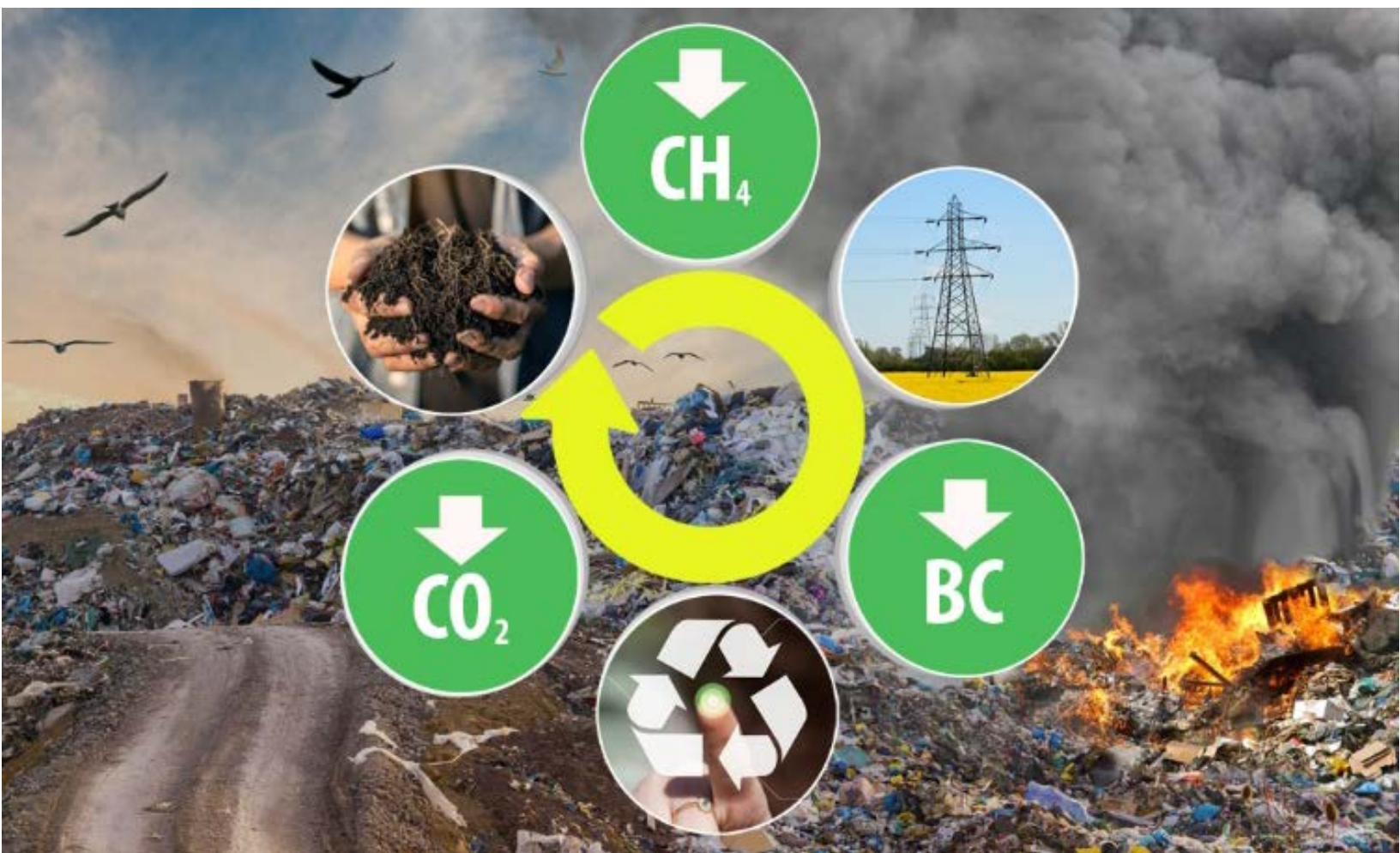# User's Manual

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

Prepared by:

Institute for Global Environmental Strategies (IGES)

Prepared on behalf:

Climate and Clean Air Coalition (CCAC) Initiative

Executive Summary

Emission Quantification Tool (EQT) developed by the Institute for Global Environmental Strategies (IGES) on behalf of the Climate and Clean Air Coalition's Municipal Solid Waste Initiative (CCAC-MSWI), which 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 the version II 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 customised 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, 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, and therefore, net BC emissions are estimated and presented separately. In the summary sheet, net GHG and SLCP emissions are summarised both with respect to individual treatment methods and various analysed 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.

