User Manual

Estimation Tool for Greenhouse Gas (GHG) Emissions from Municipal Solid Waste (MSW) Management in a Life Cycle Perspective

Version III-Chinese context

IGES Institute for Global Environmental Strategies

CCET IGES Centre Collaborating with UNEP on Environmental Technologies

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Estimation Tool for Greenhouse Gas (GHG) Emissions from Municipal Solid Waste (MSW) Management in a Life Cycle Perspective

This original tool was developed under the project of Measurement, Reporting and Verification (MRV) for low carbon development in Asia (FY2013)

December 2021

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Note to Users:

This is version III of the IGES GHG calculator, specifically developed to quantify life cycle GHG emissions from waste management systems in China. This version includes all existing waste treatment technologies. Country-specific default values and emission factors were referred to for estimating emissions from fossil energy consumption, grid electricity consumption, etc. Options for sanitary landfilling with gas recovery options have also been added.

All feedback from users is welcomed, with the aim of providing a modelling tool best suited to the requirements of local authorities and other users to facilitate sustainable waste management for climate change mitigation.

Please direct all feedback to: Dr. Nirmala Menikpura (nirmala.menikpura@mx.iges.or.jp), Dr. Dickella Gamaralalage Jagath Premakumara (premakumara@iges.or.jp) and Dr. Rajeev Kumar Singh (singh@iges.or.jp)

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Executive Summary

In 2011, IGES-Sustainable Consumption and Production (SCP) Group developed a simple spreadsheet simulation, the "IGES-GHG calculator", to facilitate the decision-making of local governments on the selection of appropriate technology and design of suitable waste management systems for climate change mitigation, as well as to evaluate their achievement or progress in GHG mitigation. In 2013, version II was developed, involving several modifications in technological and geographical coverage. This tool has since been utilized by many cities and institutions in the Asia-Pacific region for estimating GHG emissions in waste management.

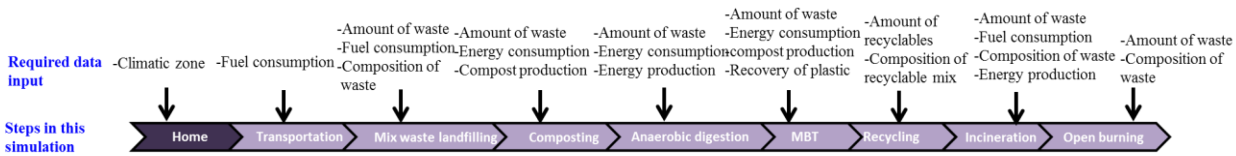
Rock Environment and Energy Institute (REEI) in China is also planning to conduct several awareness-raising seminars or workshops to support Chinese NGOs concerned with MSW management issues, to help them integrate climate policies into their project designs and master the methods used in carbon accounting for MSW management. REEI identified the IGES-GHG calculator as a user-friendly tool to introduce to the participating NGOs and other stakeholders for estimating climate impacts from the waste sector in China and approached IGES Centre Collaborating with UNEP on Environmental Technologies (CCET) for collaboration in modifying the tool. Considering the request and strong interest of REEI in modifying the tool, CCET agreed to collaborate with REEI to carry out the necessary modifications in line with China's waste management context as well as translate both the modified GHG calculator and the user manual to better assist Chinese NGOs in understanding and using the tool. CCET hereby acknowledges REEI for their kind support and contributions in translating the tool and user manual into Chinese.

This therefore is version III of the IGES GHG calculator, which was specifically developed to qualify life cycle-based GHGs emissions from waste management systems in China. This version incorporates all existing waste management options in China; for example, sanitary landfilling with gas recovery options have been newly added into the treatment options to enhance the technological coverage. The recycling sheet has been modified significantly to estimate the GHG mitigation potential from material recovery and circularity, and the waste incineration sheet has been improved to calculate the potential GHG avoidance through energy recovery options in China.

Further, in this version of the GHG calculator, the calorific value of China's fossil fuel mix and updated GHGs emission factor for grid electricity production in China are used throughout the tool to calculate GHGs emissions more precisely. In addition, updated Global warming potential (GWP) values as stated in the IPCC Fourth Assessment Report (AR4) have been used. The user manual was revised by incorporating all the improvements and modifications and both the calculator and user manual were translated into Chinese for enhanced user-friendliness.

This simulation consists of 10 spreadsheets, defined by the following names: User guidance, Home, Transportation, Mix waste open dumping/landfilling, Composting, Anaerobic Digestion, Mechanical Biological Treatment (MBT), Recycling, Incineration and Open burning. Except for

the first two sheets (User guidance and Home), users are asked to enter input data in all sheets and select the most appropriate conditions according to the waste-management practices of their local authority. Therefore, users need to prepare the required input data for each sheet in order to calculate the GHG emissions in each field, i.e., transportation, landfilling, composting, anaerobic digestion, MBT, recycling, incineration and open burning, as shown in the chart below. If a municipality lacks any of the technologies and wishes to know the climate impact, default values provided by the developer can be used.



To quantify GHG emissions from a range of waste management technologies, this simulator adopts IPCC 2006 guidelines, making the tool useful for bottom-up approaches of national greenhouse gas inventories and for the reporting of related direct emissions. Where other literature sources were used for estimations, their use is explicitly stated. Mathematical formulas have been assigned to spreadsheet cells to quantify GHG emissions from different phases of life cycles. Detailed explanations of all mathematical formulas used throughout the simulation are given in accordance with the technology in question. The simulator calculates both the total GHG emissions and GHG avoidance potentials of individual technologies, based on which net GHG emissions are calculated for all technologies individually. The net GHG emissions value reflects the overall climate impact or benefit of a particular technology taking into account the impact of all possible resource and material recovery from the waste. Hence, estimated net GHG emission values for an individual treatment method can be used as tangible figures in decision-making and policy recommendation processes.

If this simulator is applied to quantify climate benefits from an integrated waste management system, net GHG emissions from individual technologies are aggregated based on the fractions of waste treated by such technologies. Thus, estimated net GHG emissions from an integrated system indicate the overall progress attained by the system overall. This kind of holistic approach is highly beneficial as it provides a systematic methodology to quantification of potential total GHG mitigation from an entire integrated waste management system. For local governments in the process of selecting or quantifying effects of climate friendly waste management technologies, this tool could prove highly useful in estimations of the related GHG emissions.

It should be noted, however, that this version does not calculate climate impact from black carbon (BC) emissions from open burning of waste, therefore comparisons of climate impact from different scenarios are not possible. If the Chinese organization/NGO concerned wishes to estimate overall climate impact from several scenarios including the impact from black carbon, they are highly recommended to use the more advanced "Emission Quantification Tool (EQT)", developed by IGES-CCET.

Table of Contents

Introduction

Greenhouse gas (GHG) emissions resulting from conventional solid waste management practices in developing Asian countries contribute significantly to global climate change. Methane (CH_4) emissions from open dumping and landfilling – currently the two most common waste treatment methods in Asia – represent the third highest source of anthropogenic methane emissions. In addition, GHG 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-based energy. While it is possible to obtain indirect GHG savings via materials and energy recovery from waste management, local authorities responsible for waste management, however, tend to have a poor grasp of the linkage between waste management and climate change.

In this connection, the Sustainable Consumption and Production (SCP) Group at IGES has to date conducted several capacity-building workshops for local governments in Cambodia, Lao PDR and Thailand with the aim of promoting waste utilisation for climate-change mitigation. A training programme on estimation of GHG emissions from waste management practices also took place. However, personnel from local authorities found the procedure and mathematical formulas used in the estimation too complex. This led IGES to develop an initial version of the IGES GHG calculator as a simple spreadsheet simulation to facilitate local governments in estimating GHG emissions from current waste management practices, to support decision-making processes of local governments on selecting appropriate technologies for GHG mitigation, to evaluate progress made by adopting suitable waste management approaches, and to contribute to bottom-up approaches for national greenhouse gas inventory reports.

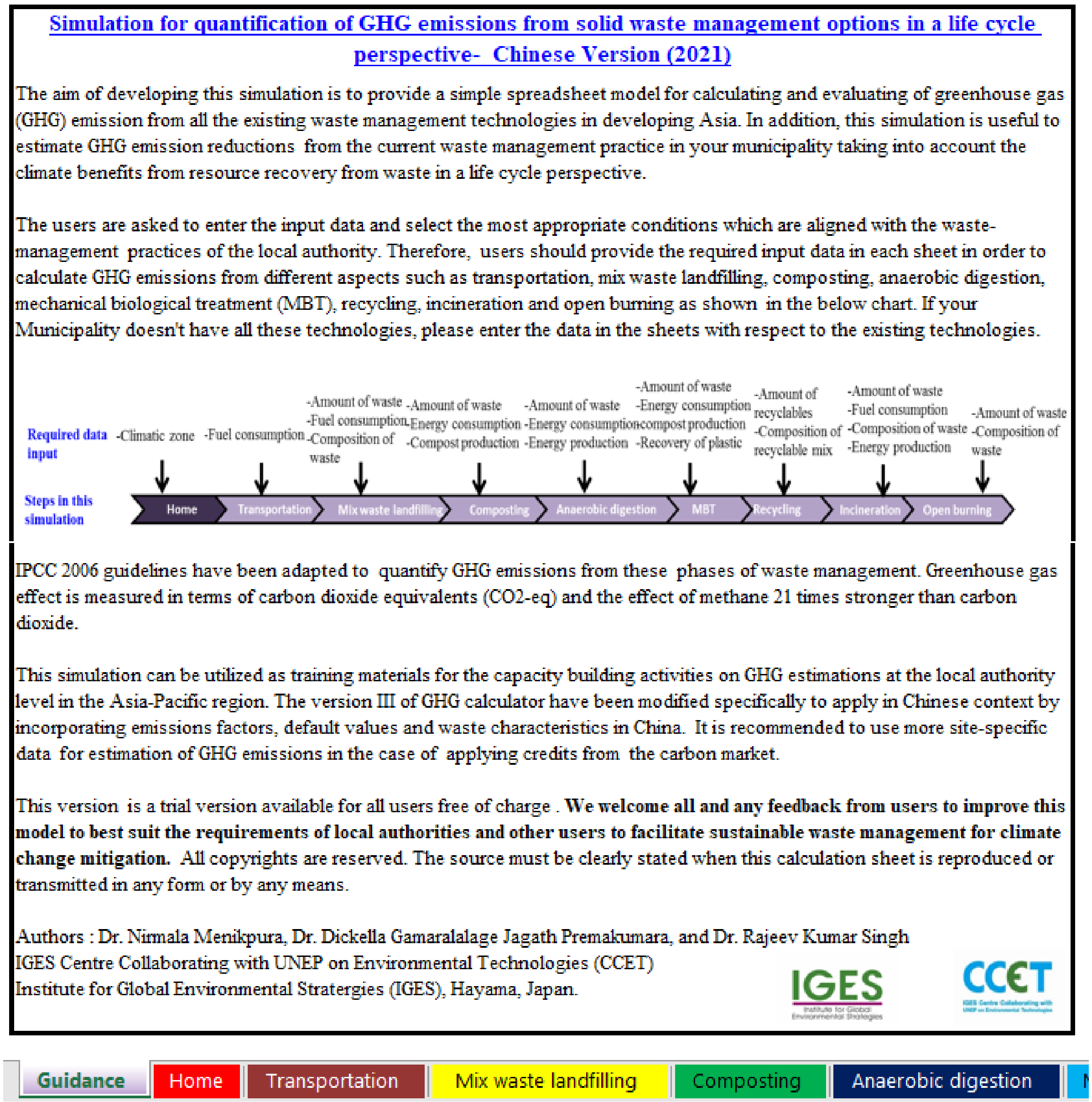
This GHG estimation model can be applied to quantify GHG emissions from individual treatment technologies as well as integrated systems. The life cycle approach (LCA) was adopted for developing this simulation. By using this model, users can see the results of both direct emissions (used for national greenhouse gas inventories and carbon markets) and GHG savings (used for decision making). Further, the model can be applied in countries across the Asia-Pacific region by selecting/entering country- or location-specific parameters at the designated points in each sheet. The current version III of the GHG calculator has been modified specifically to apply to the Chinese context by incorporating the emissions factors, default values and waste characteristics pertaining to China.

This simulation consists of 10 spreadsheets, defined using the following names: User guidance, Home, Transportation, Mix waste landfilling, Composting, Anaerobic Digestion, Mechanical Biological Treatment (MBT), Recycling, Incineration and Open burning. Other than the first two sheets (User guidance and Home), users are asked to enter the input data in all sheets and select the most appropriate conditions in accordance with the waste management practices of their local authority. Therefore, users need to provide the required input data for each sheet to calculate GHG emissions from the different fields, i.e., transportation, landfilling, composting, anaerobic digestion, MBT, recycling, incineration and open burning. If a municipality or city currently lacks any of the technologies, data on available existing technologies or selected technologies to be implemented can be entered in the corresponding sheets.

Detailed explanations of individual sheets follow in the sections below.

1. User guidance page

The first sheet of the simulator explains the aim behind developing the tool and offers guidance in its use. By reading the user guidance sheet, users will understand the types of data required to quantify GHG emissions from a waste management system with respect to existing technologies. This sheet is shown in Figure 1.



Simulation for quantification of GHG emissions from solid waste management options in a life cycle perspective- Chinese Version (2021)

The aim of developing this simulation is to provide a simple spreadsheet model for calculating and evaluating of greenhouse gas (GHG) emission from all the existing waste management technologies in developing Asia. In addition, this simulation is useful to estimate GHG emission reductions from the current waste management practice in your municipality taking into account the climate benefits from resource recovery from waste in a life cycle perspective.

