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Quantification of greenhouse gas emissions from different municipal solid waste treatment methods - case study in Ha Noi, Vietnam

Thi Mai Thao Pham*

Faculty of Environment
Ha Noi University of Natural Resources and Environment

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Abstract:

This study focuses on defining the greenhouse gas (GHG) emissions from treatment of municipal solid waste (MSW) in Ha Noi city. Firstly, the MSW samplings at Nam Son and Xuan Son landfills were collected to identify the components. Based on the statistical data on the amount and ratio of MSW collected, the volume of MSW treated by different technologies was estimated. Then, the GHG emissions were quantified by applying the Intergovernmental Panel on Climate Change (IPCC) 2006 model. The annual GHG released from MSW in Ha Noi in 2017 was 1.1 million tons of CO_{2e} from landfilling, 16.3 thousand tons of CO_{2e} from incineration, and 76,100 tons of CO_{2e} from composting. The GHG emission level from landfills is the highest (327 kg of CO_{2e} per ton of treated waste), followed by composting (189 kg of CO_{2e} per ton), and incineration (115 kg of CO_{2e} per ton). The GHG emissions from landfills comprised nearly 90% of GHG emissions from MSW disposal in Ha Noi. The results also revealed that if there are no measures to recover landfill gas for energy generation, the GHG generated from MSW treatment facilities will also contribute significantly to the greenhouse effect and climate change impact. These research results also supply the basis information for decision-makers to select the appropriate MSW treatment technologies for Ha Noi in the context of increasing population pressure and environmental pollution.

Keywords: **composting, greenhouse gas (GHG), incineration, landfill, MSW.**

Classification number: **5.1**

Introduction

Ha Noi is the capital of Vietnam and is the country's economic and political centre. It covers the second largest area of 3,344.6 km^2. The population in 2017 was 7.65 million people; 49.2% lived in urban areas and 50.8% in suburban areas, distributed among 12 urban districts, 17 suburban districts, and one town [1]. The recent trend toward urbanization has led to a rapid increase in generation of MSW. Statistics reveal that the amount of MSW in Ha Noi city averages 7,500 tons per day and it is growing by an average of 10-16% per year in urban areas [2]. Currently, MSW in Ha Noi is treated mainly by landfills without gas capture, incineration, and composting [3]. Due to the high ratio of organic matter in landfills, anaerobic decomposition creates a huge amount of CH_4 that causes a greenhouse effect 25 times higher than CO_2. According to 2006 statistics from the Intergovernmental Panel on Climate Change (IPCC) [4], CH_4 generated in landfill sites accounted for approximately 27% of the total greenhouse gas (GHG) and approximately 3-4% of total global GHG emissions.

According to the annual report of the Ha Noi People's Committee on the status of MSW generation and management in Ha Noi city, the total collected and treated MSW in 2017 was an estimated 5,300 tons per day [4], including:

i) Landfilling, which is conducted mainly at Nam Son and Xuan Son landfills. These landfills treat approximately 89.5% of waste collected; with a capacity of 4,000-4,500 tons per day, Nam Son is the largest. The MSW is unclassified at these landfills and no gas capture system has been installed.

ii) Composting, which takes place at Cau Dien, Kieu Ky, and Xuan Son composting plants. However, only 0.5% of the total collected MSW all organic waste is treated by

*Email: ptmthao@hunre.edu.vn.

this method. The output of these systems is organic humus.

iii) Incineration, which is done at Xuan Son, Thanh Cong, and Phuong Dinh waste treatment plants; with a capacity of 700 tons per day, Xuan Son is the largest. This method treats approximately 10% of MSW generated. Additionally, a recycling method is applied but the ratio is tiny and is mainly done by private companies. Emissions generated from combustion are treated to remove pollutant gases before they are discharged into the air.