Version II of the EQT builds upon the successful application of the tool's initial prototype and we welcome feedback from users for its continued improvement.

Note to User: All feedback should be sent to Dr. Nirmala Menikpura (nirmala.menikpura@mx.iges.or.jp; samanthinir@yahoo.co.in), Dr. Dickella Gamaralalage Jagath Premakumara (premakumara@iges.or.jp).

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Glossary of Terms

Term	Meaning
Greenhouse gas (GHG)	Gas in an atmosphere that 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) integrates 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 the version II 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 policy makers select and implement the most appropriate climate friendly waste management scenario for the city, monitoring should be conducted periodically (on a monthly or yearly basis) in order to track the reduction of SLCPs and GHGs emissions. For this purpose, a separate monitoring and reporting module will be developed as a part of the package to monitor the emissions reductions over time from the city's selected waste management option.

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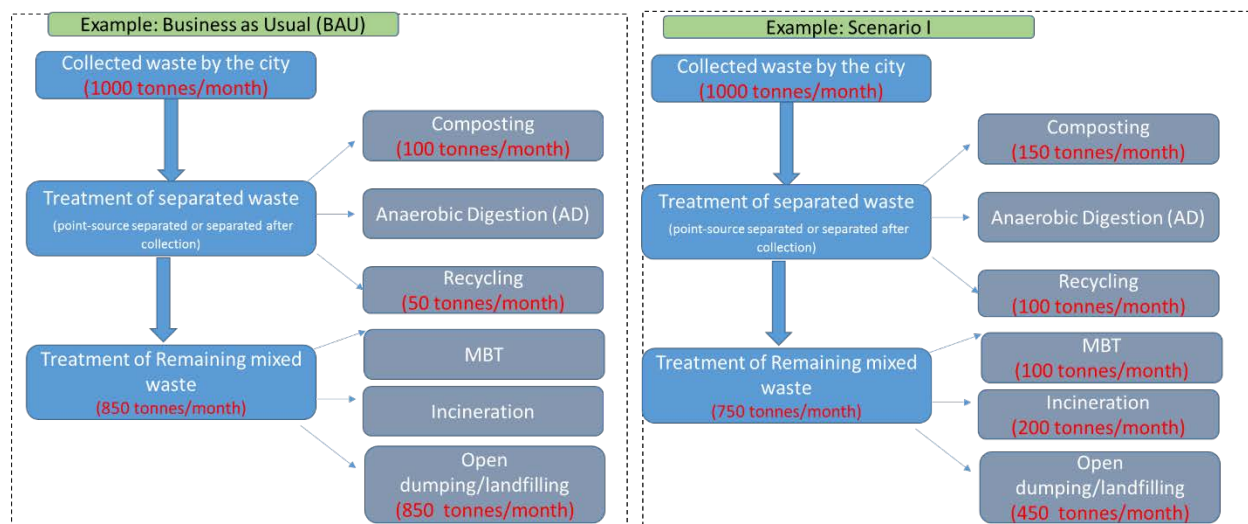
Figure 1: How to allocate amount of collected waste among technologies

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

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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.
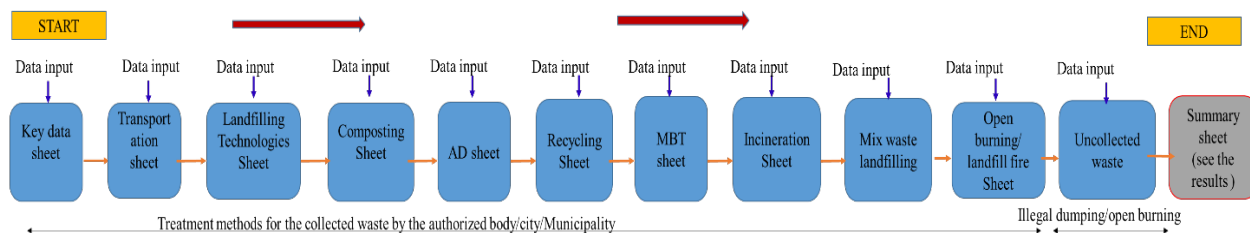
Figure 2: Direction of data entry

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. 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.

