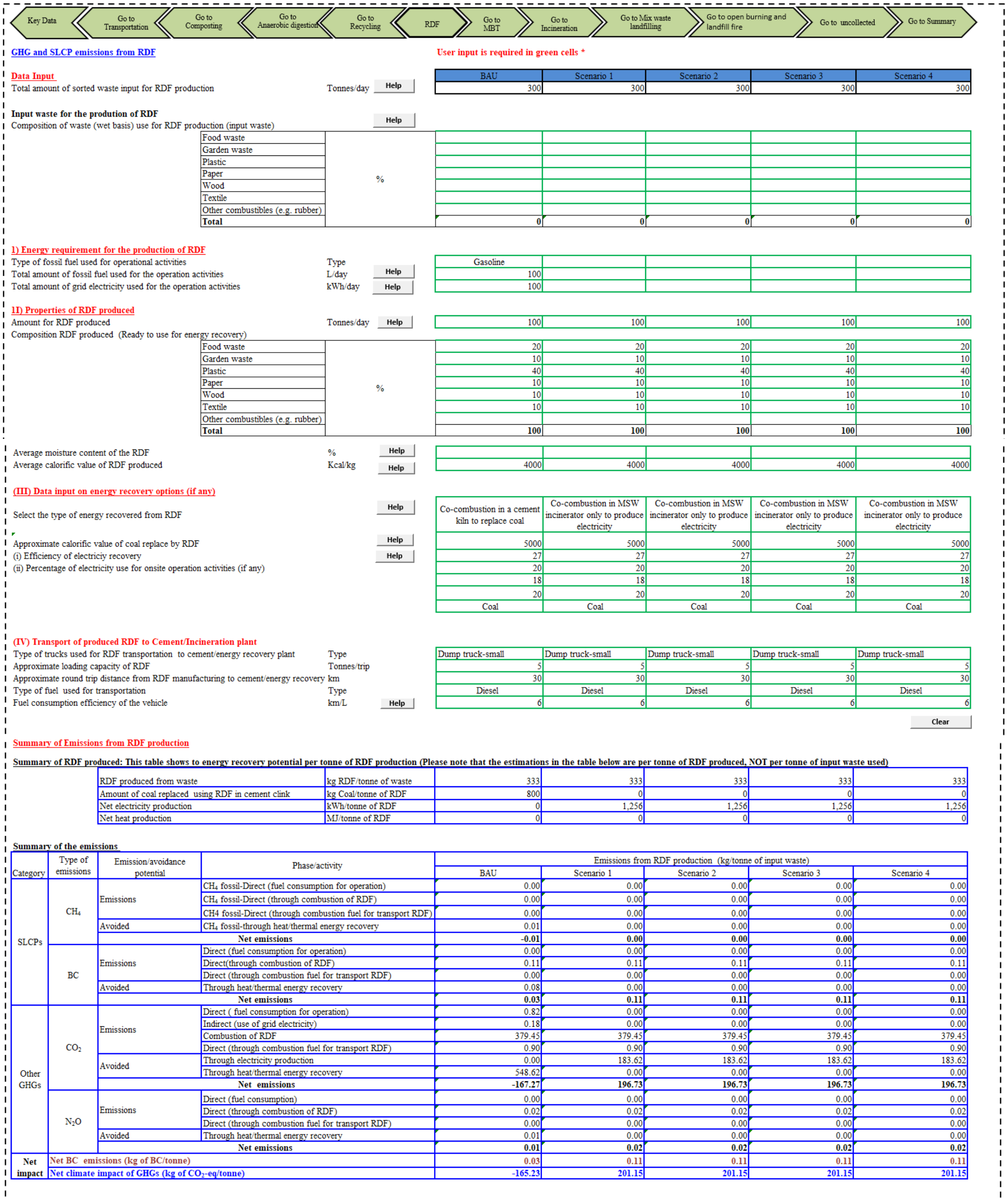
(viii) Net i$^{th}$ GHG emissions and net BC emissions can be calculated as follows;

$$Net(GHG)_{(i)} = Total(GHG)_{(i)} - Avoided(GHG)_{(i)}\,;\; Net(BC) = Total(BC) - Avoided(BC)$$

(ix) Net climate impact from all GHGs (except BC) is estimated as follows:

$$NetGHG_{(CO2-eq/tonne)} = (CO_{2(net)} \times 1 + CH_4(biogenic)_{(net)} \times 28 + CH_4(fossil)_{(net)} \times 30 + N_2O_{(net)} \times 265)$$

Net GHG emissions – Estimated as tonnes of $CO_2$-eq/tonne



Key Data | Go to Transportation | Go to Composting | Go to Anaerobic digestion | Go to Recycling | RDF | Go to MBT | Go to Incineration | Go to Mix waste landfilling | Go to open burning and landfill fire | Go to uncollected | Go to Summary

**GHG and SLCP emissions from RDF**

**User input is required in green cells ***

**Data Input**

| | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| Total amount of sorted waste input for RDF production | Tonnes/day | 300 | 300 | 300 | 300 | 300 |

**Input waste for the prodution of RDF**

Composition of waste (wet basis) use for RDF production (input waste)

| | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| Food waste | % | | | | | |
| Garden waste | % | | | | | |
| Plastic | % | | | | | |
| Paper | % | | | | | |
| Wood | % | | | | | |
| Textile | % | | | | | |
| Other combustibles (e.g. rubber) | % | | | | | |
| **Total** | | **0** | **0** | **0** | **0** | **0** |

**1) Energy requirement for the production of RDF**

| | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| Type of fossil fuel used for operational activities | Type | Gasoline | | | | |
| Total amount of fossil fuel used for the operation activities | L/day | 100 | | | | |
| Total amount of grid electricity used for the operation activities | kWh/day | 100 | | | | |

**1I) Properties of RDF produced**

| | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| Amount for RDF produced | Tonnes/day | 100 | 100 | 100 | 100 | 100 |
| Composition RDF produced (Ready to use for energy recovery) | | | | | | |
| Food waste | % | 20 | 20 | 20 | 20 | 20 |
| Garden waste | % | 10 | 10 | 10 | 10 | 10 |
| Plastic | % | 40 | 40 | 40 | 40 | 40 |
| Paper | % | 10 | 10 | 10 | 10 | 10 |
| Wood | % | 10 | 10 | 10 | 10 | 10 |
| Textile | % | 10 | 10 | 10 | 10 | 10 |
| Other combustibles (e.g. rubber) | % | | | | | |
| **Total** | | **100** | **100** | **100** | **100** | **100** |
| Average moisture content of the RDF | % | | | | | |
| Average calorific value of RDF produced | Kcal/kg | 4000 | 4000 | 4000 | 4000 | 4000 |

**(III) Data input on energy recovery options (if any)**

| | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|
| Select the type of energy recovered from RDF | Co-combustion in a cement kiln to replace coal | Co-combustion in MSW incinerator only to produce electricity | Co-combustion in MSW incinerator only to produce electricity | Co-combustion in MSW incinerator only to produce electricity | Co-combustion in MSW incinerator only to produce electricity |
| Approximate calorific value of coal replace by RDF | 5000 | 5000 | 5000 | 5000 | 5000 |
| (i) Efficiency of electriciy recovery | 27 | 27 | 27 | 27 | 27 |
| (ii) Percentage of electricity use for onsite operation activities (if any) | 20 | 20 | 20 | 20 | 20 |
| | 18 | 18 | 18 | 18 | 18 |
| | 20 | 20 | 20 | 20 | 20 |
| | Coal | Coal | Coal | Coal | Coal |

**(IV) Transport of produced RDF to Cement/Incineration plant**

| | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| Type of trucks used for RDF transportation to cement/energy recovery plant | Type | Dump truck-small | Dump truck-small | Dump truck-small | Dump truck-small | Dump truck-small |
| Approximate loading capacity of RDF | Tonnes/trip | 5 | 5 | 5 | 5 | 5 |
| Approximate round trip distance from RDF manufacturing to cement/energy recovery | km | 30 | 30 | 30 | 30 | 30 |
| Type of fuel used for transportation | Type | Diesel | Diesel | Diesel | Diesel | Diesel |
| Fuel consumption efficiency of the vehicle | km/L | 6 | 6 | 6 | 6 | 6 |

**Summary of Emissions from RDF production**

**Summary of RDF produced: This table shows to energy recovery potential per tonne of RDF production (Please note that the estimations in the table below are per tonne of RDF produced, NOT per tonne of input waste used)**

| | | | | | | |
|---|---|---|---|---|---|---|
| RDF produced from waste | kg RDF/tonne of waste | 333 | 333 | 333 | 333 | 333 |
| Amount of coal replaced using RDF in cement clink | kg Coal/tonne of RDF | 800 | 0 | 0 | 0 | 0 |
| Net electricity production | kWh/tonne of RDF | 0 | 1,256 | 1,256 | 1,256 | 1,256 |
| Net heat production | MJ/tonne of RDF | 0 | 0 | 0 | 0 | 0 |

**Summary of the emissions**

| Category | Type of emissions | Emission/avoidance potential | Phase/activity | Emissions from RDF production (kg/tonne of input waste) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
| SLCPs | $CH_4$ | Emissions | $CH_4$ fossil-Direct (fuel consumption for operation) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | $CH_4$ fossil-Direct (through combustion of RDF) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | CH4 fossil-Direct (through combustion fuel for transport RDF) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | $CH_4$ fossil-through heat/thermal energy recovery | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | **Net emissions** | | **-0.01** | **0.00** | **0.00** | **0.00** | **0.00** |
| | BC | Emissions | Direct (fuel consumption for operation) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Direct(through combustion of RDF) | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 |
| | | | Direct (through combustion fuel for transport RDF) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Through heat/thermal energy recovery | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | **Net emissions** | | **0.03** | **0.11** | **0.11** | **0.11** | **0.11** |
| Other GHGs | $CO_2$ | Emissions | Direct ( fuel consumption for operation) | 0.82 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Indirect (use of grid electricity) | 0.18 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Combustion of RDF | 379.45 | 379.45 | 379.45 | 379.45 | 379.45 |
| | | | Direct (through combustion fuel for transport RDF) | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |
| | | Avoided | Through electricity production | 0.00 | 183.62 | 183.62 | 183.62 | 183.62 |
| | | | Through heat/thermal energy recovery | 548.62 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | **Net emissions** | | **-167.27** | **196.73** | **196.73** | **196.73** | **196.73** |
| | $N_2O$ | Emissions | Direct (fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Direct (through combustion of RDF) | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| | | | Direct (through combustion fuel for transport RDF) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Through heat/thermal energy recovery | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | **Net emissions** | | **0.01** | **0.02** | **0.02** | **0.02** | **0.02** |
| Net impact | Net BC emissions (kg of BC/tonne) | | | **0.03** | **0.11** | **0.11** | **0.11** | **0.11** |
| | Net climate impact of GHGs (kg of $CO_2$-eq/tonne) | | | **-165.23** | **201.15** | **201.15** | **201.15** | **201.15** |

Figure 13:Print screen view of RDF sheet

## 2.5 Selection of technologies for treating mixed MSW

As explained previously, a percentage of organic waste and recyclables may be separated at the household level or at a material recovery facility to be treated by composting, AD and/or recycling. The remaining bulky mixed waste can be treated with MBT, incineration and landfilling/open dumping. Users should decide which disposal/treatment technique would be most appropriate for their city based on the characteristics of the mixed waste, as well as their respective technical and financial capacities. Users are subsequently requested to provide technology-specific data in relevant worksheets if they have selected those technologies in BAU or intended scenarios. Detailed specifications of MBT, incineration and landfilling (including open dumping) are described in the section below.

### 2.5.1Estimation of GHG/SLCP Emissions from Mechanical Biological Treatment (MBT)

Mechanical Biological Treatment (MBT) systems enable the recovery of materials in mixed waste and facilitate the stabilisation of the biodegradable component of the materials. In this tool, it was assumed that good quality recyclables have already been recovered (perhaps at a material recovery facility) for recycling from mixed waste streams prior to the MBT process. MBT can reduce the volume of mixed waste through the decomposition of organic substances prior to landfilling, as well as minimise GHG emissions ($CH_4$) from landfill sites. Furthermore, the MBT process enhances the separation of different material fractions, such as compostable materials and high-energy fractions (e.g. plastic) after stabilisation of waste prior to final disposal. Under optimised conditions such as homogenisation, ventilation, and/or irrigation, organic waste degrades rapidly. In fact, total mass loss during the MBT process may be as high as 50% (Phitsanulok Municipality, 2012). The stabilised material can be screened into three parts: compost-like materials; waste plastics (which can be used to produce RDF or crude oil), and inert materials.

BC emissions from MBT are mainly related to the utilisation of fossil fuel for operational activities. As far as other GHG emissions from MBT process are concerned, these emissions may also occur due to fossil fuel and grid electricity consumption for operational activities ($CO_2$, $CH_4$, $N_2O$), as well as during the degradation of organic waste ($CH_4$, $N_2O$). Generally, MBT is an aerobic process and therefore, a large fraction of the degradable organic carbon in the waste material is converted into $CO_2$. $CO_2$ emissions have biogenic origin and would not be taken into account for GHG calculations. Under good management, aerobic conditions can be maintained in the piles which would contribute to reducing $CH_4$, $N_2O$ production. However, as recommended by IPCC, $CH_4$ emission potential from degradation of waste in MBT piles is considered in the tool (4 kg $CH_4$/tonne of organic waste on a wet basis). If such $CH_4$ production takes place in the bottom layer of MBT piles, most of the $CH_4$ can be oxidised to a large extent in the aerobic sections of the piles. Due to these reasons, there would be a minimal possibility of releasing $CH_4$ into the atmosphere. According to IPCC guidelines (IPCC, 2006), MBT process also produces $N_2O$ in minor concentrations (e.g. 0.3 kg $N_2O$/tonne of organic waste on a wet basis).

