Evaluation of Greenhouse Gas Emissions from Municipal Solid Waste (MSW) Management: Case Study of Lampang Municipality, Thailand

Pantitcha Outapa*, Veerapas Na Roi-et

Faculty of Public Health, Thammasat University, Lampang, Thailand
* Corresponding author: pantitcha@gmail.com, pantitcha.o@fph.tu.ac.th

Abstract

The issue of greenhouse gas (GHG) emissions from municipal solid waste (MSW) is important in the context of climate change. Reduction of GHGs from waste disposal systems is one of the management strategies forming part of Thailand's National Economic and Social Development Plan. This project evaluated emissions from a municipal solid waste system covering transportation and disposal in Lampang Municipality, northern Thailand. GHG emissions from transportation were estimated by the Institute for Global Environmental Strategies (IGES) based on the travel distance of the vehicles, using a vehicle emission model and vehicle fuel consumption. GHG emissions during the disposal process were also estimated based mainly on the model of IGES. The results indicated that GHG emissions from sanitary landfill were highly dominated by methane (CH_4) emissions (20,346 tons CO_2eq a^{-1}). In addition, carbon dioxide (CO_2) was emitted (226 tons a^{-1}) from the transportation process. This evaluation found that GHG emission estimates based on travel distance were lower than those based on fuel consumption (44 %). Furthermore, changing from diesel fuel to compressed natural gas will reduce transportation emissions by approximately 7 %.

Keywords: Greenhouse gas; Solid waste; Municipal; Emission; Lampang Municipality

Introduction

With urbanization, population growth and economic development, solid waste disposal has become a major of environmental issue in Thailand [1-3]. In 2004, Thailand's greenhouse gas (GHG) emissions were estimated at 266 million tons, an increase of 16 % over 2000. Approximately 9.32 $TgCO_2$eq of GHG

emissions are emitted from the waste sector including disposal of solid waste on land (4.86 $TgCO_2eq$) and wastewater handling (4.43 $TgCO_2eq$) [2]. Therefore, strategies to reduce GHG emissions in all sectors are supported by the Thai government. However, GHG emissions data for municipal solid waste (MSW) management are not available for all cities in Thailand.

Municipal solid waste management includes waste collection, transportation, recovery and disposal. In developing countries, solid waste is widely disposed of in the uncontrolled or open dumps, with serious impacts on environment and human health [4]. Solid waste disposal methods including open dump (OD), sanitary landfill, controlled dump, refuse-derived fuel (RDF), thermal treatment, composting and integrated systems; all are implemented in various municipalities in Thailand [5]. However, some of these methods are inappropriate. In 2015, Thailand's Pollution Control Department (PCD) reported that Thailand has 84 sanitary landfills/ engineered landfills, 321 controlled dumps, 18 incineration sites and 23 integrated systems [6].

Methane gas is emitted directly to the atmosphere from landfills and dumpsites [7-9]. In addition, other main GHGs released from MSW management are carbon dioxide (CO_2) and nitrous oxide (N_2O) [8]. Landfills in Thailand emit approximately 40-60 % CH_4 and 45-60 % of CO_2 [10]. In Thailand, the Intergovernmental Panel on Climate Change (IPCC) guidelines provide the primary basis for estimating GHGs emitted from MSW management [11]. A GHG calculation tool developed by the Institute for Global Environment Strategies (IGES) was used for estimating the national GHG emission inventory aligned with IPCC 2006 guideline. The GHG calculation tool was developed under a measurement, reporting and verification project for low carbon development

in Asia countries. In addition, direct emissions and life cycle assessment to save GHG emissions were calculated using the tool. The model is applied to Asia Pacific countries by selecting the specific values for key parameters in the countries and systems of interest [12].

Lampang province has the country's highest number of waste disposal sites at 173 sites. Only 22 sites use sanitary disposal systems, while the others operate as open dump sites. An engineered landfill is operated in Lampang Municipality, operating since 2001 on about 1 km^2 of land. However, only 0.03 km^2 is currently used. In 2016, the site generated approximately 103.58 tons d^{-1} [5]. Food waste, plastic and paper are the main components of the waste, according to the PCD and Ministry of Energy [13]. The composition of the waste affects the amount of GHG emissions from the landfill. The total waste generated in Lampang and its composition are presented in Figure 1 [14].