The users are asked to enter the input data and select the most appropriate conditions which are aligned with the waste-management practices of the local authority. Therefore, users should provide the required input data in each sheet in order to calculate GHG emissions from different aspects such as transportation, mix waste landfilling, composting, anaerobic digestion, mechanical biological treatment (MBT), recycling, incineration and open burning as shown in the below chart. If your Municipality doesn't have all these technologies, please enter the data in the sheets with respect to the existing technologies.

IPCC 2006 guidelines have been adapted to quantify GHG emissions from these phases of waste management. Greenhouse gas effect is measured in terms of carbon dioxide equivalents (CO2-eq) and the effect of methane 21 times stronger than carbon dioxide.

This simulation can be utilized as training materials for the capacity building activities on GHG estimations at the local authority level in the Asia-Pacific region. The version III of GHG calculator have been modified specifically to apply in Chinese context by incorporating emissions factors, default values and waste characteristics in China. It is recommended to use more site-specific data for estimation of GHG emissions in the case of applying credits from the carbon market.

This version is a trial version available for all users free of charge . **We welcome all and any feedback from users to improve this model to best suit the requirements of local authorities and other users to facilitate sustainable waste management for climate change mitigation.** All copyrights are reserved. The source must be clearly stated when this calculation sheet is reproduced or transmitted in any form or by any means.

Authors : Dr. Nirmala Menikpura, Dr. Dickella Gamaralalage Jagath Premakumara, and Dr. Rajeev Kumar Singh
IGES Centre Collaborating with UNEP on Environmental Technologies (CCET)
Institute for Global Environmental Stratergies (IGES), Hayama, Japan.

Figure 1: User guidance page of the simulator

2. Home page

On the home page, users are asked to enter the name of the city/municipality and select the country and climatic zone of their country. Options such as in the drop-down list in Figure 2 are available. After entering the location and climatic zone, all country-specific data and information (e.g., GHG emissions from national grid electricity production, GHG emissions from fossil-fuel combustion) are assigned automatically to the mathematical formulas throughout the spreadsheet for quantifying GHG emissions from different phases of life cycles.

The home page has also been designed to display a summary of the GHG emissions results from a particular waste management system. At the data-entry stage, users are presented a message "Summary of GHG emissions from waste management in your municipality will appear with respect to the following activities once you enter the required data in other sheets". This alerts users to check the home page to see the overall results of GHG estimations after data entry. In the summary table, direct GHG emissions (e.g., due to fossil energy consumption, waste degradation, combustion of fossil based waste fractions), total GHG savings (e.g., via material and energy recovery and net GHG emissions) are displayed with respect to individual treatment methods and from the entire waste management system. In addition, total GHG reduction/emissions from monthly managed waste is displayed, which is useful in identifying the progress achieved.

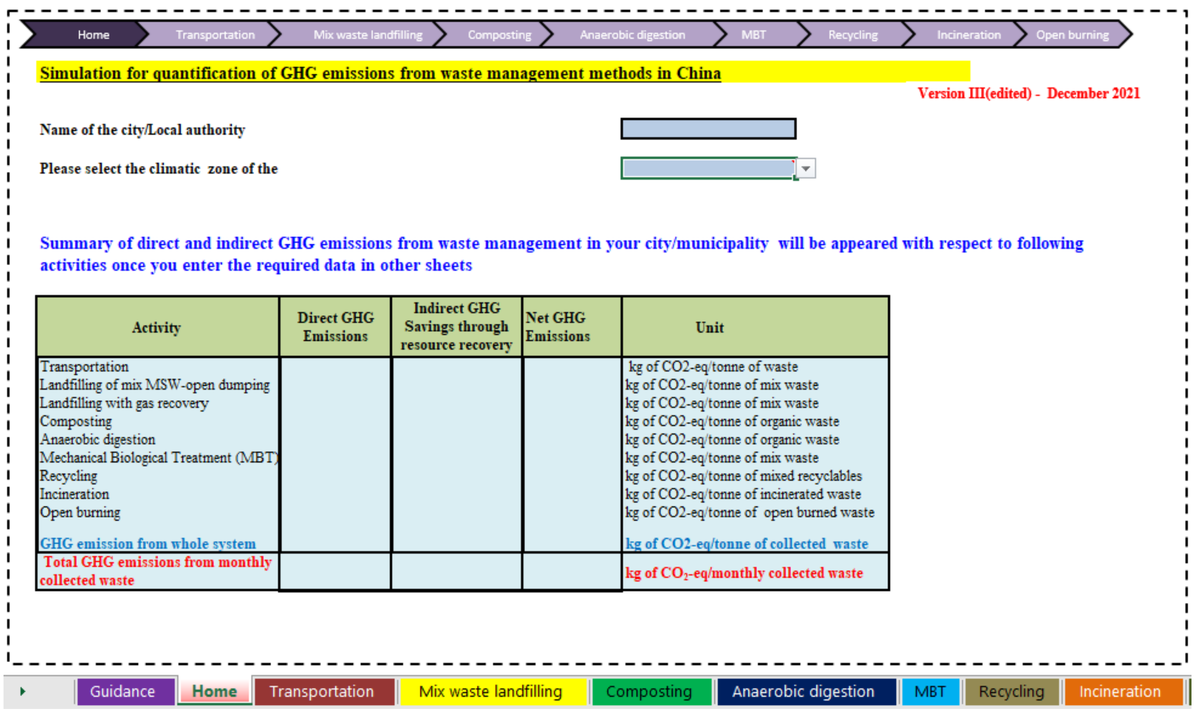


Figure 2: Home page of the simulator

3. Estimation of GHG emissions from waste transportation

MSW transportation consumes significant amounts of fossil fuels and leads to GHG emissions due to fossil-fuel combustion. Therefore, the third sheet of the simulation was developed to quantify GHG emissions generated from waste transportation. Two major types of fossil fuel are used for waste transportation in developing Asia, namely diesel and natural gas. Therefore, users are asked to enter the amounts of waste transported per month and the corresponding amounts of fossil-fuel usage with respect to the two major types of fossil fuel, as shown in Figure 3. Further, as some cities in China use electric trucks for waste transportation, users are asked to enter amounts of waste transported by electric vehicles and the monthly electricity consumption rates of all electric trucks.

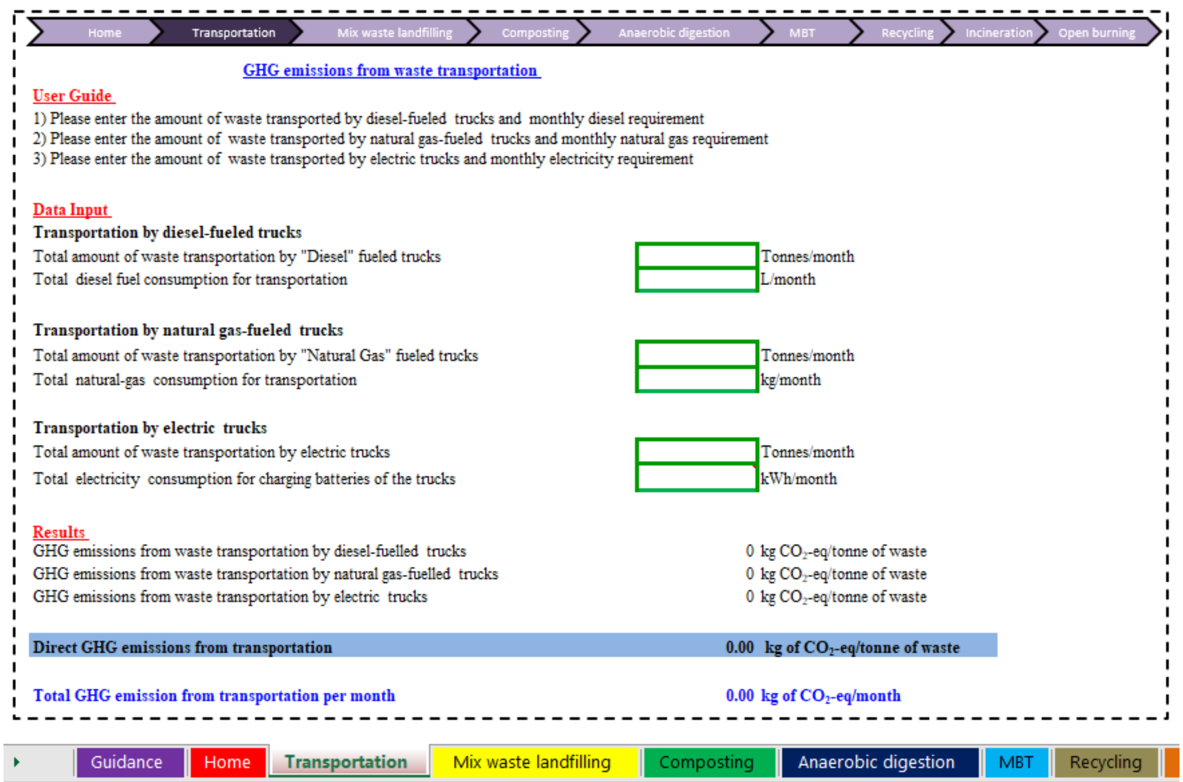


Figure 3: Page for quantification of GHG emissions from waste transportation

GHG emissions from extraction of crude oil, importation and the refining process are not included in this simulation since such emissions may not be significant (Menikpura, 2011). Also, CH_4 and N_2O emissions from fossil fuel combustion are assumed to be negligible, therefore CO_2 can be considered as the major component of GHG emissions from waste transportation. Mathematical formulas have been assigned to quantify CO_2 emissions from each type of fossil fuel.

Total GHG emissions from combustion of any kind of fossil fuel during waste transportation can be calculated as follows:

$$Emissions_{FF} = \frac{Fuel(units)}{Waste(tonnes)} \times Energy(MJ/unit) \times EF(kgCO2/MJ)$$

$Emissions_{FF}$ - Emissions from fossil fuel based vehicles (kg CO_2/tonne of waste transported)
Fuel (units) - Total amount of fossil fuel consumption per month, (diesel in Litres and Natural gas in kg)
Waste (tonnes) - Total amount of waste transported per month
Energy (MJ/unit) - Energy content of the fossil fuel (e.g., Diesel 36.42 MJ/L, Natural gas 37.92 MJ/kg)
EF - CO_2 emission factor of the fuel (e.g., diesel: 0.074 kg CO_2/MJ, Natural gas: 0.056 kg CO_2/MJ)

Total GHG emissions due to the use of electric vehicles for waste transportation can be calculated as follows:

$$Emissions_E = \frac{Electricity(kWh)}{Waste(tonnes)} \times EF(kgCO2/kWh)$$

$Emissions_E$ - Emissions from electric vehicles (kg CO_2/tonne of waste transported)
Electricity (kWh) - Total amount of electricity used per month
Waste (tonnes) - Total amount of waste transported by electric trucks per month
EF - CO_2 emission factor of grid electricity production in China (0.855 kg CO_2-eq/kWh)

Some municipalities may replace diesel fuel with natural gas with the aim of reducing GHG emissions from waste transportation. Therefore, this simulation shows the GHG emissions resulting from diesel-fueled as well as natural gas-fueled trucks per tonne of waste transportation. If a municipality uses both types of fuel and electric trucks, the results will show the aggregated effects due to the utilisation of diesel, natural gas and electricity, as shown in Figure 3. Further, monthly GHG emissions from transportation can be estimated as follows:

Monthly GHG emissions (kg CO_2-eq/month) = GHG emissions per tonne × tonne of waste transported per month

4. Estimation of GHG emissions from landfilling

Landfilling is the most common waste disposal method throughout the world. Landfill technologies have developed drastically over the last few decades, but these developments have not yet reached all parts of the world (Manfredi et al., 2009). For example, most developing countries in Asia still practice open dumping and landfilling without gas recovery, and waste is generally disposed of in open dumps without a landfill cover. While some governments promote the development of on-land disposal towards sanitary landfills, in some cases sanitary landfill technologies have been applied without landfill gas recovery systems, thus most of the landfill gas escapes into the atmosphere without any treatment or control. However, a growing trend towards sanitary landfilling with gas recovery systems as a solution to reducing the release of methane emissions into the atmosphere and for recovering energy from landfill gas has been observed in China. Therefore, an option covering GHG emissions from "sanitary landfilling with gas recovery" has been incorporated as part II in the landfill sheet in this version of the tool. If your city/municipality has no sanitary landfill with gas recovery projects, you need not enter any data in the part II field; entering data in part I under open dumping/landfilling without gas recovery suffices for estimating emissions from final disposal.

The anaerobic decomposition of MSW in open dumps and landfills eventually generates landfill gas (LFG), comprising 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 generally regarded as of biogenic origin and thus not considered as GHG (CRA, 2010). Uncontrolled emission of CH_4 from landfilling has been ranked as the third largest source of anthropogenic CH_4 emissions (IPCC, 2007).

The amount of methane generated at disposal sites depends on many factors, such as the quantity and composition of waste, moisture content, pH, and waste management practices. In general, methane production increases with higher organic content and higher moisture content at disposal sites. A managed sanitary landfill can potentially yield more methane than an unmanaged disposal site (open dump), where large amounts of waste can decay anaerobically in top layers. Deeper unmanaged solid waste disposal sites result in higher emissions of methane than shallow unmanaged sites.

To quantify GHG emissions from normal waste management disposal practices in landfills, this simulation incorporates the IPCC 2006 Waste Model. Emissions from various solid waste disposal site types can be calculated using default values adjusted for country- or region-specific waste composition and climate factors as well as circumstances at disposal sites. The IPCC guidelines strongly encourage use of the First Order Decay (FOD) model, which produces more accurate emissions estimates since it reflects the degradation rate of wastes at disposal sites (IPCC 2006).

The IPCC model utilizes the following mathematical formula to quantify GHG emissions from landfilling or open dumping:

The basic equation for the first order decay model is:

(1) $DDOC_m = DDOC_{m(0)} \times e^{-kt}$

where $DDOC_{m(0)}$ is the mass of decomposable degradable organic carbon (DDOC) at the start of the reaction when t=0 and $e^{-kt}=1$, k is the reaction constant and t is the time in years. $DDOC_m$ is the mass of DDOC at any given time.

