EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 13 (Special issue) (2020) 26-37
DOI 10.14456/ea.2020.19
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Estimation of Methane Emission from Solid Waste Landfill Site, Savannakhet Province, Lao PDR

Phoukham Niravanh[1], Chalor Jarusutthirak[2]

[1]*Department of Environmental Science, Faculty of Agriculture and Environment, Savannakhet University, Lao PDR .*

[2]*Department of Environmental Technology and Management, Faculty of Environment, Kasetsart University, Thailand.*

*Corresponding: sep11phoukham@gmail.com

Abstract

Methane (CH_4) released from solid waste landfill has been identified as a significant contributor to greenhouse gas emission in waste sector, which contributes to global warming. This study aimed to characterize new and age-defined solid waste disposed in Savannakhet landfill site. The obtained laboratory data of solid waste characteristics were used to estimate site specific emission factors, including methane generation potential (L_0) and methane generation rate constant (k). The results showed that organic carbon fraction and methane generation potential (L_0) of the waste decreased as elapsed time of landfill increased. The methane generation rate constant (k) of bulk waste was 0.155 yr^{-1}, while the k values of different components were varied depending on waste composition. The k values for paper, textile, wood, garden, and food were 0.069, 0.098, 0.088, 0.229, and 0.204 yr^{-1}, respectively. Methane emissions from landfill were calculated based on FOD method, using default and site specific values, by three models including 2000 GPG, 2006 IPCC, and LandGEM models. The results using default values showed that methane emission in the year 2016 estimated by 2000 GPG and LandGEM provided similar trends of CH_4 emission which were higher than those estimated by 2006 IPCC. Methane emissions from Savannakhet landfill site in 2016 using default values by 2000 GPG, 2006 IPCC, and LandGEM were 0.92, 0.53, and 1.00 Gg CH_4, respectively. Methane emissions using site specific values were less than those using default values, which were 0.65, 0.41, and 0.82 Gg CH_4, when estimated by 2000 GPG, 2006 IPCC, and LandGEM, respectively.

***Keywords**:* greenhouse gas, methane generation potential, methane generation rate constant, solid waste landfill

1. Introduction

Presently, global warming has become problem of public concern. This phenomenon can mostly be attributed to the trapping of enormously quantities of greenhouse gases (GHG) in the earth's atmosphere, resulting in an increase of temperatures. Solid waste landfill is one of the most important anthropogenic sources of methane emission. Methane (CH_4) is the main component of landfill gas (LFG) produced from anaerobic degradation of organic carbon in municipal solid waste (MSW) during disposal.

In Savannakhet Province, Lao PDR, most of the solid wastes are disposed of by landfilling in local area. The solid wastes are disposed, through aerobic or anaerobic biodegradation. The main degradation products of aerobic process are carbon dioxide (CO_2), water, and heat, while those of anaerobic process are methane (CH_4) and carbon dioxide (CO_2). Methane (CH_4) released from solid waste landfill has been identified as a significant contributor to greenhouse gas emissions, which contributes to global warming potential 25 times of carbon dioxide (CO_2) over a 100 years' time horizon (IPCC Fourth Assessment Report, 2007). Over the years a large number of numerical and mathematical models have been developed to estimate CH_4 emission from solid waste disposal based on first order decay (FOD) model. This approach is generally recognized and widely used, as it is recommended by the Intergovernmental Panel on Climate Change (IPCC) in the IPCC waste model (IPCC, 2006).

The FOD method recommended by IPCC considered that degradable organic carbon (DOC) containing in solid waste decays slowly by microbiological and biochemical processes throughout a few decades, during which LFG (mostly consisting of CH_4 and CO_2) are formed. As a result, emissions of CH_4 from waste deposited in a disposal site are highest in the first few years after deposition, and then gradually decline as degradable carbon in the waste is consumed by the microorganisms responsible for the decay. To estimate methane emission based on the FOD model, activity data and emission factors are required. Depending on availability of data, the FOD method can be used according to Tier I (with default activity data), Tier II (country specific activity data), and Tier III (country specific values of key parameters with half-life, methane generation potential and fraction of degradable organic carbon) (IPCC, 2006).

In Lao PDR, the FOD model with Tier I approach has been used as a standard tool for methane emission inventory from waste sector (WREA, 2000). Due to a limitation of data, the IPCC default values are being used to estimate CH_4 emission. This reflects that the estimated results may not correspond to reality with a high uncertainty in calculation. To up level of calculation, it is essential to investigate the site specific activity data and to develop country specific emission factor. However, there is no such a study in Lao PDR. This study aims to investigate site specific data of a landfill in Savannakhet Province, including waste composition, fraction of degradable organic carbon, methane generation potential (L_0), and methane generation rate constant (k). Those parameters were further used in estimation of CH_4 emission from the landfill. The result of estimation using default value and specific values obtained from the study were compared both in terms of CH_4 emission and uncertainty value. The outcome of this study can be used as a guideline to contribute hierarchy in development of country specific emission factors and calculation of CH_4 emission from solid waste landfill sites throughout Lao PDR.