A further benefit of MBT is the potential recovery of recyclables (namely if collected waste used for MBT precedes the separation of resources). Furthermore, degraded organic waste in the piles can be utilised as a compost-like product with implications for reducing utilization of conventional fertilizer. However, compostable materials derived from MBT process will be of a lower quality compared to compost derived from source segregated organic waste. Accordingly, the developer suggests to select the option "Utilization of compost-like product as a fertilizer to reduce chemical fertilizer application" only if the product meet the quality standard of compost. In these situations, avoidance of chemical fertilizer utilisation would contribute to a reduction in GHG/SLCP emissions that would otherwise occur from chemical fertilizer production process. Some cities may use stabilized compost like materials as a cover material (e.g. landfill cover or other applications). In such a situation, potential credits for avoidance emissions from conventional cover materials utilization is assumed to be negligible. Furthermore, a considerable fraction of plastic can be recovered from stabilised materials from MBT piles. The recovered plastic waste can be used to produce Residual Derived Fuel (RDF) or for extraction of crude oil via the pyrolysis process.

In order to quantify overall GHG/SLCP emissions from the entire MBT process, users are asked to provide location-specific daily average data on fossil fuel and grid electricity consumption for operational activities, amount of compost-like products used as fertilizer (if the city utilises a compost-like product for agriculture), amount of recovered plastic for RDF/crude oil production (only if the city practices this approach), additional energy requirement for RDF/crude oil production, and crude oil yield from waste plastic, among others. In the case that the city does not have such data, default values provided by the developer can be used for estimating the emissions. If the city does not recover any materials/resources from MBT process, there is no data entry requirement with respect to compost production or RDF/crude oil production. Thus, the user can leave the cells empty for the above mentioned processes. If compost-like material production, and/or RDF/crude oil production is practiced by the city, the potential avoidance of GHG/SLCP emissions will be estimated based on the user input data for avoidance of conventional fertilizer and conventional energy. It should be noted that production of energy using RDF or crude oil would not greatly comprise a climate friendly solution as this pathway of energy production has a fossil fuel-based origin (waste plastic originated as a product of virgin crude oil). In other words, emissions from combustion of crude oil produced (from the plastic) and RDF (plastic fraction) would be equivalent to the emissions of virgin fossil fuel (crude oil) combustion in order to obtain an equivalent amount of energy. Therefore, GHG/SLCP avoidance due to combustion of produced RDF or crude oil has not been accounted or credited in this tool. It was assumed that produced crude oil can be used to replace the conventional crude oil and the produced RDF can be used in cement kilns to replace the consumption of coal (i.e., the conventional scenario). Thus, GHG/SLCP emissions related to virgin oil and coal extraction, transportation and processing are included in the tool as utilisation of RDF/crude oil may indirectly influence avoidance of emissions in the virgin fossil fuel production chain. Step-by-step procedure of estimating GHGs and SLCPs emissions from MBT is shown in Box 6. Print screen view of MBT sheet is shown in Figure 14.

Box 6: Method of estimating GHG/SLCP emissions from MBT

(i) GHG/SLCP emissions from operational activities at MBT facility

$$Emissions_{GHG(i)-Operation} = \frac{Fuel(unit/day) \times NCV(MJ/unit) \times EF(kg/MJ) + EC \times EF_{el}}{AOW(tonnes/day)}$$

$Emissions_{GHG(i)-operation}$ – Emissions i[th] GHG (e.g. $CO_2$, $CH_4$, $N_2O$) from operational activities
Fuel (unit) – Total amount of fossil fuel units (kg or L) consumption per day
$NCV_{FF}$ – Net calorific value of fossil fuel consumed
EF – $CO_2$, $CH_4$, $N_2O$ emission factor of fuel (e.g. diesel: 0.074 kg $CO_2$/MJ)
EC- Electricity consumption for operation activities (kWh/day)
$EF_{el}$ –Emission factor of grid electricity production (kg $CO_2$-eq/kWh)
AOW- Amount of Waste use for MBT (tonnes/day)

(ii) SLCP (e.g. BC) emissions from operational activities at MBT plant

$$Emissions_{BC-Operation} = \frac{Fuel(unit/day) \times NCV(MJ/unit) \times EF(g/MJ)/1000}{AOW(tonnes/day)}$$

EF – EF of black carbon has given in g/MJ (divided by 1000 to convert into kg)

(iii) GHGs/SLCPs emission from waste degradation in MBT piles

$$Emission_{GHG(i)-Leakage} = EF(kg/tonne)$$

EF – Emissions of $CH_4$, $N_2O$ during degradation (kg/tonne of organic waste)

(iv) Total i[th] GHG emissions from MBT is calculated as follows;

$$Emissions_{Operation} = Emission_{Degradation} + Emission_{Degradation}$$

(v) Avoided GHG/SLCP emissions by replacing chemical fertilizer using compost-like product;

$$AvoidedGHG_{(i)Compost-like-product} = \frac{AC \times PC_{Agriculture} \times A_{GHG}}{1000}$$

$AvoidedGHG_{(i)}$– Avoided i[th]GHG from avoidance of chemical fertilizer production (kg/tonne)
AC – Amount of compost-like product recovered (kg /tonne)
$PC_{Agriculture}$ – Percentage of compost-like product use for agricultural and gardening purpose (%)
$A_{GHG(i)}$ – i[th] GHG Avoidance potential from chemical fertilizer production which is equivalent to one tonne of compost- like product (kg/tonne of compost)

(vi) Avoided GHG/SLCP emissions by recovering energy from waste plastic

$$AvoidedGHG_{(i)RDF/crude-oil} = RP \times EF_i$$

$AvoidedGHG_{(i)RDF/crude-oil}$ – Avoided i[th] GHG/SLCP from RDF/crude oil production (kg /tonne)
RP–Amount of Recovered Product (RDF-kg/tonne; Crude oil L/tonne)
$EF_i$– Emission Factor of i[th] GHG/SLCP from processing of fossil fuel (e.g. Virgin oil and coal extraction, transportation and processing (kg /unit)

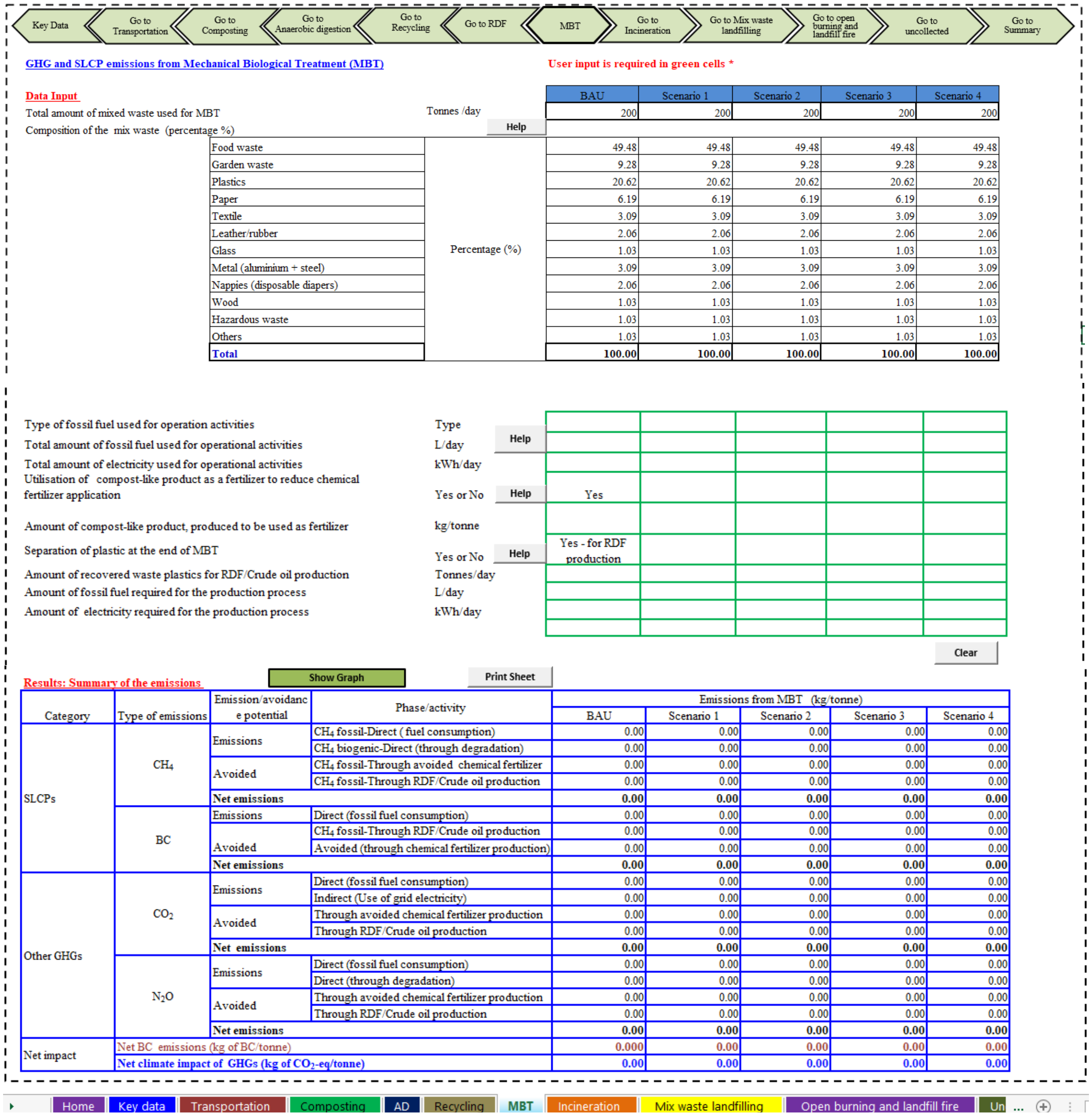
(vii) Net i[th] GHG emissions and net BC emissions can be calculated as follows;

$$Net(GHG)_{(i)} = Total(GHG)_{(i)} - Avoided(GHG)_{(i)}; \; Net(BC) = Total(BC) - Avoided(BC)$$

(viii) Net climate impact from all GHG is estimated as follow;

$$NetGHG_{(CO2-eq/tonne)} = CO_{2(net)} \times 1 + CH_4(biogenic)_{(net)} \times 28 + CH_4(fossil)_{(net)} \times 30 + N_2O_{(net)} \times 265$$

Net GHG emission – Estimated as kg $CO_2$-eq/tonne



Key Data | Go to Transportation | Go to Composting | Go to Anaerobic digestion | Go to Recycling | Go to RDF | MBT | Go to Incineration | Go to Mix waste landfilling | Go to open burning and landfill fire | Go to uncollected | Go to Summary

GHG and SLCP emissions from Mechanical Biological Treatment (MBT)

User input is required in green cells *

Data Input

| | | Unit | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|---|
| Total amount of mixed waste used for MBT | | Tonnes /day | 200 | 200 | 200 | 200 | 200 |
| Composition of the mix waste (percentage %) | | Help | | | | | |
| | Food waste | Percentage (%) | 49.48 | 49.48 | 49.48 | 49.48 | 49.48 |
| | Garden waste | | 9.28 | 9.28 | 9.28 | 9.28 | 9.28 |
| | Plastics | | 20.62 | 20.62 | 20.62 | 20.62 | 20.62 |
| | Paper | | 6.19 | 6.19 | 6.19 | 6.19 | 6.19 |
| | Textile | | 3.09 | 3.09 | 3.09 | 3.09 | 3.09 |
| | Leather/rubber | | 2.06 | 2.06 | 2.06 | 2.06 | 2.06 |
| | Glass | | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| | Metal (aluminium + steel) | | 3.09 | 3.09 | 3.09 | 3.09 | 3.09 |
| | Nappies (disposable diapers) | | 2.06 | 2.06 | 2.06 | 2.06 | 2.06 |
| | Wood | | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| | Hazardous waste | | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| | Others | | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| | Total | | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

| | Unit | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| Type of fossil fuel used for operation activities | Type | | | | | |
| Total amount of fossil fuel used for operational activities | L/day (Help) | | | | | |
| Total amount of electricity used for operational activities | kWh/day | | | | | |
| Utilisation of compost-like product as a fertilizer to reduce chemical fertilizer application | Yes or No (Help) | Yes | | | | |
| Amount of compost-like product, produced to be used as fertilizer | kg/tonne | | | | | |
| Separation of plastic at the end of MBT | Yes or No (Help) | Yes - for RDF production | | | | |
| Amount of recovered waste plastics for RDF/Crude oil production | Tonnes/day | | | | | |
| Amount of fossil fuel required for the production process | L/day | | | | | |
| Amount of electricity required for the production process | kWh/day | | | | | |

Clear

Results: Summary of the emissions | Show Graph | Print Sheet

| Category | Type of emissions | Emission/avoidance potential | Phase/activity | Emissions from MBT (kg/tonne) BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|---|---|
| SLCPs | $CH_4$ | Emissions | $CH_4$ fossil-Direct ( fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | $CH_4$ biogenic-Direct (through degradation) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | $CH_4$ fossil-Through avoided chemical fertilizer | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | $CH_4$ fossil-Through RDF/Crude oil production | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Net emissions | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | BC | Emissions | Direct (fossil fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | $CH_4$ fossil-Through RDF/Crude oil production | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Avoided (through chemical fertilizer production) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Net emissions | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other GHGs | $CO_2$ | Emissions | Direct (fossil fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Indirect (Use of grid electricity) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Through avoided chemical fertilizer production | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Through RDF/Crude oil production | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Net emissions | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $N_2O$ | Emissions | Direct (fossil fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Direct (through degradation) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Through avoided chemical fertilizer production | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Through RDF/Crude oil production | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Net emissions | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Net impact | Net BC emissions (kg of BC/tonne) | | | 0.000 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Net climate impact of GHGs (kg of $CO_2$-eq/tonne) | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |



Figure 14: Print screen view of MBT sheet

### 2.5.2 Estimation of GHG/SLCP emissions from Incineration

Waste incineration initially became a popular technology for bulky waste treatment given its potential for reducing waste mass volumes from 75% up to 90% (Charles et al., 2010). At present, cities in both developed and developing countries maintain a strong interest in moving towards waste-to-energy projects as a solution to energy challenges as well as gaining financial benefits via energy recovery from waste. Accordingly, incineration can directly eliminate methane emissions from anaerobic degradation of waste at landfill sites as well as displace some degree of fossil fuel-based electricity generation. In line with these benefits, incineration appears to be an effective short-term solution to tackling the growing waste management issues in most countries.