From equation (1), it can be understood that at the end of year 1 (going from point 0 to point 1 on the time axis) the mass of DDOC left undecomposed in the SWDS is:

(2) $DDOC_{m(1)} = DDOC_{m(0)} \times e^{-k}$

and the mass of DDOC decomposed into CH_4 and CO_2 will be:

(3) $DDOC_{mdecomp(1)} = DDOC_{m(0)} \times (1 - e^{-k})$

In a first order reaction, the amount of the product (decomposed $DDOC_m$) is always proportional to the amount of reactant ($DDOC_m$), which means that when the $DDOC_m$ was deposited is irrelevant. It also means that when the amount of $DDOC_m$ accumulated in the disposal site, added to the previous year's deposit, is known, CH_4 production can be calculated as if every year were year number one in the time series. Therefore, all calculations can be done using equations (2) and (3) in a simple spreadsheet. The default assumption is that CH_4 generation from all the waste deposited each year begins on the 1st of January in the year after deposition. The assumption is that since it takes some time for anaerobic conditions to become well established, decomposition in the first year can take place aerobically, in which methane generation does not occur. However, when the calculation includes the possibility of an earlier start to the reaction, in the year of deposition of the waste, this requires separate calculations for the deposition year.

To calculate the mass of decomposable DOC ($DDOC_m$) from the amount of waste material (W):
(4) $DDOC_{md(T)} = W_{(T)} \times DOC \times DOC_f \times MCF$

The amount of deposited DDOCm remaining undecomposed at the end of deposition year T:
(5) $DDOC_{mrem(T)} = DDOC_{md(T)} \times e^{(-k \cdot ((13-M)/12)}$

The amount of deposited DDOCm decomposed during deposition year T:
(6) $DDOC_{mdec(T)} = DDOC_{md(T)} \times (1 - e^{(-k \cdot ((13-M)/12))})$

The amount of DDOCm accumulated in the disposal site at the end of year T:
(7) $DDOC_{ma(T)} = DDOC_{mrem(T)} + (DDOC_{ma(T-1)} \times e^{-k})$

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

The amount of CH_4 generated from DOC decomposed:
(9) CH_4 $generated_{(T)} = DDOC_{mdecomp(T)} \times F \times 16/12$

The amount of CH_4 emitted from disposal site:
(10) CH_4 emitted in year T = $(\Sigma CH_4 \text{ generated}_{(T)} - R_{(T)}) \times (1 - OX_{(T)})$

Where:

- T - Year of inventory
- $W_{(T)}$ - Amount deposited in year T
- MCF - Methane Correction Factor
- DOC - Degradable organic carbon (under aerobic conditions)
- DOC_f - Fraction of DOC decomposing under anaerobic conditions (0.0–1.0)
- DDOC - Decomposable Degradable Organic Carbon (under anaerobic conditions)

$DDOC_{md(T)}$ - Mass of DDOC deposited year T
$DDOC_{mrem(T)}$ - Mass of DDOC deposited in inventory year T, remaining undecomposed at the end of year
$DDOC_{mdec(T)}$ - Mass of DDOC deposited in inventory year T, decomposed during the year
$DDOC_{ma(T)}$ - 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
$DDOC_{mdecomp(T)}$ - Total mass of DDOC decomposed in year T
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)
16/12 - Molecular weight ratio CH_4/C
$R_{(T)}$ - Recovered CH_4 in year T
$OX_{(T)}$ - Oxidation factor in year T (fraction)
k - Rate of reaction constant
M - Month of reaction start (= delay time + 7)

In order to calculate methane emissions from a landfill or open dump site, numerous default values are required, the accuracy of which determines the estimated amount of methane generation. The details of the required default values are presented in Table 1.

Table 1: Factors and default values required for application of IPCC 2006 waste model

Factor	**Unit**	**Method of derivation**
Amount of mix waste disposal	Tonnes/month	Amount/description
Amount deposited	Gg/Year	MSW disposal (tonnes/month) × 12/1000
Degradable Organic Carbon (DOC)	DOC	Derived based on IPCC default DOC content values, DOC_{MSW} = % of food waste × 0.15 + % of garden waste × 0.43 + % of paper waste × 0.4 + % of textile waste × 0.24
Fraction of DOC decomposing under Anaerobic condition (DOCf)	DOC_f	IPCC default value is 0.5
Methane generation rate constant	K	k value will depend on waste composition of the location k_{MSW} = % of food waste × 0.4 + % of garden waste × 0.17 + % of paper waste × 0.07 + % of textile waste × 0.07 + % of disposable nappies × 0.17 + % of wood and straw × 0.035
Half-lifetime (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 starts 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 (with or without gas recovery) is 0.1. For open dumpsites the OX value would be zero.
MCF for the landfill/open dumpsite	MCF	This value varies according to management practices. IPCC recommended default MCF values for Managed (has landfill cover and liner), unmanaged-deep (> 5m waste), Unmanaged-shallow (<5m waste), Uncategorized are 1, 0.8, 0.4 and 0.6 respectively.

In this simulator, to calculate the total potential GHG emissions from open dumping or sanitary landfilling with or without gas recovery in a particular location, users are asked to enter monthly average data such as amounts of mixed waste for landfilling, fossil fuel utilisation for operational activities at the landfill and the composition of mixed MSW. Users are also asked to select the type of landfill from a drop-down list, as seen in Figure 4. To calculate GHG emissions from the landfill, the sum total of the different fractions of waste needs to be 100%, otherwise an error message is displayed until the total is adjusted to 100%.

If a city has a sanitary landfill with gas recovery project, this tool assumes the disposal waste composition is similar to the waste composition disposal types under part I. The remaining technology-specific data such as daily disposal amounts, starting and ending years of waste disposal of a particular site, amount of fossil fuel and grid electricity consumption for operational activities, efficiency of gas collection, method of treatment of recovered landfill gas and starting and ending year of landfill gas collection, etc. need to be provided in part II.

The methane production per tonne of waste by degradation throughout the life cycle is calculated and presented as kg of CH_4 production per tonne of waste under option I and option II. In addition, total GHG emissions from mixed waste are calculated as follows:

GHG emissions from option I: GHG emissions from mixed waste landfilling/open dumping = CH_4 emissions per tonne of waste × GWP_{CH4} + GHG emissions from operational activities

GHG emissions from option II: GHG emissions from each tonne of mixed waste in sanitary landfill with gas recovery = GHG emissions from operational activities + (CH_4 emissions per tonne of waste – Collected CH_4) × GWP_{CH4} – Avoided GHGs through recovered electricity/landfill gas for thermal energy

In the above, GWP_{CH4} - Global Warming Potential of CH_4 (the GWP of CH_4 was considered as 25 times higher than CO_2 on a time horizon of 100 years).

Based on this estimated value, the simulation can be used to calculate monthly GHG emissions from mixed MSW landfilling for specific locations.

Monthly GHG emissions (kg CO_2-eq/month) = GHG emissions per tonne of waste disposed in option I × Total amount of waste landfilled/open dumped (tonnes/month) in option I + GHG emissions per tonne of waste disposed in option II × Total amount of waste of sanitary landfill with gas recovery (tonnes/month)

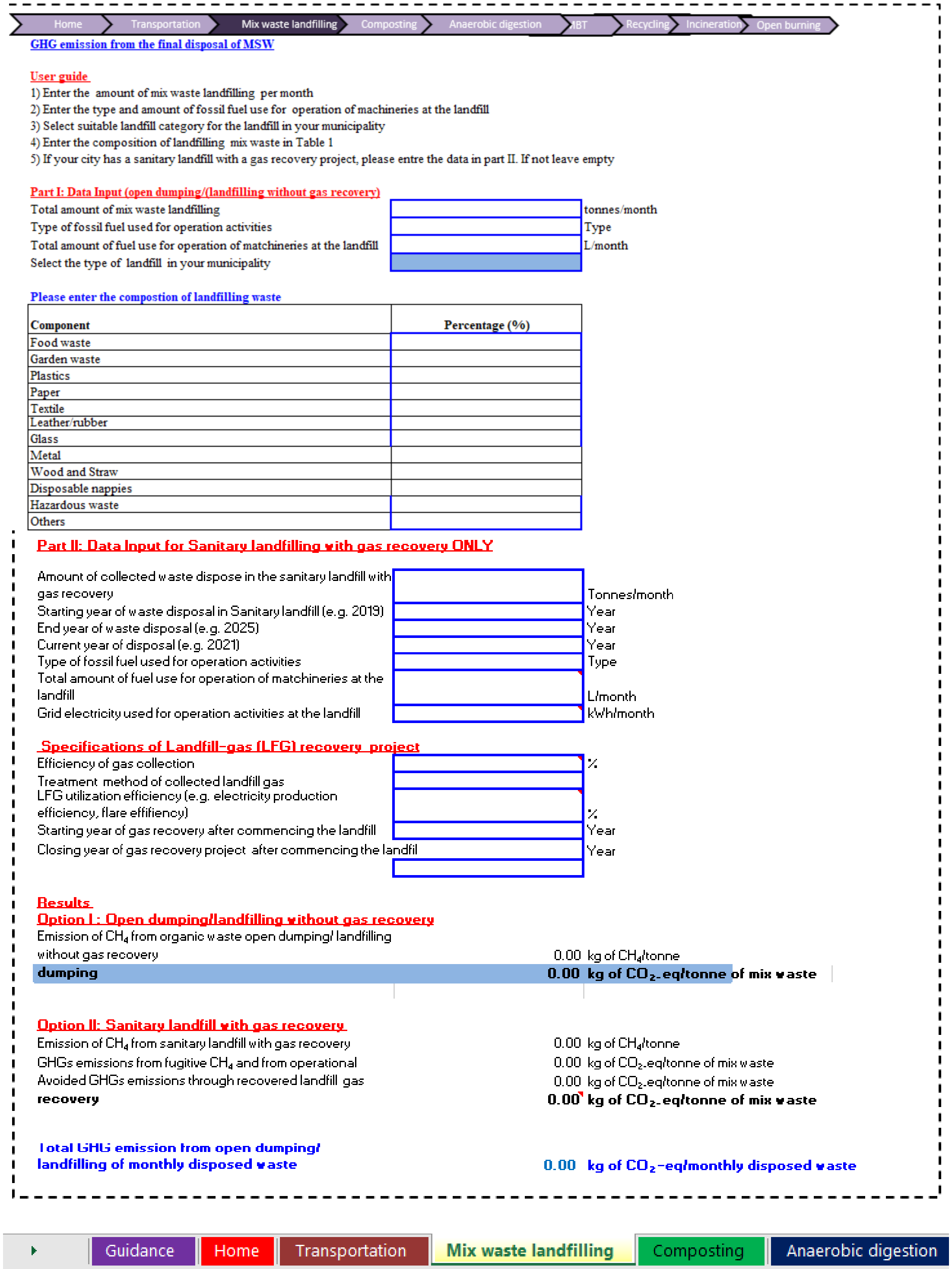


Figure 4: Page for quantification of GHG emissions from landfilling

5. Estimation of GHG emissions from composting

Recognition of the importance of organic waste composting has steadily risen in developing Asia. Of the technologies that utilize organic waste, local governments prefer composting as it is simple, easy to manage and low cost. As a waste management option, it is one of the most popular in Asia. The fourth excel sheet of this simulator was designed for quantification of the potential GHG emission mitigation from composting technology.

There are two major ways composting can cause GHG emissions: from utilisation of fossil energy (e.g., electricity and diesel) for composting operations and from organic waste degradation.

As regards organic waste degradation as a cause of GHG emissions, composting is an aerobic degradation process whereby a large fraction of the degradable organic carbon in the waste material is converted into CO_2; however, such CO_2 emissions are of biogenic origin and not accounted for in GHG calculations. Further, CH_4 can be generated from anaerobic degradation of waste in deep layers of composting piles; however, this is mostly oxidised in the aerobic sections of compost piles. Composting can also produce emissions of N_2O in minor concentrations. In this study, IPCC-published average default emission factors (e.g., 4 kg CH_4/tonne of organic waste on a wet basis and 0.3 kg N_2O/tonne of organic waste on a wet basis) were used to quantify the GHG emissions from composting (IPCC, 2006).

Significant amounts of marketable compost can potentially be produced from one tonne of organic waste, which can be used for agricultural purposes to replace conventional fertilizer. As reported in the literature, one tonne of good-quality compost can be used in place of chemical fertilizer, since it is capable of suppling the essential nutrients: 7.1 kg of nitrogen (N), 4.1 kg of phosphorus (P_2O_5) and 5.4 kg of potassium (K_2O) per tonne of compost (Patyk, 1996)[1]. Based on these figures, the GHG mitigation potential in terms of GHGs avoided through not using chemical fertilizer, as estimated in this model, equates to 21.29 kg CO_2, 0.003 kg CH_4, 0.069 kg N_2O per tonne of compost (Bovea et al., 2010). However, in practice, this co-benefit should not be included in the calculation if farmers do not accordingly decrease their use of chemical fertilizer after applying compost.

In order to calculate all values related to potential emissions and avoidance, users are asked to enter monthly average data such as the amount of organic waste used for composting, fossil-fuel utilisation for operational activities, total amounts of compost produced and percentage of produced compost used for agricultural activities, as shown in Figure 5.

The following mathematic formulas have been assigned to the spreadsheet cells to quantify the GHG emissions from composting.

[1] This figure can be changed if site-specific or country-specific data is available.

