CHAPTER 3 METHODOLOGY

3.1 Introduction

The methodologies adopted for this research consist mainly of primary research and secondary data collection. The relationship between each type of data is illustrated in Figure 3.1.

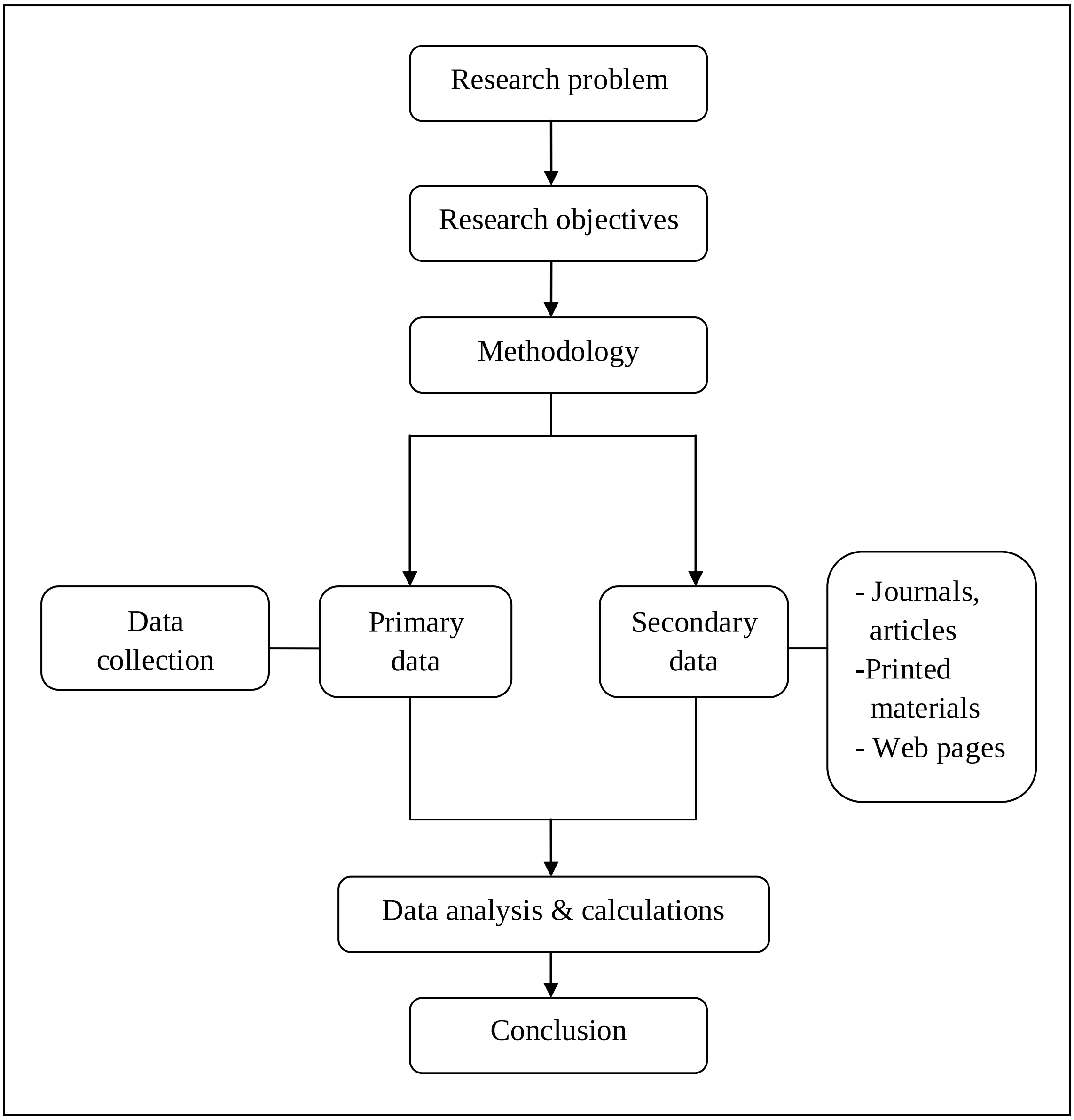

Figure 3.1: Methodology of research

3.2 Project Boundary

There are 15 sectors for CDM projects, one of them is “Waste handling and disposal”, which included recycling, composting and landfill gas generation (UNFCCC, 2006a). Under the small scale CDM projects, there are 72 approved methodologies (UNFCCC, 2006b). Composting is a process of biological treatment of biomass. As the project activity involves converting MSW into compost, hence the most appropriate small scale CDM methodologies is to be adopted in this research is AMS III.F: Avoidance of methane emissions through controlled biological treatment of biomass (Version 08, Scope 13). Under the methodology, the annual emission reductions shall not exceed 60 ktCO_2e/y throughout crediting period (UNFCCC, 2011a).

The results of this research focus on emissions within the project boundary (Figure 3.2). In accordance with the AMS III.F, the project boundary is defined as a physical location:

a) where MSW would be disposed at and methane emissions occur in absence of project activity

b) where treatment of biomass through composting occurs

c) where soil application takes place by using compost that is being produced, and