GHG emissions were reported by the Ministry of Energy, Thailand for each sector, including household, agricultural, industrial, business, transportation and others. However, the GHG emissions were only estimated from activities of combustion, coal mining fugitive and oil and natural gas fugitive [15]. In 2011, Lampang Municipality joined in the project of carbon footprint for low carbon cities supported by the Thailand Greenhouse Gas Management Organization (TGO). In 2012, total GHG emissions from Lampang Municipality were 128,596.61 tons CO_2eq released from house-hold activities, transportation and waste management sectors, respectively [16]. Moreover, solid waste management accounted for approximately 25.23 % of GHG emissions [17]. Therefore, GHG emissions estimation is important to improve the data base for comparing to other studies and supporting the mitigation measures of GHG reduction.
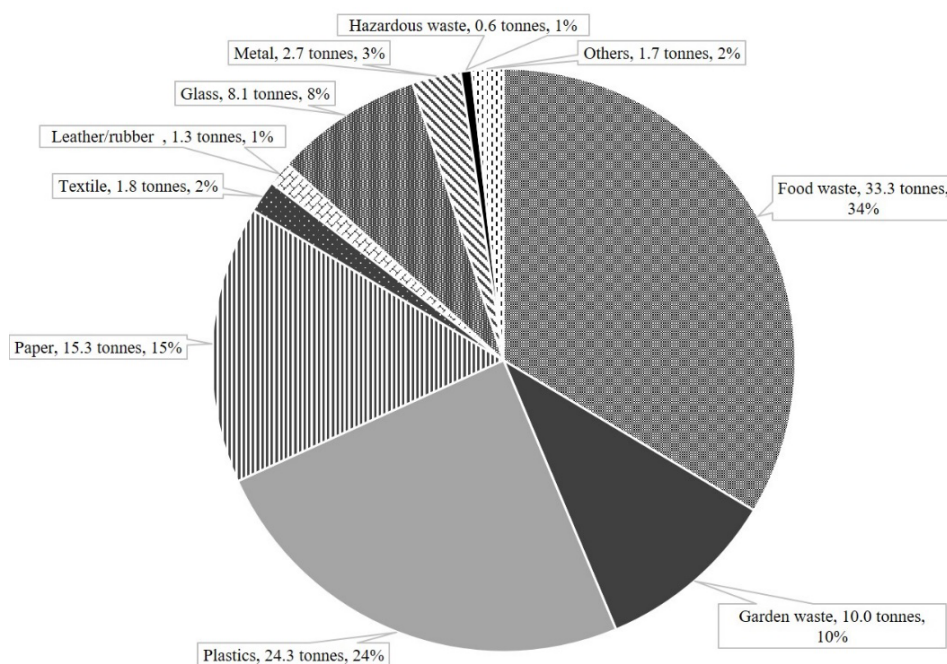
Figure 1 Total waste generated (tons d^{-1}) and waste composition (%) of Lampang Municipality in 2012.

This study evaluated GHG emissions including CO_2, N_2O and CH_4 from transportation and waste disposal processes from MSW management in the case of Lampang Municipality. GHG emissions from transportation process were estimated using a GHG calculator (Institute for Global Environment Strategies: IGES model) based on fuel consumption (L) and mobile source based on the travel distance of the vehicles (km). Moreover, GHG emissions from waste disposal processes were calculated based on total waste volume and composition, using the IGES model. Finally, various scenarios were presented for investigating the potential of GHG emission reduction from MSW management. As for solid waste collection, most waste was collected each day by 21 vehicles. The recovery process (material recovery) was performed before waste collection, transportation and disposal processes. Therefore, waste collection and recovery were not estimated the GHG emissions in this case.

Material and methods

This study focused on the main three gases (CO_2, N_2O and CH_4) generated from MSW management. The secondary data (i.e. driving cycle, vehicle distance travelled, characteristics of vehicles, fuel amounts, waste composition, amount of waste) were collected from reports, organizations of government and field surveys. The GHG emissions from transportation and landfill were calculated using the IGES model. In order to propose an alternative tool for estimating GHG emissions, the international emission model or mobile source emission model was selected to estimate GHG emissions from transportation then compared to the emissions calculated by the IGES model. The scenario is presented to reduce GHG emissions from the transportation process then the results of CO_2, N_2O and CH_4 emissions from MSW management were compared with other studies. The CO_2, N_2O and CH_4 emissions were converted to the unit of CO_2eq (carbon dioxide equivalent) on the Global Warming Potential (GWP) of 100-year

time horizon. Multiplication factors of 1, 310 and 25 are used for CO_2, N_2O and CH_4, respectively [18]. The year 2012 was selected as the base year.