GHG emissions from operational activities due to fossil fuel combustion are calculated as follows. As mentioned earlier, CH_4 and N_2O emissions from fossil fuel combustion are assumed to be negligible, and thus were not included in this equation.

$$Emissions_{Operation} = \frac{Fuel(L)}{Waste(tonnes)} \times Energy(MJ/L) \times EF(kgCO2/MJ)$$

$Emissions_{operation}$ - Emissions from operational activities (kg CO_2/tonne of waste transported)
Fuel (L) - Total amount of fossil fuel consumption per month
Waste (tonnes) - Total amount of organic waste utilisation per month
Energy (MJ/unit) - Energy content of the fossil fuel (e.g., Diesel 36.42 MJ/L)
EF - CO_2 emission factor of the fuel (e.g., diesel: 0.074 kg CO_2/MJ)

GHG emissions from waste degradation are calculated as follows:

$$Emission_{Degradation} = E_{CH4} \times GWP_{CH4} + E_{N2O} \times GWP_{N2O}$$

Where:
$Emissions_{Degradation}$ - Emissions from organic waste degradation (kg CO_2/tonne of organic waste)
E_{CH4}- Emissions of CH_4 during organic waste degradation (kg of CH_4/tonne of waste); in this model, the default value of 0.4 (average value given by IPCC (IPCC, 2006)) is used. This value should be updated to the site-specific one if available.
GWP_{CH4} - Global warming potential of CH_4 (25 kg CO_2/kg of CH_4)[2]
E_{N2O} - Emissions of N_2O during waste degradation (kg of N_2O/tonne of waste); in this model, the default value of 0.3 (average value given by IPCC (IPCC, 2006)) is used. This value should be updated to the site-specific one if available.
GWP_{N2O} - Global warming potential of N_2O (298 kg CO_2/kg of N_2O)[2]

Total GHG emissions from composting is calculated by adding GHG emissions from operations and waste degradation.

Total GHG emissions from composting = $Emissions_{Operation} + Emission_{Degradation}$

Avoided GHG emissions by replacing chemical fertilizer with compost is calculated as follows:

$$AvoidedGHG_{Compost} = AC \times PC_{Agriculture} \times A_{GHG}$$

Avoided $GHG_{Compost}$ - Avoided GHG from composting due to avoidance of chemical fertilizer production (kg CO_2-eq/tonne of waste)
AC - Amount of compost produced (tonne of compost/tonne of waste)

[2] The literature gives different GWP values for CH_4 and N_2O. However, this model uses values of 25 and 298 for CH_4 and N_2O respectively, which are GWP values based on AR4, since most of the published research makes use of AR4 values. GWP values given are based on a 100-year timescale.

$PC_{Agriculture}$ - Percentage of compost use for agricultural and gardening purpose (%)
A_{GHG} - GHG avoidance potential due to avoided chemical fertilizer production, equivalent to one tonne of compost (kg CO_2-eq/tonne of compost)

However, A_{GHG} should be excluded if compost users do not reduce chemical fertilizer use after application of compost.
In addition, as a result of initiating a composting facility, a significant amount of organic waste landfilling can be reduced and thereby GHG emissions from organic waste degradation in the landfill can be avoided. However, the avoided GHGs emissions will be accounted as a lower methane emission potential from the landfilling sheet due to the reduction of organic waste in the mixed waste landfilled.

Total avoided GHG emissions (kg CO_2-eq per tonne of organic waste) = Avoided GHG from compost use and replacement of chemical fertilizer

In order to understand the overall climate benefit or impact from composting technology, net GHG emissions can be calculated as follows:

$$\text{Net GHG emissions from composting} = \text{Total GHG emissions} - \text{Total GHG avoidance}$$

If the estimated net GHG emissions is a positive value (e.g., due to consumption of excessive amounts of fossil fuel or ineffective utilisation of produced compost for agricultural and gardening), users should understand that the current composting system is still contributing to climate impact and therefore further improvements are needed to mitigate GHG emissions. If the result is a net negative GHG emissions value, this indicates potential GHG savings from composting and the possibility of compost use as a carbon sink.

Further, monthly GHG emissions from composting can be estimated as follows:

Monthly GHG emissions (kg CO_2-eq/month) = GHG emissions per tonne × Total amount of waste used for composting per month

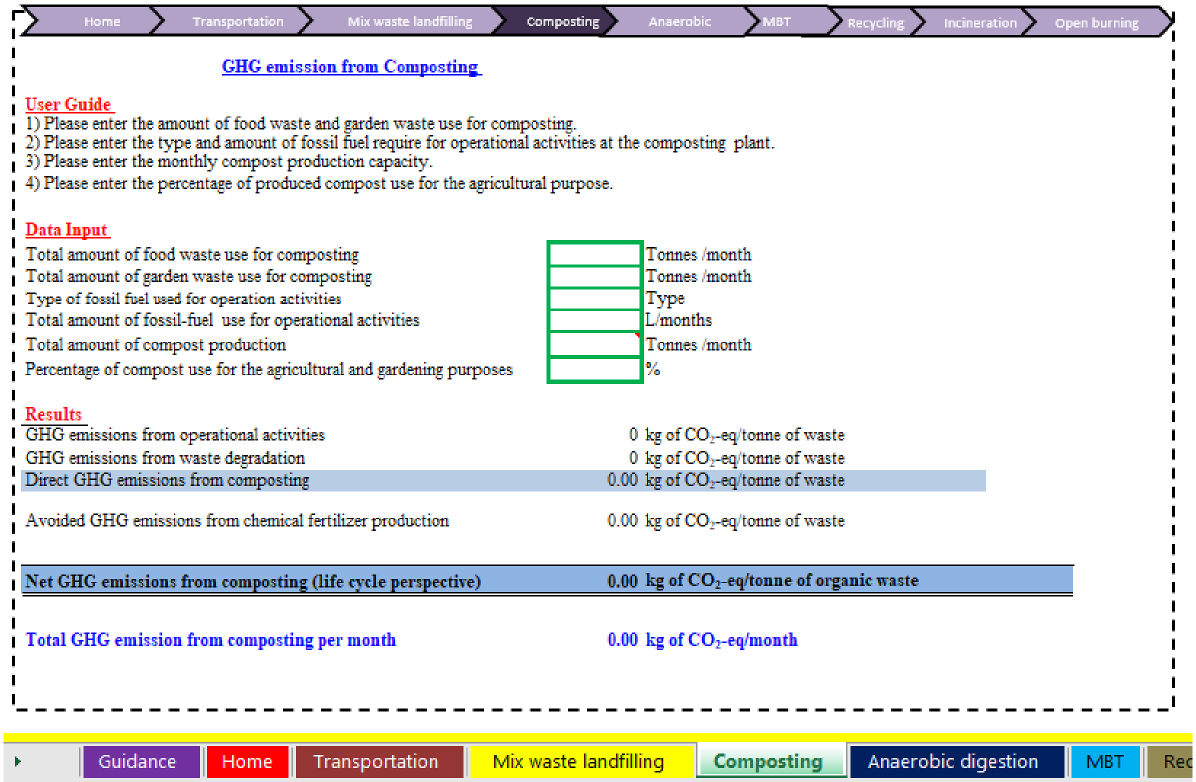


Figure 5: Page for quantification of GHG emissions from waste composting

6. Estimation of GHG emissions from anaerobic digestion

Of the various biological treatment methods available, interest is growing throughout developing Asia in the application of anaerobic digestion as a potential technology to treat organic waste. Anaerobic digestion is the most cost effective method due to its potential high energy recovery and low environmental impact.

In order to quantify overall GHG emissions from anaerobic digestion, a spreadsheet was designed to quantify both GHG emissions and GHG avoidance. There are two major ways that anaerobic digestion can result in GHG emissions: i) from fossil fuel (e.g., electricity and diesel) utilisation for operations; and ii) from the reactor, due to unavoidable leakages. This model uses the average default value (2 kg of CH_4/tonne of dry organic waste; IPCC, 2006) for methane emissions due to unavoidable leakages. This value should be updated to the site-specific one if available.

Anaerobic digestion has the potential to produce significant amounts of energy as biogas, with a calorific value of 20–25 MJ/m^3, is the major output. Biogas can be converted to thermal energy (heat) or electricity via various technologies, such as by burning it in small engines (<200 kW) or large internal-combustion engines (up to 1.5 MW) which can generate significant amounts of electricity (Pöschl et al., 2010). The produced electricity or thermal energy can be used to replace fossil-fuel-based conventional electricity and thermal energy production and thereby reduce the GHG emissions from those conventional processes.

Similarly to the outcome of composting technology, anaerobic digestion also helps avoid organic waste landfilling and thereby the corollary GHG emissions implicit in the degradation of organic waste in landfills.

In order to calculate all such potential emissions and avoidance from a particular anaerobic digestion facility, users are asked to enter monthly average data, such as amounts of organic waste used for anaerobic digestion, fossil-fuel use for operational activities, electricity use for operational activities, approximate moisture content of the influent (waste and water mix), and type of output from anaerobic digestion (electricity or thermal energy), as shown in Figure 6.

At the local authority level, accurately determining the water content of the influent can pose a challenge as the sample needs to be dried for 24 hours in an oven at 105–110^{0}C. However, the figure can be approximated based on the mixing ratio of waste and water. For instance, if 1 tonne of vegetable waste is mixed with 1 tonne of water to make the influent, the total moisture content would be 1.6 tonnes (approximate moisture content of vegetable waste is 60%). Therefore, the moisture content of the influent would be 80% (1.6 tonnes/2 tonnes ×100).

The following mathematic formulas have been assigned to the spreadsheet cells to quantify the GHG emissions and GHG avoidance from anaerobic digestion with respect to the data entered by the user.

Users are asked to select the product of anaerobic digestion; if they select the option “electricity”, the potential electricity production will be automatically calculated under the “outputs” corresponding to the data input, as can be seen in Figure 6. This is then calculated based on several figures obtained from the literature. A detailed quantification approach for “calculation of biogas and electricity” is shown in the lower part of the same spreadsheet.

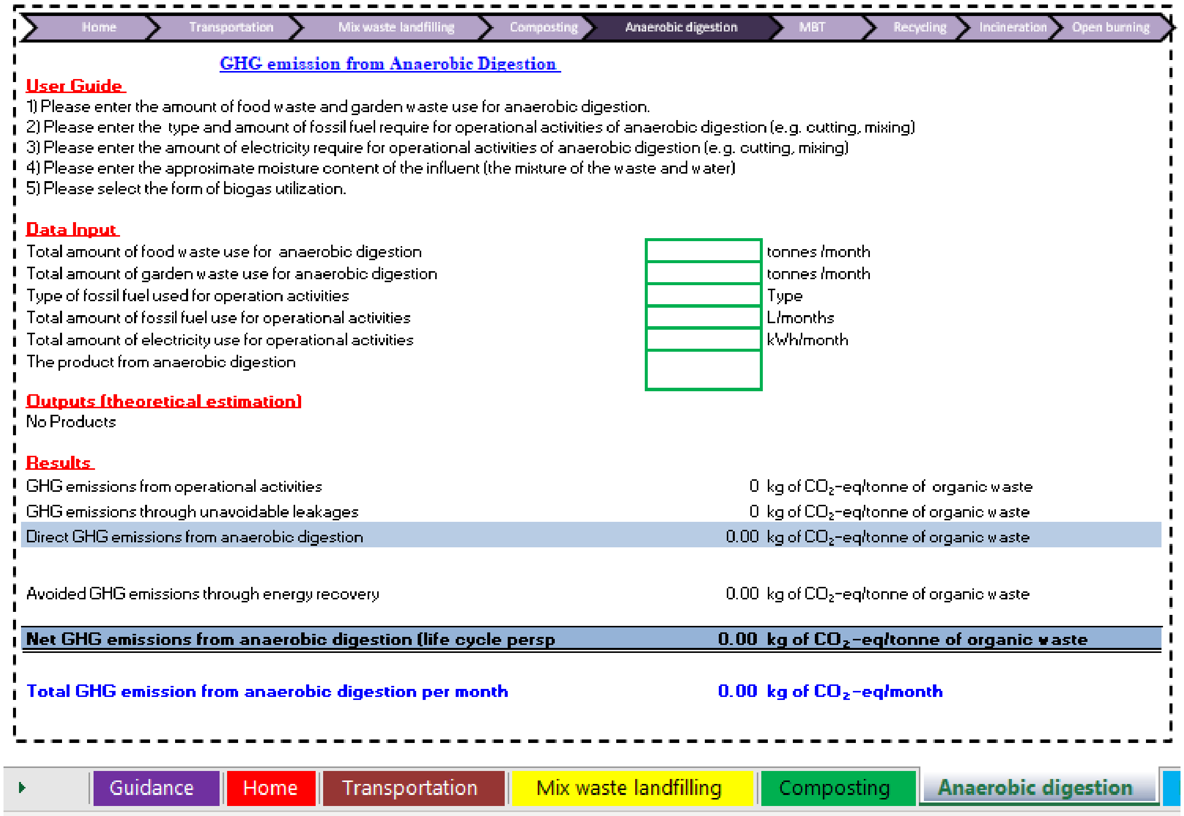


Figure 6: Page for quantification of GHG emissions from anaerobic digestion

Emissions of CO_2 owing to fossil fuel combustion and utilisation of electricity for machine operation can be calculated as follows. As mentioned earlier, CH_4 and N_2O emissions from fossil fuel combustion are considered to be negligible.

$$Emissions_{Operation} = (FC \times NCV_{FF} \times EF_{CO2}) + (EC \times EF_{el})$$

$Emissions_{Operation}$ - Emissions from operational activities (kg CO_2/tonne of organic waste)
FC - Fuel consumption apportioned to the activity type (mass or volume/tonne of organic waste)
NCV_{FF} - Net calorific value of the fossil fuel consumed (MJ/unit mass or volume)
EF_{CO2} - Emission factor of CO_2 by combustion of fossil fuel (kg of CO_2/MJ)
EC - Electricity consumption for operational activities (MWh/tonne of organic waste)
EF_{el} - Emission factor of country grid electricity production (kg CO_2-eq/MWh)

GHG emissions (mainly CH_4) due to leakages from the anaerobic digestion system can be calculated as follows:

$$Emissions_{Treatment} = E_{CH4} \times 1000 \times GWP_{CH4}$$

$Emissions_{Treatment}$ - Emissions from treatment of organic waste (kg CO_2/tonne of organic waste)
E_{CH4} - Emissions of CH_4 due to leakages (kg of CH_4/kg of wet weight)
1000 - Conversion factor to calculate dry matter content per tonne of organic waste

GWP_{CH4} - Global warming potential of CH_4 (25 kg CO_2/kg of CH_4)

Total GHG emissions from anaerobic digestion can be calculated by adding GHG emissions from operational activities and GHG emissions due to leakages.