d) where the transportation of waste and compost occurs

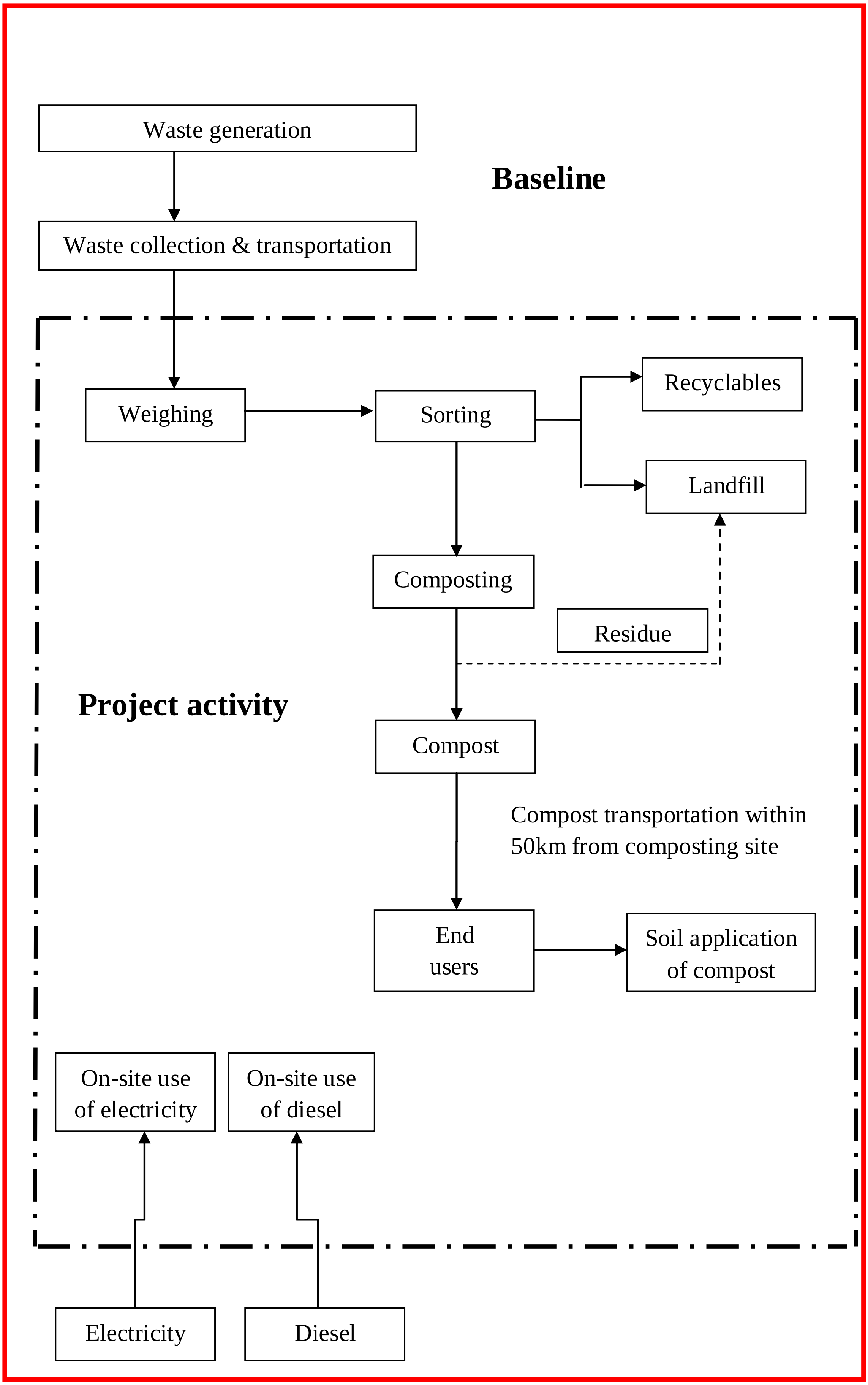

Figure 3.2: Project boundary

Currently, the MSW is collected from waste generation source (Selayang and Rawang) and transported to Bukit Tagar Sanitary Landfill for disposal. Bukit Tagar Sanitary Landfill is located 50km from Kuala Lumpur with easy access from North-South Expressway through Bukit Tagar interchange. It covers a land area of 700 amidst oil palm plantation in Hulu Selangor district. Bukit Tagar Sanitary Landfill is designed as a fully engineered Level IV landfill with capacity up to 40 years for MSW and non-toxic waste.

Bukit Tagar Sanitary Landfill is the place where methane is emitted into the atmosphere and is called the baseline scenario. By setting up the project activity at Rawang, instead of sending the MSW to the landfill, it will be sent to the composting plant for biomass treatment to produce a stable and humus-like product called compost (Farell et al., 2009). Organic components will be sorted out from other recyclables and inorganic matter. Recyclables will be sold while the inorganic matter will be disposed at the landfill.

Diesel and electricity driven equipments will be used at the composting plant, such as wood chipper, turning machine, skid face loader and forklift. After being packaged into 5-kg per bag, the compost will be distributed for soil application, approximately 50km from the composting plant. Diesel is required for transportation of compost from composting plant to soil application site. The project flow and project boundary is given in Figure 3.2. This process goes on for 10 years, which is the typical CDM project duration, starting from 2010 to 2019.

3.2.1 Description of the Project Activity