Implementation of waste-to-energy technologies which are well-designed to meet local needs (technical and financial capacity, waste characteristics) would significantly contribute to GHG/SLCP mitigation and energy recovery processes. However, there is a high possibility of failure if this technology is implemented in developing countries without proper adaptation to local conditions as incineration is designed mostly for the waste management context of developed countries. The inefficiency of incineration has been identified as a common obstacle in most existing plants in developing countries and some cases failures have been reported as a result of such inefficiencies. Waste composition and moisture content of the waste have a strong bearing on the efficiency of incineration. In fact, high moisture content can lead to a higher percentage of energy being consumed (e.g. grid electricity) to produce power from waste: in many developing countries, the majority of combustibles consist of a high percentage of organic waste which has less calorific value, and would lead to low incineration efficiency. Low efficiency of incineration in turn can produce higher GHG/SLCP emissions. By using this tool, users can check the suitability of incineration technology for their city at the outset based on the waste characteristics (e.g. low heating value of the waste). Some cities may have more than one incinerator and therefor this version of the tool facilitate emissions estimations from 3 types of incinerators in each scenarios. If the tool advises that incineration is an appropriate technology for the city, then the user may choose that option; if not, the user should choose another technology for mixed and bulky waste treatment. It should be noted that incineration is a relatively expensive, capital-intensive treatment option, frequently involving substantial operating and maintenance costs with low financial returns. Therefore, developing cities need to be careful when selecting and adapting incineration technologies to meet local conditions.

Waste composition is the key input that directly influences the magnitude of the GHG/SLCP emissions from incineration. The waste composition for incineration has been automatically derived based on the composition of collected waste and the fractions of collected waste use for other technologies. The magnitude of $CH_4$ and $N_2O$ emissions largely depends on the type of the incinerator chosen and on the management practices involved. Therefore, users are asked to choose the type of incineration (e.g. Continuous-stoker, Continuous-fluidised bed, Semi-continuous-stoker, Semi-continuous-fluidised bed) from the dropdown list. In addition, users should provide other key data such as the type of fossil fuel used for operational activities (e.g. operation of machine, initial combustion), amount of fossil fuel and grid electricity consumption, efficiency of electricity and heat recovery (if available), percentage of electricity produced and heat use for on-site operational activities etc. for estimating GHG/SLCP from incineration.

Some cities may not have the requisite data associated with incineration. In such situations, default values (energy consumption data, efficiencies of electricity and heat recovery) provided by the developer based on available data in existing literature can be used. For instance, if an incineration facility is designed only for electricity recovery, average efficiency can be 15-30% (part of generated electricity is utilised for on-site activities, which may amount to 20-50% depending on the management practices involved). If the incineration plant is designed only for heat recovery, the average efficiency can be 80-90%. If the incineration is designed for both heat and power, average electricity efficiency would be 15% and heat efficiency can be 50-60%. In developing countries, it is often difficult to locate long-term consumers of heating services. Therefore only electricity production can be assumed with an average electrical efficiency of 20% (DEFRA, 2013).

There is a possibility to release a significant amount of fossil fuel-based $CO_2$ during the combustion process, with corresponding impacts on the climate. It should be noted that municipal waste incinerates a heterogeneous mixture of wastes; it has potential to produce both fossil fuel and biogenic $CO_2$. Only the climate-relevant $CO_2$ emissions from the combustion of fossil fuel-based waste such as plastics, certain textiles, rubber, liquid solvents, and waste oil are considered for GHG emissions estimation (IPCC, 2006b). The $CO_2$ emissions from the combustion of biomass materials (e.g. paper, food and wood waste) contained in the waste are biogenic emissions and should not be taken into account in GHG emissions estimation (IPCC, 2006b). IPCC default values for dry matter content of different type of waste, total carbon content, fossil carbon fraction and oxidation factors have been incorporated in this tool in order to quantify fossil fuel-based $CO_2$ from incineration process. AS defined by EMEP/EEA (2016), BC emission factor from incineration is considered as 0.322kg/tonne of waste.

In addition, as stated before, there is a possibility to emit $CH_4$ and $N_2O$ during the combustion process; however, the magnitude of these emissions depends on the type of incinerator and associated management practices of the incineration plant. Therefore, these emissions will be estimated based on the user input data and type of incineration technology.

After providing all the required input data, results of three incinerators in each scenario will appear in separate tables. In the last result table, shows the aggregated emission due to all kind of incinerators in the city. If the estimated net GHG/SLCP emissions from incineration retain a positive value, it implies that incineration continues to have climate impacts. Conversely, if the results are negative, these, net negative GHG/SLCP values may be attributed to an avoidance of a large percentage of emissions associated with conventional electricity and heat production processes. Therefore, enhancing the efficiency of heat and electricity recovery processes are expected to positively contribute to achieving a GHG/SLCP mitigation target. Step-by-step procedures for calculating GHG/SLCP emissions from incineration is presented in Box 6. A print screen view of the incineration sheet is shown in Figure 14.

Box 7: Method of estimating GHG/SLCP emissions from incineration

(i) GHG/SLCP emissions from operational activities at incineration facility

$$Emissions_{GHG(i)-Operation} = \frac{Fuel(unit/day) \times NCV(MJ/unit) \times EF(kg/MJ) + EC \times EF_{el}}{AOW(tonnes/day)}$$

$Emissions_{GHG(i)-operation}$ – Emissions i^th^ GHG (e.g. $CO_2$, $CH_4$, $N_2O$) from operational activities
Fuel (unit) – Total amount of fossil fuel units (kg or L) consumption per day
$NCV_{FF}$ – Net calorific value of fossil fuel consumed
EF – $CO_2$, $CH_4$, $N_2O$ emission factor of fuel (e.g. diesel: 0.074 kg $CO_2$/MJ)
EC- Grid electricity consumption for operation activities (kWh/day)
$EF_{el}$ –Emission factor of grid electricity production (kg $CO_2$-eq/kWh)
AOW- Amount of Waste incinerated (tonnes/day)

(ii) SLCP (e.g. BC) emissions from operational activities at incineration plant

$$Emissions_{BC-Operation} = \frac{Fuel(unit/day) \times NCV(MJ/unit) \times EF(g/MJ)/1000}{AOW(tonnes/day)}$$

EF – EF of black carbon has given in g/MJ (divided by 1000 to convert into kg)

(iii) Quantify the GHG (e.g. fossil $CO_2$) emissions from combustion of waste

$$CE = \sum_i (SW_i \times dm_i \times CF_i \times FCF_i \times OF_i) \times \frac{44}{12}$$

i - type of fossil fuel-based waste incinerated such as textiles, rubber and leather, plastics
CE - Combustion Emissions (kg $CO_2$/tonne)
$SW_i$-total amount of $i^{th}$ type of waste (wet weight) incinerated (kg/tonne of waste)
dmi - dry matter content in the waste (partially wet weight) incinerated
$CF_i$ -fraction of carbon in the dry matter (total carbon content), (fraction; 0.0-1.0)
$FCF_i$ - fraction of fossil carbon in the total carbon, (fraction; 0.0-1.0)
$OF_i$ - oxidation factor, (fraction; 0.0 – 100%)
44/12 - conversion factor from C to $CO_2$

(iv) Total $i^{th}$ GHG emissions from incineration is calculated as follows;

$$TotalGHG/SLCP_{(i)} = Emission_{Degradation} + Emission_{Combustion}$$

(vi -a) Avoided GHG/SLCP emissions via heat recovery

$$AvoidedGHG/SLCP_{(i)} = LHV_{waste} \times E_{HR} \times OC \times EF_i$$

(vi-b) Avoided GHG/SLCP emissions via electricity recovery

$$AvoidedGHG/SLCP_{(i)} = LHV_{waste} \times \frac{E_{ER}}{CF} \times OC \times EF_{el(i)}$$

Avoided $GHG/SLCP_{(i)}$– Avoided $i^{th}$ GHG or SLCP from heat recovery from incineration (MJ /tonne)
$LHV_{waste}$ – Low Heating Value of mixed waste (MJ/tonne)
$E_{HR}$–Efficiency of Heat Recovery (%); OC– Percentage of onsite Consumption (%)
$EF_i$-Emission Factor of $i^{th}$ GHGs/SLCPs from avoided fossil fuel combustion (kg/MJ) to provide equivalent amount of energy
$E_{ER}$-Efficiency of Electricity Recovery (%); CF- Conversion Factor (3.6 MJ/kWh)
$EF_{el}$ –Emission factor $i^{th}$ GHGs from grid electricity production (kg $CO_2$-eq/kWh)

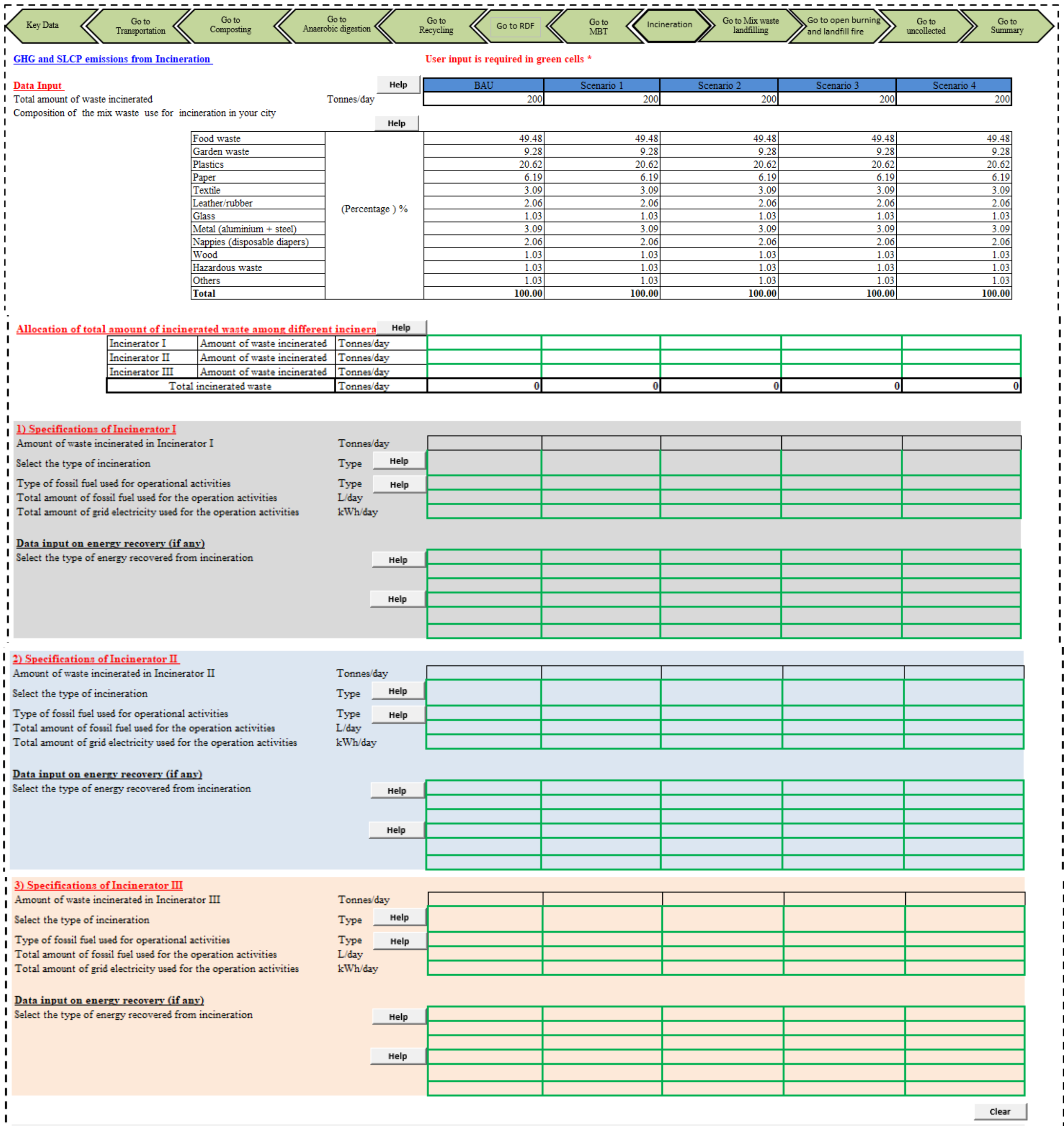
(v) Net i[th] GHG emissions and net BC emissions can be calculated as follows;

$$Net(GHG)_{(i)} = Total(GHG)_{(i)} - Avoided(GHG)_{(i)}\,;\; Net(BC) = Total(BC) - Avoided(BC)$$

(vi) Net climate impact from all GHGs (except BC) is estimated as follows:

$$NetGHG_{(CO2-eq/tonne)} = (CO_{2(net)} \times 1 + CH_4(biogenic)_{(net)} \times 28 + CH_4(fossil)_{(net)} \times 30 + N_2O_{(net)} \times 265)$$

Net GHG emissions – Estimated as tonnes of $CO_2$-eq/tonne



Key Data | Go to Transportation | Go to Composting | Go to Anaerobic digestion | Go to Recycling | Go to RDF | Go to MBT | Incineration | Go to Mix waste landfilling | Go to open burning and landfill fire | Go to uncollected | Go to Summary

GHG and SLCP emissions from Incineration

User input is required in green cells *

Data Input

| | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| Total amount of waste incinerated | Tonnes/day | 200 | 200 | 200 | 200 | 200 |

Composition of the mix waste use for incineration in your city

| | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| Food waste | (Percentage ) % | 49.48 | 49.48 | 49.48 | 49.48 | 49.48 |
| Garden waste | | 9.28 | 9.28 | 9.28 | 9.28 | 9.28 |
| Plastics | | 20.62 | 20.62 | 20.62 | 20.62 | 20.62 |
| Paper | | 6.19 | 6.19 | 6.19 | 6.19 | 6.19 |
| Textile | | 3.09 | 3.09 | 3.09 | 3.09 | 3.09 |
| Leather/rubber | | 2.06 | 2.06 | 2.06 | 2.06 | 2.06 |
| Glass | | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| Metal (aluminium + steel) | | 3.09 | 3.09 | 3.09 | 3.09 | 3.09 |
| Nappies (disposable diapers) | | 2.06 | 2.06 | 2.06 | 2.06 | 2.06 |
| Wood | | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| Hazardous waste | | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| Others | | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| **Total** | | **100.00** | **100.00** | **100.00** | **100.00** | **100.00** |

Allocation of total amount of incinerated waste among different incinera

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Incinerator I | Amount of waste incinerated | Tonnes/day | | | | | |
| Incinerator II | Amount of waste incinerated | Tonnes/day | | | | | |
| Incinerator III | Amount of waste incinerated | Tonnes/day | | | | | |
| Total incinerated waste | | Tonnes/day | 0 | 0 | 0 | 0 | 0 |