Total GHG emissions = $Emissions_{Operation}$ + $Emissions_{Treatment}$

In addition, mathematical formulas were derived to estimate the potential avoidance of GHG emissions due to electricity production or use of biogas as thermal energy. If a municipality develops an anaerobic digestion facility for electricity production from biogas, the contribution for potential GHG avoidance can be calculated as follows:

$$AvoidanceGHG_{Electricity} = C_{Biogas} \times P_{CH4} \times E_{CH4} \times \frac{1}{CF_{Energy}} \times E_{Powerplant} \times EF_{el}$$

Avoidance $GHG_{Electricity}$ - Total GHG avoidance due to electricity production (kg CO_2 –eq/tonne of organic waste
C_{Biogas} - Used amount of biogas (m^3/tonne of organic waste)
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)

If a municipality develops an anaerobic digestion facility to use biogas as a thermal energy source, the GHG avoidance potential can be calculated as follows:

$$AvoidanceGHG_{Thermal} = C_{Biogas} \times P_{CH4} \times E_{CH4} \times EF_{CO2}$$

Avoidance $GHG_{Thermal}$ - Total GHG avoidance due to thermal energy production (kg CO_2 –eq/tonne of organic waste
C_{Biogas} - Collected amount of biogas (m^3/tonne of organic waste)
P_{CH4} - Percentage of CH_4 in biogas (%)
E_{CH4} - Energy content of CH_4 (MJ/m^3)
EF_{CO2} - Emission factor of CO_2 by combustion of liquid petroleum gas (LPG) (kg of CO_2/MJ) (In this model, it was assumed LPG consumption can be substituted by using biogas.)

Total avoided GHG emissions from anaerobic digestion can be calculated as follows:

$$\text{Total avoided GHG emissions (kg CO2} - \text{eq per tonne of organic waste)}$$
$$= \text{Avoided GHG from energy recovery}$$

In order to understand the overall climate benefit or impact from anaerobic digestion as an organic waste management option, net GHG emissions are calculated as follows:

$$\text{Net GHG emissions from anaerobic digestion (kg CO2} - \text{eq per tonne of organic waste)} \\ = \text{Total GHG emissions} \;\; - \;\; \text{Total GHG avoidance}$$

Similarly to composting technology, if the estimated net GHG emissions is as a positive value, this means that the anaerobic digestion technology is still contributing to climate impact and therefore the efficiency of energy recovery should be further improved for mitigating GHG emissions. If the result is a net negative GHG emission value, this indicates a potential GHG saving from anaerobic digestion and the possibility to act as a carbon sink. Furthermore, monthly GHG emissions/savings from a particular municipality can be calculated by using the estimated results of GHG emissions/ savings per tonne of organic waste.

Monthly GHG emissions/savings (kg CO_2-eq/month) = GHG emissions per tonne of organic waste × Total amount of organic waste use for anaerobic digestion per month (tonnes)

7. Estimation of GHG emissions from Mechanical Biological Treatment (MBT)

Generally, Mechanical Biological Treatment (MBT) is used as a pre-treatment either before thermal treatment or as the final disposal of solid waste. MBT can reduce the volume of waste through the decomposition of organic substances prior to landfilling, minimise GHGs emissions (methane) from landfill sites, and enhance separation into different material fractions, such as compost-like materials and high-energy fractions after stabilisation of waste prior to final disposal. MBT facilitates the rapid degradation of organic waste under optimised conditions (homogenisation, ventilation, irrigation), and the total mass loss during the process is as high as 50%. The stabilised material can be screened into three parts, such as compost-like materials, waste plastics (use to produce Refuse-derived fuel (RDF)) and inert materials.

Regarding GHG emissions from the MBT process, the major cause of GHG emissions is utilisation of fossil fuel, grid electricity for operational activities in the various stages, and degradation of organic waste. Under good management, there is a very low possibility for GHG to be produced from waste piles if the organic waste degradation occurs under aerobic conditions. If CH_4 production can take place in the bottom layer of MBT piles, most of the CH_4 can be oxidised under the aerobic sections of the piles, minimising the possibility of CH_4 release into the atmosphere. 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. Such CO_2 emissions have biogenic origin and are not factored in to GHG calculations. According to IPCC guidelines, the MBT process also produces N_2O in minor concentrations. In this simulation, IPCC-published average values of 4 kg CH_4/tonne of organic waste on a wet basis (range of 0.03–8.0 kg CH_4/tonne of waste) and 0.3 kg

N_2O/tonne of organic waste on a wet basis (range of 0.06–0.6 kg N_2O/tonne of waste) are used to quantify GHG emissions from degradation of organic waste in MBT piles.

Similarly to composting and anaerobic digestion technology, the MBT process can contribute to minimised organic waste landfilling in developing Asia, thereby avoiding the GHG emissions that would otherwise be implicit in the degradation of organic waste in landfills. In addition, the degraded organic waste can be used as compost, which consequently reduces amounts of chemical fertilizer used. Avoidance of chemical fertilizer use greatly contributes to reduced GHG. However, owing to concerns over heavy metal contamination in the compost-like product from MBT stemming from mixed waste, levels of such contamination should be determined prior to decision-making on whether the material should be used as compost.

Further, there is growing interest in developing Asia on the recovery of the plastic fraction from degraded mixed waste to produce refuse-derived fuel (RDF) or for extraction of crude oil via the pyrolysis process. While additional energy is required to produce RDF or crude oil, energy recovery from plastic via either process helps reduce GHG. By accounting for the total potential GHG avoidance, the overall contribution of MBT to climate impacts can be estimated.

In order to quantify overall GHG emissions from MBT, a spreadsheet was designed into this simulation for calculating both GHG emissions and GHG avoidance potentials from MBT processes. As with other spreadsheets, users are asked to enter monthly average data of MBT processes such as amounts of total waste for MBT, the types and amounts of fossil fuel required for operational activities at the MBT plant, and the amount of electricity required for operations at the MBT plant. Further, if users answer “Yes” for the option “Utilisation of degraded materials as compost”, they can then enter data related to compost production such as the monthly amount produced and the percentage used for soil amendment. If the above option is answered with “No”, no data needs to be input regarding compost production.

The next step is to select the answer to the option of “Separation of plastic at the end of MBT” from the drop-down list. If users select either “Yes-for RDF production” or “Yes-for crude oil production,” they are asked to enter such data as the amount of recovered waste plastics for crude oil/RDF production, diesel required for crude oil/RDF production, electricity required for crude oil/RDF production and percentage of produced crude oil/RDF used for energy production. If “No” is selected, no data needs to be input regarding production of RDF/crude oil.

If users enter all the required data, the amount of compost used for crop production and amount of RDF/crude oil used for energy purpose per tonne of waste input in the MBT plant will be displayed in the output. Furthermore, this simulation calculates GHG emissions, GHG avoidance and net GHG emissions from the entire MBT process per tonne of waste input.

Emissions of CO_2 owing to fossil-fuel combustion and utilisation of electricity for operating machines at MBT plants can be calculated as follows. As mentioned before, in this simulation, CH_4, N_2O emissions from fossil-fuel combustion are considered negligible.

$$Emissions_{Operation} = (FC \times NCV_{FF} \times EF_{CO2}) + (EC \times EF_{el})$$

$Emissions_{Operation}$ - Emissions from operational activities (kg CO_2/tonne of waste)
FC - Fuel consumption apportioned to the activity type (mass or volume/tonne of waste)
NCV_{FF} - Net calorific value of the fossil fuel consumed (MJ/unit mass or volume)
EF_{CO2} - Emission factor of CO_2 by combustion of fossil fuel (kg of CO_2/MJ)
EC - Electricity consumption for operational activities (MWh/tonne of waste)
EF_{el} - Emission factor of country grid electricity production (kg CO_2-eq/MWh)

GHG emissions from waste degradation in MBT piles are calculated as follows:

$$Emission_{Degradation} = E_{CH4} \times OW_{Percentage} \times GWP_{CH4} + E_{N2O} \times OW_{Percentage} \times GWP_{N2O}$$

Where:
$Emissions_{Degradation}$ - Emissions from organic waste degradation (kg CO_2/tonne of organic waste)
E_{CH4} - Emission of CH_4 during organic waste degradation (kg of CH_4/tonne of organic waste)
$OW_{Percentage}$ - Percentage of organic waste in the mixed waste (%)
GWP_{CH4} - Global warming potential of CH_4 (25 kg CO_2/kg of CH_4)
E_{N2O} - Emission of N_2O during waste degradation (kg of N_2O/tonne of waste)
GWP_{N2O} - Global warming potential of N_2O (298 kg CO_2/kg of N_2O)

Total GHG emissions from MBT are calculated by adding GHG emissions from operational activities to GHG emissions from degradation of organic waste under the anaerobic condition in the deep layers of the piles.

Total GHG emissions = $Emissions_{Operation}$ + $Emissions_{Treatment}$

Furthermore, if the recovered plastic fraction is used for the production of RDF or crude oil, the GHG emissions from those processes is estimated in this simulation by using the mathematical formula below:

$$Emissions_{RDF\ /\ crudeoil\ production} = (FC \times NCV_{FF} \times EF_{CO2}) + (EC \times EF_{el})$$

$Emissions_{Operation}$ - GHG Emissions from RDF and crude oil production (kg CO_2/tonne of waste)
FC - Fuel consumption apportioned to the operational activities (mass or volume/tonne of waste)
NCV_{FF} - Net calorific value of the fossil fuel consumed (MJ/unit mass or volume)
EF_{CO2} - Emission factor of CO_2 by combustion of fossil fuel (kg of CO_2/MJ)
EC - Electricity consumption for operational activities (MWh/tonne of waste)
EF_{el} - Emission factor of country grid electricity production (kg CO_2-eq/MWh)

As mentioned before, there are several ways for the MBT process to contribute to GHG mitigation. The GHG avoided by utilising degraded organic materials as compost can be estimated as follows:

$$AvoidedGHG_{Compost} = AC \times PC_{Agriculture} \times A_{GHG}$$

$AvoidedGHG_{Compost}$ - Avoided GHG from composting due to avoidance of chemical fertilizer production (kg CO_2-eq/tonne of waste)

AC - Amount of Compost produced (tonne of compost/tonne of waste input)

$PC_{Agriculture}$ - Percentage of produce Compost use for agricultural purpose (%)

A_{GHG} - GHG avoidance potential from chemical fertilizer production, equivalent to one tonne of compost (kg CO_2-eq/tonne of compost)

It should be noted that the production of energy using RDF or crude oil does not greatly contribute as a climate friendly solution due to its fossil-fuel-based origin (waste plastic originated as a product of virgin crude oil). In other words, the emissions from combustion of RDF and crude oil would be equivalent to the emissions in virgin fossil fuel combustion. Therefore, GHG avoidance due to combustion of the produced RDF or crude oil is not accounted for in this simulation. However, GHG emissions related to virgin oil extraction, transportation and processing of fuel are included since utilisation of RDF/crude oil may indirectly influence avoidance in the virgin fuel production chain. It also needs to be noted that the produced RDF or crude oil can substitute for the virgin crude oil production process and thus contribute to fossil-fuel savings and avoided abiotic resource depletion.

Total avoided GHG emissions from MBT can be calculated as follows:

$$\begin{aligned}&\text{Total avoided GHG emissions (kg CO2} - \text{eq per tonne of waste)}\\ &\quad = \text{Avoided GHG from replacement of chemical fertilizer using compost like product}\\ &\qquad + \text{Avoided GHG emissions from virgin fossil fuel production}\end{aligned}$$

In the next step, which is important, net GHG emissions are estimated to understand the overall climate benefit or impact from the MBT process. Net GHG emissions are calculated as follows:

$$\begin{aligned}&\text{Net GHG emissions from MBT (kg CO2} - \text{eq per tonne of waste)}\\ &\quad = \text{Total GHG emissions} - \text{Total GHG avoidance}\end{aligned}$$

If the estimated net GHG emissions is as a positive value, this means the MBT process still contributes to climate impact. However, a significant GHG reduction can be expected as compared to the case of 100% landfilling of generated waste without prior treatment. If the result is a net negative GHG emissions value, this indicates the potential GHG saving from MBT and the possibility to act as a carbon sink.

Furthermore, monthly GHG emissions/savings from a particular municipality/location can be calculated by using the estimated results of GHG emissions or savings per tonne of waste management by means of MBT.