Two methods of transportation and disposal processes were considered to estimate GHG emissions in the study, as follows:

Method I: GHG emissions from transportation and disposal processes were calculated by the International Vehicle Emission (IVE) model and IGES model, respectively.

Method II: GHG emissions from transportation and disposal process were calculated by the IGES model. The concept of the study is shown in Figure 2.

1) Bottom up approach

1.1) Mobile source emission model

The IVE model was used to calculate the GHG emission factors in this study. It was developed by the University of California at Riverside, granted by the US Environmental Protection Agency. Moreover, the IVE model is suited to use in developing countries, and has been used in India, Mexico, Iran, Vietnam and Thailand. The model allows selection from over 1,200 vehicle engine technologies and has the advantage of taking into account other air pollutants emitted by vehicles [19].

Figure 2 Conceptual framework of the study.

Emissions from motorcycles, heavy duty vehicles and all type of vehicles in Hanoi (Vietnam), Chennai (India) and Tehran (Iran), were estimated by the IVE model. The results found that advanced technology significantly reduced air pollutants and GHG emissions emitted from the vehicles [20-22]. Moreover, toxic air pollutants emitted from all vehicle types were estimated by IVE model in Bangkok urban area, Thailand. It was found that by using more advanced vehicle technologies, benzene emissions can be reduced by approximately 2,000 tons per year [23].

The model has two main components for input data: a location file and a fleet file. Driving cycle, average speed, characteristics of fuel, temperature and humidity represent the location data. The fleet file defines the characteristics of vehicles, including fuel type, size of vehicles, engine type, vehicle standard, vehicle distance travelled, etc. The Bangkok driving cycle developed by the PCD is also input to the model. Results from the model are shown as emission factors or emissions. The mathematical formula of the model is given in Eq. 1 [19].

In this study, emissions were estimated for the 21 collection vehicles with average age of 5 years in the Lampang Municipality area. The vehicles were categorized into 3 types by gross weight (light, medium and heavy) as shown in the Table 1. Additionally, the Euro III emission standard for all vehicles was used in this study. GHG emission factors were calculated then total emissions estimated using the GHG emission factors and travel distance data. The emission was calculated by Eq. 2.

$$Emission\ factor = \text{B x K}_{(1)}\text{x K}_{(2)} \text{x K}.....\text{x K}_{(x)} \qquad \text{(Eq. 1)}$$

Where B = base emission factor of vehicles, K = series of correction factors (i.e. ambient temperature, ambient humidity, fuel quality variables, vehicle specific power).

$$\sum \text{EI}_{ij} = \text{EF}_{ij}\text{x VKT}_{ij} \qquad \text{(Eq. 2)}$$

Where i = predicted year, j = vehicle type (light, medium, heavy), EI = emission inventory (tons a^{-1}), EF = emission factor (g km^{-1}) and VKT = vehicle kilometer travelled (km y^{-1}).

Table 1 Gross weight and amount of vehicles

Size category	Gross weight (kg)	Number of vehicles
Light	4,082-6,250	5
Medium	6,251-14,969	3
Heavy	> 14,970	13
Total		21

1.2) GHG calculator for solid waste sector (IGES model)

The IGES model was developed for calculating GHG emissions including direct emissions and GHG savings from treatment technologies and integrated systems under life the cycle assessment (LCA) approach, modified to improve the model. GHG emissions of waste management technologies were adopted from the IPCC 2006 Guidelines. The model covers transportation, mixed waste landfilling, composting, anaerobic digestion, mechanical biological treatment (MBT), recycling, incineration and open burning. In addition,

specific technologies implemented locally can be selected as an input into the model. Hence, the model is suitable for a bottom-up approach to building up a nationwide GHG emission inventory [24]. Furthermore, the model was compared with other tools for quantifying black carbon emissions and reductions from waste management activities at a workshop on GHGs organized by ISWA/UN Environment. In a comparison between IFEU-KfW tool and IGES tool, the programming in the IGES tool proved more user-friendly [25-26].