1) Specifications of Incinerator I

| | |
|---|---|
| Amount of waste incinerated in Incinerator I | Tonnes/day |
| Select the type of incineration | Type |
| Type of fossil fuel used for operational activities | Type |
| Total amount of fossil fuel used for the operation activities | L/day |
| Total amount of grid electricity used for the operation activities | kWh/day |

Data input on energy recovery (if any)

Select the type of energy recovered from incineration

2) Specifications of Incinerator II

| | |
|---|---|
| Amount of waste incinerated in Incinerator II | Tonnes/day |
| Select the type of incineration | Type |
| Type of fossil fuel used for operational activities | Type |
| Total amount of fossil fuel used for the operation activities | L/day |
| Total amount of grid electricity used for the operation activities | kWh/day |

Data input on energy recovery (if any)

Select the type of energy recovered from incineration

3) Specifications of Incinerator III

| | |
|---|---|
| Amount of waste incinerated in Incinerator III | Tonnes/day |
| Select the type of incineration | Type |
| Type of fossil fuel used for operational activities | Type |
| Total amount of fossil fuel used for the operation activities | L/day |
| Total amount of grid electricity used for the operation activities | kWh/day |

Data input on energy recovery (if any)

Select the type of energy recovered from incineration

Clear

**Results- Summary of Emissions**

Summary of Emissions-Incinerator I

**Energy recovery potential**

| | | | | | | |
|---|---|---|---|---|---|---|
| Low Heating Value/Calorific value of waste | MJ/kg | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Net electricity production | kWh/tonne | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Net heat production | MJ/tonne | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Summary of the emissions**

| Category | Type of emissions | Emission/avoidance potential | Phase/activity | Emissions from incineration (kg/tonne) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
| SLCPs | $CH_4$ | Emissions | $CH_4$ fossil-Direct (fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | $CH_4$ fossil-Direct (through combustion) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | $CH_4$ fossil-through heat recovery | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | **Net emissions** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| | BC | Emissions | Direct (fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Direct(through combustion) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Through heat recovery | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | **Net emissions** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| Other GHGs | $CO_2$ | Emissions | Direct ( fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Indirect (use of grid electricity) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Combustion of waste | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Through electricity production | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Through heat recovery | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | **Net emissions** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| | $N_2O$ | Emissions | Direct (fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Direct (through combustion) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Through heat recovery | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | **Net emissions** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| **Net impact** | **Net BC emissions (kg of BC/tonne)** | | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| | **Net climate impact of GHGs (kg of $CO_2$-eq/tonne)** | | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |

Show Graph | Print Sheet

Net emission: summary of emissions from overall incineration activities (This Table shows aggregated emissions from different type of incinerators)

| Category | Type of emissions | Emission/avoidance potential | Phase/activity | Emissions from incineration (kg/tonne) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
| SLCPs | $CH_4$ | Emissions | $CH_4$ fossil-Direct (fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | $CH_4$ fossil-Direct (through combustion) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | $CH_4$ fossil-through heat recovery | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | **Net emissions** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| | BC | Emissions | Direct (fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Direct(through combustion) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Through heat recovery | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | **Net emissions** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| Other GHGs | $CO_2$ | Emissions | Direct ( fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Indirect (use of grid electricity) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Combustion of waste | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Through electricity production | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Through heat recovery | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | **Net emissions** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| | $N_2O$ | Emissions | Direct (fuel consumption) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | Direct (through combustion) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Avoided | Through heat recovery | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | **Net emissions** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| **Net impact** | **Net BC emissions (kg of BC/tonne)** | | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| | **Net climate impact of GHGs (kg of $CO_2$-eq/tonne)** | | | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |

Figure 15: Print screen view of incineration sheet

### 2.5.3 Estimation of GHG/SLCP emissions from landfilling

Open dumping and landfilling are among the more common waste disposal practices in most cities of the developing world. There are numerous environmental issues generated by landfills. As far as climate impacts are concerned, $CH_4$ emissions from landfill technologies have been ranked as the third largest anthropogenic $CH_4$ emission source (IPCC, 2007). Despite the fact that landfill technologies have improved over the last few decades, these developments have not yet reached all parts of the world (Manfredi et al., 2009) due to lack of technological and financial capacity at the city level. For instance, cities in developing countries practice very primary disposal methods like open dumping and sanitary landfilling (top cover, leachate treatment system) even without a gas recovery system. These simple disposal methods have well-documented adverse impacts on human health, economies and the environment, including climate change. On the other hand, developed countries widely utilise advanced landfill methods such as sanitary landfilling with gas recovery systems. At present, there is a growing interest even in developing countries to move towards landfill gas-to-energy projects, which aim to achieve substantial co-benefits including GHG/SLCP reduction. Anaerobic degradation of mixed waste in open dumps and landfills eventually generates landfill gas (LFG) which contains approximately 60% methane ($CH_4$) and 40% carbon dioxide ($CO_2$). The $CH_4$ component of LFG contributes to global warming whereas the $CO_2$ component is regarded as being biogenic in origin and is thus not considered for GHG accounting (CRA, 2010).

The amount of methane generated at the disposal sites depends on many factors such as type of landfill/dump site, quantity and composition of waste, moisture content, and climatic situation. This sheet has been designed to quantify GHG/SLCP emissions from different types of landfills/open dumps which exist in both developed and developing countries. As far as the type of landfill/open dumps are concerned, by using this tool, users can estimate the emissions (e.g. $CH_4$) from both managed and un-managed types of landfills/open dumps, see Table 2. The tool facilitate to quantify up to three different types of landfill/open dump from each scenario.

Table 2: Type of landfills/dump sites includes in the tool

| Type of landfill | | Methane Correction Factor (MFC) | Oxidation factor (fraction) |
|---|---|---|---|
| Well- Managed (has landfill cover and liner) | Sanitary landfill without gas recovery | 1.0 | 0.1 |
| | Sanitary landfill with gas recovery | 1.0 | 0.1 |
| | Managed- semi-aerobic | 0.5 | 0 |
| Unmanaged | Open dumping-deep (> 5m waste) | 0.8 | 0 |
| | Open dumping- shallow (<5m waste) | 0.4 | 0 |
| | Uncategorised | 0.6 | 0 |

$CH_4$ generation rate and the oxidation rate (through the landfill cover) would depend on the landfill type. For instance, a managed sanitary landfill has the potential of producing a greater $CH_4$ yield than in an unmanaged disposal site (open dumps) where large amount of waste can decay aerobically in the top layers. Deeper unmanaged solid waste disposal sites have greater $CH_4$ emissions than shallow unmanaged sites. The Methane Correction Factor (MCF) gives an indicator on $CH_4$ production potential (see Table 2). In the tool, users should select the type of landfill in their city from the drop-down list, with respect to BAU and intended scenarios. If the city has more than one type of landfill/open dump, such data should be included in each scenario.

Total amounts of $CH_4$ generation from the landfill/open dump in large measure depend on waste composition. The composition of landfilled/open dumped waste will be automatically displayed based on user input in the key data sheet. If the city utilises a percentage of collected waste for other technologies like composting, AD or recycling, the new waste composition will be derived and displayed. If there is no waste separation for those technologies prior to landfilling, the composition of the collected waste will appear as the composition of disposal waste with respect to the corresponding scenario.

Data entry section has been divided into three parts. In the Part I, user should allocate total amount of waste disposal at landfills/open dumps among the different disposal sites in each scenario. If a city has more than one landfill/open dump, they should enter such data in Part I. Just after entering the amount of waste dispose at each site, if there is any fire/waste burning, user should mention the approximate percentage of waste burn/fire in that disposal site. This information will be used to quantify the GHG/SLCP emissions from open burning and landfill fire in the next sheet. If there has been no fire incident at the landfills/open dumpsites, the user can leave the cells for "% of disposed waste ultimately fired/open-burned in site I, site II, site III" empty.

The next part of data entry is "specifications of the landfill/open dump" and this data must be entered for any kind of landfill/open dump, users should enter all the data asked under part II. In this section, user should provide location-specific data on the type of landfill, starting year of the disposal site, end year of the disposal site, current year of disposal, estimated growth of annual disposal (%), type of fossil fuel use for operation, amount of fossil fuel as well as grid electricity required for the operation. If the user is unaware of the energy consumption data for operational activities, default values provided by the developer in 'user help' can be used to estimate the energy consumption in daily basis.

Part III is to provide input data only if the landfill type is 'Sanitary landfill with gas recovery'. Under the 'Specifications of Landfill-gas recovery project', the user should provide values for the efficiency of gas collection, the treatment method of LFG, LFG utilisation efficiency, starting year and closing year of LFG recovery project, type of fossil fuel which is replaced by recovered LFG (if LFG use for heating/cooking). If the user does not know the efficiency of the gas collection, LFG utilisation efficiency for electricity production etc., default values provided by the developer in 'user help' can be used. If the city does not have 'sanitary landfilling with gas recovery' option the user can leave cells empty in the 'Specifications of landfill-gas recovery session. Although the sanitary landfill with gas recovery option may exist without an energy recovery system, the user can still leave the cells empty. However, landfill gas flaring may be the option in the case of 'No energy recovery' choice from sanitary landfill with gas recovery. Flaring would create particulate matter (PM) in the form of BC. However, currently available emissions quantification methods would not be sufficient to quantify BC emissions from landfill gas flaring and these estimations needs to be included in the future.

After completing data entry in the first landfill/open dump, the user are advised to move to the second and then third landfill/open dump and enter the required data.

The basic concept used in the IPCC 2006 Waste Model has been adopted in this tool to quantify CH4 emissions from different types of landfills. The guidelines of IPCC strongly encourage the use of the First Order Decay (FOD) model, which produces more accurate emissions estimates as it reflects the degradation rate of wastes in a disposal site (IPCC 2006). The model assumes that decomposition in the first year can happen aerobically where $CH_4$ generation is not taking place. In addition, other GHGs and BC emissions will be estimated based on the fossil energy and grid electricity consumption for operational activities. The step-by-step procedure for calculation of GHG/SLCP emissions from landfill/open dump technologies is shown in Box 8.

Box 8: Method of estimating GHG/SLCP emissions from landfilling/open dumping

(i) GHG/SLCPs emission from operational activities at landfill/open dump

$$Emissions_{GHG(i)-Operation} = \frac{Fuel(unit/day) \times NCV(MJ/unit) \times EF(kg/MJ) + EC \times EF_{el}}{AOW(tonnes/day)}$$

$Emissions_{GHG(i)-operation}$ – Emissions i[th] GHG (e.g. $CO_2$, $CH_4$, $N_2O$) from operational activities
Fuel (unit) – Total amount of fossil fuel units (kg or L) consumption per day
$NCV_{FF}$ – Net calorific value of fossil fuel consumed
EF – $CO_2$, $CH_4$, $N_2O$ emission factor of fuel (e.g. diesel: 0.074 kg $CO_2$/MJ)
EC- Grid electricity consumption for operation activities (kWh/day)
$EF_{el}$ –Emission factor of grid electricity production (kg $CO_2$-eq/kWh)
AOW- Amount of Waste landfill (tonnes/day)
(ii) SLCPs (e.g. BC) emissions from operational activities landfill/open dump

$$Emissions_{BC-Operation} = \frac{Fuel(unit/day) \times NCV(MJ/unit) \times EF(g/MJ)/1000}{AOW(tonnes/day)}$$

EF – EF of black carbon has given in g/MJ (divided by 1000 to convert into kg)

(iii) $CH_4$ emissions from waste degradation in the landfill (based on IPCC 2006 waste model)
The basic equation for the first order decay model is:
$DDOC_m = DDOC_{m(0)} \times e^{-kt}$
$DDOC_{m(0)}$ - mass of decomposable degradable organic carbon (DDOC) at the start of the reaction, k - reaction constant; t - time in years. $DDOC_m$ - mass of DDOC at any time.

Mass of decomposable DOC ($DDOC_m$) amount of waste material;
$DDOC_{md(T)} = W_{(T)} \times DOC \times DOC_f \times MCF$
$DDOC_{md(T)}$ - mass of DDOC deposited year T; $W_{(T)}$ - amount deposited in year T; MCF - Methane Correction Factor; DOC - Degradable organic carbon; $DOC_f$ - Fraction of DOC decomposing under anaerobic conditions (0.0-1.0)
The amount of deposited DDOCm remaining at the end of deposition year T:
DDOCmrem(T) = DDOCmd(T) × e(-k • ((13-M)/12)
DDOCmrem(T) - mass of DDOC deposited in year T, remaining at the end of year; M - Month of reaction start

The amount of deposited DDOCm decomposed during deposition year T:
DDOCmdec(T) = DDOCmd(T) × (1 – e (-k • ((13-M)/12)))
DDOCmdec(T) - mass of DDOC deposited decomposed during the year T

The amount of DDOCm accumulated in the disposal site at the end of year T
$DDOC_{ma(T)} = DDOC_{mrem(T)} + ( DDOC_{ma(T-1)} \times e^{-k})$
$DDOC_{ma(T)}$ - total mass of DDOC left (not decomposed) at end of year T.
$DDOC_{ma(T-1)}$ - total mass of DDOC left not decomposed at end of year T-1

The total amount of DDOCm decomposed in year T
$DDOC_{mdecomp(T)} = DDOC_{mdec(T)} + (DDOC_{ma(T-1)} \times (1 - e^{-k}))$
$DDOC_{mdecomp(T)}$ - total mass of DDOC decomposed in year T.