2. Materials and Methods

2.1 Location of study site

Savannakhet province was selected in this study as a representative of special economic zone province in country. Savannakhet province is located in East-West Economic corridor of Greater Mekong Sub region (GMS), linking Vietnam, Lao PDR, Thailand, and Myanmar. Savan-Seno Special Economic Zone (SSEZ) has started developing since 2003, and the categories of business activities planned to be developed in the SSEZ include export-processing zone, free trade zone, free service and logistic center. This situation leads to a presumably increase of MSW in the near future. Savannakhet sanitary landfill is located in the east of the Savannakhet city at a distance of about 11 km from the city center, exactly lies between 16º32′25.3′′N and 104º49′28.4′′E. Approximately 70% of MSW generated in Kaisone Phomvihan District which was major city of Savannakhet Province was transported to landfill site. The landfill has been receiving waste for more than 17 years as it was established and started operation in 2000.

The landfill has a total site area of 13.5 ha and disposal area of 4 ha, including four cells for solid waste disposal.

2.2 Characterization of age-defined waste

2.2.1 Solid waste sampling and sorting

Solid waste samples at varying ages were taken from Savannakhet landfill site at different parts of landfill site. The study site is divided into 4 sections depending on time of landfilling. As shown in Figure 5, the solid waste samples obtained from section 1 reflected the waste at the age of 5 years. Section 2 provided the waste sample at the ages of 3-4 years. The sample at the age of 1 year was collected from section 3, while new waste was directly obtained from garbage truck, prior to dumping in section 4. The aged samples were taken by bulldozer with backhoe at the depth of 3 meters, approximately, while the new samples were taken directly from the garbage truck delivered to the landfill site. The sampling was conducted in July (rainy season) of 2016. The average temperature at the site was 28.2 °C and average monthly precipitation was 245.3 mm.

The amount of 50 kg of each sample was gathered and then conducted a quartering until the amount of 5 kg was achieved. Then 5 kg of waste sample was manually sorted into 11 types of wastes according to IPCC (2006), including:

(1) food waste
(2) garden (yard) and park waste
(3) paper and cardboard
(4) wood
(5) textiles
(6) nappies (disposable diapers)
(7) rubber and leather
(8) plastics
(9) metal
(5) textiles
(10) glass
(11) others (e.g., ash, dirt, dust, soil, electronic waste)

Each composition was weighted to calculate the percentage of waste compositions by equation (1) according to ASTM D5231-5292. The composition containing organic matters of age-defined wastes, including food, garden, paper, wood, textile, and nappies, were kept into containers and delivered to laboratory for further analyses.

$$C = \frac{(w_1 \times 100)}{w_2} \quad (1)$$

where: C = percentage composition of waste, w_1 = weight of waste in each composition (kg), w_2 = total weight of waste (kg)

2.2.2 Proximate Analysis

Different compositions of solid waste as mentioned earlier were analyzed in laboratory. The main purpose was to determine moisture content, volatile matter, ash content, and organic carbon of the age-defined municipal solid wastes. The following procedures are the approaches for characterization of solid waste samples.

2.2.2.1 Moisture

Moisture content was determined according to ASTM E1756-01 standard. Three grams of municipal solid waste was placed into an oven at 105°C for two hours. The sample was then stabilized in desiccator and reweighed. The difference in weight represents the moisture content of the sample indicating in percentage. The moisture content of solid waste can be calculated according to equation (2).

$$M = (\frac{w - d}{w}) \times 100 \quad (2)$$

where: M = moisture content, wet basis (%), w = initial (wet) weight of sample (g), d = final (dry) weight of sample (g)

2.2.2.2 Volatile matter, ash content, and organic carbon

Volatile matter is the portion of wastes which is converted into gas before and during combustion at high temperature. The samples after determination of moisture content also used to determine the volatile matter content. The dried waste samples were then heated at 550°C for 1 hour to determine the volatile matter. After combustion the samples were weighed to determine dry weight of ash. At this stage the volatile matters and ash content were calculated according to equations (3) and (4), respectively.

$$\%V = \left(\frac{weight\ of\ dry\ sample - ash\ weight}{dry\ sample\ weight}\right)\times 100 \quad (3)$$

$$\%ash = \left(\frac{ash\ weight}{dry\ sample\ weight}\right)\times 100 \quad (4)$$

Percentage of organic carbon in age-defined composition was calculated by using equation (5).

$$Organic\ carbon(\%) = \frac{(100 - ash)}{1.8} \quad (5)$$

2.3 Simplified approaches to estimate site specific emission factors

Emission factors including methane generation potential (L_0) and methane generation rate constant (k) were determined by using simplified methods described by Ishii & Furuichi (2013) and Machado *et al*. (2009). According to these approaches, organic carbon in different waste components of age-defined waste samples were analyzed. Then methane generation potential (L_0) was calculated by considering biodegradable fraction and methane generation potential of each component, as shown in equations (6)-(8).

$$L_0 = \frac{BF_w \times C_m}{1 + w} \quad (6)$$

$$BF_w(t) = \sum_{i=1}^{n} BF_i \times FR_i \times \left[\frac{VS(t)}{VS_0}\right] \quad (7)$$

$$C_m = \frac{\sum_{i=1}^{n} BF_i \times FR_i \times C_{m_i}}{BF_w} \quad (8)$$

where: L_0 = methane generation potential (m^3 CH_4/Mg), BF_w = biodegradable fraction, C_m = MSW organic matter methane generation potential (m^3 CH_4/dry-Mg), w = water content (wet basis), VS = volatile solids (fraction), FR = fraction in the waste composition, t = elapsed time (year), i = fraction of waste composition