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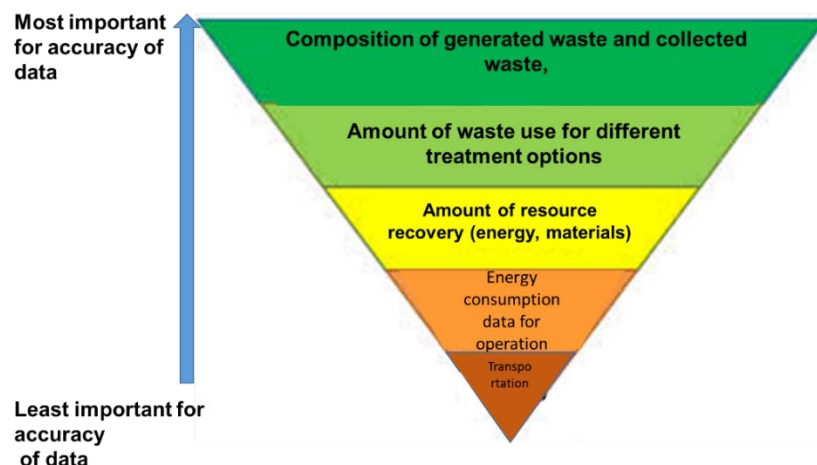
Figure 3: Hierarchical importance regarding accuracy of the data

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

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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.

Net GHG/SLCP emissions	=	Total GHG/SLCP emissions from treatment technology	-	GHG/SLCP avoidance via resource recovery
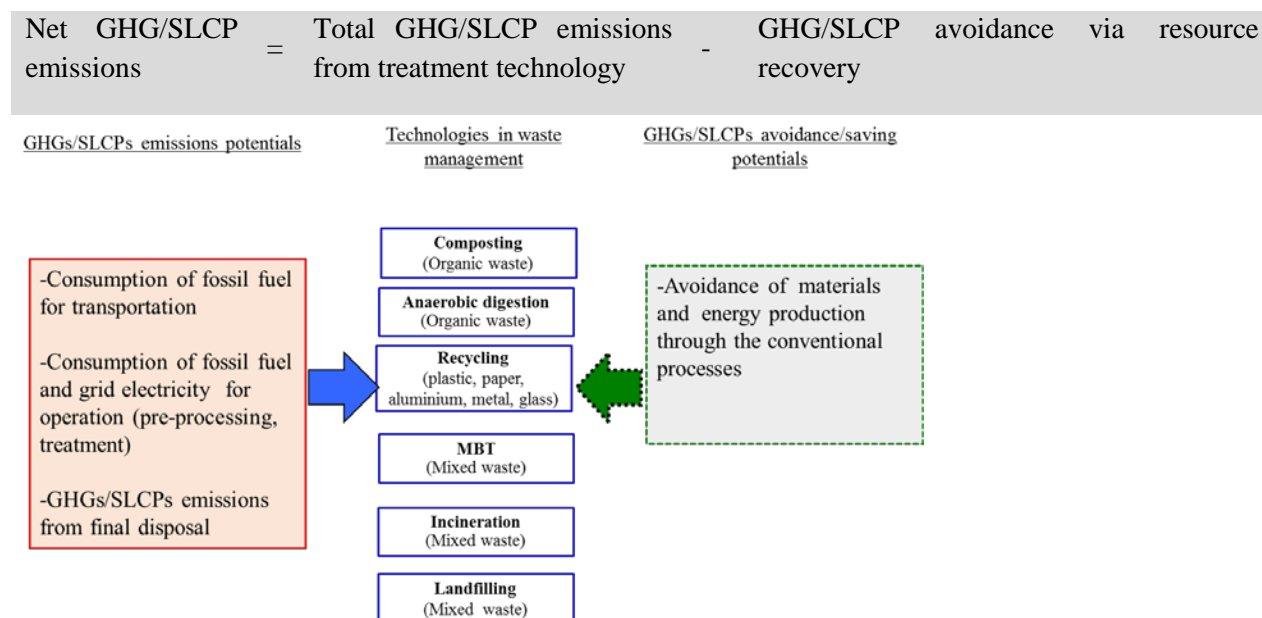
Figure 4: GHGs/SLCPs emissions and avoidance potential via LCA concept