Kota Kinabalu Composting Plant is the most recent and similar scenario to this project activity. Hence, the project activity adopted most of its technology and parameters with some necessary adjustments. The project owner is the MSW contractor of local municipality, called City Council of Selayang. The amount of MSW collected depends on the projects granted. MSW collected from residential areas (terraces, apartments and flats) and shops will be transported to the composting plant. The MSW will be weighed before unloaded at the reception area for sorting. Organic materials will be sorted out from other MSW before sending for composting process by using skid face loader. Same as Kota Kinabalu Composting Plant, recyclables will be collected, baled and stored for sale. The remaining inorganic materials will be sent to the landfill.

The feedstock to the composting plant includes food waste, garden waste and wood. Garden waste is high in nitrogen content. Therefore, wood waste will be milled by a wood chipper into saw dust and added as a carbon source to maintain a suitable nutrient balance of carbon-to-nitrogen. 50% of the cells of the fungi and bacteria involved in composting are made of carbon while nitrogen is important for protein synthesis and cell growth. 25:1 to 40:1 by weight is the recommended C:N ratio for MSW composting. Lower ratios (high nitrogen content) cause unpleasant odor and create an anaerobic condition due to the insufficient oxygen supplied into the increasing composting process. At higher ratios (low nitrogen content), bacteria's optimum population is limited due to the prohibited cell growth (UNFCCC, 2008b). Hence, C:N ratio will be monitored during crediting period.

The feedstock will be piled on a paved surface with perforated troughs to prevent leachate from composting penetrates into the groundwater. The leachate is called runoff. The runoff will be collected in a retention pond which is then used to supply sufficient moisture content to the piles.