The transportation and waste disposal processes were considered for the GHG emissions calculation from MSW management in the study. As for the transportation process, the GHG emissions were calculated from the fossil fuel combustion including diesel fuel and compressed natural gas (CNG). Moreover, the major gas of GHG emissions from waste transportation was CO_2. CH_4 and N_2O were emitted in small amounts during fuel combustion and were not considered in this model. Mathematical formula in this process is given in Eq. 3 [12].

In addition, a landfill operating in Lampang manages the MSW disposal process. Therefore, GHG emissions released from the landfill was estimated from the mathematical formula of the IGES model as shown in Eq. 4.

CH_4 is the major GHG emitted from waste disposal sites such as landfills. Emission levels depend on a range of factors including pH, moisture content, amount and mixture of waste and the waste management process itself. CH_4 generally increases with higher organic and moisture content. Therefore, the composition of landfill is needed as an input into the model e.g. food waste, garden waste, plastic waste, paper, textile, leather, rubber, glass, metal, hazardous waste and others. The total amount of mixed waste (tons month^{-1}) and diesel fuel (L month^{-1}) used are also input to the model. Finally, the specific type of landfill MSW management needs to be selected for calculating GHG emissions.

To estimate GHG emissions from the landfill in site, all parameters of mix waste were based on the model's default values which themselves refer to the IPCC model. The fractions of mixing waste input to the model were from waste data collected in the study area. Approximately 10,146 L per month of diesel fuel was consumed for collection and transportation of a total of approximately 3,000 tons per month of mixed waste. However, diesel fuel consumption used for operation of the landfill was not considered in the study.

$$\text{Emission} = \frac{\text{Fuel (units)}}{\text{Waste (tons)}} \times \text{Energy} \left(\frac{\text{MJ}}{\text{unit}}\right) \times \text{Emission Factor} \left(\frac{\text{KgCO2}}{\text{MJ}}\right) \qquad \text{(Eq. 3)}$$

Where Emissions = emissions from transportation (kg CO_2 per ton of waste transported), Fuel = total amount of fossil fuel consumption per month, (diesel in liters and CNG in kg), Waste = total amount of waste transported per month (tons), Energy = energy content of the fossil fuel (diesel: 36.42 MJ L^{-1}, CNG: 37.92 MJ kg^{-1}) and Emission Factor = CO_2 emission factor of the fuel (diesel: 0.074 kg CO_2 MJ^{-1}, CNG: 0.056 kg CO_2 MJ^{-1})

$$\text{DDOC}_m = \text{DDOC}_{m(0)} \text{x } e^{-kt} \qquad \text{(Eq. 4)}$$

Where $\text{DDOC}_{m(0)}$ = the mass of decomposable degradable organic carbon (DDOC) at the start of the reaction, when t=0 and e^{-kt}=1, k = the reaction constant and t is the time in year and DDOC_m = the mass of DDOC at any time

2) Scenario analysis

In order to optimize transportation of MSW, national energy policy was taken into consideration in this study. CNG is an alternative fuel for use in vehicles especially heavy-duty vehicles such as trucks, buses, etc. Changing diesel fuel to CNG fuel can be considered as a set of scenario development (CNG scenario). The scenario could be based on the assumption that CNG will reduce GHG emissions emitted from vehicles. The baseline scenario was determined as the MSW management current situation in Lampang municipality and then compared to the CNG scenario. The database for baseline scenario was present in Table 2.

Table 2 Data used as the baseline scenario

Parameters	Baseline scenario	Base data
Transportation process		
VKT (km a^{-1})		Method I
o Light	330,480	
o Medium	156,960	
o Heavy	167,760	
Fuel amount (L a^{-1}): Diesel	121,756	Method II
Disposal process		
Waste amount (tons a^{-1})	36,000	Method I, II

Note: Data are estimated from Lampang Municipality [14]

Results and discussion

The estimation of GHG emissions was based on travel distance (km) and fuel consumption (L). Emissions from vehicles during transportation using diesel fuel, as calculated by the IVE model from 2012-2016 (5 years) were approximately 226-227 and 0.02-0.03 tons of CO_2 and N_2O, respectively (Figure 3). Between 2012 and 2016, GHG emissions were not significantly different in the study. Using the IGES model, estimated CO_2 emissions were higher (328.14 tons a^{-1}). GHG emissions calculated using default emission factors based on travel distance (g km^{-1}) was higher than the GHG emissions calculated under emission factors based on fuel consumption. The IGES model did not consider N_2O emissions. The GHG emission from sanitary landfill calculated by the IGES model was highly contributed by the landfill methane (CH_4) emission (20,345.50 tons CO_2eq a^{-1}). The calculations take into account the fractions of mixed waste generated, including food waste, garden waste, etc.