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
Key data sheet	Climatic zones of the countries are defined based on IPCC waste model, (1) Moist and Wet Tropical = Mean Annual Precipitation (MAP) $\geqslant$ 1000 mm , Mean Annual Temperature (MAT) >20 $^{\circ}$ C (ii) Dry Tropical = Mean Annual Precipitation (MAP) < 1000 mm, Mean Annual Temperature (MAT) >20 ℃ (iii) Dry Temperate = Mean Annual Precipitation (MAP)/Potential Evapotranspiration (PET) <1 , Mean Annual Temperature (MAT) 0-20 ℃ (iv) Wet Temperate = Mean Annual Precipitation (MAP)/Potential Evapotranspiration (PET) >1 , Mean Annual Temperature (MAT) 0-20 ℃	IPCC, 2014
	Economic level of the countries (1) Lower-income -Gross National Income (GNI) per capita- $1,045 or less, (2) Lower-middle-income GNI per capita $1,045-$4,125 (3) Lower-middle-income GNI per capita $4,125-$12,746 (4) High income- GNI per capita $12,746 or more	The World Bank, 2013
	Per capita waste generation rate for different economic level Lower income -0.6; Lower middle income -0.78; Upper middle income-1.16; High income-2.13 (kg/capita/day)	The World Bank, 2013
	Waste collection rate based on the development level of the country 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
	Emission Factors for grid electricity production (The values cannot be presented here as it is a long list)	IGES, 2014; Ecometrica, 2011
	Calorific values of fossil fuel	IPCC,2006 d Staffell, 2011

Transportation	Fossil fuel and grid electricity consumption rate at transfer station Electricity consumption – 2.5 kWh/tonne Diesel fuel consumption -0.125 L/tonne	Diaz,R. and Warith,M. 2006
	Black Carbon (BC) emission factor from different type of vehicles 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 climate impact from different GHGs; Methane (CH_4)-28; Fossil methane (CH_4) – 30; Nitrous Oxide (N_2O)-265	IPCC, 2013.
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
	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

Recycling	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
MBT	Emission factor from waste degradation in MBT piles (4 kg of CH_4/tonne of wet organic waste; 0.3 kg of N_2O/tonne of wet organic waste)	IPCC, 2006 a
	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%) (ii) For heat: Average efficiency of heat recovery is 80-90% (for only heat recovery option). (iii) For heat and power : Average electricity efficiency 15% and heat efficiency 50-60% 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 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
Landfilling	Fossil fuel consumption for operational activities (e.g. for operation of machineries (bulldozers, backhoes etc.) (0.8L per tonne of landfilled waste). 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 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	IPCC, 2006 a
	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 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, 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 enter 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
(1) Collected amount by the city or private/authorized companies	Tonnes/day	40080	40080	40080	40080	
(2) Collected amount by informal collectors (e.g. mainly the recyclables)	Tonnes/day					
(3) Uncollected amount	Tonnes/day	21582	21582	21582	21582	
Total generated waste	**Tonnes/day**	61662	61662	61662	61662	0

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 composition in green cells

Components	IPCC Default waste composition (%) for Southeast Asia	County/location specific **generated waste** composition (%)	County/location specific **collected** waste composition (%)
Food waste		45.05	45.05
Garden waste		7.22	7.22
Plastics		10.56	10.56
Paper		8.61	8.61
Textile		1.61	1.61
Leather/rubber		0.44	0.44
Glass		2.34	2.34
Metal (aluminium + steel)		4.22	4.22
Nappies/diapers (disposable)		0.00	0.00
Wood			
Hazardous waste			
Others		19.95	19.95
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.

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.