The results of methane generation potential (L_0) of age-defined waste can be used to calculate methane generation rate constant (k) as expressed in equation (9).

$$\frac{L_0(t)}{L_0} = e^{-kt} \quad (9)$$

2.4 Estimation of methane emission

Methods for estimation of CH_4 emission are based on first order decay (FOD) principles. Three methods were approached in this study to estimate CH_4 emission from solid waste landfill sites including 2000 IPCC good practice guidance (2000 GPG) and 2006 IPCC guidelines (2006 IPCC) given by IPCC, as well as LandGEM by US.EPA. The detailed methods of each approach for estimation of CH_4 emission were described as follows:

2.4.1 2000 Good Practices Guidance (2000 GPG)

The 2000 GPG presents equations based on the derivative of the general FOD equation in revised 1996 IPCC guideline. Methane generation during solid waste disposal and CH_4 emission from landfill site can be calculated by equations (10) and (11), respectively.

$$CH_4 generation\ in\ year\ t(Gg/yr) = \sum_x \left[\begin{array}{c} A \times k \times MSW_T(x) \times \\ MSW_F(x) \times L_0(x) \times e^{-k(t-x)} \end{array}\right] \quad (10)$$

where: t = year of inventory, x = year for which input data should be added, A = $(1-e^{-k})/k$; normalisation factor which corrects the summation, k = methane generation rate constant (1/yr), MSW_T (x) = total municipal solid waste (MSW) generated in year (Gg/yr), MSW_F (x) = fraction of MSW disposed at SWDS in year x, L_0(x) = methane generation potential (Gg CH_4/Gg waste), MCF(x) = methane correction factor in year x (fraction), DOC(x) = degradable organic carbon in year x (fraction) (Gg C/Gg waste), DOC_F = fraction of DOC dissimilated, F = fraction by volume of CH_4 in landfill gas, 16/12 = conversion from C to CH_4

$$CH_4 emission\ in\ year\ t(Gg/yr) = \left[\begin{array}{c} CH_4 generated \\ in\ year\ t - R(t) \end{array}\right] \times (1 - OX) \quad (11)$$

where: R(t) = recovered CH_4 in inventory year t (Gg/yr), OX = oxidation factor (fraction)

According to 2000 GPG, methane generation potential (L_0) can be calculated by using equation (12).

$$L_0 = MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \quad (12)$$

where: L_0 = methane generation potential (Gg CH_4/Gg waste), MCF = CH_4 correction factor (defaults value for manage landfill 0.8), DOC = degradable organic carbon (Gg C/Gg waste), DOC_F = fraction of DOC that can be decomposed (default 0.77), F = fraction of CH_4 in generated landfill gas (default 0.50), 16/12 = molecular weight ratio CH_4/C (ratio)

2.4.2 2006 IPCC Guidelines (2006 IPCC)

The FOD model was introduced in 2006 IPCC guidelines (IPCC, 2006), The advantage of this model is that it incorporates time parameters to reflect the decay process of carbon in waste. To estimate CH_4 emission based on 2006 IPCC, the following steps are applied:

1) Decomposable DOC from waste disposal data

$$DDOCm = W \times DOC \times DOC_F \times MCF \quad (13)$$

where: $DDOC_m$ = mass of decomposable DOC deposited, (Gg), W = mass of waste deposited, (Gg), DOC = degradable organic carbon in the year of deposition,fraction, (Gg C/Gg waste), DOC_F = fraction of DOC that can be decomposed (default value 0.50), MCF = CH_4 correction factor for aerobic decomposition in the year of deposition (default value for manage landfill 0.8)

2) Mass of DOC accumulated at the of year T.

$$DDOCma_T = DDOCmd_T \times \left(DDOCma_{T-1} \times e^{-k}\right) \quad (14)$$

3) Mass of DOC decomposed in year T.

$$DDOCm\ decomp_T = DDOCma_{T-1} \times \left(1 - e^{-k}\right) \quad (15)$$

where: $DDOCma_T$ = DDOCm accumulated in the SWDS at the end of year T, $DDOCmd_T$ = mass of DDOC disposed in the SWDS in year T, $DDOCma_{T-1}$ = DDOCm accumulated in the SWDS at the end of year (T - 1), DDOCm $decomp_T$ = DDOCm decomposed in year T, k = reaction constant, $k = \frac{In(2)}{t_{1/2}}$ (yr^{-1}), $t_{1/2}$ = half-life time (y)

4) Methane generation from DDOCm decomposed.

$$CH_4generated_T = DDOCm\ decomp_T \times F \times \frac{16}{12} \quad (16)$$

where: CH_4 $generated_T$ = amount of CH_4 from decomposable material, DDOCm $decomp_T$ = DDOCm decomposed in year T, Gg, F = fraction of CH_4, by volume, in generated landfill gas, 16/12= molecular weight CH_4/C (ratio)