The amount of $CH_4$ generated from DOC decomposed
$CH_4$ $generated_{(T)} = DDOC_{mdecomp(T)} \times F \times 16/12$
$CH_4$ $generated_{(T)}$ - $CH_4$ generated in year T; F - Fraction of $CH_4$ by volume in generated landfill gas (0.0 – 1.0); 16/
Molecular weight ratio $CH_4$/C

The amount of $CH_4$ emitted from disposal site
$CH_4$ emitted in year T = $(\Sigma CH_4 \text{ generated }_{(T)} - R_{(T)}) \times (1 - OX_{(T)})$
$R_{(T)}$- Recovered $CH_4$ in year T; $OX_{(T)}$ - Oxidation factor in year T (fraction)

$$CH_4(pertonne) = \frac{\sum_0^t CH_4}{\sum_0^t AOW}$$

0-t= total emission during year 0 to t
AOW = Amount of waste dispose during year 0 to t

(iv )Total i[th] GHG/SLCP emissions from landfilling/open dumping

$$TotalGHG / SLCP_{(i)} = Emission_{Degradation} + Emission_{Degradation}$$

(v-a) Avoided GHG/SLCP emissions via use of LFG for heating or replacing conventional fuel

$$AvoidedGHG / SLCP_{(i)} = LFG(collected)(m^3 / tonne) \times P_{CH4} \times HV_{CH4} \times EF_i$$

(v-b) Avoided GHG/SLCP emissions via electricity recovery

$$AvoidedGHG / SLCP_{(i)} = LFG(collected)(m^3 tonne) \times P_{CH4} \times HV_{CH4} \times \frac{E_{ER}}{CF} \times EF_{el(i)}$$

Avoided $GHG_{(i)}$– Avoided i[th] GHG/SLCP from electricity production from LFG (kg of $CO_2$-eq/tonne)
LFG(collected)- Collected LFG ($m^3$/tonne)
$P_{CH4}$ –Percentage (%) of $CH_4$ in LFG (%)
$HV_{CH4}$-Heating value of $CH_4$ ($MJ/m^3$)
$EF_i$-Emission Factor of i[th] GHG/SLCP from avoided fossil fuel combustion (kg/MJ) to provide equivalent amount of energy
$E_{ER}$-Efficiency of Electricity Recovery (%); CF- Conversion Factor (3.6 MJ/kWh)
$EF_{el}$ –Emission factor i[th] GHG from grid electricity production (kg $CO_2$-eq/kWh)

(vi) Net i[th] GHG emission and net BC emissions can be calculated as follows;

$$Net(GHG)_{(i)} = Total(GHG)_{(i)} - Avoided(GHG)_{(i)}; \; Net(BC) = Total(BC) - Avoided(BC)$$

(vii) Net climate impact from all GHGs (except BC) is estimated as follow;

$$NetGHG_{(CO2-eq/tonne)} = (CO_{2(net)} \times 1 + CH_4(biogenic)_{(net)} \times 28 + CH_4(fossil)_{(net)} \times 30 + N_2O_{(net)} \times 265)$$

Net GHG emission – Estimated as tonnes of $CO_2$-eq/tonne

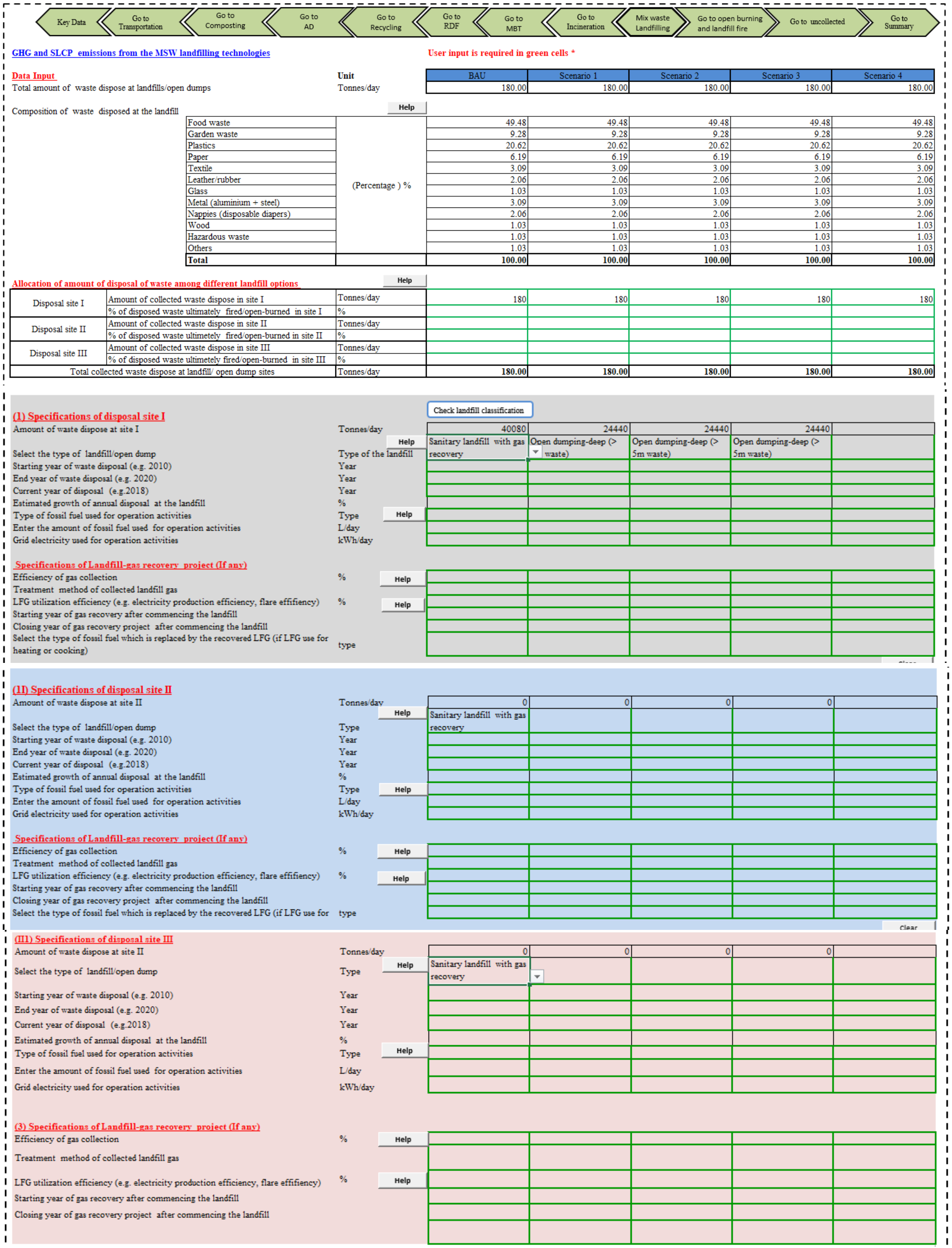
GHG/SLCP emissions from each type of landfill/open dump has calculated per tonne of disposed waste in each disposal site, see Figure 15. In order to calculate the net impact from overall disposal activities, if there are more than one type of disposal site, net GHG/SLCP emission from entire landfill management is calculated and presented in a separate table, in which emission from individual sites has been aggregated for a particular scenario.

Users should take note that in order to calculate the $CH_4$ generation from landfill/ open dump site using the IPCC 2006 waste model, numerous default values are required. The amount of $CH_4$ generation and collection will be highly dependent on those default values. The required default values for the IPCC 2006 waste model and the approaches of deriving those factors based on waste characteristics is presented in Table 3. All these default values have been assigned to mathematical formulae in the tool and therefore user input is not required for these default values. It should that though $CH_4$ emissions from a landfill would last several decades, the emissions (e.g. $CH_4$) that will happen in the future have been accounted and shown as life cycle emissions with respect to per tonne of disposed waste.

Once the user entered all the required information/data in the landfill sheet with respect to different type of landfills/open dumps in each scenario, emissions will be calculated and displayed in the results tables. The results emissions from disposal site I, site II and site III, will be displayed in separate tables on the basis of emission per tonne of dispose waste in each site. These results will be useful for users to compare the emissions from different type of landfill/open dump in the same city/Municipality. Then the net GHG/SLCP emissions from disposal practices in each scenario has been shown in the last Table in which emissions from individual site have been aggregated taking into account the fraction of total collected waste dispose at each site. Emissions have been calculated as per tonne of disposed waste. A print screen view of the landfill sheet is shown in Figure 15 and Figure 16.

Table 3: The required factors and default values for application of IPCC 2006 waste model

| Factor | Unit | Method of deriving |
|---|---|---|
| Amount deposited | Gg/Year | MSW disposal (tonnes/day) ×365/1000 |
| Degradable Organic Carbon(DOC) | DOC | Derived based on IPCC default DOC content values, $DOC_{MSW}$ = % of food waste×0.15+ % of garden waste×0.43 + % of paper waste × 0.4 + % of textile waste × 0.24 |
| Fraction of DOC decomposing under Anaerobic condition ($DOC_f$) | $DOC_f$ | IPCC default value is 0.5 |
| Methane generation rate constant | k | k value will depend on waste composition of the location $k_{MSW}$ =% of food waste×0.4+ % of garden waste×0.17 + % of paper waste × 0.07 + % of textile waste × 0.07 + % of disposal nappies × 0.17+ % of wood and straw × 0.035 |
| Half- life time(t1/2, years) | h=In(2)/k | Can be calculated based on derived k value |
| exp1 | exp(-k) | Can be calculated based on derived k value |
| Process start in decomposition year, month M | M | IPCC recommended value is after 12 months |
| Exp2 | exp(-k((13-M)/12 | Can be calculated based on derived k and M values |
| Fraction to $CH_4$ | F | IPCC recommended value is 0.5 |
| Methane Oxidation on Landfill cover | OX | IPCC recommended value for sanitary landfill with landfill cover is 0.1. for open dumpsites the OX value would be zero |
| MCF for the landfill/open dumpsite | MCF | According to the management practices, this value will be changed, IPCC recommended default MCF values for Managed (has landfill cover and liner), unmanaged-deep (> 5m waste), Unmanaged-shallow (<5m waste), Uncategorised are 1, 0.8, 0.4 and 0.6 respectively. |


Key Data | Go to Transportation | Go to Composting | Go to AD | Go to Recycling | Go to RDF | Go to MBT | Go to Incineration | Mix waste Landfilling | Go to open burning and landfill fire | Go to uncollected | Go to Summary

GHG and SLCP emissions from the MSW landfilling technologies

User input is required in green cells *

| Data Input | | Unit | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|---|
| Total amount of waste dispose at landfills/open dumps | | Tonnes/day | 180.00 | 180.00 | 180.00 | 180.00 | 180.00 |
| Composition of waste disposed at the landfill | Food waste | (Percentage ) % | 49.48 | 49.48 | 49.48 | 49.48 | 49.48 |
| | Garden waste | | 9.28 | 9.28 | 9.28 | 9.28 | 9.28 |
| | Plastics | | 20.62 | 20.62 | 20.62 | 20.62 | 20.62 |
| | Paper | | 6.19 | 6.19 | 6.19 | 6.19 | 6.19 |
| | Textile | | 3.09 | 3.09 | 3.09 | 3.09 | 3.09 |
| | Leather/rubber | | 2.06 | 2.06 | 2.06 | 2.06 | 2.06 |
| | Glass | | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| | Metal (aluminium + steel) | | 3.09 | 3.09 | 3.09 | 3.09 | 3.09 |
| | Nappies (disposable diapers) | | 2.06 | 2.06 | 2.06 | 2.06 | 2.06 |
| | Wood | | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| | Hazardous waste | | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| | Others | | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| | **Total** | | **100.00** | **100.00** | **100.00** | **100.00** | **100.00** |

Help

Allocation of amount of disposal of waste among different landfill options Help

| | | Unit | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|---|
| Disposal site I | Amount of collected waste dispose in site I | Tonnes/day | 180 | 180 | 180 | 180 | 180 |
| | % of disposed waste ultimately fired/open-burned in site I | % | | | | | |
| Disposal site II | Amount of collected waste dispose in site II | Tonnes/day | | | | | |
| | % of disposed waste ultimetely fired/open-burned in site II | % | | | | | |
| Disposal site III | Amount of collected waste dispose in site III | Tonnes/day | | | | | |
| | % of disposed waste ultimetely fired/open-burned in site III | % | | | | | |
| Total collected waste dispose at landfill/ open dump sites | | Tonnes/day | **180.00** | **180.00** | **180.00** | **180.00** | **180.00** |

Check landfill classification

(1) Specifications of disposal site I

| | Unit | | | | | |
|---|---|---|---|---|---|---|
| Amount of waste dispose at site I | Tonnes/day | 40080 | 24440 | 24440 | 24440 | |
| Select the type of landfill/open dump | Type of the landfill | Sanitary landfill with gas recovery | Open dumping-deep (> waste) | Open dumping-deep (> 5m waste) | Open dumping-deep (> 5m waste) | |
| Starting year of waste disposal (e.g. 2010) | Year | | | | | |
| End year of waste disposal (e.g. 2020) | Year | | | | | |
| Current year of disposal (e.g.2018) | Year | | | | | |
| Estimated growth of annual disposal at the landfill | % | | | | | |
| Type of fossil fuel used for operation activities | Type | | | | | |
| Enter the amount of fossil fuel used for operation activities | L/day | | | | | |
| Grid electricity used for operation activities | kWh/day | | | | | |

Specifications of Landfill-gas recovery project (If any)

| | Unit | | | | | |
|---|---|---|---|---|---|---|
| Efficiency of gas collection | % | | | | | |
| Treatment method of collected landfill gas | | | | | | |
| LFG utilization efficiency (e.g. electricity production efficiency, flare effifiency) | % | | | | | |
| Starting year of gas recovery after commencing the landfill | | | | | | |
| Closing year of gas recovery project after commencing the landfill | | | | | | |
| Select the type of fossil fuel which is replaced by the recovered LFG (if LFG use for heating or cooking) | type | | | | | |

(1I) Specifications of disposal site II

| | Unit | | | | | |
|---|---|---|---|---|---|---|
| Amount of waste dispose at site II | Tonnes/day | 0 | 0 | 0 | 0 | |
| Select the type of landfill/open dump | Type | Sanitary landfill with gas recovery | | | | |
| Starting year of waste disposal (e.g. 2010) | Year | | | | | |
| End year of waste disposal (e.g. 2020) | Year | | | | | |
| Current year of disposal (e.g.2018) | Year | | | | | |
| Estimated growth of annual disposal at the landfill | % | | | | | |
| Type of fossil fuel used for operation activities | Type | | | | | |
| Enter the amount of fossil fuel used for operation activities | L/day | | | | | |
| Grid electricity used for operation activities | kWh/day | | | | | |

Specifications of Landfill-gas recovery project (If any)

| | Unit | | | | | |
|---|---|---|---|---|---|---|
| Efficiency of gas collection | % | | | | | |
| Treatment method of collected landfill gas | | | | | | |
| LFG utilization efficiency (e.g. electricity production efficiency, flare effifiency) | % | | | | | |
| Starting year of gas recovery after commencing the landfill | | | | | | |
| Closing year of gas recovery project after commencing the landfill | | | | | | |
| Select the type of fossil fuel which is replaced by the recovered LFG (if LFG use for | type | | | | | |