Two main stages during composting process are as below:

- 30-day aerobic process

  Due to its lesser feedstock compared to Kota Kinabalu Composting Plant, the organic materials will be piled into a smaller windrows of size 1.5 meters (height) x 2.5 meters (width) x 50 meters (length) each, estimated 2 windrow per day. Runoff collected at the retention pond will be re-circulated onto the windrows to maintain the moisture content at 60% at the beginning of the composting process, 55%-60% during the first and second week and 50%-55% for the remaining composting period. The windrows will be turned two times per week by turner to give sufficient oxygen for aerobic decomposition, and at the same time to mix well the residues (UNFCCC, 2008b). Temperature will be taken daily using a portable temperature probes until the temperature rise is below 5 ℃ above the ambient temperature even after turning. At this point, the active composting is deemed as complete (NL EVD Internationaal, 2010).

- 30-day maturation phase

  After the 30 days, the windrows will be transferred using a loader to the maturation period for 30 days.

After the whole period, the mass loss was up to 50% caused by the lost of carbon dioxide and water vapor and the bulk density increases from 550kg/m^3 to 1000kg/m^3 (NL EVD Internationaal, 2010). Compost will be sent to a screening unit by a skid face loader to separate the coarse from the fine compost. Fine compost is packed in 5kg-bags and transported to end users. The coarse compost will be added back to the fresh windrow as activator to start the composting process. Monitoring during crediting period will be done to improve efficiency of composting and ensure the quality of final product, such as temperature and oxygen measurements (UNFCCC, 2008b).

3.2.2 Emission Sources Included and Excluded from Baseline and Project Activity

In general, CO_2 and water (H_2O) are generated from well managed compost pile resulting from aerobic decomposition (Lou, 2008). However, even in well managed compost pile, CH_4 will be generated from anaerobic decomposition of organic waste at early stage of composting due to its heterogeneity (Bogner et al., 2007; Brown and Subler, 2007; Miguel et al., 2010). On the other hand, aerobic nitrification and denitrification process during composting generate nitrous oxide (N_2O) (Kebreab et al., 2006). Both CH_4 and N_2O are potent GHG, with GWP 21 and 310, respectively (IPCC, 2006). Despite of their high GWP compared to CO_2, the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) made an assumption that only CO_2 is emitted during composting. This is because CH_4 emission ranged from less than 1% to a few per cent of the initial carbon content of the material (Beck-Friis, 2001; Detzel et al., 2003; Arnold, 2005) while N_2O is less than 0.5%-5% of the initial N content of the material

(Petersen *et al.*, 1998; Hellebrand 1998; Vesterinen, 1996; Beck-Friis, 2001; Detzel et al., 2003).

All the emission sources involved in baseline and project activity are tabulated in Table 3.1.

3.3 Data Collection

This research involved MSW collected from Rawang and Selayang. Data on MSW was collected from every Monday to Saturday (62 days). Municipal solid waste was collected daily from specific garbage trucks, approximately 2.5 tonnes to 6.0 tonnes capacity. Unloaded MSW from each truck was divided into eight portions. Two portions were selected randomly for sampling. The waste was separated manually in accordance with the waste streams stated in the CDM methodology under UNFCCC, called AMS III.F: Avoidance of methane emissions through controlled biological treatment of biomass (Version 08, Scope 13) (thereafter known as AMS III.F) (UNFCCC, 2009a) as below:

i. Wood and wood products
ii. Pulp, paper and cardboard (other than sludge)
iii. Food, food waste, beverages and tobacco (other than sludge)
iv. Textiles
v. Garden, yard and park waste, and
vi. Inerts (such as glass, plastic, metal and rubber)

Table 3.1: Emission sources included and excluded from baseline and project activity