Figure 8: Key datasheet: Energy consumption data

2.2 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. Emission factors have been given for three types of vehicles namely; modern vehicles, old vehicles, and both modern and old vehicles. 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. 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.

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 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.

Figure 9: Print screen view of transportation sheet

2.3 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.

2.3.1 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 ith 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 ith 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 ithGHG 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$_{GHG(i)}$ – ith GHG Avoidance potential from chemical fertilizer production which is equivalent to one tonne of compost (kg/tonne of compost)

(vi) Net ith GHG emissions and net BC emissions can be calculated as follows:

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

(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

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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.

Figure 10: Print screen view of composting sheet

2.3.2 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$_{GHG(i)}$-operation – Emissions ith 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 ith 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$_{(i)}$ – ith 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$_i$–ith 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 ith 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:
$$AvoidedGHG/SLCP_{(i)} = AC \times PC_{Agriculture} \times A_{GHG}$$

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AvoidedGHG$_{(i)}$– Avoided ithGHG 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$_{GHG(i)}$ – ith GHG Avoidance potential from chemical fertilizer production which is equivalent to one tonne of compost (kg/tonne of compost)

(viii) Net ith 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

Figure 11: Print screen view of AD sheet

2.3.3 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 ith 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 ith 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 ith 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 ith 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 ith Emissions per tonne Virgin material production. (kg/tonne)

(v) Net ith GHG emissions and net BC emissions from recycling;

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

(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

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)

			BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total amount of cleaned recyclables collected by the city		Tonnes/day [Help]	0	5160	5160	5160	0

Composition (percentage %) of cleaned recyclables collected by the city [Check available amount]

		BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Paper and cardboard			33.50	33.50	33.50	
Plastic			41.00	41.00	41.00	
Aluminium	Percentage (%)		8.20	8.20	8.20	
Metal/Steel			8.20	8.20	8.20	
Glass			9.10	9.10	9.10	
Total		0.00	100.00	100.00	100.00	0.00

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

			BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total amount of mixed recyclables collected by the informal collectors		Tonnes/day [Help]	0	0	0	0	0

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

		BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Paper and cardboard						
Plastic						
Aluminium	Percentage (%)					
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		Type of recyclables				
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		Type of recyclables				
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	Emissions from recycling activities (kg/tonne of mixed recyclable waste)				
				BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
SLCPs	CH₄	Emissions	CH₄ 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	CO₂	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**
	N₂O	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 CO₂-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 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.

2.4.1Estimation 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 5. Print screen view of MBT sheet is shown in Figure 13.

Box 5: 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 ith 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

GHG and SLCP emissions from Mechanical Biological Treatment (MBT)

User input is required in green cells *

Data Input

			BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total amount of mixed waste used for MBT	Tonnes /day		0	0	0	0	0
Composition of the mix waste (percentage %)	Help						
	Food waste						
	Garden waste						
	Plastics						
	Paper						
	Textile						
	Leather/rubber						
	Glass	Percentage (%)					
	Metal (aluminium + steel)						
	Nappies (disposable diapers)						
	Wood						
	Hazardous waste						
	Others						
	Total		0.00	0.00	0.00	0.00	0.00

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	CH₄	Emissions	CH₄ fossil-Direct (fuel consumption)	0.00	0.00	0.00	0.00	0.00
			CH₄ biogenic-Direct (through degradation)	0.00	0.00	0.00	0.00	0.00
		Avoided	CH₄ fossil-Through avoided chemical fertilizer	0.00	0.00	0.00	0.00	0.00
			CH₄ 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
			CH₄ fossil-Through RDF/Crude oil production	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	CO₂	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
	N₂O	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 CO₂-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 landfill fire | Un … ⊕

Figure 13: Print screen view of MBT sheet

2.4.2 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

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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 6: Method of estimating GHG/SLCP emissions from incineration

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(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 ith type of waste (wet weight) incinerated (kg/tonne of waste)
dm_i - 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 ith 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 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	Help	0	0	0	0	0

Composition of the mix waste use for incineration in your city   Help

		BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Food waste						
Garden waste						
Plastics						
Paper						
Textile						
Leather/rubber	(Percentage) %					
Glass						
Metal (aluminium + steel)						
Nappies (disposable diapers)						
Wood						
Hazardous waste						
Others						
Total		0.00	0.00	0.00	0.00	0.00