Clear

(I1I) Specifications of disposal site III

| | Unit | | | | | |
|---|---|---|---|---|---|---|
| Amount of waste dispose at site II | Tonnes/day | 0 | 0 | 0 | 0 | |
| Select the type of landfill/open dump | Type | Sanitary landfill with gas recovery | | | | |
| Starting year of waste disposal (e.g. 2010) | Year | | | | | |
| End year of waste disposal (e.g. 2020) | Year | | | | | |
| Current year of disposal (e.g.2018) | Year | | | | | |
| Estimated growth of annual disposal at the landfill | % | | | | | |
| Type of fossil fuel used for operation activities | Type | | | | | |
| Enter the amount of fossil fuel used for operation activities | L/day | | | | | |
| Grid electricity used for operation activities | kWh/day | | | | | |

(3) Specifications of Landfill-gas recovery project (If any)

| | Unit | | | | | |
|---|---|---|---|---|---|---|
| Efficiency of gas collection | % | | | | | |
| Treatment method of collected landfill gas | | | | | | |
| LFG utilization efficiency (e.g. electricity production efficiency, flare effifiency) | % | | | | | |
| Starting year of gas recovery after commencing the landfill | | | | | | |
| Closing year of gas recovery project after commencing the landfill | | | | | | |

Figure 16: Print screen view of landfill sheet (data entry)

Results: Summary of the emissions

**Summary of Emissions-Disposal Site I**

| Category | Type of emissions | Emissions/avoidance | Emissions | Emissions from landfill management (kg/tonne) BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|---|---|
| SLCPs | $CH_4$ | Emissions | $CH_4$ fossil-Direct (Fuel consumption) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | $CH_4$ biogenic- Direct (Waste degradation) | 37.515 | 28.879 | 28.879 | 28.879 | 0.000 |
| | | Avoidance | $CH_4$ biogenic- Avoided (LFG recovery) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | $CH_4$ fossil- Avoided (through energy recovery) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | **Net emissions** | **37.515** | **28.879** | **28.879** | **28.879** | **0.000** |
| | BC | Emissions | Direct (fuel consumption) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | Avoidance | Avoided (through energy recovery) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | **Net emissions** | **0.000** | **0.000** | **0.000** | **0.000** | **0.000** |
| Other GHGs | $CO_2$ | Emissions | Direct (Fuel consumption) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | Indirect (grid electricity consumption) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | Avoidance | Avoided (through energy recovery) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | **Net emissions** | **0.000** | **0.000** | **0.000** | **0.000** | **0.000** |
| | $N_2O$ | Emissions | Direct (Fuel consumption) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | Avoidance | Avoided (through energy recovery) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | **Net emissions** | **0.000** | **0.000** | **0.000** | **0.000** | **0.000** |
| Net impact | Net BC emissions (kg of BC/tonne) | | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | Net climate impact of GHGs (kg of $CO_2$-eq/tonne) | | | **1,050.413** | **808.602** | **808.602** | **808.602** | **0.000** |

**Summary of Emissions-Disposal Site III**

| Category | Type of emissions | Emissions/avoidance | Emissions | Emissions from landfill management (kg/tonne) BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|---|---|
| SLCPs | $CH_4$ | Emissions | $CH_4$ fossil-Direct (Fuel consumption) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | $CH_4$ biogenic- Direct (Waste degradation) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | Avoidance | $CH_4$ biogenic- Avoided (LFG recovery) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | $CH_4$ fossil- Avoided (through energy recovery) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | **Net emissions** | **0.000** | **0.000** | **0.000** | **0.000** | **0.000** |
| | BC | Emissions | Direct (fuel consumption) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | Avoidance | Avoided (through energy recovery) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | **Net emissions** | **0.000** | **0.000** | **0.000** | **0.000** | **0.000** |
| Other GHGs | $CO_2$ | Emissions | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | Indirect (grid electricity consumption) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | Avoidance | Avoided (through energy recovery) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | **Net emissions** | **0.000** | **0.000** | **0.000** | **0.000** | **0.000** |
| | $N_2O$ | Emissions | Direct (Fuel consumption) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | Avoidance | Avoided (through energy recovery) | 0.0000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | **Net emissions** | **0.000** | **0.000** | **0.000** | **0.000** | **0.000** |
| Net impact | Net BC emissions (kg of BC/tonne) | | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | Net climate impact of GHGs (kg of $CO_2$-eq/tonne) | | | **0.000** | **0.000** | **0.000** | **0.000** | **0.000** |

Show Graph Print Sheet

**Net emission summary from entire landfill management (This Table shows aggregated emissions from different type of landfills)**

| Category | Type of emissions | Emissions/avoidance | Emissions | Emissions from landfill management (kg/tonne) BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|---|---|
| SLCPs | $CH_4$ | Emissions | $CH_4$ fossil-Direct (Fuel consumption) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | $CH_4$ biogenic- Direct (Waste degradation) | 37.515 | 28.879 | 28.879 | 28.879 | 0.000 |
| | | Avoidance | $CH_4$ biogenic- Avoided (LFG recovery) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | $CH_4$ fossil- Avoided (through energy recovery) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | **Net emissions** | **37.515** | **28.879** | **28.879** | **28.879** | **0.000** |
| | BC | Emissions | Direct (fuel consumption) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | Avoidance | Avoided (through energy recovery) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | **Net emissions** | **0.000** | **0.000** | **0.000** | **0.000** | **0.000** |
| Other GHGs | $CO_2$ | Emissions | Direct (Fuel consumption) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | Indirect (grid electricity consumption) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | Avoidance | Avoided (through energy recovery) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | **Net emissions** | **0.000** | **0.000** | **0.000** | **0.000** | **0.000** |
| | $N_2O$ | Emissions | Direct (Fuel consumption) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | Avoidance | Avoided (through energy recovery) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | **Net emissions** | **0.000** | **0.000** | **0.000** | **0.000** | **0.000** |
| **Net impact** | **Net BC emissions from dispose waste in landfills (kg of BC/tonne)** | | | **0.000** | **0.000** | **0.000** | **0.000** | **0.000** |
| | **Net climate impact of GHGs from dispose waste in landfills (kg of CO2-eq/tonne)** | | | **1050.413** | **808.602** | **808.602** | **808.602** | **0.000** |

... AD Recycling MBT Incineration Mix waste landfilling Open burning and landfill fire Uncollected waste Summary User guide Figures ...

Figure 17: Print screen view of landfill sheet (the results)

### 2.4.4. Estimation of GHG/SLCP from open burning and landfill fire

Open burning of garbage at the disposal site and landfill fire is very harmful to health and environment. Open burning of MSW is happening in most of the developing countries which causes severe damage on environmental and health. Open burning of waste and landfill fire are the sources of GHG/SLCP emissions. Intentional burning of waste on solid waste disposal sites is sometimes used as a management practice in some countries to reduce the volume of waste. In addition, unintentional fires/accidental fires occur in disposal sites in some countries due to various reasons. In the landfills fire occur when waste disposed of in a landfill ignites and spreads due to unavailability of landfill cover. Due to all these waste burning/fire at the disposal sites, there is a possibility for emissions of GHG/SLCP.

In this tool, a separate sheet has been designed to quantify the GHG/SLCP emissions from open burning and landfill fire from disposal sites where the collected mix waste has been disposed. In this sheet, the amount of waste and the composition of waste that fire or burn at the disposal sites will be automatically appeared based on the user input data in mixed waste landfill sheet about "amount of mix waste ultimately being fired/ burned openly in disposal site I, II and III". User should not entre any data in this sheet and the emissions with respect to open burning/landfill fire that occur at disposal sites will appear in a separate table.

In the result table, fossil fuel-based $CO_2$, $CH_4$ and BC emissions from open burning/landfill fire will estimated per tonne of waste burned/fired at the disposal sites. The quantification procedure of emissions from open burning/landfill fire is presented in Box 8 and The print screen view of open burning/landfill fire sheet is shown in Figure 18.

Box 9: Method of estimating GHG/SLCP emissions from open burning/landfill fire

(i) $CH_4$ emissions from open burning/landfill fire

$$Emissions_{CH_4} = EF(kg / tonne)$$

EF-Emission Factor of $CH_4$ during waste burning/fire (kg/tonne of waste) (emission factor given by Wiedinmyer et al, 2014)

ii) SLCPs (e.g. BC) emissions from open burning/landfill fire

$Emissions_{BC} = EF(kg / tonne)$ (Emission factor given by Bond et al. 2013)

EF-Emission Factor of BC from waste (kg/tonne of waste)

(iii) Quantify the GHGs (e.g. fossil based $CO_2$) emissions from open burning/landfill fire

$$E = \sum_i (SW_i \times dm_i \times CF_i \times FCF_i \times OF_i) \times \frac{44}{12}$$

i - type of fossil based waste openly burned/fired in the disposal sites such as textiles, rubber and leather, plastics
E - Emissions (kg $CO_2$/tonne of burn/fire waste)
$SW_i$-total amount of $i^{th}$ type of waste (wet weight) openly burned/fired (kg/tonne of waste)
dmi - dry matter content in the waste (partially wet weight) openly burned
$CF_i$ -Fraction of Carbon in the dry matter (total carbon content), (fraction; 0.0-1.0)
$FCF_i$ - Fraction of Fossil Carbon in the total carbon, (fraction; 0.0-1.0)
$OF_i$ - oxidation factor (0-58%)
44/12 - conversion factor from C to $CO_2$

(vii) Net climate impact from all GHGs (except BC) is estimated as follow;

$$NetGHG_{(CO2-eq/tonne)} = (CO_{2(net)} \times 1 + CH_4(biogenic)_{(net)} \times 28)$$

Net GHG emission – Estimated as tonnes of $CO_2$-eq/tonne

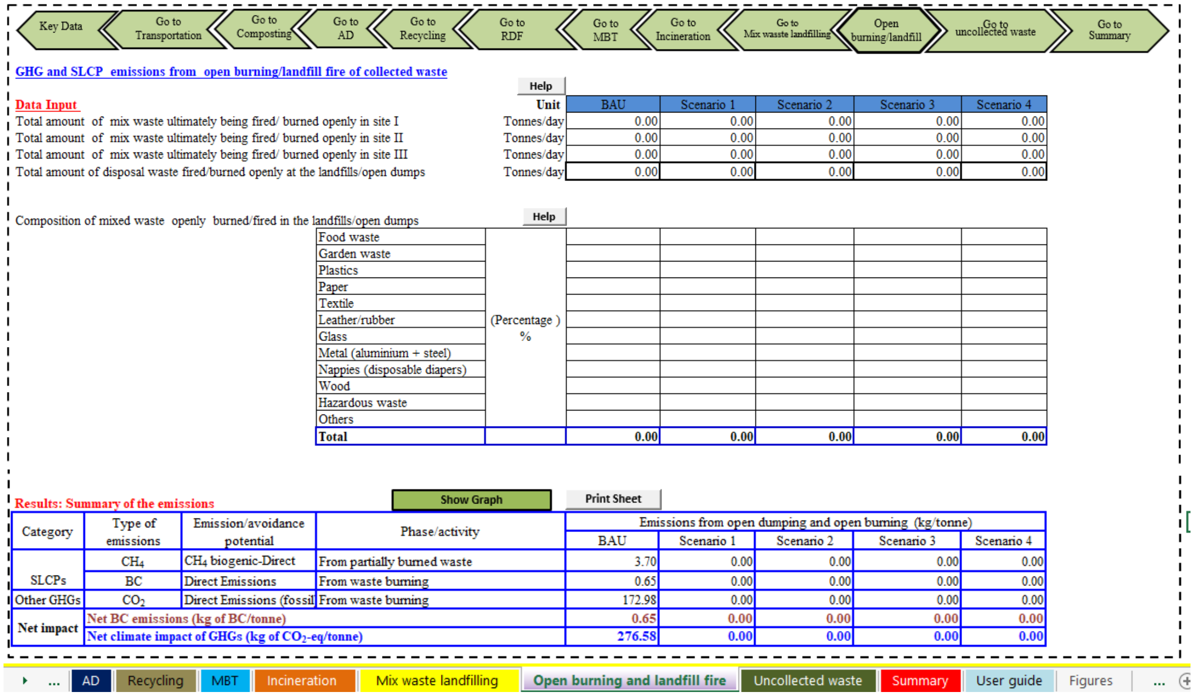



Figure 18: Print screen view of open burning/landfill fire sheet

### 2.5.5 Estimation of GHG/SLCP from uncollected waste

In general, cities in both developed and developing countries are unable to ensure 100% waste collection service coverage for various reasons. In fact, according to a World Bank assessment, collection rates through formal routes in low income countries are less than 50%, whilst in middle income countries, the rate is 50-80%. High income countries have a collection rate of more than 90% (World Bank, 2012). A large part of the waste in cities is valuable fractions like recyclables collected by the informal sector. The remaining waste is the “uncollected” fraction which is often disposed of in illegal dump sites (in the form of scattered dumping or wild dumping) and open burning sites.

There is an increasing trend of uncontrolled burning for massive amounts of uncollected waste in developing countries as people believe that it is the least expensive, easiest means of reducing waste volumes and a way to eliminate garbage from their vicinity. However, these kinds of primary methods can no longer be accepted due to serious threats to the environment and local communities. BC and fossil fuel-based $CO_2$ emissions from open burning are causing considerable climate impact, as well as affecting public health by reducing ambient air quality.

In this tool, a separate worksheet has been designed to quantify the GHG/SLCP emissions from uncollected waste. In this sheet, the amount of uncollected waste and the composition of such waste will appear automatically based on the user input data in the key data sheet. If the user enters the uncollected waste composition in the 'user guide page', that composition data will appear here.

If not, uncollected waste composition is considered to be similar to the composition of collected waste. The composition of uncollected waste is assumed to be similar in all scenarios. As for input data, the user should provide the percentage of uncollected waste openly burned and the percentage of uncollected waste openly dumped. These percentages might be approximate values based on general observation and experiences in waste management in the city. Unlike other technologies, fossil fuel does not require any operational or maintenance activities, therefore there are no GHG/SLCP emissions with respect operational activities.