Recent studies have examined the GHG emissions resulting from various waste treatment technologies; in 2016, Singh, et al. [5] did so at landfills in India. The research evaluated GHG emissions from three different landfills and showed the potential to generate electricity from landfill gas collection systems. In 2019, Zhang, et al. [6] monitored the GHG emissions from a typical limited-controlled landfill according to the guidance of the UK Environment Agency to obtain representative data from the heterogeneous surface of the landfill. The research had identified the CH_4 and CO_2 emission fluxes from the landfill area. This is advisable to devote more attention to and determine potential solutions for reduction of GHG emissions from a limited-controlled landfill. In 2017, Dong, et al. [7] evaluated GHG emissions from the waste sectors in Hong Kong using IPCC 2006 guidelines. The analysis results indicated that the GHG emissions from landfills decreased while total GHG emissions from the entire waste sector increased, mainly due to emissions from the combustion of petroleum for ignition. It revealed that incineration also contributes to the increase of GHGs in waste treatment. In 2009, Manfredi, et al. [8] accounted for GHG emissions from different landfilling technologies in Denmark; these included open dump, conventional landfills with flares and with energy recovery, and landfills receiving low-organic-carbon waste. The results illustrated that GHG emissions from conventional landfills lacking a CH_4 collection system were the major contribution to the total GHGs. This research also concluded that utilization of landfill gases for electricity generation contributed to reduce environmental impacts from landfilling. Additionally, Ritchie, et al. (2009) [9] compared GHG emissions from landfills with waste-to-energy technologies in Vancouver, Canada. The results indicated that GHG emissions from the waste-to-energy facilities were higher than those of the landfills due to plastics remaining in the waste stream. In 2017, Hwang, et al. [10] estimated GHG emissions at nine different technological incineration facilities in Korea by measuring the GHG concentrations in the flue gas samples. The research indicated that the emissions of IPCC default values were estimated to be higher than those of the plant-specific emission factors. In 2010, Chen, et al. [11] studied estimates of CO_2 emissions from MSW incineration in Taipei city, demonstrating the correlation between GHG emissions and components of waste. Additionally, Marchi, et al. (2017) [12] applied IPCC 2006 guidelines to calculate GHG emissions from different waste treatment methods. The research results helped to orient emission-reduction strategies and environmental impacts of the waste sector in the central Italy.

In 2014 in Vietnam, Ngan, et al. (2004) [13] conducted a study to calculate CH_4 emissions from MSW in Can Tho city. Based on the city's population size and economic development conditions, predictions were made about the total amount of CH_4 gas to be generated from MSW landfills in 2020. In 2015, Tuyen, et al. [14] estimated CH_4 emissions from municipal waste landfills in Thu Dau Mot city, Binh Duong province. Based on the different scenarios of the MSW management and treatment master plan of the province, the research results assessed the potential for reclaiming and reusing CH_4 gas from waste disposal activities to 2030. In 2014 in Hue city, Tuan, et al. [15] estimated the reduction potential of CH_4 emissions from the landfill and from composting. Based on different scenarios, the study revealed that CH_4 can be reduced by changing from landfilling to composting. Giang, et al. (2013) [16] also applied IPCC 2006 guidelines to evaluate the GHG mitigation potential from MSW treatment in Vietnam via landfilling and composting systems by creating various management scenarios. This research illustrated that GHG emissions from waste treatment can be reduced if energy-recovery methods are applied.

The above-mentioned studies estimated GHG emissions from MSW treatment. However, the authors used only statistical data on MSW proportion or default values from IPCC 2006 without identifying the true data from study areas. In addition, further studies on GHG emissions from the composting method have not been conducted. According to the Vietnamese Prime Minister's Decision No. 609/QD-TTg on 25 April 2014, approving a master plan for solid waste disposal in Ha Noi to 2030, with a vision to 2050, the estimate of GHG emissions from various MSW treatment technologies is one of the most important objectives. Therefore, this study was conducted to identify the current MSW components in Ha Noi city and estimate the amount of GHG emissions from different MSW treatment methods. The research results will update the GHG emissions data from the waste sector to help decision-makers select suitable technologies for MSW treatment.