5) Methane emission from SWDS

$$CH_4emission\ (Gg) = [\textstyle\sum_x CH_4generated_{xT} - R_T] \times (1 - OX_T) \quad (17)$$

where: CH_4 emission = CH_4 emitted in year T, Gg, T = inventory year, x = waste category or type/material, R_T = recovered CH_4 in year T, Gg, OX_T = oxidation factor in year T, (fraction)

2.4.3 LandGEM

LandGEM is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in MSW landfills. The software provides a relatively simple approach to estimating landfill gas emissions. The model parameters including k and L_0 were applied in this decomposition equation. Model defaults are based on empirical data from U.S. landfills as shown in equation (18) . Field test data can also be used in place of model defaults when available.

$$Q_{CH_4} = \sum_{t=1}^{n} \sum_{j=0.1}^{1} kL_0 \left(\frac{M_t}{10}\right) \bullet e^{-kt_{ij}} \quad (18)$$

where: Q_{CH4} = annual methane generation in the year of the calculation (m^3/year), i = 1 year time increment, n = (year of the calculation) - (initial year of waste acceptance), j = 0.1 year time increment, k = methane generation rate ($year^{-1}$), L_0 = potential methane generation capacity (m^3 CH_4/Mg), M_i = mass of waste accepted in the i^{th} year (Mg), t_{ij}= age of the j^{th}

section of waste mass M_i accepted in the i^{th} year (decimal years, e.g., 3.2 years)

3. Results and Discussion

3.1 Municipal solid waste in Savannakhet Province

Savannakhet landfill site disposal mostly received MSW from Kaisone Phomvihan District which is a major city of Savannakhet Province. Approximately 70% of MSW generated has been delivered to the landfill site since 2000. The landfill has a total area of 4 ha with a depth in a range of 5-8 m. Previous study revealed that MSW generation rates was 0.75 kg/person/day and total amount of solid waste was 51 tonnes/day (IGES, 2012). The annual amount of solid waste disposal related to the growth of population. Figure 1 exhibited the trends of population growth and solid waste disposed in the landfill site from 2000 to 2016. The amount of solid waste delivered to landfill site rapidly increased after 2005 because of higher efficiency on solid waste collection and governmental policy on solid waste management.

3.2 Solid waste composition and characterization

Composition of MSW at Savannakhet landfill site was investigated, as shown in Table 1. The study indicated that main composition of MSW at landfill site were biodegradable organic carbon fraction, including paper, food waste, garden waste, wood, textile, and leather, while the remaining consisted of non-biodegradable organic compounds, i.e. plastic and rubber, and inorganic compounds, e.g. glass, metal, and others. It was found that biodegradable fractions of MSW accounted for 45.3%, which was lower than that reported by IGES (2012). The great discrepancies were found in the components of food, rubber, metal, and glass. It can be explained that the new waste samples in this study were collected directly from garbage trucks, not from landfill site, therefore some recyclable components, eg. plastic, metal, and glass, were possibly separated prior to dumping to landfill site.

3.3 Estimation of site specific emission factor

3.3.1 Methane generation potential (L_0)

Fractions of organic carbon in different age-defined waste were used to estimate methane generation potential (L_0). Table 2 listed the parameters involved in estimation of the L_0 value. The results showed that L_0 of new waste (year 2016) were 66.54 m^3 CH_4/Mg which was highest compared to the older-aged wastes. As the waste was deposited longer in the landfill, the L_0 was found to decrease due to organic fraction in the waste was gradually degraded by microorganisms. The L_0 values of the wastes in years of 2015, 2013, 2012, and 2011 were found to be 58.86, 46.95, 40.75, and 28.44 m^3 CH_4/Mg, respectively. The decrease of L_0 values was corresponded to the reduction of organic carbon fraction.

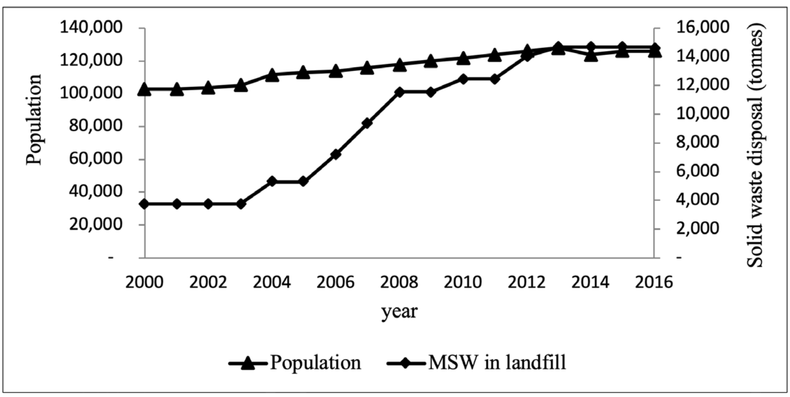

Figure 1. Population number of Savannakhet Province and solid waste disposal at Savannakhet landfill site

Table 1. MSW composition at Savannakhet landfill

Types	% Composition	
	This study	IGES (2012)
Paper	9	9
Textile	2	1
Wood	7	8
Garden	14	6
Food	13	54
Nappies	2	1
Rubber&Leather	8	1
Plastic	19	15
Metal	10	1
Glass	14	2
Others	2	2
Total	100	100