Allocation of total amount of incinerated waste among different incinera   Help

			BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
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	Help
Type of fossil fuel used for operational activities	Type	Help
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   Help

Help

2) Specifications of Incinerator II

Amount of waste incinerated in Incinerator II	Tonnes/day	
Select the type of incineration	Type	Help
Type of fossil fuel used for operational activities	Type	Help
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   Help

Help

3) Specifications of Incinerator III

Amount of waste incinerated in Incinerator III	Tonnes/day	
Select the type of incineration	Type	Help
Type of fossil fuel used for operational activities	Type	Help
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   Help

Help

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 14: Print screen view of incineration sheet

2.4.3 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 to 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 CH_4 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 7.

Box 7: Method of estimating GHG/SLCP emissions from landfilling/open dumping

---

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

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

$Emissions_{GHG(i)\text{-}operation}$ – 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) $\times$ 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) $\times$ (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 = (ΣCH_4 generated $_{(T)} - R_{(T)}) \times (1 - OX_{(T)})$

$R_{(T)}$ - Recovered CH_4 in year T; $OX_{(T)}$ - Oxidation factor in year T (fraction)

$$CH_4(per tonne) = \frac{\sum_{0}^{t} CH_4}{\sum_{0}^{t} AOW}$$

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

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

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

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

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

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

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 ith 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;

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

(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. This 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 has 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) $\times 365/1000$
Degradable Organic Carbon(DOC)	DOC	Derived based on IPCC default DOC content values, DOC_{MSW} = % of food waste$\times 0.15$+ % of garden waste$\times 0.43$ + % of paper waste $\times$ 0.4 + % of textile waste $\times$ 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$\times 0.4$+ % of garden waste$\times 0.17$ + % of paper waste $\times$ 0.07 + % of textile waste $\times$ 0.07 + % of disposal nappies $\times$ 0.17+ % of wood and straw $\times$ 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 Anaerobic digestion | Go to Recycling | 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 mix waste dispose at landfills/open dumps	Tonnes/day	40080.00	24440.00	24440.00	24440.00	0.00

Composition of mixed waste disposed at the landfill [Help]   Chart Area

Composition		BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Food waste		45.05	36.93	36.93	36.93	
Garden waste		7.22	5.91	5.91	5.91	
Plastics		10.56	8.66	8.66	8.66	
Paper		8.61	7.05	7.05	7.05	
Textile	(Percentage) %	1.61	2.64	2.64	2.64	
Leather/rubber		0.44	0.72	0.72	0.72	
Glass		2.34	1.92	1.92	1.92	
Metal (aluminium + steel)		4.22	3.46	3.46	3.46	
Nappies (disposable diapers)		0.00	0.00	0.00	0.00	
Wood		0.00	0.00	0.00	0.00	
Hazardous waste		19.95	32.72	32.72	32.72	
Others		0.00	0.00	0.00	0.00	
Total		**100.00**	**100.00**	**100.00**	**100.00**	**0.00**

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	40080	24440	24440	24440	
	% of disposed waste ultimately fired/open-burned in site I	%	60.00				
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					

(1) Specifications of disposal site I   [Check landfill classification]

	Unit	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
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 (> 5m 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	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
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	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
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	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
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					

(II1) Specifications of disposal site III

	Unit	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
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	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
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 15: 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
		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

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

Show Graph | Print Sheet

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 16: 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 17.

Box 8: 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 ith type of waste (wet weight) openly burned/fired (kg/tonne of waste)
dm_i - 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

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GHG and SLCP emissions from open burning/landfill fire of collected waste

Data Input

	Unit	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total amount of mix waste ultimately being fired/ burned openly in site I	Tonnes/day	24048.00	0.00	0.00	0.00	0.00
Total amount of mix waste ultimately being fired/ burned openly in site II	Tonnes/day	0.00	0.00	0.00	0.00	0.00
Total amount of mix waste ultimately being fired/ burned openly in site III	Tonnes/day	0.00	0.00	0.00	0.00	0.00
Total amount of disposal waste fired/burned openly at the landfills/open dumps	Tonnes/day	24048.00	0.00	0.00	0.00	0.00