Activity	Source	Gas	Included/ Excluded	Justification/ explanation
Baseline	Emission from decomposition of waste at the landfill	CH_4	Included	Important source of emission
		CO_2	Excluded	CO_2 emissions from the decomposition of organic waste are biogenic and are not accounted
Project Activity	On-site emissions due to composting	CH_4	Excluded	The composting process is aerobic hence emission of CH_4 is considered to be negligible
		CO_2	Excluded	CO_2 emissions from the decomposition of organic waste are biogenic and are not accounted
	On-site use of fossil fuel	CH_4	Excluded	The emission is considered negligible
		CO_2	Included	Important source of emission
	On-site use of grid electricity	CH_4	Excluded	The emission is considered negligible
		CO_2	Included	Important source of emission
	Off-site use of fossil fuel for waste transportation	CH_4	Excluded	The emission is considered negligible
		CO_2	Excluded	Distance between waste generation source and landfill is higher than distance between waste generation source and composting plant. There is no incremental in distance. Hence, no incremental emission.
	Off-site use of fossil fuel for compost transportation for soil application	CH_4	Excluded	The emission is considered negligible
		CO_2	Included	No compost production in baseline. Hence, incremental emission will be generated by incremental distance

Adopted from: Project 2217: Municipal Solid Waste based Composting at Kolhapur, Maharashtra (UNFCCC, 2009b)

Municipal solid waste samples were taken to estimate the total weight of MSW collected:

Total waste collected = Total waste collected February 2011– April 2011

(Eq. 3.1)

Each waste category was sorted out and weighed. Thereafter, weight per day of a particular waste category was derived. From there, the percentage of each waste category was calculated:

Percentage = Weight per day of a particular waste category/total waste collected daily **(Eq. 3.2)**

3.4 Explanation of Methodological Choices

This research focused on estimating the GHG emissions that would result from MSW being disposed at the baseline scenario that is Bukit Tagar Sanitary Landfill, compared to emissions from one proposed project activity - a composting plant for organic portions in MSW.

3.4.1 Baseline Emissions

In accordance with AMS III.F, baseline emissions are the amount of methane released to the atmosphere without the existence of the proposed project activity due to the decay of biomass and organic components within the project boundary. The MSW is collected and originally disposed at Bukit Tagar Sanitary Landfill. Baseline emissions exclude methane emissions which required to be removed or combusted to comply with the prevailing regulations. The baseline emissions, BE_y were calculated using the following Eq.3.3 based on paragraph 17 of AMS III.F:

$$\mathbf{BE_y = BE_{CH4,SWDS,y} - (MD_{y,reg} * GWP_{CH4}) + (MEP_{y,ww} * GWP_{CH4}) + BE_{CH4,manure,y}} \quad \textbf{(Eq. 3.3)}$$

Where:

$BE_{CH4,SWDS,y}$	Yearly methane generation potential of the solid waste composted or anaerobically digested by the project activity during the years *x* from the beginning of the project activity (x = 1) up to the year *y* estimated as per latest version of the "tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site" (tCO_2e)
$MD_{y,reg}$	Amount of methane that would have to be captured and combusted in the year *y* to comply with the prevailing regulations (tCO_2e)
$MEP_{y,ww}$	Methane emission potential in the year *y* of the wastewater co-composted. The value of this term is zero if co-composting of wastewater is not included in the project activity (tCO_2e)
$BE_{CH4,manure,y}$	Where applicable, baseline emissions from manure composted by the project activities, as per the procedures of AMS-III.D (tCO_2e)
GWP_{CH4}	Global Warming Potential for methane (21)

Current GWP is 25 (IPCC, 2007a). However, the IPCC First Assessment Report has set GWP of CH_4 as 21 (IPCC, 1990) and it has been adopted by UNFCCC and is currently applied in CDM projects (Coutha et al., 2011). Hence, GWP 21 is used in the calculation of this research.

Without the project activity, methane will be generated at Bukit Tagar Sanitary Landfill and released into the atmosphere. The amount of methane emissions was calculated based on the "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site (Version 05)" (UNFCCC, 2008a), from the years *x* (x=1, which is year 2010) up to the year *y* (y=10, which is year 2019). The tool was based on a multi-phase model, which is First Order Decay (FOD) model. In the model, each type of waste *j* has its respective different decay rate k_j and fractions of degradable organic carbon (DOC_j). Only organic waste is included in this model. The amount of methane produced in the year *y*, $BE_{CH4,SWDS,y}$ was calculated by using following Eq. 3.4:

$$BE_{CH4,SWDS,y} = \varphi * (1-f) * GWP_{CH4} * (1-OX) * 16/12 * F * DOC_f * MCF * \sum_{x=1}^{y} \sum_{j} W_{j,x} * DOC_j * e^{-k_j * (y-x)} * (1-e^{-k_j})$$