Table 2. Parameters involving in calculation of methane generation potential (L_0)

Parameter	New waste (2016)	2015	2013	2012	2011
MSW organic matter methane generation potential (C_m) (m^3 CH_4/dry-Mg)	489.34	569.98	702.18	823.58	1,021.54
biodegradable fraction of the waste as a whole (BF_w)	0.20	0.15	0.10	0.07	0.04
methane generation potential (L_0) (m^3 CH_4/Mg)	66.54	58.86	46.95	40.75	28.44

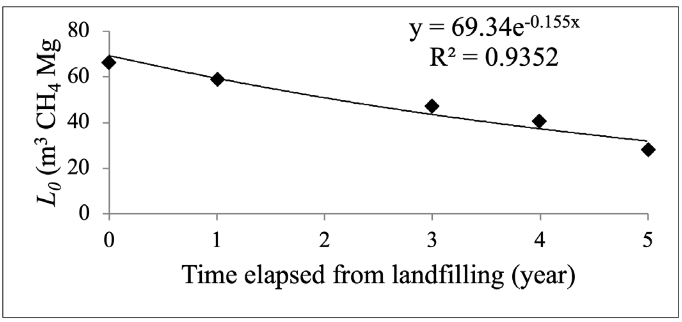

Figure 2. Methane generation potential (L_0) at different elapsed time of landfill and curve fitting for k value.

3.3.2 Methane generation rate constant (k)

3.3.2.1 k value based on bulk waste (2000 GPG)

The value of *k* was estimated by the change of L_0 values at different elapsed time of landfill. Figure 2 shows the trends of L_0 values as the age of waste became older in landfill site. The curve was fit with exponential equation, by which the *k* value was obtained. The results showed that the *k* value was 0.155 yr^{-1}. This value was comparable to that suggested by IPCC (2006), which was 0.17 yr^{-1} for bulk waste in tropical wet climate zone. The result was compared with that studied by Wangyao *et al.* (2010), obtained from field and laboratory experimental results. The obtained value of *k* in the study of Wangyao *et al.* (2010) was about 0.2 $year^{-1}$, which was equal to the upper range of the suggested value for bulk waste in the

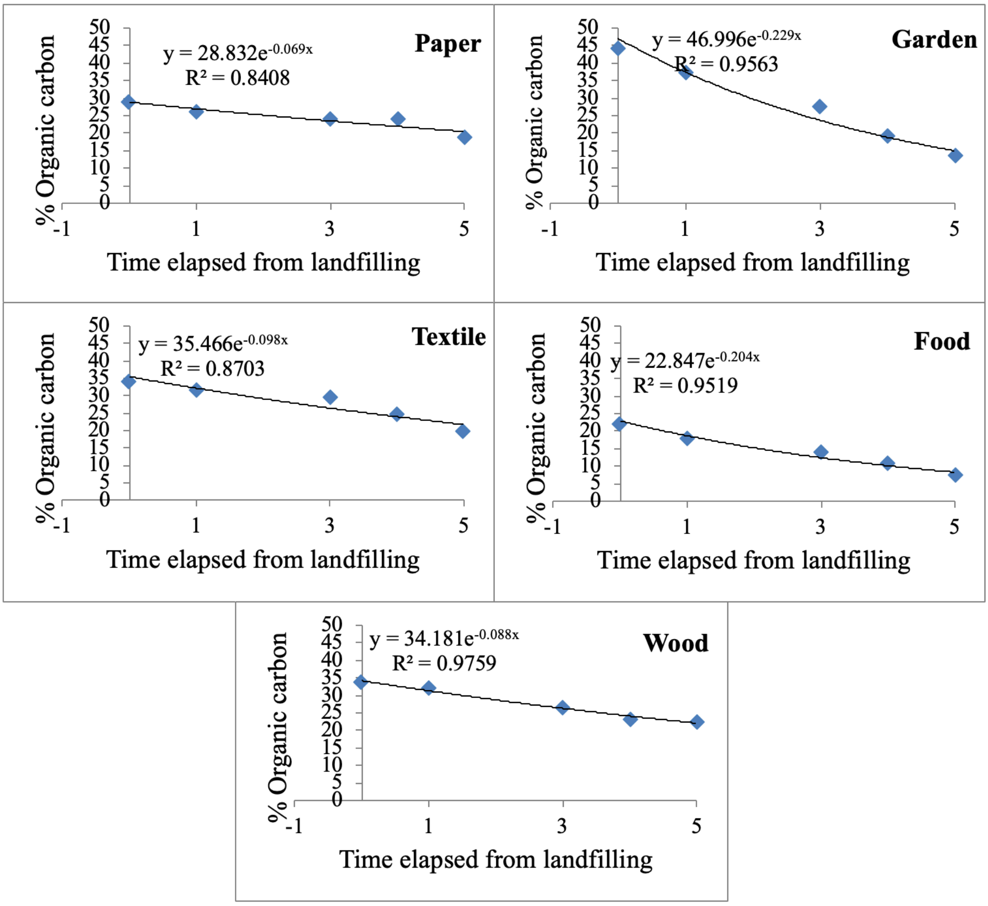

Figure 3. The *k* values for each component of waste (a) Paper, (b) Textile, (c) Wood, (d) Garden, (e) Food, and (f) Nappies