Methodology

Method to determine the MSW composition

The composition of MSW at Nam Son and Xuan Son landfills was determined to provide the input data for calculating GHG emissions from different MSW treatment methods in Ha Noi instead of using the default values from the IPCC 2006 guidelines. The two samplings at each landfill were taken at the same time each day at the burial cells after the trucks dumped their garbage loads and before the garbage was compressed. In this research, the coning and quartering method was applied. The MSW samples were placed in a conical heap. This heap was then divided vertically into four equal parts by two lines at right angles to each other. Two opposite quarters were then mixed with each other into one sample. The two other quarters were discarded. This procedure was repeated until the established sample size reached 150 kg as in the guideline of TCVN 9461:2012, the standard test method for determining the composition of unprocessed municipal solid waste in Vietnam [17]. Large or long objects were cut into smaller pieces (5-10 cm) before the sample was taken for sorting. The samples were manually classified and separated into 11 components (food, biodegradable organic matter, garden waste, paper, cardboard, wood chips...) according to the classification of IPCC 2006 [5] and the Vietnamese system [18].

Methods to qualify GHG emissions

Landfill:

The CH_4 and CO_2 emissions in landfills derive mainly from the decomposition of organic components. In this study, the IPCC 2006 method was selected for calculating the amount of CH_4 generated. This method assumes that the degradable organic carbon (DOC) composition will decompose slowly over many years (approximately 10), and that CH_4 is formed during that period. In stable conditions, the CH_4 produced depends mainly on the amount of carbon accumulated in burial cells. CO_2 emission was not included in the IPCC 2006 method because it had been calculated in the Agriculture, Forest, and Land Use Sector (AFOLU). According to the IPCC 2006 (Chapter 3, Volume 5) [19], CH_4 emission from landfills after one year is calculated as in Equation (1):

$$CH_{4emission} = \{\sum_x \left[MSW_x \times L_0(x) \times \left(\left(1 - e^{-kt}\right) \times e^{-k(t-x)}\right)\right] - R(t)\} \times (1 - OX) \quad (1)$$

where $CH_{4\ emission}$ is CH_4 emitted in year t (tons/year), MSW_x is mass of waste deposited in year t (tons/year), L_o is the CH_4 generation potential (tons) (calculated by Equation 2), t is inventory year, x is opening year of disposal site or first year of data available, k is reaction constant ($k = \ln(2)/t_{1/2}$ ($year^{-1}$)), $t_{1/2}$ is half-life time (y), R(t) is recovered CH_4 in year t (tons/year), and OX is oxidation factor in year t.

Data on the amount of MSW in landfills from 2007 to 2017 were collected from the annual report of the Ha Noi People's Committee [20] and the Ha Noi GHG emission inventory report in 2015 [21]; they are illustrated in Fig. 1. The amount of MSW gradually increased over the years in line with the growing population.

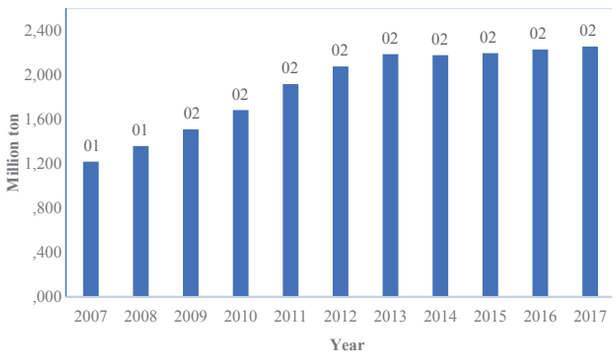

Fig. 1. Amount of MSW treated in landfills from 2007 to 2017 [20, 21].

CH_4 generation potential (L_o) is calculated by Equation (2):

$$L_o = MCF \times DOC \times DOC_f \times F \times \frac{16}{12} \quad (2)$$

where MCF (Methane correction Factor) is the CH_4 correction factor for aerobic decomposition in the year of deposition, DOC is degradable organic carbon in the year of deposition (tons C/tons waste) (calculated by Equation 3), DOC_f is the fraction of DOC that can decompose, F is the fraction of CH_4 in generated landfill gases, and 16/12 is the molecular weight ratio of CH_4/C.

$$DOC = 0.15A + 0.2B + 0.4C + 0.43D + 0.24E + 0.15F \quad (3)$$

where A is food waste (%); B is garden waste (%); C is pulp, paper, and cardboard (%); D is wood and wood products (%); E is rags (%); F is diapers (%). These above ratios are used from the true survey data.