The CNG scenario was assumed for all new vehicles. Result of the GHG emissions calculation found that CO_2 emission was decreased from the baseline. In this scenario, CH_4 emission was also estimated from the IVE model. It may result from CNG fuel evaporation being included. Total GHG emissions estimated from the transportation process from the CNG scenario is about 217 tons CO_2eq a^{-1}, which was also the lowest compared with the others. The GHG emissions calculated under both methods and CNG scenario are compared in Table 3 and the total of GHG emissions of all processes are shown in Figure 4.

GHG emissions from MSW management including transportation and the landfill site in Lampang Municipality were estimated by Sampattagul and Khomyan [17] based on energy use. The comparison of results to previous work [17] found that the GHG emissions released from MSW management in Lampang Municipality were approximately 58 % (Method I) and 57 % (Method II) lower than those studies (Figure 5). In this context, there are different methods for calculating GHG emissions from MSW management that depend on the purposes of the specific study.
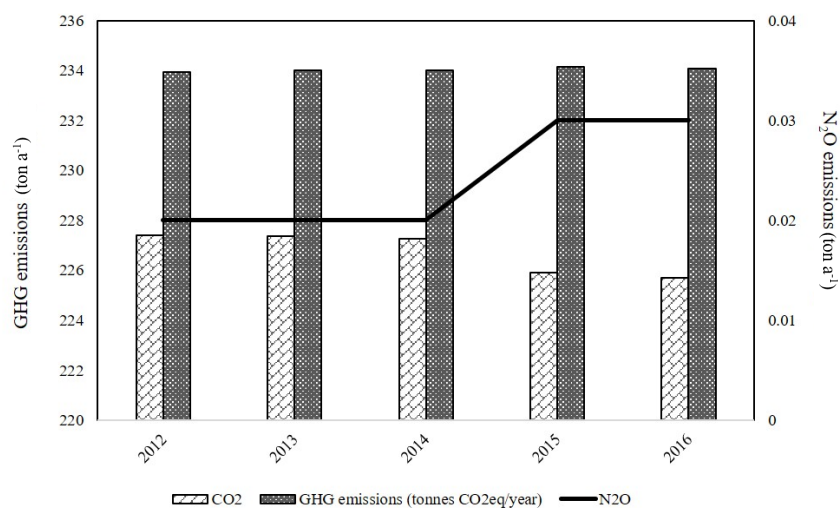
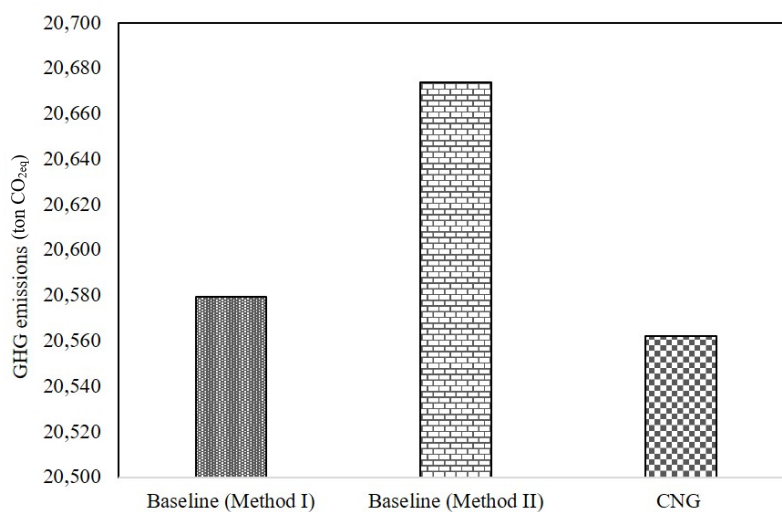**Figure 3** GHG emissions of vehicles from waste transportation process.