Table 3. Values of methane generation rate constant (*k*) of different MSW fraction

Source	Paper	Textile	Wood	Garden	Food	Nappies
In this study	0.069	0.098	0.088	0.229	0.204	0.021
IPCC	0.070	0.070	0.035	0.170	0.400	0.170

Source: IPCC (2006)

tropical climate zone in 2006 IPCC guidelines. Moreover, Ishigaki *et al.* (2008) measured the methane emissions from different-aged landfills in Hanoi, Vietnam. The fitting of the measured methane emissions of landfills to the FOD model suggested a first-order reaction rate of 0.51 year^{-1}. Ishigaki *et al.* (2008) claimed that the high *k* values possibly caused by high content of rapidly degradable organic carbon in waste combined with high temperature and moisture content, stimulating anaerobic degradation and high biogas production rate.

3.3.2.2 k value based on biodegradable components (2006 IPCC)

The k values of each waste composition were obtained from results of the ratio of degradable organic carbon (DOC) in waste samples of varying ages. Figure 3 exhibited the declining trends of DOC contents in different compositions of solid waste. The exponential curve was fitted with the obtained data. Then the *k* values of individual biodegradable components were identified and compared with the default values suggested in 2006 IPCC guidelines. as listed in Table 3. The k values for paper, textile, wood, garden, food, and nappies were 0.069, 0.098, 0.088, 0.229, 0.204, and 0.021, respectively. The *k* value for paper was comparable to the default value recommended by IPCC 2006 and Wangyao *et al.* (2010). Whereas, the *k* value for food was less than that of IPCC 2006 and Wangyao *et al.* (2010), possibly due to low percentage of food composition in solid waste during studied time. However, the *k* value for food was similar to De la Cruz and Barlaz (2010), Eleazer *et al.* (1997), Levis and Barlaz (2011).

3.4 Estimation of methane emission from solid waste landfill site

3.4.1 FOD method: 2000 GPG

The calculation of CH_4 emission according to 2000 GPG used methane generation potential (L_0) and methane generation rate constant (*k*) of bulk waste as input parameters. The default and site specific values were used to compare the results of CH_4 emission. Figure 4 shows that the estimates of methane emission from landfill sites in the 2016 was 0.92 and 0.65 Gg CH_4 when the default and site specific values were used, respectively (see more details in Appendix Table B1). It was found that the CH_4 emission estimated using site specific emission factors was lower than that using default values because L_0 and k of site specific values were less than the default values.

3.4.2 FOD method: 2006 IPCC

The estimation of CH_4 emission from landfill site calculated by 2006 IPCC approach was illustrated in Figure 5. The results of methane emission from landfill sites in 2016 were 0.41 and 0.53 Gg CH_4 using default and site specific values, respectively. The result estimated with site specific values was found to be higher than that obtained using the default values. It can be explained that the obtained methane generation rate constant (*k*) of individual components of waste were higher than the default values, especially textile, wood, and garden waste.

3.4.3 LandGEM

The results of methane emission in the 2016 calculated by LandGEM were 1.00 and 0.82 Gg CH_4 when using default and site specific values, respectively. It was found that the CH_4 emission results using site specific emission factors were lower than the results using default value because L_0 and *k* of site specific obtained less than default values, as shown in Figure 6.

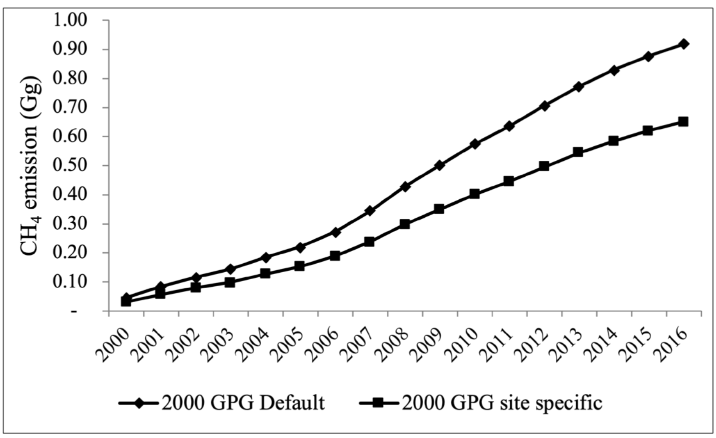

Figure 4. Methane emission estimated by 2000 GPG approach comparing between default and site specific emission factors