Monthly GHG emissions/savings (kg CO_2-eq/month) = GHG emissions per tonne of waste × Total amount of waste used for MBT per month (tonnes)

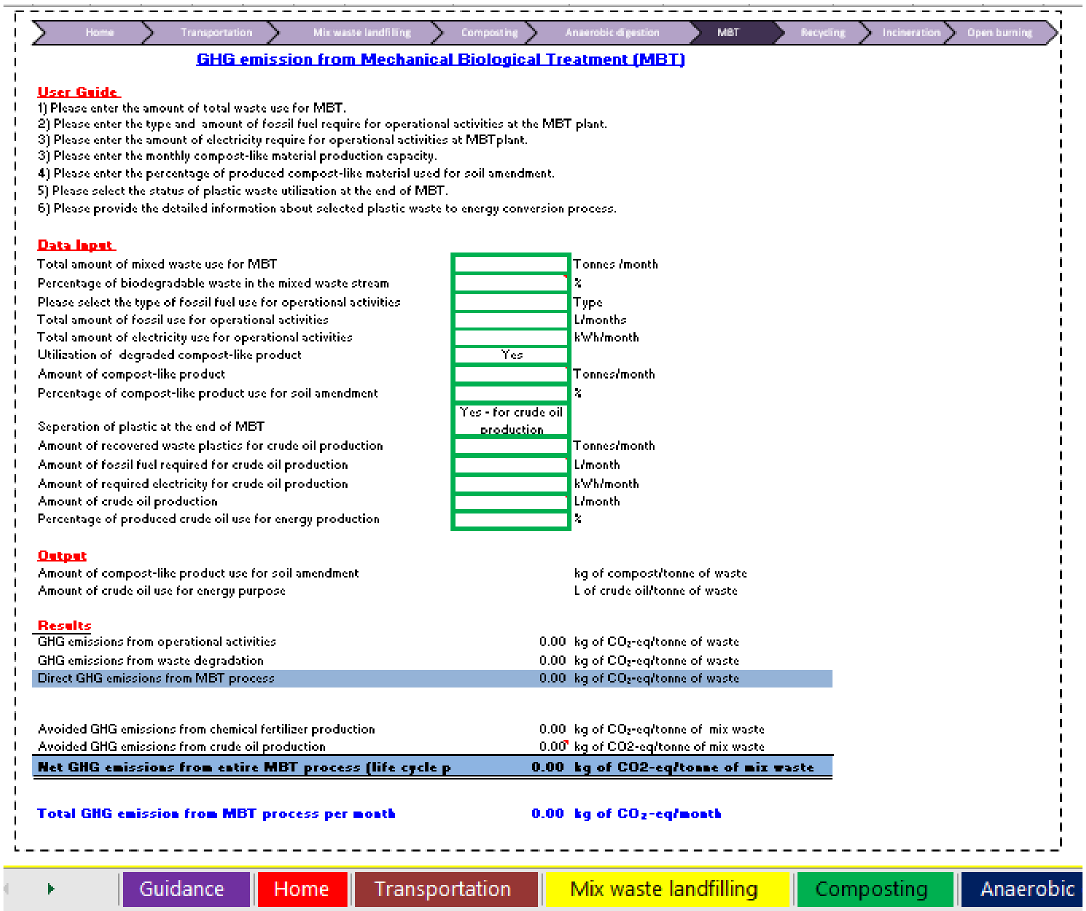


Figure 7: Page for quantification of GHG emissions from MBT

8. Estimation of GHG emissions from recycling

It has been convincingly argued and proved that recycling is an extremely sustainable, option owing to the significant amounts of valuable materials recoverable through the related processes. Consequently, this can create highly advantageous outcomes in the environmental, economic and social fields. One of the key environmental benefits from recycling is its significant contribution to GHG mitigation, thus incorporating recycling into integrated waste management represents a crucial measure in driving the entire system towards sustainability.

As with other technologies, the recycling process also contributes to significant GHG emissions. Recycling is not a simple process and requires much energy for pre-processing at the sorting facility, transportation of pre-processed recyclables to the recycling facilities by heavy-duty trucks, as well as recycling processes for different types of recyclables at various recycling facilities. All these activities emit considerable amounts of GHG. On the other hand, materials recovered from recycling processes can be used in place of the virgin production of equivalent amounts of materials, thereby avoiding the otherwise extensive GHG emissions generated in the production of virgin resources. Therefore, estimation of net GHG emissions from recycling schemes plays a key part in decisions on overall climate impacts.

Recycling entails more than a one-stage process. Sorted recyclables in a particular municipality may need to be sent to various recycling facilities located in different provinces. Therefore, obtaining site-specific data related to recycling of different types of recyclables is a challenging issue, and data on country-specific GHG emissions from recycling are difficult to obtain. In order to carry out a detailed assessment of GHG emissions reduction from recycling activities in a particular location, data are required related to the composition of recyclables, operational activities in pre-processing facilities, total fossil fuel and electricity required for pre-processing activities (cleaning, particle size reduction, baling, etc.), transportation distance to recycling facilities, fossil energy and electricity consumption data for recycling, country-specific emissions factors from fossil energy combustion and grid electricity production, recyclability of different recyclables, as well as amounts of recovered materials. This makes recycling a complex process, requiring the involvement of different levels of stakeholders. For instance, at the municipal level, the availability of data is generally limited to amounts of monthly generated recyclables and composition thereof, and numerous types of other data need to be obtained from transportation companies and recycling companies. Due to the unavailability of these data at the local authority level, it is difficult to calculate overall life cycle GHG emissions from recycling processes more precisely.

This version of the tool offers more flexibility on quantifying GHG emissions from recycling. Users are presented two options: to enter location-specific data (if available) or choose the default values provided by the developer. Option I estimates emissions based on location-specific data; cities may cooperate with relevant recycling/smelting companies to collect this data. Recycling companies generally maintain records of monthly data (e.g., operational capacity, total fossil fuel and electricity consumption for operational activities, recyclability of each type of recyclable). Once the location-specific data has been entered in the given table, GHG emissions can be calculated with respect to data on waste composition provided by the user. If location-specific information is unknown, users can use option II. Under this option, GHG emissions are estimated based on default values, for which up-to-date values were incorporated into the present tool using recently published default values obtained from the literature by the developer.

GHG emissions from recycling are calculated based on emissions of CO_2 generated through fossil fuel combustion and utilisation of electricity for operating machines at sorting plants and recycling facilities. As mentioned earlier, in this simulation, CH_4, and N_2O emissions from fossil fuel combustion are considered negligible. GHG emissions from each type of waste recycling can be calculated as follows:

$$Emissions_{Recycling} = (FC \times NCV_{FF} \times EF_{CO2}) + (EC \times EF_{el})$$

$Emissions_{Recycling}$ - Emissions from recycling (kg CO_2/tonne of recyclables)
FC - Fuel consumption apportioned to the activity type (mass or volume/tonne of recyclables)
NCV_{FF} - Net calorific value of the fossil fuel consumed (MJ/unit mass or volume)
EF_{CO2} - Emission factor of CO_2 by combustion of fossil fuel (kg of CO_2/MJ)
EC - Electricity consumption for operational activities (MWh/tonne of recyclables)
EF_{el} - Emission factor of country grid electricity production (kg CO_2-eq/MWh)

In order to quantify the GHG avoidance potential, materials recovered from each type of recyclable need to be accounted for, which can be estimated as follows:

Recovery of materials (kg/tonne of recyclable) = Amount of recyclables (kg/tonne) × Recyclability (%)

According to the literature, the recyclability of major recyclables such as paper, plastic, aluminium, metal and glass is 90–95%. In this case, amounts of recovered materials would be equal to the amounts of potential avoidance of virgin resources. The developer has provided the default GHG emission values of different types of materials produced through virgin production process chains and these default values are utilized to estimate the avoided emissions. Users should be aware that default factors provided in the tool for the calculation of total GHG avoidance emissions are independent of country-specific data as they are average global values. However, it would increase the accuracy of the overall result if specific emissions factors for China could be used.

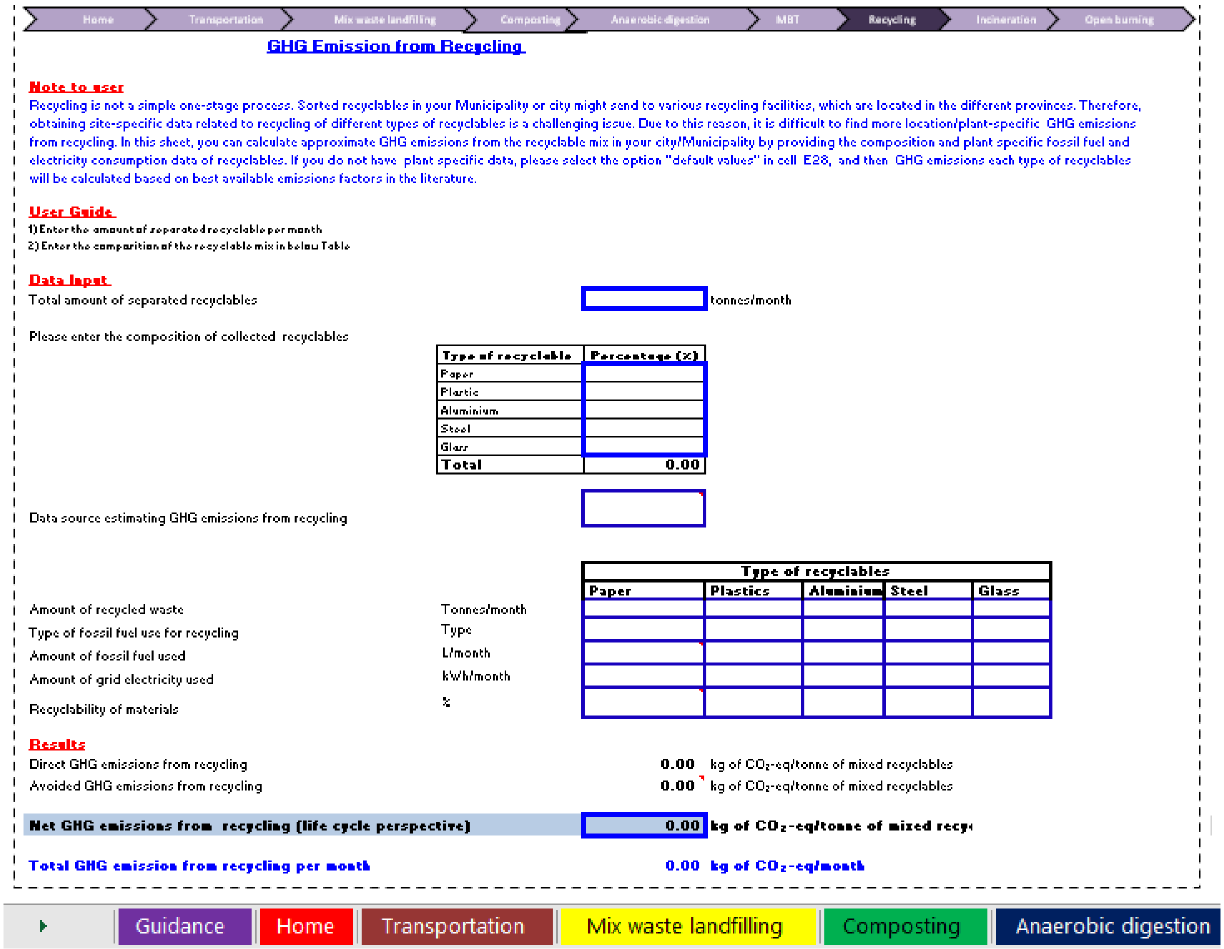


Figure 8: Page for quantification of GHG emissions from recycling

In order to quantify the total GHG emissions from a recycling scheme, the following formula can be adopted:

GHG emissions from Recyclable mix (kg of CO_2-eq/tonne of recyclables) = GHG emission from paper (kg CO_2-eq/tonne) × Percentage of paper waste (%) + GHG emission from plastics (kg CO_2-eq/tonne) × Percentage of plastics (%) + GHG emission from glass (kg CO_2-eq/tonne) × Percentage of Glass (%) + GHG emission from Aluminium (kg CO_2-eq/tonne) × Percentage of Aluminium (%) + GHG emission from metal (kg CO_2 -eq/tonne) × Percentage of Metal (%)

A similar approach can be followed to quantify the GHG avoidance potential per tonne of mixed recyclables. Once this quantification is done, net GHG emissions can be estimated as follows:

$$\text{Net GHG emissions from Recycling (kg CO2} - \text{eq per tonne of mixed recyclables)} = \text{Total GHG emissions} - \text{Total GHG avoidance}$$

If the estimated net GHG emissions remain as a positive value, this implies the recycling process still contributes to climate impact. In most cases, a net negative GHG emissions value may be expected due to the avoidance of high GHG emissions that would be incurred from virgin resource production chains otherwise. If the result is a net negative GHG emission value, this indicates the potential GHG saving from the recycling process chain and the possibility to act as a carbon sink. Based on the estimated net GHG emissions value from recycling per tonne of mixed recyclables, monthly GHG emissions/savings from the municipality/location in question can be calculated. This estimation provides the overall climate impacts from recycling.

Monthly GHG emissions/savings (kg CO_2-eq/month) = GHG emissions per tonne of mixed recyclables × Total amount of waste recycled per month (tonnes)

Note that compared to other waste management technologies, the resulting GHG mitigation potential from appropriate recycling schemes calculated by this tool can be somewhat surprising, thus it is necessary to quantify GHG emissions more precisely and concisely from the related recycling businesses. IGES has developed more comprehensive simulations for quantifying overall climate benefits from particular recycling systems taking into account location-specific data. This type of holistic approach involving a systematic methodology can be highly beneficial for quantification of the potential GHG mitigation realised from recycling businesses, as the results can be used when applying for carbon credits under the new market mechanisms.

9. Estimation of GHG emissions from incineration

Initially, waste incineration was commissioned with the main goal of decreasing the waste mass by 75% and volume by up to 90%. Currently, energy recovery from waste as a solution to the energy crisis, as well as the financial benefits realised via energy recovery, are receiving much attention. This has led to growing interest in the application of incineration as a near-term solution for tackling the growing waste management problems in developing Asia. As regards climate impact, incineration can directly eliminate methane emissions from anaerobic degradation at the landfill site (anaerobic degradation is the standard practice in developing Asia) and also displace fossil fuel-based electricity generation.

In general, the application of waste-to-energy technologies tailored to local situations can significantly contribute to GHG mitigation and energy recovery. However, inefficiencies related to their operation represent a common obstacle to most existing incineration plants in developing Asia, which has resulted in cases of failed schemes. Two of the factors with the largest impact on incineration plant efficiency are the composition and moisture content of waste.