Other fractions (DOC_f, F, MCF, OX, and k) are used from the default value of IPCC 2006 for unclarified MSW, in which: $DOC_f = 0.5$, F = 0.5, MCF = 0.6, OX = 0.1, and k is shown in Table 1.

Table 1. Reaction constant (k) [19].

Symbol	Composition	Used value	Symbol	Composition	Used value
A	Food, organic matters	0.4	D	Milled wood	0.035
B	Garden garbage (leaves, twigs, grass...)	0.17	E	Rags	0.7
C	Paper, cartons	0.07	F	Diapers	0.17

Composting:

CO_2, CH_4, and N_2O are all by-products of the composting process. As mentioned above, CO_2 emissions from composting were not included in the IPCC 2006 method. CH_4 and N_2O emissions from composting can be estimated by using the default method of IPCC 2006 (Chapter 4, Volume 5) [22] and given in Equations (4) and (5) below:

$$CH_{4Emission} = \sum_i (M_i \times EF\_CH_{4i}) \times 10^{-3} - R \quad (4)$$

$$N_2O_{Emission} = \sum_i (M_i \times EF\_N_2O_i) \times 10^{-3} \quad (5)$$

where $CH_{4Emission}$ is total CH_4 emissions in the inventory year (tons/year), $N_2O_{Emission}$ is total N_2O emissions in the inventory year (tons/year), M_i is mass of organic waste treated by biological treatment type i (tons/year), EF_CH_{4i} is the emissions factor for treatment i (gCH_4/kg waste treated), $EF\_N_2O_i$ is the emissions factor for treatment i (gN_2O/kg waste treated), 10^{-3} is the conversion factor from kilogram to ton, i is composting or anaerobic digestion, and R is total amount of CH_4 recovered in the inventory year (tons/year).

Currently, Ha Noi conducts composting only as a biological treatment method. The composted waste is organic matter with a certain moisture content; it is necessary to ensure proper moisture for microorganisms. Therefore, the default factors of IPCC 2006 guidelines are used for calculation.

Because the MSW treated at the composting plants is moist, the default values of wet weight were chosen for calculation (CH_4 = 4 (gCH_4/kg wet waste) and N_2O = 0.3 (gN_2O/kg wet waste)). Ha Noi city has no biogas recovery facilities, so the total amount of CH_4 recovered in an inventory year (R) is irrelevant. Due to the lack of statistical data on MSW treated by composting before 2014, this study estimated GHG generation only from composting methods during 2014-2017. The MSW treated by this method is illustrated in Fig. 2. The amount of MSW treated by composting technology gradually decreased over time due to the unstable fertilizer quality. This, in turn, led to inadequate funds for operation, so private enterprises did not prioritize investment.

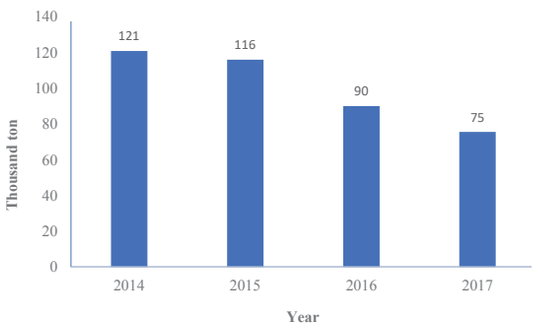

Fig. 2. Amount of MSW treated by composting [21].

Incineration:

In this research, the GHG emissions deriving from incineration are only estimated. The emissions from open burning are not known due to the lack of data. CO_2, CH_4, and N_2O emissions from waste incineration are calculated as in Equations (6), (7), and (8), respectively (IPCC 2006, Chapter 5, Volume 5) [23].

$$CO_{2Emission} = MSW \times \sum(WF_i \times dm_i \times CF_i \times FCF_i \times OF_i) \times \frac{44}{12} \quad (6)$$

where $CO_{2Emission}$ is CO_2 emission in the inventory year (tons/year); MSW is the total amount of MSW as wet weight incinerated (tons/year); WF_i is the fraction of waste type/material of component i in the MSW (as wet weight incinerated); dm_i is dry matter content in the component i of the MSW incinerated; CF_i is the fraction of carbon in the dry matter of component i; FCF_i is the fraction of fossil carbon in the total carbon of component i; OF_i is the oxidation factor; 44/12 is the conversion factor from C to CO_2 (with: $\sum WF_i = 1$); and i is the component of the MSW incinerated such as paper/cardboard, textiles, food waste, wood, garden (yard) and park waste, disposable nappies, rubber and leather, plastics, metal, glass, and other inert waste.