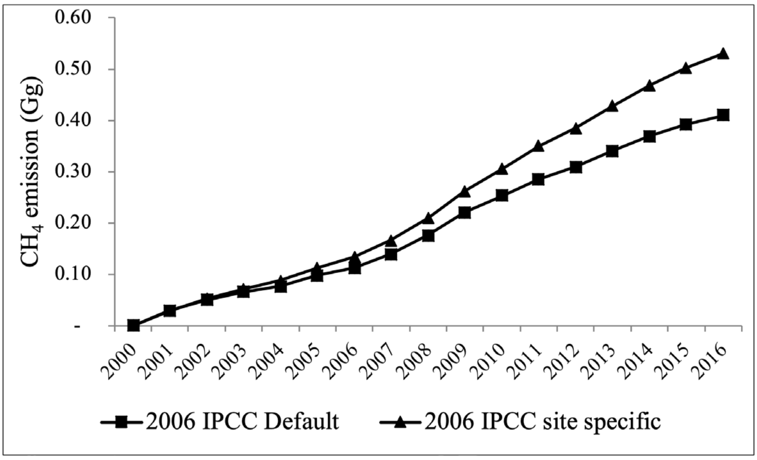

Figure 5. Methane emission estimated by 2006 IPCC comparing between default and site specific emission factors

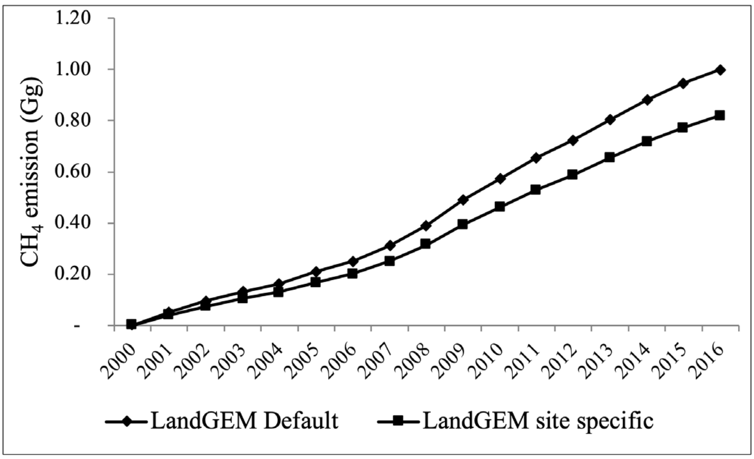

Figure 6. Methane emission estimated by LandGEM model comparing between default and site specific values

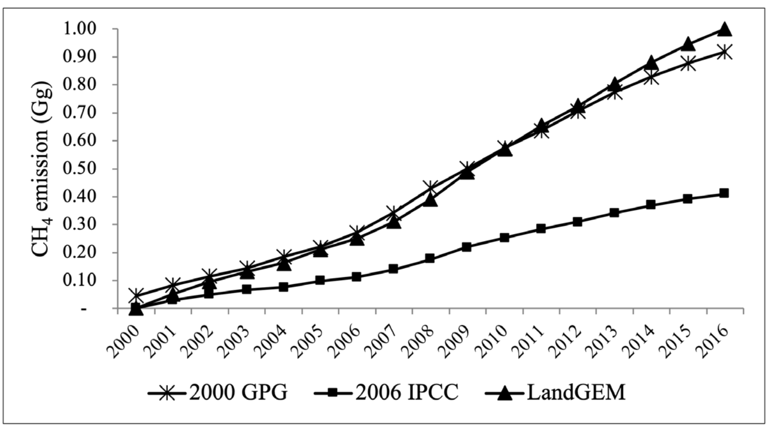

Figure 7. Comparison of estimated methane emission by different approaches using default values

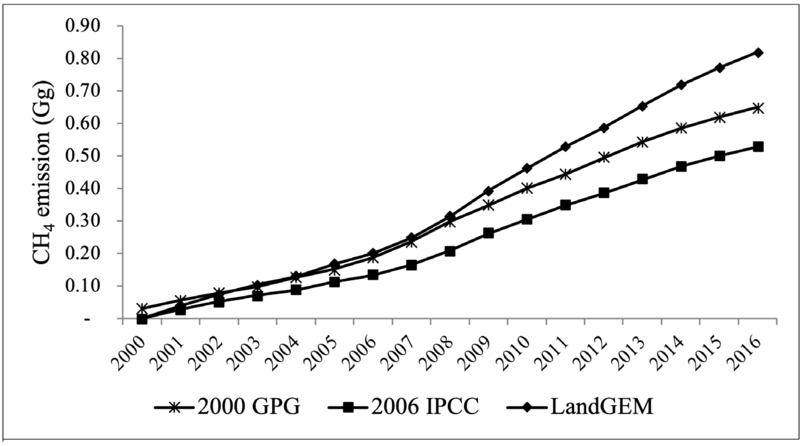

Figure 8. Comparison of estimated methane emission by different approaches using site specific emssion factors

3.4.4 Comparison of methane emission among three models

Methane emission calculated by three different models using default and site specific values are shown in Figure 7 and 8, respectively. The results showed that the values calculated based on LandGEM and 2000 GPG provided similar trends of CH_4 emission because L_0 and k values were equal, whereas less trends were obtained from 2006 IPCC method because the value of fraction of DOC that can be decomposed (DOCF) used in 2006 IPCC was less than the DOCF applied in 2000 GPG.

Additionally, the k values used in 2006 IPCC were identified based on waste composition, while 2000 GPG and LandGEM use the k value of bulk waste.

4. Conclusion

The characterization of age-defined solid waste disposed in Savannakhet landfill site found that volatile matter and organic carbon became decreased as the elapsed time of landfilling increased, reflecting decomposition of organic carbon by microorganisms during landfilling.