In order to carry out a detailed assessment of GHG emissions from incineration in a particular location, data are required related to the composition of combustibles, total fossil fuel and grid electricity requirement for on-site operations. To calculate the potential GHG avoidance through energy recovery, the type of energy recovered, efficiency of electricity and heat recovery, percentage of electricity/heat recovered used for onsite operations, etc. need to be provided by the user. The user guide provided gives all the information needed regarding the specific data that need to be input.

The incineration process releases significant amounts of CO_2 into the atmosphere, which greatly increases the greenhouse effect. However, as recommended in the IPCC guidelines, only the climate-relevant CO_2 emissions generated from the combustion of fossil based waste are considered for GHG emissions estimation (IPCC, 2006). Since municipal waste for incineration is a heterogeneous mixture, in terms of sources of CO_2 a distinction is drawn between carbon of biogenic and carbon of fossil origin. Only CO_2 emissions resulting from the oxidation of waste of fossil-based materials such as plastics, certain textiles, rubber, liquid solvents, and waste oil are considered; CO_2 emissions from the combustion of biomass materials (e.g., paper, food and wood waste) contained in the waste are considered biogenic emissions and are not accounted for in GHG emission estimations (IPCC, 2006). This tool uses IPCC default values for the dry matter content of different types of waste, total carbon content, fossil carbon fraction and oxidation factors in order to quantify GHG from incineration processes.

Further, as stated in the IPCC guidelines, greenhouse gases CH_4 and N_2O may be emitted during the combustion process, the magnitudes of which depend on the type of incinerator and management practices. This tool therefore includes an option to choose the type of incineration technology, and provides the related default values for CH_4 and N_2O emissions automatically.

GHG emissions resulting from the use of fossil fuel and grid electricity for plant operations can be quantified as in the following formula:

$$Emissions_{Operation} = (FC \times NCV_{FF} \times EF_{CO2}) + (EC \times EF_{el})$$

$Emissions_{Operation}$ - Emissions from operations (kg CO_2/tonne of combustibles)
FC - Fuel consumption for on-site activities (mass or volume/tonne of combustibles)
NCV_{FF} - Net calorific value of the fossil fuel consumed (MJ/unit mass or volume)
EF_{CO2} - Emission factor of CO_2 due to combustion of fossil fuel (kg of CO_2/MJ)
EC - Electricity consumption for on-site activities (MWh/tonne of combustibles)
EF_{el} - Emission factor of country grid electricity production (kg CO_2-eq/MWh)

The IPCC recommended Tier 2 approach was adapted for use (IPCC, 2006) in this simulation to quantify the fossil CO_2 emissions from combustion of one tonne of wet MSW.

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

CE - Combustion emissions (kg CO_2/tonne of waste)
SW_i - Total amount of solid waste of type i (wet weight) incinerated (kg/tonne of waste)
dmi - Dry matter content in the waste (partially wet weight) incinerated

CF_i - Fraction of carbon in the dry matter (total carbon content) (fraction; 0.0–1.0)
FCF_i - Fraction of fossil carbon of total carbon (fraction; 0.0–1.0)
OF_i - Oxidation factor (fraction; 0.0–100%)
44/12 - Conversion factor from C to CO_2
i - Type of fossil-based waste incinerated, such as textile, rubber, leather, plastics

When waste is incinerated, most of the carbon in the combustion product oxidises to CO_2, while a minor fraction may oxidise incompletely due to the inefficiency of the combustion process, which results in some of the carbon being unburned or only partly oxidised. However, for waste incineration, it is assumed that combustion efficiency is close to 100 %, thus OF_i can be assumed as 1.

Once the quantification for CO_2 emissions from the above phases is complete, life cycle GHG emissions from incineration can be calculated, as follows:

Total GHG emissions from incineration (kg of CO_2-eq/tonne) = OE + CE

TE - Operation emissions (kg CO_2-eq/tonne of combustibles)
CE - Combustion emissions (kg CO_2-eq/tonne of combustibles)

The total GHG avoidance potential from incineration can be calculated as follows:

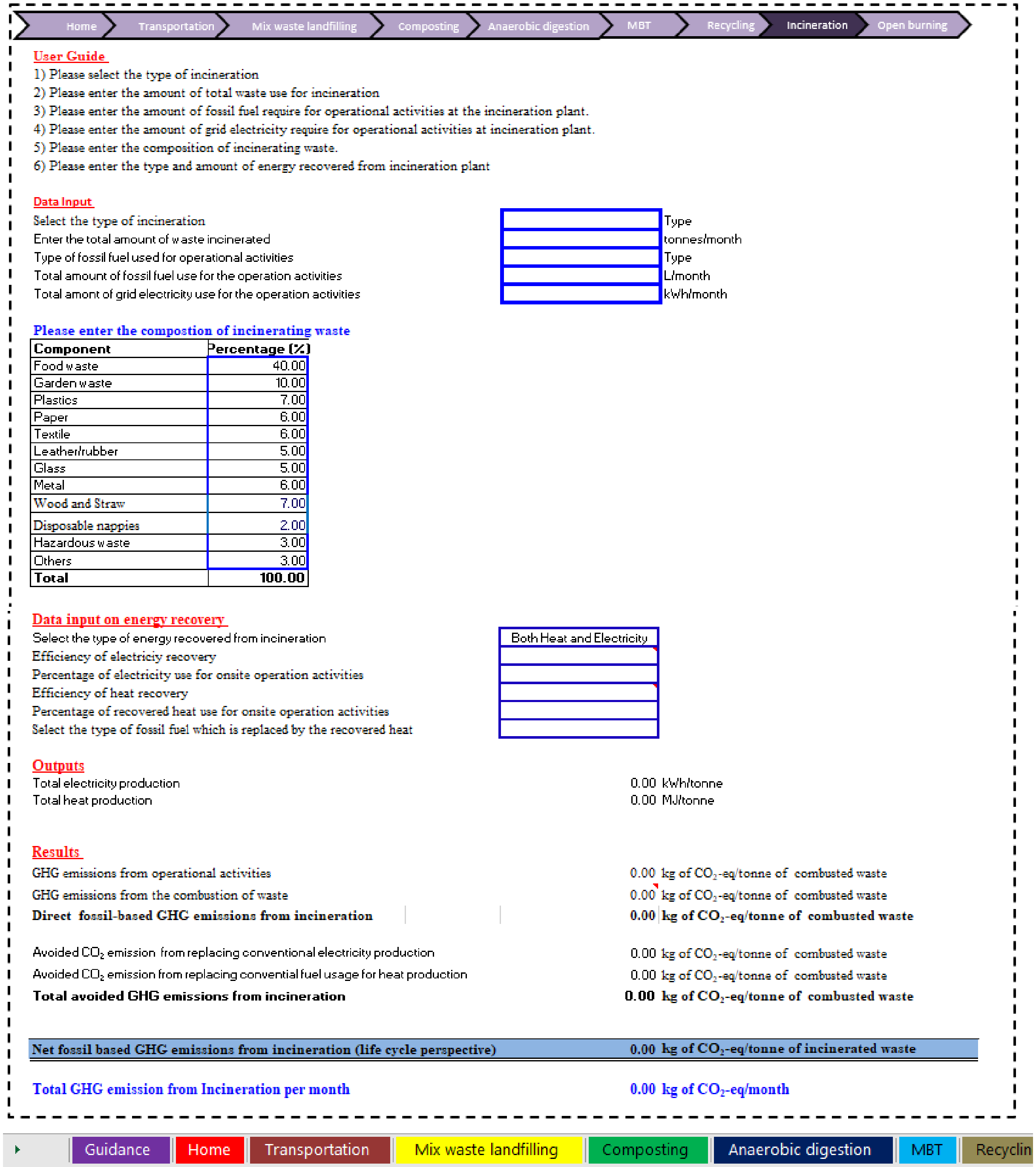
$$\text{Total avoided GHG emissions (kg CO2} - \text{eq / tonne of combustibles)}$$
$$= \text{Avoided GHG from replacement of equivelent amount of conventional electricity}$$
$$+ \text{Avoided GHG from replacement of equivelent amount of heat which is produced via fossil fuel}$$

In the next step, estimation of net GHG emissions can be carried out to understand the overall climate benefit or impact of the incineration process. Net GHG emissions from incineration can be estimated as follows:

$$\text{Net GHG emissions from incineration (kg CO2} - \text{eq per tonne of combustibles)} = \text{Total GHG emissions} - \text{Total GHG avoidance}$$

As with any other technology, if the estimated net GHG emissions from incineration results in a positive value, this means it contributes to climate impact. If the incineration results in a net negative GHG emissions value, it can be assumed to have avoided a massive amount of GHG emissions that would have otherwise occurred due to the conventional production of electricity and heat as well as landfilling of organic waste. A net negative GHG emissions value also indicates the potential GHG saving from incineration. Based on the estimated net GHG emissions value from incineration per tonne of combustibles, monthly GHG emissions/savings for a particular municipality/location can be calculated. This estimation provides the overall climate impacts from incineration.

Monthly GHG emissions/savings (kg CO_2-eq/month) = GHG emissions per tonne of wet waste combustion × Total amount of waste combusted per month (tonnes)


Home | Transportation | Mix waste landfilling | Composting | Anaerobic digestion | MBT | Recycling | Incineration | Open burning

User Guide
1) Please select the type of incineration
2) Please enter the amount of total waste use for incineration
3) Please enter the amount of fossil fuel require for operational activities at the incineration plant.
4) Please enter the amount of grid electricity require for operational activities at incineration plant.
5) Please enter the composition of incinerating waste.
6) Please enter the type and amount of energy recovered from incineration plant

Data Input
Select the type of incineration — Type
Enter the total amount of waste incinerated — tonnes/month
Type of fossil fuel used for operational activities — Type
Total amount of fossil fuel use for the operation activities — L/month
Total amont of grid electricity use for the operation activities — kWh/month

Please enter the compostion of incinerating waste

Component	Percentage (%)
Food waste	40.00
Garden waste	10.00
Plastics	7.00
Paper	6.00
Textile	6.00
Leather/rubber	5.00
Glass	5.00
Metal	6.00
Wood and Straw	7.00
Disposable nappies	2.00
Hazardous waste	3.00
Others	3.00
Total	**100.00**

Data input on energy recovery
Select the type of energy recovered from incineration — Both Heat and Electricity
Efficiency of electriciy recovery
Percentage of electricity use for onsite operation activities
Efficiency of heat recovery
Percentage of recovered heat use for onsite operation activities
Select the type of fossil fuel which is replaced by the recovered heat

Outputs
Total electricity production — 0.00 kWh/tonne
Total heat production — 0.00 MJ/tonne

Results
GHG emissions from operational activities — 0.00 kg of CO_2-eq/tonne of combusted waste
GHG emissions from the combustion of waste — 0.00 kg of CO_2-eq/tonne of combusted waste
Direct fossil-based GHG emissions from incineration — 0.00 kg of CO_2-eq/tonne of combusted waste

Avoided CO_2 emission from replacing conventional electricity production — 0.00 kg of CO_2-eq/tonne of combusted waste
Avoided CO_2 emission from replacing convential fuel usage for heat production — 0.00 kg of CO_2-eq/tonne of combusted waste
Total avoided GHG emissions from incineration — 0.00 kg of CO_2-eq/tonne of combusted waste

Net fossil based GHG emissions from incineration (life cycle perspective) — 0.00 kg of CO_2-eq/tonne of incinerated waste

Total GHG emission from Incineration per month — 0.00 kg of CO_2-eq/month

Guidance | Home | Transportation | Mix waste landfilling | Composting | Anaerobic digestion | MBT | Recyclin

Figure 9: Page for quantification of GHG emissions from incineration

10. Estimation of GHG emissions from open burning

There is an increasing trend in the use of uncontrolled burning of massive amounts of waste in open dump sites and landfill sites, based on the belief it is the cheapest and easiest means of volume reduction and disposal of combustible materials, and has minimal land requirements. However, such form of primary waste disposal is becoming ever less acceptable due to the serious threats it poses to local environments and communities. Regulations are therefore needed to prohibit such unacceptable practices.

Besides the fossil-based CO_2 emissions from combustion, open burning is responsible for various toxic by-products that arise from incomplete combustion, such as hydrocarbons, particulate matter and black carbon, benzene and carbon monoxide. Recent research has shown that black carbon is the second largest contributor to global temperature increases, with CO_2 remaining as the number one contributor to global warming. However, default values have yet to be published by the IPCC or any other international organization to quantify the climate impact of black carbon. This tool therefore only accounts for fossil-based CO_2 emissions to quantify climate impact; however, future versions of the tool will need to incorporate options to estimate black carbon emissions and related climate impacts, due to the serious nature of this substance.

In open burning, as opposed to managed landfilling, there are no operational or maintenance requirements, therefore there are no energy consumption-related GHG emissions.