$$CH_{4Emission} = \sum_i (IW_i \times EF\_CH_{4i}) \times 10^{-6} \quad (7)$$

$$N_2O_{Emission} = \sum_i (IW_i \times EF\_N_2O_i) \times 10^{-6} \quad (8)$$

where $CH_{4Emission}$ is CH_4 emissions in the inventory year (tons/year), IW_i is the amount of solid waste of type i incinerated (tons/year), EF_CH_{4i} is the aggregate CH_4 emission factor (g CH_4/ton of waste), $EF\_N_2O_i$ is the aggregate N_2O emission factor (g N_2O/ton of waste), 10^{-3} is the conversion

factor from kilogram to ton, and i is the category or type of waste incinerated. Due to the lack of data on CH_4 and N_2O emission factors for each type of waste incinerated, the emission factors from the IPCC 2006 default values (EF_CH_4 = 0.2 g/ton MSW and EF_N_2O = 50 g/ton MSW) are used for calculation.

In this study, the Global Warming Potentials (GWPs) from IPCC 2006 [5] are used to change CH_4 and N_2O to CO_{2e} in which the GWP of CH_4 = 25 CO_2 and N_2O = 298 CO_2. These numbers are calculated for a 100-year time horizon. As in the composting case, GHG emissions from incineration were estimated from 2014 to 2017. The amount of MSW treated by this method was collected from the National Environmental Thematic Report in 2017 [2] and the Maintenance Committee of the Technical Infrastructure Works, Ha Noi Department of Construction (Fig. 3). The amount of MSW incinerated increased annually, except in 2017, because the Phuong Dinh and Thanh Cong plants were closed for maintenance.

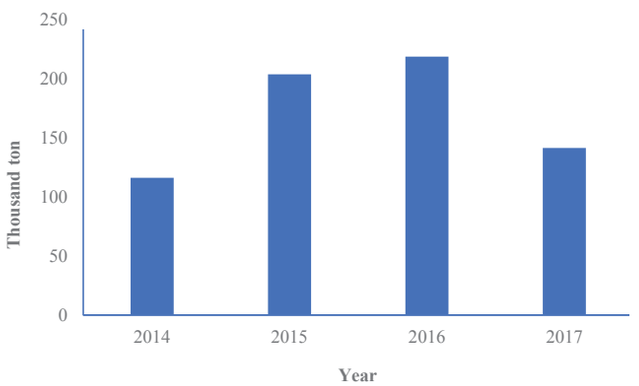

Fig. 3. Amount of MSW treated by incinerators [2].

Because combustion technology applied at incineration plants in Ha Noi (incinerator includes 01 primary combustion chamber, 01 secondary combustion chamber, 02 heat chambers and dust settlements, primary furnace temperature reaches: 800-900^{0}C; secondary furnace temperature reaches 1,200^{0}C) is similar to that from the IPCC default, other fractions such as dry matter content in the component i of the MSW incinerated (dm_i), carbon in the dry matter of component i (CF_i), fossil carbon in the total carbon of component i (FCF_i), and oxidation factor (OF_i = 100) from the IPCC 2006 default values are used for calculation (Table 2).

Table 2. Fractions of dm_i, CF_i, FCF_i, WF_i [23].