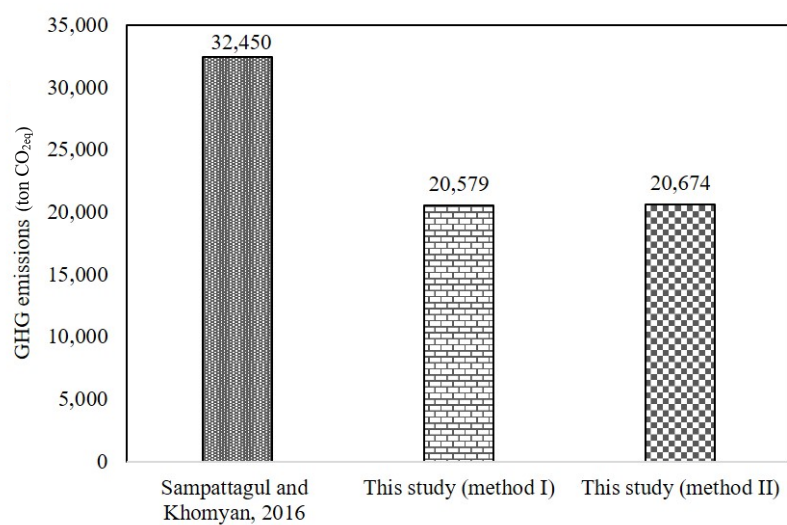**Figure 4** Total GHG emissions of all waste management processes.

Figure 5 Comparison of results of this study to the previous research.

54

App. Envi. Res. 40(1) (2018): 46-56

Table 3 GHG emissions resulting from the model

Scenario	Transportation (tons a^{-1})				Disposal (tons a^{-1})
	CO_2	N_2O	CH_4	CO_2eq	CO_2eq
Baseline (Method I)	227.41	0.02	-	233.95	20,345.50
Baseline (Method II)	328.14	-	-	328.14	20,345.50
CNG	201.51	0.02	0.41	216.70	20,345.50

Conclusion

This study focused on greenhouse gas emissions from MSW management in Lampang Municipality, Thailand. Two main processes including transportation and disposal were considered. The GHG emissions released from MSW management were estimated by two methods. The GHG emissions calculation based on travel distance by the IVE model considered the age, driving cycle and technology of vehicles. This model can be considered as a tool for estimating GHG emissions emitted from vehicles in developing countries. Approximately 44 % of the GHG emissions calculation based on travel distance was lower than those based on fuel consumption. GHG emissions released approximately 20,346 tons CO_2eq a^{-1} from Lampang Municipality. This was lower than the GHG estimated from landfill of another study which used different methods. Total GHG emissions emitted from MSW management in Lampang Municipality were approximately 20,579.45 and 20,673.64 tonsCO_2eq a^{-1} under Method I and Method II, respectively. Additionally, replacing CNG fuel to diesel fuel of vehicles will reduce GHG emissions by approximately 17 tons CO_2eq a^{-1}.

Acknowledgements

References

[1] Chen, Y.C., Lo, S.L. Evaluation of green-house gas emissions for several municipal solid waste management strategies. Journal of Cleaner Production, 2016, 113, 606-612.

[2] Office of Natural Resources and Environmental Policy and Planning (ONEP). Thailand's second national communication. Bangkok. 2010, 143.

[3] Woon, K.S., Lo, I. MC. Greenhouse gas accounting of the proposed landfill extension and advance incineration facility for municipal solid waste management in Hong Kong. Science of the Total Environment, 2013, 458-460, 499-507.

[4] Jain, N., Meena, S., Tak, R. Engineered Landfill site design municipal solid waste of Jaipur, India. International Journal of Civil Engineering 2016, 3(7), 2348-8352.

[5] Pollution Control Department (PCD). Municipal waste disposal places in Thailand. [Online] Available from: http://infofile.pcd.go.th/waste/waste-20Apr11.pdf [Accessed 17 March 2017].

[6] Pollution Control Department (PCD). Thailand state of municipal waste report 2016. Waste and Hazardous Substance Management Bureau, Bangkok 2017, 20.

[7] Jha, K.A., Sharma, C., Singh, N., Ramesh, R., Purvaja, R., Gupta, K.P. Greenhouse gas emissions from municipal solid waste management. Chemosphere, 2008, 71(4), 750-758.