(Eq. 3.4)

Where:

φ	Model correction factor to account for model uncertainties (0.9)
f	Fraction of methane captured at the solid waste disposal site (SWDS) and flared, combusted or used in another manner (0.55)

GWP_{CH4}	Global Warming Potential (GWP) of methane, valid for the relevant commitment period (21)
OX	Oxidation factor (reflecting the amount of methane from SWDS that is oxidized in the soil or other material covering the waste) (0.1)
16/12	Stoichiometric ratio of carbon to methane
F	Fraction of methane at the SWDS gas (volume fraction) (0.5)
DOC_f	Fraction of degradable organic carbon (DOC) that can decompose (0.5)
MCF	Methane correction factor (1.0)
$W_{j,x}$	Amount of organic waste type j prevented from disposal in the SWDS in the year *x* (tonnes)
DOC_j	Fraction of degradable organic carbon (by weight) in the waste type j
k_j	Decay rate for the waste type j
j	Waste type category (index)
x	Year during the crediting period: x runs from the first year of the first crediting period (x=1) to the year y for which avoided emissions are calculated(x=y)
y	Year for which methane emissions are calculated

Steps for calculation of baseline emissions are as below:

Step 1: For each type of organic waste, calculate weight fraction W_x of each category of organic waste *j* for the given year *x*, started from year 2010. A consistent 2% annual increase (assumption) was then applied to calculate $W_{j,x}$ from 2011 until 2019.

Step 2: Divide the equation into 2 parts:

Part a: $\sum_{x=1}^{y} * e^{-k_j * (y-x)} * (1-e^{-k_j})$

For every category of organic waste, calculate the decay rate for every year, *y* (1 to 10) during the crediting period.

Part b: Multiply $\varphi * (1-f) * GWP_{CH4} * (1-OX) * 16/12 * F * DOC_f * MCF$ with **part a**, $W_{j,x}$ and DOC_j in every year, to calculate methane emission for every type of organic waste.

Step 3: The same calculations were repeated for the remaining years. Add up all the methane emissions generated each year from x=1 to x=y to calculated the baseline emissions.

3.4.2 Project Emissions

In order to reduce the GHG emissions from baseline scenario, instead of disposing the collected MSW into landfill, it was proposed to be sent to a composting plant for separation. Organic components will be converted into compost, while recyclables will be sold (called as project activity). The project emissions include all possible project emissions due to energy (electricity and diesel) used throughout the whole composting process which involved screening, chopping of wood for size reduction, turning of compost piles/ heaps, upload feedstock and compost, transportation of waste to composting plant and compost. The project emissions, PE_y were calculated by using the following Eq. 3.5 based on paragraph 20 of AMS III-F:

$$\mathbf{PE_y = PE_{y,transp} + PE_{power} + PE_{y,phy\ leakage} + PE_{y,compost} + PE_{y,runoff} + PE_{y,res\ waste}}$$

(Eq. 3.5)

Where:

$PE_{y,transp}$ Emissions from incremental of transport in the year *y* (tCO_2e)

$PE_{y,power}$ Emissions from electricity or fossil fuel consumption in the year *y* (tCO_2e)

$PE_{y,phy\ leage}$ In case of anaerobic digestion: methane emissions from physical leakage of the anaerobic digester in the year *y* (tCO_2e)

$PE_{y,compost}$ In case of composting: methane emissions during composting process in the year *y* (tCO_2e)

$PE_{y,runoff}$ In case of composting: methane emissions from runoff in the year *y* (tCO_2e)

$PE_{y,res\ waste}$ In the case of residual waste/ slurry/ products are subjected to anaerobic storage or disposed in a landfill: methane emissions from the anaerobic decay of the residual waste/ products (tCO2e)