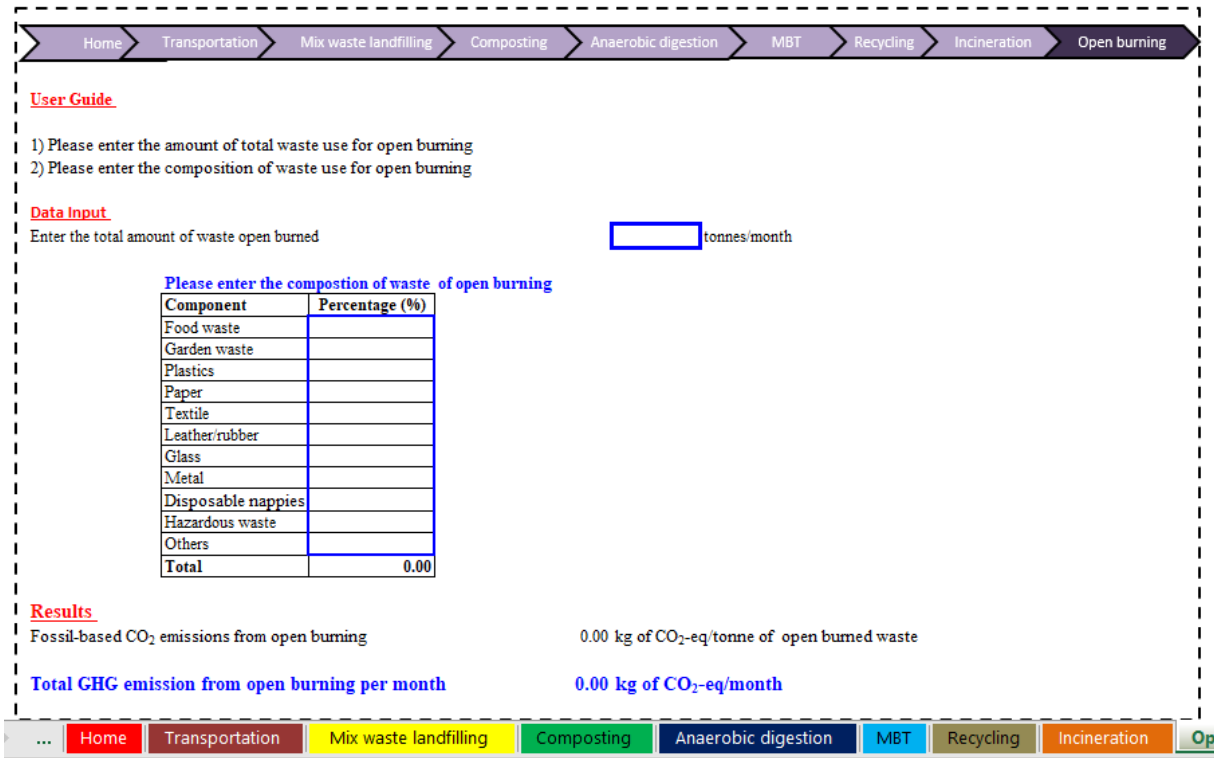
The IPCC recommended Tier 2 approach was adapted for use (IPCC, 2006) in this simulation to quantify the fossil CO_2 emissions from open burning of wet MSW. As explained in the IPCC guidelines, for open burning, all the default values are similar to those for incineration, except the oxidation factor. In open burning, a higher fraction of waste is incompletely oxidized due to inefficiencies in the combustion process, thus this tool utilizes the IPCC recommended oxidation factor (OF) for open burning: 58%.

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

CE - Combustion emissions (kg CO_2/tonne of waste)
SW_i - Total amount of solid waste of type i (wet weight) open burning (kg/tonne of waste)
dmi - Dry matter content in the waste (partially wet weight) incinerated
CF_i - Fraction of carbon in the dry matter (total carbon content) (fraction; 0.0–1.0)
FCF_i - Fraction of fossil carbon in the total carbon (fraction; 0.0–1.0)
OF_i - Oxidation factor (0.0–100%)
44/12 - Conversion factor from C to CO_2
i - Type of fossil based waste open burnt such as textiles, rubber, leather, plastics

Once the quantification for fossil-based CO_2 emissions from open burning is complete, the resulting value can be considered as the gross GHG emissions. Unlike other treatment methods, open burning involves no potential for avoidance of GHG emissions in the process, therefore net GHG emissions are equal to gross GHG emissions.

To faithfully quantify the overall climate impact of open burning, ideally emissions from black carbon need to be included. As mentioned before, an option to input the related figures will need to be incorporated into the version of the tool for China in the future.


Home | Transportation | Mix waste landfilling | Composting | Anaerobic digestion | MBT | Recycling | Incineration | Open burning

User Guide

1) Please enter the amount of total waste use for open burning
2) Please enter the composition of waste use for open burning

Data Input
Enter the total amount of waste open burned tonnes/month

Please enter the compostion of waste of open burning

Component	Percentage (%)
Food waste	
Garden waste	
Plastics	
Paper	
Textile	
Leather/rubber	
Glass	
Metal	
Disposable nappies	
Hazardous waste	
Others	
Total	0.00

Results
Fossil-based CO_2 emissions from open burning 0.00 kg of CO_2-eq/tonne of open burned waste

Total GHG emission from open burning per month 0.00 kg of CO_2-eq/month

... | Home | Transportation | Mix waste landfilling | Composting | Anaerobic digestion | MBT | Recycling | Incineration | Op

Figure 10: Page for quantification of GHG emissions from open burning

Estimation of GHG Emissions from an Integrated Solid Waste Management System

This simulation can be applied to quantify the climate benefits from individual treatment technologies as well as integrated waste management systems. To estimate net GHG emissions from an integrated system, net GHG emissions from individual technologies are aggregated based on the fractions of waste they are intended to treat. By aggregating different types of waste such as organic waste, recyclables, combustibles and mixed MSW, GHG emissions can be estimated on a per-tonne basis for waste managed in a particular location. The following mathematical formula is used for this estimation in the "Home" sheet:

Net GHG emissions from integrated system (kg CO_2-eq/tonne of waste) =

Net GHG emissions from landfilling (kg CO_2-eq/tonne of mix waste landfilling) × Percentage of waste use for landfilling + Net GHG emissions from composting (kg CO_2-eq/tonne of organic waste) × Percentage of waste use for composting + Net GHG emissions from anaerobic digestion (kg CO_2-eq/tonne of organic waste) × Percentage of waste use for anaerobic digestion + Net GHG emissions from MBT (kg CO_2-eq/tonne of organic waste) × Percentage of waste use for MBT + Net GHG emissions from recycling (kg CO_2-eq/tonne of sorted recyclables) × Percentage of waste use for recycling + Net GHG emissions from incineration (kg CO_2-eq/tonne of combustibles) × Percentage of waste use for incineration + Net GHG emissions from open burning (kg CO_2-eq/tonne of waste) × Percentage of waste use for open burning

The estimated net GHG emissions figure realised by an integrated system indicates the overall progress of the individual systems combined. A summary of the GHG emissions from individual treatment methods as well as the integrated system overall is displayed in the "Home" page, as shown in Figure 11.

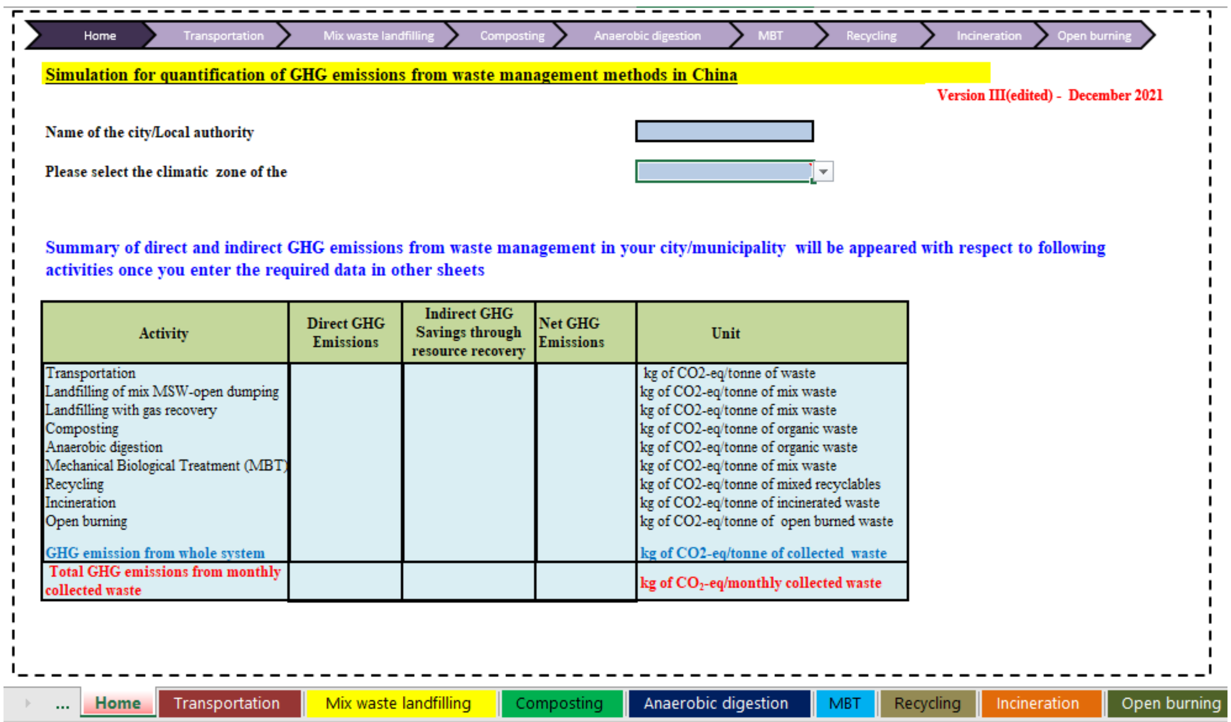


Figure 11: Summary view of GHG emissions presented on the Home page

This kind of holistic approach is highly beneficial as it provides a systematic methodology to quantification of potential total GHG mitigation from an entire integrated waste management system. The resultant GHG emissions estimations can feed into local government decision-making processes for selecting climate friendly waste management technologies, thus the tool offers high utility.

Limitations of the simulations and possible improvements

As mentioned earlier, simple spreadsheet simulators used to quantify GHG emissions, such as in this tool, can offer high utility at the local authority level. However, certain limitations need to be borne in mind in relation to the development and application of this life cycle assessment tool. One of such is that certain data (e.g., waste composition) may not be available at the local authority level. While the authors made every effort to produce a user-friendly tool, users may experience some difficulty in gathering the essential data required.

In this version of the tool, all waste treatment technologies are included. Further, certain assumptions were made in developing the simulation that may affect the accuracy of the final results. For instance, compared with other waste management technologies, the figures for GHG mitigation potential from appropriate recycling schemes can be somewhat surprising when calculated using this tool. Therefore, it is necessary to quantify the actual GHG emissions from recycling businesses more precisely and concisely at the local authority level. In this respect, due to the lack of country-specific data, this version of the simulator uses publicly available default values and emissions factors obtained from global sources. However, it is recommended to use country- or location-specific emission factors with respect to the material recycling practiced in China.

In this simulator, landfilling and open dumping were considered as the base scenario for comparison purposes since most developing Asian countries practice such primary disposal methods. However, in some cases, other technologies such as incineration or MBT should be considered as the base scenario, depending on the city or municipality in question. The authors are aware of these issues and intend to update the tool with options covering the various base scenarios in the future. Other modifications to improve the overall level of user friendliness are also being considered by the authors.

Any comments or suggestions from users would be greatly appreciated, with a view to further improvements to this simulator.

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Annex I: List of data required

Step/treatment	Type of data required	Unit
Transportation	Amount of waste transported diesel-fueled trucks	Tonnes/month
	Monthly diesel requirement	L/Month
	Amount of waste transported by natural gas-fueled trucks	Tonnes/Month
	Monthly natural gas requirement	Kg/Month
	Total amount of waste transportation by electric trucks	Tonnes/Month
	Total electricity consumption of trucks	kWh/Month
Mix waste landfilling (open dumping/sanitary landfilling without gas recovery)	Amount of mixed waste landfilling per month	Tonnes/month
	Amount of diesel fuel use for operation of machinery at landfill	L/Month
	Composition of waste	%
Mix waste landfilling Sanitary landfilling with gas recovery	Amount of collected waste disposed in sanitary landfill with gas recovery	Tonnes/month
	Total amount of fuel used for operation of machinery at landfill	L/Month
	Grid electricity used for operational activities at landfill	kWh/month
	Efficiency of gas collection	%
	LFG utilization efficiency	%
	Type of fossil fuel replaced by the recovered LFG	Type
Composting	Amount of food waste and garden waste used for composting	Tonnes/Month
	Amount of fossil-fuel used for operational activities	L/Month
	Total amount of compost production	Tonnes/Month
	Percentage of compost used for agricultural and gardening purposes	**%**
Anaerobic digestion	Amount of food waste and garden waste used for anaerobic digestion	Tonnes/Month
	Amount of fossil diesel used for operational activities	L/Month
	Amount of electricity used for operational activities	kWh/month

Mechanical Biological Treatment (MBT)	Amount of waste used for MBT	Tonnes/month
	Amount of fossil fuel required for operational activities	L/Month
	Amount of electricity required for operational activities	kWh/month
	Amount of compost-like material produced	Tonnes/Month
	Approximate percentage of produced compost-like material used for soil amendment	%
Recycling	Amount of separated recyclables	Tonnes/Month
	Composition of the recyclable mix	%
	Amount of recycled waste	Tonnes/Month
	Type of fossil fuel used for recycling	Type
	Amount of fossil fuel used	L/Month
	Amount of grid electricity used	kWh/Month
	Recyclability of materials	%
Incineration	Amount of total waste used for incineration	Tonnes/Month
	Amount of fossil fuel used for operational activities	L/Month
	Amount of grid electricity used for operational activities	kWh/Month
	Composition of combustibles	%
	Amount of electricity produced	kWh/Month
	Percentage of electricity used for on-site activities	%
	Amount of heat recovered	MJ/Month
	Percentage of recovered heat used for onsite activities	%
Open Burning	Amount of waste open-burnt	Tonnes/month
	Composition of waste	%

User Manual

Estimation Tool for Greenhouse Gas (GHG) Emissions from Municipal Solid Waste (MSW) Management in a Life Cycle Perspective

Version III-Chinese context

Authors Dr. Nirmala Menikpura, Dr. Dickella Gamaralalage Jagath Premakumara, and Dr. Rajeev Kumar Singh

Contact Dr. Dickella Gamaralalage Jagath Premakumara (premakumara@iges.or.jp) and Dr. Rajeev Kumar Singh (singh@iges.or.jp)

IGES Centre Collaborating with UNEP on Environmental Technologies (CCET)
Institute for Global Environmental Strategies (IGES)
2108-11 Kamiyamaguchi, Hayama, Kanagawa 240-0115 Japan