MSW composition	dm_i(%)	CF_i(%)	FCF_i(%)	WF_i
Food, organic matter	40	38	0	64.2
Garden garbage (leaves, twigs) grass...)	40	49	0	6.2
Paper, cartons	90	46	1	3.2
Milled wood	85	50	0	3.4
Rags	80	50	20	2.6
Diapers	40	70	10	1.8
Plastic	100	75	100	2.6
Rubber, leather	84	67	20	2.3
Metals	100	NA	NA	1.6
Glass and porcelain	100	NA	NA	2.5
Other types	90	3	100	9.6

Results and discussion

Composition of MSW in Ha Noi

Table 3 illustrates that the components of MSW are somewhat different between Xuan Son and Nam Son. The proportion of organic waste in Xuan Son (64.2%) is more than that Nam Son (58.4%). This result is consistent with MSW components in Ha Noi reported in the 2016 National Environmental Status Report (54-77%) [24]. It is lower than that of Thu Dau Mot city, Binh Duong province (78.5%) [14], and Can Tho city (80%), while recyclable components are the same [13]. These results may depend on the collected sources; Nam Son landfill receives MSW from metropolitan areas Nam Tu Liem, Bac Tu Liem, Soc Son, Dong Anh, Me Linh, and Thanh Tri districts while Xuan Son treats MSW from Son Tay town and remaining suburban districts. In the urban areas, residents more frequently buy food from supermarkets that has been pre-processed to remove unused parts while suburban residents can harvest directly from the garden. As a result, the garden garbage rate in Xuan Son is twice as high as that in Nam Son, while the rate of recyclable substances such as paper and cartons in Nam Son (6%) is higher than that in Xuan Son (3%). The results tend to be similar for other inorganic waste components. It probably relies on keeping garbage for sale to recycling facilities of suburban residents. Generally, the proportion of MSW components depends on living habits, standards, economic conditions, and the civilization of each region.

Table 3. Composition of MSW in Nam Son and Xuan Son landfills.

No.	Composition	Nam Son (%)	Xuan Son (%)	Average
1	Food, organic matter	58.8	64.2	61.5
2	Garden garbage (leaves, twigs, grass...)	2.8	6.2	4.5
3	Paper, cartons	6.0	3.2	4.6
4	Milled wood	3.6	3.4	3.5
5	Rags	2.9	2.6	2.8
6	Diapers	2.3	1.8	2.1
7	Plastic	3.2	2.6	2.9
8	Rubber, leather	2.3	2.3	2.3
9	Metals	2.0	1.6	1.8
10	Glass and porcelain	3.9	2.5	3.2
11	Sludge	0.2	0.4	0.3
12	Other types	12.0	9.3	10.7

Quantification of GHG emissions from different MSW treatment methods

GHG emissions from landfills:

CH_4 emissions at landfills in Ha Noi city are calculated according to Equations (1), (2), and (3) in which the Degradable Organic Carbon (DOC) values (Table 4) were calculated based on the average rate of each component of MSW in Xuan Son and Nam Son landfills and the default coefficient values in the IPCC 2006 [19]. Because of the lack of data on MSW composition in the past, the field survey results in the research are used to calculate CH_4 emission from landfills in 2007-2017.

Table 4. DOC value.

No.	Symbol	Composition	DOC (%)
1	A	Food, organic matter	8.8
2	B	Garden garbage (leaves, twigs, grass...)	0.6
3	C	Paper, cartons	2.4
4	D	Milled wood	1.6
5	E	Rags	0.7
6	F	Diapers	0.5
DOC = 0.15A + 0.2B + 0.4C + 0.43D + 0.24E + 0.24F			14.6

With the input parameters of the IPCC 2006 model determined, the calculation results revealed that CH_4 emissions increase with time and amount of MSW buried. CH_4 in year t is generated from the biodegradation of organic ingredients that existed in landfills in previous years. With the calculation starting from 2007, the results are presented in Table 5.

Table 5. CH_4 generated at landfills from 2008-2017 (in tons).

Year	CH_4	CO_{2eq}
2008	7,626	190,650
2009	13,692	342,300
2010	18,750	468,750
2011	23,302	582,550
2012	26,884	672,100
2013	30,467	761,675
2014	33,692	842,300
2015	36,894	922,350
2016	39,244	981,100
2017	41,100	1,027,500
Total	271,651	6,791,275

The results revealed that, in 2008, approximately 7,626 tons of CH_4 was emitted per year, equivalent to 190,650 tons of CO_{2e} per year. In 2017, the amount of CH_4 emission was 41,100 tons per year, equivalent to 1,027,500 tons of CO_{2e} per year. The total amount of CO_{2e} emissions in the period 2007-2017 was 6,791,275 tons. The calculation result reveals that food waste was the main source of $CO_{2e,}$ emissions accounting for 90% of total CO_{2e} emissions into the environment. The remaining waste components such as paper, wood, and cloth accounted for only 10% of total CO_{2e} emissions. If no gas recovery methods or measures to minimize GHGs generated from landfills are implemented, these emissions will increase the greenhouse effect and exacerbate climate change.