3.4.2.1 Emissions from incremental transport distances, $PE_{y,transp}$

Transport distance may increase due to incremental distance between:

i) MSW collection points and composting plant compared to landfill

ii) Composting plant and compost application sites

$PE_{y,transp}$ was calculated by using the following Eq. 3.6 based on paragraph 21 of AMS III-F:

$$\mathbf{PE_{y,transp} = (Q_y / CT_y) * DAF_w * EF_{CO2} + (Q_{y,treatment,i} / CT_{y,treatment,i}) * DAF_{treatment,\mathit{i}} * EF_{CO2}} \quad \textbf{(Eq. 3.6)}$$

Where:

Q_y	Quantity of waste composted in the year *y* (tonnes)
CT_y	Average truck capacity for waste transportation (tonnes/truck)
DAF_w	Average incremental distance for waste transportation (km/truck)
EF_{CO2}	CO_2 emission factor from fuel use due to transportation ($kgCO_2$/km, IPCC default values or local values may be used)
i	Type of compost
$Q_{y, treatment,i}$	Quantity of compost *i* produced in the year *y* (tonnes)
$CT_{y, treatment,i}$	Average truck capacity for compost *i* transportation (tonnes/truck)
$DAF_{treatment,i}$	Average distance for compost *i* transportation (km/truck)

3.4.2.2 Emissions from power consumption, $PE_{y,power}$

Sources of power include diesel and electricity which are required by the composting machineries to operate. $PE_{y,power}$ was calculated by using the following Eq. 3.7 – Eq. 3.9 based on AMS I-D:

$$\mathbf{PE_{y,power} = PE_{y,\ diesel\ on\text{-}site} + PE_{y,electricity}} \quad \textbf{(Eq. 3.7)}$$

Where:

$PE_{y,diesel}$ Emissions through fossil fuel consumption on-site in the year *y* (tCO_2e)

$PE_{y,electricity}$ Emissions through electricity consumption in the year *y* (tCO_2e)

$$\mathbf{PE_{y,diesel\ on\text{-}site} = V_{y,diesel} * EF_{CO2}} \qquad \textbf{(Eq. 3.8)}$$

Where:

$V_{y,diesel}$ Volume of diesel used in the year *y* (litres/y)

EF_{CO2} CO_2 emission factor for diesel use due to power generation ($kgCO_2$/litre)

$$\mathbf{PE_{y,\ electricity} = EG_y * CEF_{elec,y}} \qquad \textbf{(Eq. 3.9)}$$

Where:

EG_y Amount of electricity consumed in the year *y* (MWh)

$CEF_{elec,y}$ CO_2 emission factor for electricity consumed (tCO_2/MWh)

3.4.2.3 Emissions from physical leakage, $PE_{y,phy\ leakage}$

In case of anaerobic digestion, emissions from physical leakage of the anaerobic digester and recovery system shall be included as part of project emissions. $PE_{y,phy\ leage}$ was calculated by using the following Eq. 3.10 based on paragraph 23 of AMS III-F:

$$\mathbf{PE_{y,phy\ leakage} = Q_y * EF_{anaerobic} * GWP_{CH4}} \qquad \textbf{(Eq. 3.10)}$$

Where:

$EF_{anearobic}$ Emission factor for anaerobic digestion of organic waste (t CH_4/tonne waste treated). Emission factors can be based on facility/site-specific measurements, country specific values or IPCC default values (table 4.1, Chapter 4, Volume 5, 2006 IPCC Guidelines for National Greenhouse Gas Inventories). IPCC default values are 2g CH_4/kg waste treated on a dry weight basis and 1g CH_4/kg waste treated on a wet weight basis.

3.4.2.4 Emissions from composting, $PE_{y,compost}$

In case of composting, emissions during composting process, $PE_{y,compost}$ was calculated by using the following Eq. 3.11 based on paragraph 24 AMS III.F as below:

$$\mathbf{PE_{y,compost} = Q_y * EF_{composting} * GWP_{CH4}} \qquad \textbf{(Eq. 3.11)}$$

Where:

$EF_{composting}$ Emission factor for composting of waste (t CH_4/tonne waste treated). Emission factors can be based on facility/site-specific measurements, country specific values or IPCC default values (table 4.1, Chapter 4, Volume 5, 2006 IPCC Guidelines for National Greenhouse Gas

Inventories). IPCC default values are 10g CH_4/kg waste treated on a dry weight basis and 4g CH_4/kg waste treated on a wet weight basis.