$CH_4$ emissions from scattered/wild dumping of uncollected waste can be very low. Generally the height of the waste pile is very low and the majority of waste degrades aerobically. However, in this sheet it was assumed that emissions from open dumping of uncollected waste would be similar to emissions from unmanaged-shallow (<5m waste) dumpsites. The IPCC 2006 waste model is used to quantify the potential $CH_4$ emissions from open dumping of uncollected waste.

CH4 emissions from open burning was estimated based on the emission factor In order to quantify the BC from open burning, emission factors published by Bond et al. (2013) were used (0.65 kg of BC/tonne of waste). In addition, the IPCC recommended Tier 2 approach was adapted to quantify fossil fuel-based $CO_2$ from open burning of textile, rubber, leather, plastic components (IPCC, 2006). As explained in IPCC guidelines, for open burning of waste, all the default values are similar to the incineration except the oxidation factor. In the open burning process, a higher fraction of waste oxidizes incompletely due to inefficiencies in the combustion process, so the IPCC recommended oxidation factor (OF) for open burning is 58%. Step-by-step procedure of calculating GHG/SLCP emissions from uncollected waste is shown in Box 10.

Box 10: Method of estimating GHG/SLCP emissions from uncollected waste

(i) GHG (e.g. $CH_4$) emissions from open dumping

$CH_4$ emission from open dumping was estimated by using IPCC 2006 waste model. Detailed calculation procedure shown under landfilling sheet (see Box 7)

(ii) $CH_4$ emissions from open burning

$$Emissions_{CH_4} = EF(kg/tonne)$$

EF-Emission Factor of $CH_4$ during open burning (kg/tonne of waste) (emission factor given by Wiedinmyer et al, 2014)

iii) SLCPs (e.g. BC) emissions from waste burning (Emission factor given by Bond et al. 2013)

$$Emissions_{BC} = EF(kg/tonne)$$

EF-Emission Factor of BC from waste (kg/tonne of waste)

(iv) Quantify the GHGs (e.g. fossil based $CO_2$) emissions from burning of waste

$$E = \sum_i (SW_i \times dm_i \times CF_i \times FCF_i \times OF_i) \times \frac{44}{12}$$

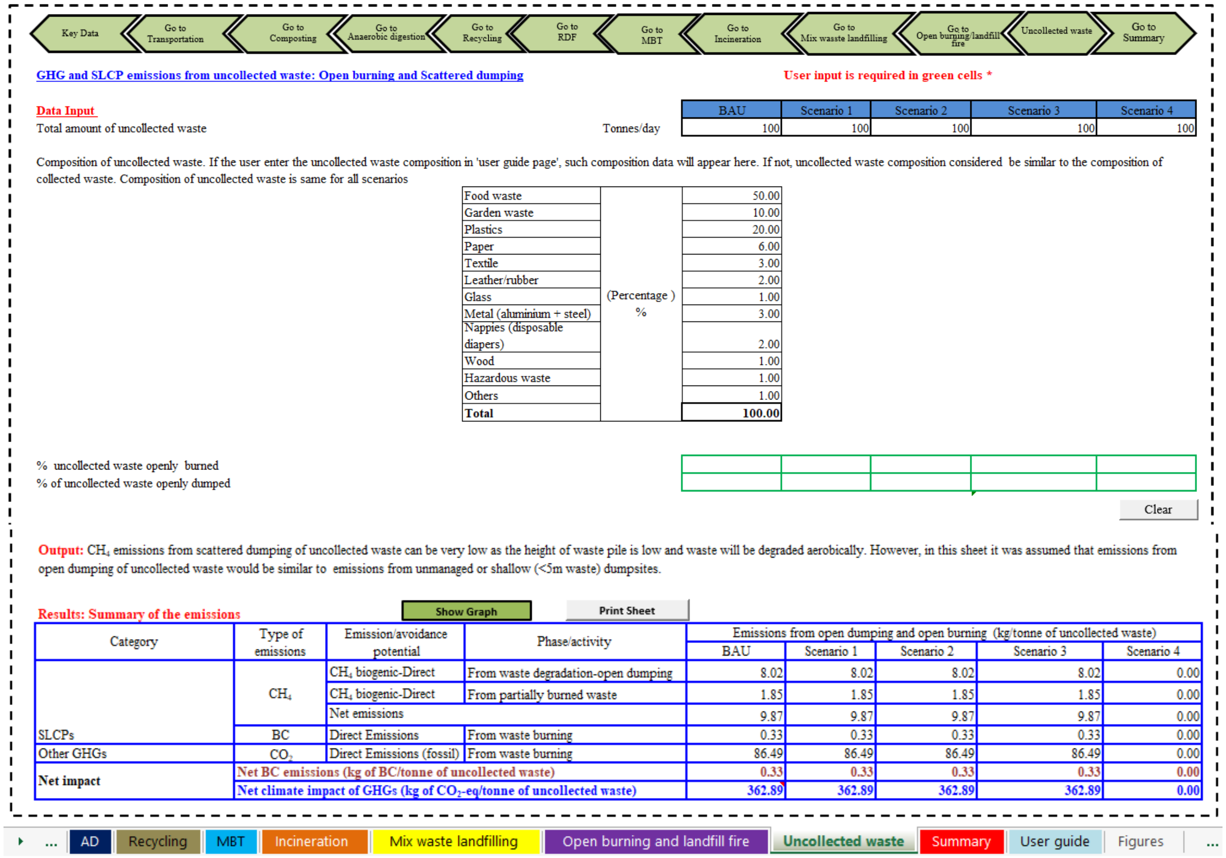
i - type of fossil based waste openly burned such as textiles, rubber and leather, plastics
E - Emissions (kg $CO_2$/tonne of waste)
$SW_i$-total amount of $i^{th}$ type of waste (wet weight) openly burned (kg/tonne of waste)
dmi - dry matter content in the waste (partially wet weight) openly burned
$CF_i$ -Fraction of Carbon in the dry matter (total carbon content), (fraction; 0.0-1.0)
$FCF_i$ - Fraction of Fossil Carbon in the total carbon, (fraction; 0.0-1.0)
$OF_i$ - oxidation factor ( 0-58%)
44/12 - conversion factor from C to $CO_2$

(v) Net climate impact from all GHGs (except BC) is estimated as follow;

$$NetGHG_{(CO2-eq/tonne)} = (CO_{2(net)} \times 1 + CH_4(biogenic)_{(net)} \times 28)$$

Net GHG emission – Estimated as tonnes of $CO_2$-eq/tonne

Once the quantification is completed for fossil fuel-based $CO_2$/BC emissions from open burning and $CH_4$ emissions from illegal dumping, these can be considered as gross GHG/SLCP emissions. Unlike other treatment methods, open burning and open dumping of uncollected waste has no possibility for avoidance of GHG/SLCP emissions through resource recovery. Therefore, net GHG/SLCP emissions would be equal to the gross GHG/SLCP emissions process. The print screen view of uncollected waste sheet is shown in Figure 19.



Key Data | Go to Transportation | Go to Composting | Go to Anaerobic digestion | Go to Recycling | Go to RDF | Go to MBT | Go to Incineration | Go to Mix wasste landfilling | Go to Open burning/landfill fire | Uncollected waste | Go to Summary

GHG and SLCP emissions from uncollected waste: Open burning and Scattered dumping

User input is required in green cells *

Data Input

| | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|---|
| Total amount of uncollected waste | Tonnes/day | 100 | 100 | 100 | 100 | 100 |

Composition of uncollected waste. If the user enter the uncollected waste composition in 'user guide page', such composition data will appear here. If not, uncollected waste composition considered be similar to the composition of collected waste. Composition of uncollected waste is same for all scenarios

| | | |
|---|---|---|
| Food waste | (Percentage ) % | 50.00 |
| Garden waste | | 10.00 |
| Plastics | | 20.00 |
| Paper | | 6.00 |
| Textile | | 3.00 |
| Leather/rubber | | 2.00 |
| Glass | | 1.00 |
| Metal (aluminium + steel) | | 3.00 |
| Nappies (disposable diapers) | | 2.00 |
| Wood | | 1.00 |
| Hazardous waste | | 1.00 |
| Others | | 1.00 |
| **Total** | | **100.00** |

% uncollected waste openly burned
% of uncollected waste openly dumped

Clear

**Output:** $CH_4$ emissions from scattered dumping of uncollected waste can be very low as the height of waste pile is low and waste will be degraded aerobically. However, in this sheet it was assumed that emissions from open dumping of uncollected waste would be similar to emissions from unmanaged or shallow (<5m waste) dumpsites.

**Results: Summary of the emissions**

Show Graph | Print Sheet

| Category | Type of emissions | Emission/avoidance potential | Phase/activity | Emissions from open dumping and open burning (kg/tonne of uncollected waste) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | BAU | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
| SLCPs | $CH_4$ | $CH_4$ biogenic-Direct | From waste degradation-open dumping | 8.02 | 8.02 | 8.02 | 8.02 | 0.00 |
| | | $CH_4$ biogenic-Direct | From partially burned waste | 1.85 | 1.85 | 1.85 | 1.85 | 0.00 |
| | | Net emissions | | 9.87 | 9.87 | 9.87 | 9.87 | 0.00 |
| | BC | Direct Emissions | From waste burning | 0.33 | 0.33 | 0.33 | 0.33 | 0.00 |
| Other GHGs | $CO_2$ | Direct Emissions (fossil) | From waste burning | 86.49 | 86.49 | 86.49 | 86.49 | 0.00 |
| **Net impact** | **Net BC emissions (kg of BC/tonne of uncollected waste)** | | | **0.33** | **0.33** | **0.33** | **0.33** | **0.00** |
| | **Net climate impact of GHGs (kg of $CO_2$-eq/tonne of uncollected waste)** | | | **362.89** | **362.89** | **362.89** | **362.89** | **0.00** |

... | AD | Recycling | MBT | Incineration | Mix waste landfilling | Open burning and landfill fire | Uncollected waste | Summary | User guide | Figures | ...

Figure 19: Print screen view of uncollected waste sheet

## 2.5 Summary of GHG/SLCP emissions

An individual worksheet has been designed to estimate the technology specific emissions from each type of waste management option in consideration of their entire life cycle. It is preferable for users to have several technologies in their BAU or intended scenarios. Therefore, this tool facilitates showing the aggregated climate effect of each scenario for users to compare systems (scenarios) and choose the most climate-friendly technologies for their city. The summary sheet has been designed to indicate the overall results of the estimations in the form of a summary. Users are requested to refer to the summary sheet once they enter all the required data in the individual sheets in order to compare scenarios and make decisions on most climate friendly waste management options.

The first table in the summary sheet shows the mass balance of the generated waste with respect to each scenario. Users can compare the summary of total waste generation, total collected and treated waste by the city, collected and treated waste by informal sector, total uncollected waste (scattered/wild dumping waste) with respect to different scenarios that they have chosen to compare. If a considerable amount of waste is being uncollected, an automatic message will appear to remind the user that their city needs to implement a proper plan to improve their management practices and address the uncollected waste.

The second table shows the net emissions from individual treatment technologies under the different scenarios. Net GHG/SLCP emissions from individual treatment methods are shown in "kg/tonne". Units in "kg" are used here in order to show the magnitude of small amounts of emissions such as BC. In addition, the climate impact from per tonne generated waste is calculated for an integrated system whereas the net GHG/SLCP emissions from individual technologies have been further aggregated. Aggregated net GHG/SLCP emissions from each scenario have been calculated as "kg of each GHG/SLCP (e.g. $CH_4$, BC, $CO_2$, $N_2O$) emissions per tonne of generated waste". However, user must be interested to measure the emissions for different unit. Therefore, to measure the accumulated emissions from each scenario, an option has been given to the user to change the unit of measurements based on their preferences. The tool facilitates to measure the climate impact of each scenario for four types of functional units given below.

1. Emissions per tonne of generate waste
2. Emissions per tonne of collected waste
3. Emissions from yearly generated waste
4. Emissions from yearly collected waste

User can change the functional unit in the dropdown list and estimate the emissions for any of the unit listed above based on their interest and effectiveness for policy making process. In the summery sheet, aggregated impact from different technologies has been presented with respect to BAU practice and intended scenarios. The following approach has been used to quantify the aggregated net emissions in each scenario.

Net GHGs/SLCP emissions from the integrated system (tonnes/per tonne of generated waste) =

> Net GHG/SLCP emissions from waste transportation (kg/per tonne of waste) × Fraction of generated waste is transported + Net GHG/SLCP emissions from composting (kg /per tonne of organic waste) × Fraction of generated waste use for composting + Net GHG/SLCP emissions from AD (kg /per tonne of organic waste) × Fraction of generated waste use for AD + Net GHG/SLCP emissions from recycling (kg /per tonne of recyclables) × Fraction of generated waste use for recycling + Net GHG/SLCP emissions from RDF production (kg /per tonne of input waste) × Fraction of generated waste use for RDF production+ Net GHG/SLCP emissions from MBT (kg/tonne of mixed waste) × Fraction of generated waste use for MBT + Net GHG/SLCP emissions from incineration (kg /tonne of mixed waste) × Fraction of generated waste use for incineration + Net GHG/SLCP emissions from landfilling (kg/tonne of mixed waste) × Fraction of generated waste use for landfilling + Net GHG/SLCP emissions from uncollected waste (kg /per tonne of uncollected waste) × Fraction of generated waste remained as uncollected

Net BC emissions per tonne of generated/collected waste in each scenario are shown in a separate row as they are one of the major SLCPs that this tool aims to quantify. With the exception of BC, net emissions of other gases have been aggregated as $CO_2$-eq considering the Global Warming Potential (GWP) values of $CO_2$, $CH_4$, $N_2O$ (see Figure 19). The aggregated net climate impact from each scenario can be used to compare BAU practices with other intended scenarios to select the most optimal waste management option for climate change mitigation. It should be noted that GWP value of BC has not been finalised yet by the recognised body (e.g. IPCC) and therefore, net BC emissions from each scenario are shown separately. For comparison purposes, net climate impact from BC and other GHGs are shown graphically, as can be seen in Figure 20. All in all, by comparing the magnitude of net BC emissions and other GHGs emissions, users can choose the most climate-friendly waste management option for the city.