[8]   Hoklis, C., Sharp, A. Greenhouse gas emission from municipal solid waste in Phnom Penh, Cambodia. GMSARN International Journal, 2014, 8, 73-78.

[9]   Scheutz, C., Pedersen, B.R., Petersen, H.P., Jørgensen, B.J.H., Ucendo, B.I.M, Mønster, G.J., Samuelsson, J., Kjeldsen, P. Mitigation of methane emission from an old unlined landfill in Klintholm, Denmark using a passive biocover system. Waste Management, 2014, 34(7), 1179-1190.

[10]   Babel, S., Vilaysouk, X. Greenhouse gas emissions from municipal solid waste management in Vientiane, Lao PDR. Waste Management and Research, 2016, 34(1), 30-37.

[11]   Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds.) Guidelines for national greenhouse gas inventories, Prepared by the National Greenhouse Gas Inventories Programme, Intergovernmental Panel on Climate Change (IPCC). Published: IGES, Japan, 2016.

[12]   Menikpura, N., Sang-Arun, J. User manual estimation tool for greenhouse gas (GHG) emissions from municipal solid waste (MSW) management in a life cycle perspective, Version II (edited) - Simulation User Guide. Institute of Global Environment Strategies, Japan, 2013, 138.

[13]   Ministry of Energy. Feasibility study on solid waste to electrical power with incinerator technology. Department of Alternative Energy Development and Efficiency, Bangkok, 2015, 17.

[14]   Lampang Municipality. Physical properties of solid waste materials study in Lampang Municipality. Lampang, Thailand, 2012.

[15]   Ministry of Energy. Greenhouse gas emissions. [Online] Available from: http://www.thaienergydata.in.th/output_co2.php [Accessed 10 January 2017].

[16]   Thailand Greenhouse Gas Management Organization (TGO). Multidimensional of 'Lampang - Udon' to low carbon city. [Online] Available from: http://www.tgo.or.th/2015/thai/news_detail.php?id=717 [Accessed 10 January 2017].

[17]   Sampattagul, S., Khomyan, C. City carbon footprint evaluation and GHG mitigation options planning survey for low carbon city. In proceeding of Heat and Mass Transfer in Thermal and Process Equipment, Suratthani, Thailand, March, 2016.

[18]   Lakeman, J.A. Intergovernmental Panel on Climate Change (IPCC). Climate change 1995, The Science of climate change: Summary for policymakers and technical summary of the Working Group I Report. Published: The Press Syndicate of the University of Cambridge, Australia, 1996, 22.

[19]   International Sustainable Systems Research Center (ISSRC). IVE model user's manual version 2.0 May, 2008. [Online] Available from: http://www.issrc.org/ive/ [Accessed 4 September 2016].

[20]   Nesamani, K.S. Estimation of automobile emissions and control strategies in India. Science of the Total Environment, 2010, 408, 1800-1811.

[21]   Oanh, K.N.T., Phuong, T.M.T., Permadi, D.A. Analysis of motorcycle fleet in Hanoi for estimation of air pollution emission and climate mitigation co-benefit of technology implementation. Atmospheric Environment, 2012, 59, 438-448.

[22] Shafie-Pour, M., Tavakoli, A. On-road vehicle emissions forecast using IVE simulation model. International Journal of Environmental Research, 2013, 7(2), 367-376.

[23] Outapa, P., Thepanodh, S. Development of air toxic emission factor and inventory of on-road mobile sources. Air, Soil and Water Research, 2014, 7, 1-10.

[24] Menikpura, S.N.M., Sang-Arun, J., Bengtsson, M. Integrated solid waste management: An approach for enhancing climate co-benefits through resource recovery. Journal of Cleaner Production, 2013, 58, 34-42.

[25] Donahue, J. Opportunities for incorporating black carbon into municipal solid waste emissions quantification Tools, 2013. [Online] Available from: http://waste.ccacknowledge.net/sites/default/files/files/events_documents/1.3%20Stratus%20Report_Joseph%20Donahue.pdf [Accessed 3 September 2017].

[26] Vogt, R. Accounting systems for short-lived climate pollutants and greenhouse gas mitigation in the waste management sector, 2015. [Online] Available from: https://www.ifeu.de/abfallwirtschaft/pdf/UBA%20texte_55_2015.pdf [Accessed 3 September 2017].