Composition of mixed waste openly burned/fired in the landfills/open dumps   [Help]

Food waste		45.05				
Garden waste		7.22				
Plastics		10.56				
Paper		8.61				
Textile		1.61				
Leather/rubber	(Percentage) %	0.44				
Glass		2.34				
Metal (aluminium + steel)		4.22				
Nappies (disposable diapers)		0.00				
Wood		0.00				
Hazardous waste		19.95				
Others		0.00				
Total		**100.00**	**0.00**	**0.00**	**0.00**	**0.00**

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)				
				BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
SLCPs	CH$_4$	CH$_4$ biogenic-Direct	From partially burned waste	3.70	0.00	0.00	0.00	0.00
	BC	Direct Emissions	From waste burning	0.65	0.00	0.00	0.00	0.00
Other GHGs	CO$_2$	Direct Emissions (fossil)	From waste burning	172.98	0.00	0.00	0.00	0.00
Net impact	Net BC emissions (kg of BC/tonne)			0.65	0.00	0.00	0.00	0.00
	Net climate impact of GHGs (kg of CO$_2$-eq/tonne)			276.58	0.00	0.00	0.00	0.00

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

Figure 17: Print screen view of open burning/landfill fire sheet

2.4.5 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.

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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 9.

Box 9: 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 ith 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 18.

Figure 18: 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 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) + 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 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$_2$O	CH$_4$	BC	CO$_2$	N$_2$O	CH$_4$	BC	CO$_2$	N$_2$O
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 19: Print screen view of summary table of GHGs/SLCPs

Summary of GHG and SLCP emissions from waste management in Philippir — Print Summary

Summary of waste generation, collection and utilization for different treatment options

Conditions	Tonnes/day				
	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total waste generatio	61,662	61,662	61,662	61,662	
Total collected and treated waste by the city	40,080	40,080	40,080	40,080	
Total collected and treated waste by informal sector					
waste (Scattered waste/wild dump/illegal dump)	21,582	21,582	21,582	21,582	

Summary of waste generation and utilization

- Total waste generation
- Total collected and treated waste by the city
- Total collected and treated waste by informal sector
- Total uncollected waste (Scattered waste/wild dump/illegal dump)

Please choose the prefered 'Unit' for emission — calculate emissions from yearly generated was

Summary of net GHG/SLCP emissions from waste management

Description	Technology	Unit	BAU				Scenario 1				Scenario 2				Scenario 3				Scenario 4			
			CH$_4$	BC	CO$_2$	N$_2$O	CH$_4$	BC	CO$_2$	N$_2$O	CH$_4$	BC	CO$_2$	N$_2$O	CH$_4$	BC	CO$_2$	N$_2$O	CH$_4$	BC	CO$_2$	N$_2$O
Waste collection and transportation by the	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	0.000	0.001	2.630	0.000				
Treatment for separated waste	Composting						3.999	0.001	-0.360	0.282	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	-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	28.879	0.000	0.000	0.000				
	Open burning/landfill		3.700	0.650	172.982																	
Uncollected waste	Open burning/scattered		9.871	0.325	86.491		8.021	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	15.580	0.113	-77.072	0.048	0.000	0.000	0.000	0.000
BC emissions from yearly generated waste:		Tonnes	8,321.93				2,559.72				2,559.72				2,538.23				0.00			
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				8,368,551.49				0.00			

Recommendation: As far as BC emissions is concerned, Scenario 3 has the lowest emissions and which seems to be the best option for your city
As far as other GHGs emissions is concerned, Scenario 3 has lowest net GHG emissions. Technological options used in this scenario seems to be the most appropriate choice for the city

GHGs/SLCPs emission per tonne of generated waste: kg/tonne

BC emissions from yearly generated waste: Tonnes

Climate impact from GHGs emissions from yearly generated waste: Tonnes of CO2-eq

[Sheet tabs: AD | Recycling | MBT | Incineration | Mix waste landfilling | Open burning and landfill fire | Uncollected waste | Summary | User guide | Figures]

Figure 20: 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.

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