3.4.2.5 Emissions from runoff, $PE_{y,runoff}$

In case of composting, emissions from runoff, $PE_{y,runoff}$ was calculated by using the following Eq. 3.12 based on paragraph 25 of AMS III.F:

$$PE_{y,runoff} = Q_{y,ww,runoff} * COD_{y,ww,runoff} * B_{o,ww} * MCF_{ww,treatment} * UF_b * GWP_{CH4} \quad \text{(Eq. 3.12)}$$

Where:

$Q_{y,ww,runoff}$	Volume of the runoff water treated in the year *y* (m^3)
$COD_{y,ww,runoff}$	Chemical Oxygen Demand of runoff water leaving the composting facility in the year *y* (tonnes/m^3)
$B_{o,ww}$	Methane producing capacity of the runoff water (CH_4/kg COD)
$MCF_{ww,treatment}$	Methane correction factor of the wastewater treatment system where the runoff water is treated (MCF values as per Table III.F.1)
UF_b	Model correction factor to account for model uncertainties

3.4.2.6 Emissions from residual waste, $PE_{y,res\ waste}$

Methane emission from anaerobic storage and/ or disposed in a landfill of the residual waste/ slurry/ products/ composts from biological treatment, $PE_{y,res\ waste}$ was calculated as per the latest version of the "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site".

3.4.3 Emissions Reduction

The emissions reduction of the project activity was measured as the difference between the baseline emissions and the total of the project emission and leakage by using the following Eq. 3.13:

$$\mathbf{ER_y = BE_y - (PE_y + Leakage)} \qquad \textbf{(Eq. 3.13)}$$

Where:

BE_y Baseline emissions in the year *y* ($tCO2e$)

PE_y Project activity emissions in the year *y* ($tCO2e$)

Leakage Project leakage in the year *y* ($tCO2e$)

The above equations are summarized in Table 3.2.

Table 3.2: Equations summary

Parameter	Description	Equations
BEy	Baseline emissions in the year, *y* (tCO_2e)	$BE_{CH4,SWDS,y} - (MD_{y,reg} * GWP_{CH4}) + (MEP_{y,ww} * GWP_{CH4}) + BE_{CH4,manure,y}$
PE_y	Project emissions in the year, *y* (tCO_2e)	$PE_{y,\ transp} + PE_{power} + PE_{y,\ phy\ leakage} + PE_{y,\ compost} + PE_{y,\ runoff} + PE_{y,\ res\ waste}$
$PE_{y,\ transp}$	Emissions through incremental transportation in the year *y* (tCO_2e)	$(Q_y / CT_y) * DAF_w * EF_{CO2} + (Q_{y,\ treatment,i} / CT_{y,\ treatment,i}) * DAF_{treatment,i} * EF_{CO2}$
$PE_{y,\ power}$	Emissions from the diesel or electricity consumption in the year, *y* (tCO_2e)	$PE_{y,diesel\ on\text{-}site} + PE_{y,electricity}$
$PE_{y,diesel\ on\text{-}site}$	Emission through diesel consumption in composting process in the year, *y* (tCO_2e)	$V_{y,fuel} * EF_{CO2}$
$PE_{y,electricity}$	Emission through electricity consumption in composting process in the year, *y* (tCO_2e)	$EG_y * CEF_{elec,y}$
$PE_{y,\ phy\ leakage}$	Emissions from physical leakage of the anaerobic digestor in the year, *y* (tCO_2e)	$Q_y * EF_{anaerobic} * GWP_{CH4}$
$PE_{y,compost}$	Emissions from composting process in the year, *y* (tCO_2e)	$Q_y * EF_{composting} * GWP_{CH4}$
$PE_{y,runoff}$	Emissions from the runoff in the year, *y* (tCO_2e)	$Q_{y,ww,runoff} * COD_{y,ww,runoff} * B_{o,ww} * MCF_{ww,treatment} * UF_b * GWP_{CH4}$
ER_y	Emissions reduction in the year, *y* (tCO_2e)	$BE_y - (PE_y + Leakage)$