Based on the total amount of MSW landfilled [20, 21] and the total estimated GHG amount from 2008 to 2017, GHG emissions from the landfills in Ha Noi would be 327 kg of CO_{2e} per ton of MSW treated. This value is nearly same as the case study of conventional landfills in Denmark (300 kg of CO_{2e} per ton) [6]; is lower than that from the Vancouver landfill (382 kgCO_{2e} per ton) in Canada [25]; and is higher than that in China (259.5 kg of CO_{2e} per ton) with a biodegradable fraction (almost 60-70%) [26]. This difference is due to the waste properties, weather

characteristics, and various infrastructures in these research areas.

GHG emissions from composting:

Composting is an aerobic process in which a large fraction of DOC in the waste components is converted into CO_2 [22]. CH_4 is formed because anaerobic digestion takes place in the compost pile when not enough oxygen is supplied. Composting releases CH_4 from 1% to a few percent of the initial carbon content and N_2O from 0.5% to 5% of the initial nitrogen content. Poor composting is likely to produce more of both CH_4 and N_2O [14]. By applying Equations (4) and (5), CH_4 and N_2O generated by composting are displayed in Table 6.

Table 6. Total amount of CH_4 and N_2O generated by composting (in tons).

Year	CH_4	CO_{2e} from CH_4	N_2O	CO_{2e} from N_2O	Total CO_{2e}
2014	483	12,075	36.22	10,794	22,869
2015	463	11,575	34.72	10,347	21,922
2016	360	9,000	26.97	8,037	17,037
2017	302	7,550	22.63	6,744	14,294
Total	1,608	40,200	120.54	35,922	76,122

Table 6 illustrates that total CH_4 emissions from 2014 to 2017 amounted to 1,608 tons (equivalent to 40,200 tons of CO_{2e}); N_2O emissions amounted to 120.54 tons (equivalent to 35,922 tons of CO_{2e}). The total amount of CO_{2e} generated in 2017 decreased by 37% compared to 2014. The reason is that the MSW treated by composting decreased due to high investment and operational costs but low income from the sale of composting fertilizer. Based on the total amount MSW composted and the total GHG generated annually from 2014 to 2017, the GHG emissions resulting from composting facilities in Ha Noi would be 189 kg of CO_{2e} per ton of MSW treated. This value is within the GHG emissions range (3.2-262 kg of CO_{2e} per ton of MSW) from the research results of Melissa, et al. (2017) [25] in Panama with the same composting technology and waste humidity.

GHG emissions from incineration:

Equation (6) was used to estimate CO_2 generated from incinerators. Because incineration is mainly implemented in Xuan Son, the clarification results from the Xuan Son landfill are used for calculations in this case. The CO_2 emissions from MSW incineration are presented in Table 7.

Table 7. CO_2 emissions from incineration (in tons).

MSW composition	2014	2015	2016	2017
Food, organic matter	-	-	-	-
Garden garbage (leaves) twigs, grass...)	-	-	-	-
Paper, cartons	56	99	106	69
Milled wood	-	-	-	-
Rags	884	1,549	1,664	1,076
Diapers	214	375	403	261
Plastic	8,288	14,522	15,596	10,085
Rubber, leather	1,100	1,928	2,071	1,339
Metals	-	-	-	-
Glass and porcelain	-	-	-	-
Other types	1,102	1,930	2,073	1,340
Total	11,645	20,404	21,912	14,169

Total CO_2 emissions from incinerators during the period 2014-2017 were 68,000 tons, with the highest in 2016 (21,912) and the lowest in 2014 (11,645). In the comparison of different MSW components, burnt plastic generates the highest CO_2 emissions by years; the total CO_2 emission from plastic in four years was 48,500 tons, which accounted for 71% of total CO_{2e} emissions.