Please choose the prefered 'Unit' for emissions estimation | Calculate emissions from yearly generated waste

**Summary of net GHG/SLCP emissions from waste management**

| Description | Technology | Unit | BAU | | | | Scenario 1 | | | | Scenario 2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $CH_4$ | BC | $CO_2$ | $N_2O$ | $CH_4$ | BC | $CO_2$ | $N_2O$ | $CH_4$ | BC | $CO_2$ | $N_2O$ |
| Waste collection and transportation by the city | Transportation | **kg /tonne** (unit ' kg ' used here to show the magnitude of small amount of emissions) | 0.000 | 0.003 | 3.362 | 0.000 | 0.000 | 0.001 | 3.026 | 0.000 | 0.000 | 0.001 | 3.026 | 0.000 |
| Treatment for separated waste | Composting | | | | | | 3.999 | 0.001 | -0.360 | 0.282 | 3.999 | 0.001 | -0.360 | 0.282 |
| | Anaerobic digestion | | | | | | | | | | | | | |
| | Recycling | | | | | | -0.011 | -0.017 | -1,314.173 | -0.003 | -0.011 | -0.017 | -1,314.173 | -0.003 |
| Treatment for mixed waste | MBT | | | | | | | | | | | | | |
| | Incineration | | | | | | | | | | | | | |
| | Landfilling | | 37.515 | 0.000 | 0.000 | 0.000 | 28.879 | 0.000 | 0.000 | 0.000 | 28.879 | 0.000 | 0.000 | 0.000 |
| | Open burning/landfill fire | | 3.700 | 0.650 | 172.982 | | | | | | | | | |
| Uncollected waste | Open burning/scattered dumping | | 9.871 | 0.325 | 86.491 | | 8.021 | 0.325 | 86.491 | | 8.021 | 0.325 | 86.491 | |
| GHGs/SLCPs emission per tonne of generated waste: | | **kg/tonne** | **14.652** | **0.370** | **101.097** | **0.000** | **15.580** | **0.114** | **-76.736** | **0.048** | **15.580** | **0.114** | **-76.736** | **0.048** |
| BC emissions from yearly generated waste: | | **Tonnes** | 8,321.93 | | | | 2,559.72 | | | | 2,559.72 | | | |
| Climate impact from GHGs emissions from yearly generated waste: | | **Tonnes of CO2-eq** | 11,509,868.49 | | | | 8,376,236.23 | | | | 8,376,236.23 | | | |

Figure 20: Print screen view of summary table of GHGs/SLCPs

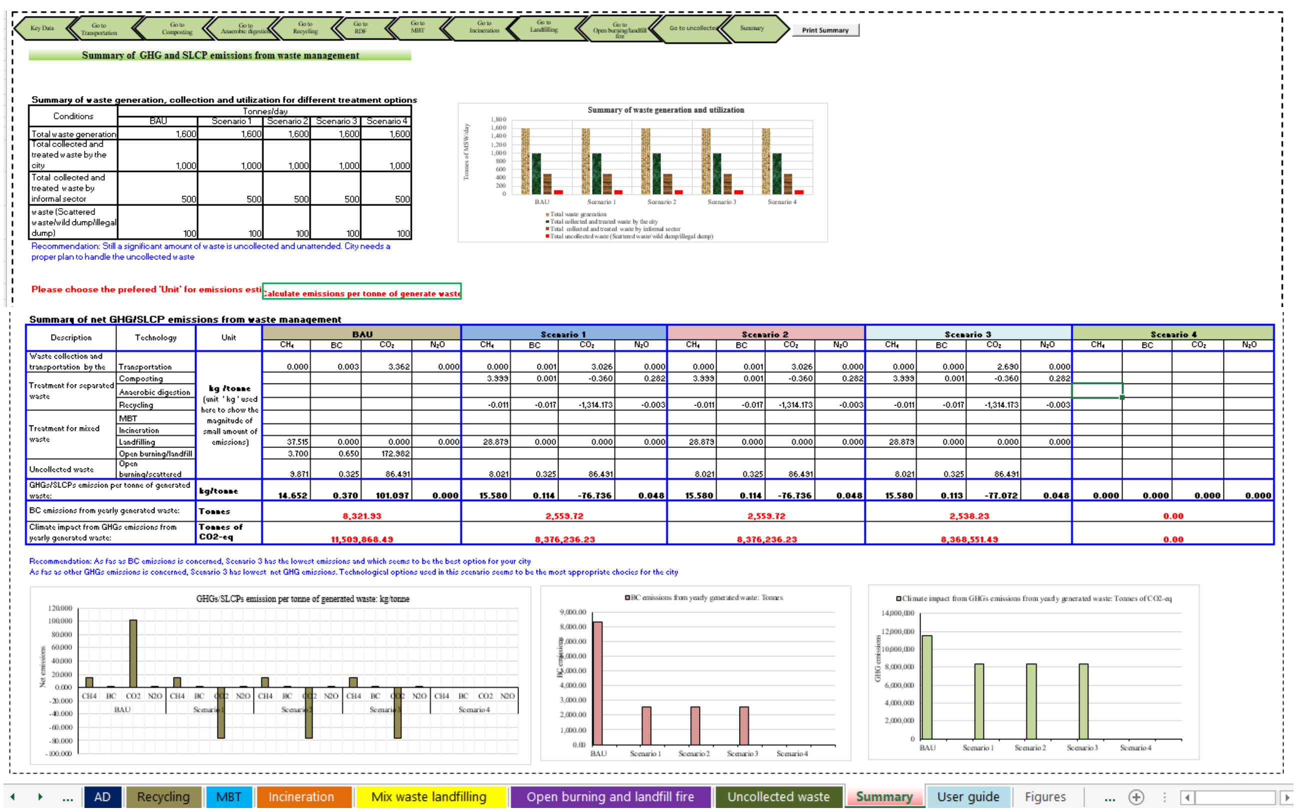


Figure 21: Print screen view of summary sheet

### 3.0 Suggestions and possible improvements

Most cities in developing Asia are not very familiar with the importance of accurate data collection and procedures on systematic data recording. Some guidance has been provided in the user manual but it may not be fully sufficient. Therefore, training sessions should be planned for city officials on how to collect and record accurate data at the city level.

In this tool the IPCC waste model has been used to estimate the emissions from landfill technologies. This IPCC waste model would be sufficient to compare the scenarios on the $CH_4$ emissions potential from landfilling technologies considering the entire life cycle (e.g. 100 years) for decision-making purposes. If the city is interested in a more accurate estimation for the purpose of applying to the carbon market (e.g. CDM), more specific landfill models like methodologies recommended by the UNFCCC can be used.

There are a lot of ongoing research on effect of BC on climate change and more reliable emission factors will be published in the future. The emission factor of BC needs to be updated when more reliable data is available. If GWP values of BC are recommended by a recognized body such as the IPCC, climate impact from BC should be aggregated in terms of $CO_2$-eq for facilitating a smooth decision-making process.

### References

Arena, U., Mastellone, M.L. and Perugini, F. 2003. The environmental performance of alternative solid waste management options: a life cycle assessment study. Chemical Engineering Journal, 96; 207–222.

Astrup,T., Møller,J. and Fruergaard, T. 2009. Incineration and co-combustion of waste: accounting of greenhouse gases and global warming contributions. Waste Management & Research, 27: 789–799.

Bond et al., 2013. Bounding the role of black carbon in the climate system: A scientific assessment. In: Journal of Geophysical Research: Atmospheres, Vol. 118, 5380-5552, doi: 10.1002/jgrd.50171, 2013

Bovea, M.D., Ibáñez-Forés, V., Gallardo, A. and Colomer-Mendoza, F.J. 2010. Environmental assessment of alternative municipal solid waste management strategies. A Spanish case study. Waste Management, 30; 2383–2395.

Brentrup, F. and Brentrup, F. 2008. Energy efficiency and greenhouse gas emissions in European nitrogen fertilizer production and use. Avenue E. van Nieuwenhuyse 4/6 B-1160, Brussels, Belgium.

Carbon footprint, 2024. International electricity factors, Available in https://www.carbonfootprint.com/international_electricity_factors.html

Charles H. K., Lam, A. W. M. I., Barford, J.P. and McKay, G. 2010. Use of Incineration MSW Ash: A Review. Sustainability, 2: 1943-1968.

Cherubini, F., Bargigli, S. and Ulgiati, S. 2008. Life cycle assessment (LCA) of waste management strategies; Landfilling, sorting plant and incineration. Energy, 34 (12), 2116-2123.

Conestoga-Rovers & Associates (CRA), 2010. Landfill gas management facilities design guidelines, Richmond, British Colombia. Available in http://www.env.gov.bc.ca/epd/mun-waste/waste-solid/landfills/pdf/Design-guidelines-final.pdf

DEFRA, 2013. Incineration of Municipal solid waste. Department for environment, food and rural affairs. Available in https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/221036/pb13889-incineration-municipal-waste.pdf

Diaz,R. and Warith, M. 2006. Life-cycle assessment of municipal solid wastes: Development of the WASTED model. Waste Management, 26; 886–901.

Ecometrica, 2011. Electricity specific emission factor. Available in http://ecometrica.com/assets/Electricity-specific-emission-factors-for-grid-electricity.pdf.

EMEP/EEA air pollutant emission inventory guidebook, 2016. Paper and pulp industry. Technical guidance to prepare national emission. ISSN 1977-8449. Available in http://efdb.apps.eea.europa.eu

European Aluminium Inductry, 2013. Available in http://european-aluminium.eu/media/1329/environmental-profile-report-for-the-european-aluminium-industry.pdf

IFEU, 2009. SWM-GHG calculator. Available in http://www.ifeu.org/english/index.php?bereich=abf&seite=klimarechner

IGES, 2024. Institute for Global Environmental Strategies. List of Grid Emission Factors, version 11.4. Available at: https://pub.iges.or.jp/pub/iges-list-grid-emission-factors

IPCC, 2006 (a). Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds.). Published: IGES, Japan.

IPCC, 2006 (b). Incineration and Open Burning of Waste. Available in http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_5_Ch5_IOB.pdf

IPCC, 2006 (c). Waste generation, composition and management data. Available in http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_2_Ch2_Waste_Data.pdf

IPCC, 2006 (d). Energy, 2006 IPCC guidelines. Available inhttps://www.ipcc.ch/meetings/session25/doc4a4b/vol2.pdf

IPCC, 2007. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds) Cambridge University Press, Cambridge, United Kingdom and New York, USA.

IPCC, 2014. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Available in http://www.ipccnggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Glossary_Acronyms_BasicInfo/Glossary.pdf

IPCC. 2013. Climate Change 2013. The Physical Science Basis. Contribution of Working Group 1 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Kool, A., Marinussen, M. and Blonk, H. 2012. GHG Emissions of N, P and K fertilizer production, Blonk Consultants. Available in http://blonkconsultants.nl/upload/pdf/PDV%20rapporten/fertilizer_production%20D03.pdf

Manfredi S., Tonini. D., Christensen, T.H. and Scharff, H. 2009. Landfilling of waste: accounting of greenhouse gases and global warming contributions. Waste Management & Research, 27: 825–836.

Mendes, M. R., Aramaki, T. and Hanaki, K. 2004. Comparison of the environmental impact of incineration and landfilling in São Paulo City as determined by LCA. Resources, Conservation and Recycling, 41, 47–63.

Menikpura S.N.M., Gheewala, S.H. and Bonnet, S. 2012. Evaluation of the effect of recycling on sustainability of municipal solid waste management in Thailand. Waste and Biomass Valorisation Journal, 4(2), 237-257.

Møller J., Boldrin A. and Christensen, T.H. 2009. Anaerobic digestion and digestate use: accounting of greenhouse gases and global warming contribution. Waste Management Research, 27(8):813-24.

Ostrem, K. 2004. Greening waste: anaerobic digestion for treating the organic fraction of municipal solid wastes. Earth Engineering Centre, University of Colombia. Available in http://www.wtert.gr/Pdfs/anaerobic_digestion_Ostrem_Thesis.pdf

Patyk, A. 1996. Balance of Energy Consumption and Emissions of Fertilizer Production and Supply. Reprints from the International Conference of Life Cycle Assessment in Agriculture, Food and Non-Food Agro-Industry and Forestry: Achievements and Prospects, Brussels, Belgium, 4-5 April 1996.

Pitsanulok Municipality, 2012. Personal communication with Phistanulok Municipality, Thailand

Rx3 rethink recycle remake, 2012. Life Cycle Assessment of Irish compost production and agricultural use. Available in http://www.cre.ie/web/wp-content/uploads/2010/12/Compost-Life-Cycle.pdf

Rigamonti, L., Grosso, M., & Biganzoli, L. (2012). Environmental Assessment of Refuse-Derived Fuel Co-Combustion in a Coal-Fired Power Plant. Journal of Industrial Ecology, 16(5), 748-760.

Staffell, I. 2011. The Energy and Fuel Data Sheet. University of Birmingham. Available in http://wogone.com/science/the_energy_and_fuel_data_sheet.pdf

The World Bank, 2012. What a Waste: A Global Review of Waste Management. Available in www.worldbank.org/urban.

UNFCCC, 2006. Clean Development Mechanism, Project Dosing Document Form. Available in http://cdm.unfccc.int/Projects/DB/DNV-CUK1194442031.0/view

UNFCCC, 2012. Indicative simplified baseline and monitoring methodologies for selected small-scale CDM project activity categories. Recovery and recycling of materials from E-waste. Available in https://cdm.unfccc.int

UNFCCC. 2012. Recycling and virgin production of plastic. Available in https://cdm.unfccc.int/Panels/ssc_wg/meetings/039/ssc_039_an04.pdf

Warinchamrap Municipality, 2012. Personal communication with Warinchamrap Municipality, Thailand

World Aluminium, 2010. Available in http://www.world-aluminium.org/media/filer_public/2013/10/17/2010_life_cycle_inventory_report.pdf

World Bank, 2018, What a Waste 2. Available in https://datatopics.worldbank.org/what-a-waste/

World Bank, 2013. Country and Lending Groups. Available in http://data.worldbank.org/about/country-and-lending-groups

World Steel Association, 2011. Methodology report. Life cycle inventory study for steel products. Available in https://www.worldsteel.org/en/dam/jcr:6a222ba2-e35a-4126-83ab-5ae5a79e6e46/LCA+Methodology+Report.pdf

WRAP, 2009. Anaerobic digestate. Available in http://www.organicsrecycling.org.uk/uploads/category1060/Financial_impact_assessment_for_anaerobic_digestate.pdf