Methane emissions from solid waste landfill in Savannakhet Province, Lao PDR were estimated based FOD method, comparing between default and obtained site specific values. Different approaches were used to estimate including 2000 GPG, 2006 IPCC, and LandGEM. The results using default values showed that methane emission during the year 2000-2016 estimated by 2000 GPG and LandGEM provided similar trends of CH_4 emission which were higher than those estimated by 2006 IPCC. Methane emissions in the year 2016 estimated by 2000 GPG, 2006 IPCC, and LandGEM using default values were 0.92, 0.53, and 1.00 Gg, respectively. While using site specific values, methane emissions were 0.65, 0.41, and 0.82 Gg, when estimated by 2000 GPG, 2006 IPCC, and LandGEM, respectively, which were less than those using default values.

References

Blaha, D., K. Bartlett, P. Czepiel, R. Harris, and P. Crill. 1999. Natural and anthropogenic methane sources in New England. Atmospheric Environment. 33(2): 243-255.

Bo-Feng, C., L. Jian-Guo, G. Qing-Xian, N. Xiao-Qin, C. Dong, L. Lan-Cui1, Z. Ying and Z. Zhan-Sheng. 2014. Estimation of methane emissions from municipal solid waste landfills in China based on point emission sources. Advances in Climate Change Research. 5: 81-91.

Campuzano, R and S. González-Martínez. 2016. Characteristics of the organic fraction of municipal solid waste and methane production: A review. Waste Management. 54:3-12.

Chakraborty, M., C. Sharma, J. Pandey, N. Singh and P. K. Gupta. 2011. Methane emission estimation from landfills in Delhi: A comparative assessment of different methodologies. Atmospheric Environment. 45(39): 7135-7142.

Cheremisinoff, N. P. 2003. Handbook of solid waste management and waste minimization technologies, Butterworth-Heinemann.

De Gioannis, G., A. Muntoni, G. Cappai and S. Milia. 2009. Landfill gas generation after mechanical biological treatment of municipal solid waste. Estimation of gas generation rate constants. Waste Management. 29: 1026-1034.

De la Cruz, F. B and M. A. Barlaz. 2010. Estimation of waste component-specific landfill decay rates using laboratory-scale decomposition data. Environmental Science and Technology. 44: 4722–4728.

Eleazer, W. E., W. S. Odle, Y.S. Wang and M. A. Barlaz. 1997. Biodegradability of municipal solid waste components in laboratory scale landfills. Environmental Science and Technology. 31: 911–917.

Institute for Global Environmental Strategies (IGES). 2012. A guide for improving municipal solid waste management and promoting urban organic waste utilization in Lao PDR.

Intergovernmental Panel on Climate Change (IPCC). 2006. Climate change. The supplementary to the IPCC. Scientific Assessment Cambridge University Press, UK.

Ishii, K and T. Furuichi. 2013. Estimation of methane emission rate changes using age-defined waste in a landfill site. Journal of Waste Management. 33(9): 1861-1869.

Ishigaki, T., V. C. Chu, N. N. Sang, M. Ike, K. Otsuka, M. Yamada and Y. Inoue. 2008. Estimation and field measurement of methane emission from waste landfills in Hanoi, Vietnam. Journal of Material Cycles and Waste Management. 10: 165-172.

Levis, J. W and M.A. Barlaz. 2011. Is biodegradability a desirable attribute for discarded solid waste? Perspectives from a national landfill greenhouse gas inventory model. Environmental Science Technology. 45: 5470–5476.

Kim, H. and T. G. Townsend. 2012. Wet landfill decomposition rate determination using methane yield results for excavated waste samples. Waste Management. 32(7): 1427-1433.

Kumar, A. and M. P. Sharma. 2014. Estimation of GHG emission and energy recovery potential from MSW landfill sites. Sustainable Energy Technologies and Assessments. 5: 50-61.

Machado, S. L., M. F. Carvalho, J.-P. Gourc, O. M. Vilar and J. C. F. do Nascimento. 2009. Methane generation in tropical landfills: Simplified methods and field results. Waste Management 29(1): 153-161.

Mou, Z., C. Scheutz and P. Kjeldsen. 2015. Evaluating the methane generation rate constant (*k* value) of low-organic waste at Danish landfills. Waste Management. 35: 170-176.

Tchobanoglous, G., H. Theisen and S. Vigil. 1993. Integrated solid waste management: engineering principles and management issues. McGraw-Hill, Inc., New York.

Thompson, S., J. Sawyer, R. Bonam and J. E. Valdivia. 2009. Building a better methane generation model: validating models with methane recovery rates from 35 Canadian landfills. Journal of Waste Management. 29: 2085-2091.

Wangyao K., M. Yamada, K. Endo, T. Ishigaki, T. Naruoka, S. Towprayoon, C. Chiemchaisri and N. Sutthasil. 2010. Methane Generation Rate Constant in Tropical Landfill. Journal of Sustainable Energy & Environment. 1: 181-184.

Water Resources and Environment Administration (WREA). 2010. The Strategy on Climate Change of the Lao PDR.