Equations (7) and (8) were applied to estimate CH_4 and N_2O emissions from incineration. The results are displayed in Table 8.

Table 8. CH_4 and N_2O emissions from MSW incineration (in tons).

Year	CH_4	CO_{2e} from CH_4	N_2O	CO_{2e} from N_2O	Total CO_{2e}
2014	0.023	0.580	5.796	1,727	1,728
2015	0.041	1.016	10.155	3,026	3,027
2016	0.044	1.091	10.906	3,250	3,251
2017	0.028	0.705	7.052	2,102	2,102
Total	0.136	3.392	33.909	10,105	10,108

From 2014 to 2017, total emissions of CH_4 and N_2O were 136 kg of CH_4 (~3.4 tons of CO_{2e}) and 3.391 tons of N_2O (~10,105 tons of CO_{2e}); the total CO_{2e} generated was 10,109 tons. The amount of CO_2 is the main GHG emission from incineration; it accounts for 87% of total GHG

emissions from incineration. On average, CO_{2e} emitted from this treatment method is 115 kg of CO_{2e} per ton of waste. This value in Korea is 134±17 kg of CO_2 per ton of waste [11]. It is a bit larger than that in the Ha Noi case. The GHG emissions at incineration plants are different due to operational systems (i.e., stoker, fluidized bed, moving grate, rotary kiln, and kiln and stoker), therefore, this result is valid only for the current case. If, in the future, Hanoi invests new waste incinerator systems with other technologies, the GHG generated on the volume of waste treated should be re-estimated to avoid errors.

The GHG emission levels of the different MSW treatment methods in Ha Noi are presented in Fig. 4. The figure illustrates that landfills generate the highest amount of GHG emissions, 1.94 times higher than composting and 3.19 times higher than incineration. The reason is that the anaerobic process at landfills continues to happen after the cell is fully filled. In addition, the MSW is usually treated immediately after it is transported to the composting and incineration facilities. These data illustrate that landfills will contribute more significantly to long-term environmental impacts than other MSW disposal methods.

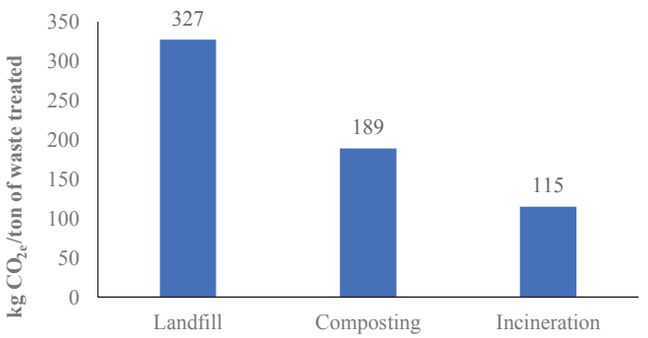

Fig. 4. CO_{2e} emissions from the different treatment methods.

Conclusions

The research results demonstrate that organic waste is the main component of MSW in Ha Noi (61.5%). Currently, Ha Noi has three main MSW treatment methods; landfilling accounts for approximately 89.5% of the total amount of waste collected, followed by incineration (10%), and finally composting (0.5%). The GHG released from MSW treatment in Ha Noi city in 2017 was 6.7 million tons of CO_{2e} from landfills, 16,300 tons of CO_{2e} from incineration, and 76,100 tons of CO_{2e} from composting. The GHG emissions from landfills is the highest (367 kg of CO_{2e} per ton of waste treated), 1.94 times higher than that from composting (189 kg of CO_{2e} per ton) and 3.19 times higher than that from incineration (115 kg of CO_{2e} per ton). The GHG emissions from landfills comprise nearly 90% of GHG emissions from MSW disposal activities in Ha Noi. The results also indicate that if no gas-recovery measures (especially on CH_4) are introduced for energy production, the GHG generated from MSW treatment facilities will contribute significantly to the greenhouse effect and exacerbate climate change. These research results provide the basis information for decision-makers to consider when determining appropriate MSW treatment technology for Ha Noi in the context of increasing population pressure and environmental pollution.

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