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Assessment of potential greenhouse gas mitigation of available household solid waste treatment technologies

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Abstract - Current household solid waste treatment practices in most cities in Vietnam caused a great amount of direct greenhouse gas (GHG) emissions. Available solid waste treatment technologies should be seriously taken into consideration as a wedge of GHG mitigation in waste sector base on presently Vietnamese economic conditions. This study aims to evaluate the potential amount of GHG mitigation from current domestic solid waste treatment technologies in Vietnam including landfills and composting from various management scenarios. In oder to use Tier 2 model of IPCC 2006 for GHG estimation from landfills, an analysis on current household solid waste management system of the city was obtained by using material flow analysis approach. A case study in Hanoi, the capital city of Vietnam was carried out in this research. As a result, there was a reduction of over 70% of the amount of CH_4 emissions and up to 53% of total GHG saving ($CO_{2\text{-eq}}$) from avoiding organic waste to landfill. In addition, applying an energy recovery from LFG system to available landfills would lead to aproximately 75% of GHG saved compare to current emission of waste sector.

Keywords – *municipal solid waste, composting, landfill, landfill gas recovery, greenhouse gas reduction.*
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1. Introduction

Since the pre-industrial era, atmospheric concentrations of methane (CH_4) have increased more than doubled (ISWA, 2010) and waste sector is claimed as one of large sources of anthropogenic CH_4 emissions, which contributed significantly to global warming over the last decades. Solid waste treatment technologies play as an important role of direct greenhouse gas emission as well as greenhouse gas mitigation. However, in developing world countries including Vietnam, investments in new treatment technologies might take long time as well as vast sum of funds, so it would appear as unreasonable choices in a short-term period. Therefore, an improvement of solid waste management system and making use of available technologies would be more sustainable for current socio-economic conditions of Vietnam in order to reduce GHG emission.

This study aimed to assess the impact of household solid waste treatment practices towards GHG mitigation for the waste sector defined by Intergovernmental Panel on Climate Change (IPCC). Therefore, authors propose to use the 2006 IPCC method to evaluate greenhouse gas emission (IPCC, 2006). A case study for Hanoi, the capital city of Vietnam in 2011 has been experimented under some possible scenarios simulated using available technologies. However, when exploring the correlation between municipal solid waste treatment and GHG emission, the volume and physical composition of the waste matter must be taken into account (Thanh & Matsui, 2012). Due to the lack of statistical data on waste stream, a material flow analysis (MFA), therefore, has been carried out on household solid waste management system in order to obtain a database of waste stream for applying the Tier 2 model of 2006 IPCC guidelines.

The 2006 IPCC provided a methodology for annual accounting of GHG emissions for the waste sector, defined by the IPCC, is different from how the waste management industry perceives itself (Gentil, Christensen, & Aoustin, 2009). Certainly, the reporting methodology of the IPCC waste sector identifies only the direct emissions of post-consumer waste management and recycling, intermediate waste facilities as well as waste transportation are excluded. The method is crucial in assessment of the potential of GHG emission/mitigation associated with all activities or sectors within a reporting country according to IPCC.

Material flow analysis (MFA) is a systematic assessment of the flow of different materials through a defined space and within a certain time (Belevi, 2002) based on the law of the conservation of material, the results of an MFA can be controlled by a simple material balance comparing all inputs, stocks, and outputs of processes (Brunner & Rechberger, 2004). It is this study, a MFA for the household solid waste stream were experimented to define the actual amount of different materials of waste disposed in landfills.

2. Metarials and methods

2.1. Materials

Research target area

Hanoi city had a great size of population of around 6.5 million in 2010 including urban residents of about 2.7 million and people living in countryside acounted for 3.8 million (HSO, 2011). The concerning targets of the research were an systematic analysis of the household waste stream of the city in 2011 and a calculation of the directed GHG emission according to the 2006 IPCC guidelines such as CH_4 and N_2O emitted from landfill and composting plant activities. The 3 main landfills and 3 composting facilities in Hanoi was taken into acount in this study including Nam Son, Xuan Son, Kieu Ki as well as Cau Dien, Kieu Ki, Seraphin respectively.

In order to assess the potential contribution of GHG mitigation of solid waste management alternatives for Hanoi city, some reasonable waste management scenarios were assumed with the priority given to the continuing use of existing solid waste treatment technologies and implementation of improving collection efficiency and separation at source. In addition, the authors used an assumption that technological upgrade to landfill with active landfill gas (LFG) recovery system from available ones in order to assess the potential contribution for GHG mitigation of renewable energy production from LFG. According to Spokas et al. (2006), this paper proposed to use default values for percent recovery of 85% for a landfill with clay final cover and active LFG recovery. Scenarios description was illustrated in Table 1.

Table 1. Scenarios descriptions

Scenarios	Collection rate	Separation at source	Technologies description
HT (business as usual)	Urban area 95% Countryside 60%	Not separate at source	Available technologies: Landfilled without LFG recovery Composting
S1	100%.	Waste separation at source Increase the percentage of waste recoverd to 80%	Available technologies: Landfilled without LFG recovery Composting 100% organic waste
S2	100%	Waste separation at source Increase the percentage of waste recoverd to 80%	LFG recovery application: Landfills with LFG recovery with the rate of 85% of CH_4 recovered Composting 100% organic waste

Waste quantity and composition data

The data of household waste used for analysis in this study have been obtained from published report in 2011 of Hanoi urban environment one member limited company (URENCO, 2011) and National report on environment 2011: solid waste by Ministry of Natural Resource and Environment (MONRE, 2011). In addition, research data conducted by JICA was used in the study. The household waste generation and collection rate of urban area and countryside area of Hanoi in 2011 have been introduced in those reports above and also calculated in Table 2. The household solid waste information including waste quantity and composition by physical categories of the city in 2011 as well as landfills was provided by URENCO and MONRE, also calculated and summarized in Table 3.

According to URENCO, the amount of waste not collected in 2011 was 1165 tons per day, meanwhile that of waste treated was only 3972 tons per day according to JICA (2011), accounted for only 75% of collected waste quantity 5335 tons per day. The low percentage of waste to treatment facilities was possibly as a result of recycle activities through waste pickers and junk-man which are improperly controlled as well as low efficiency of waste collection activities. The preferably recycled waste was collected through many activities of including mostly junk-shops and waste pickers on street as well as landfills. The percentage of waste recycled was at about 10% of total waste generation (MONRE, 2011), mainly recovered in some recycling villages which are private and small producers, as a result it was difficult to determine the amount of recycled waste exactly.

Table 2. Household waste generation and collection of Hanoi in 2011

Area	Collection efficiency	Amount (t/d)
Waste generation in the whole city	-	6500
Waste generation in urban area	-	4100
Waste generation in countryside area	-	2400
Waste collected in urban area	95%	3895
Waste collected in countryside area	60%	1440
Total waste collected		5335

Table 3. The composition of waste of the city and landfills in 2011

Type of waste	Percentage (%)	Percentage of waste composition in landfills			Moisture (%)
		Nam Son	Xuan Son	Kieu Ki	
Paper [i]	3.80	6.53	5.38	5.47	57.63
Plastic [i]	3.29	13.57	8.35	11.89	53.91
Nylon [i]	7.32	-	-	-	53.91
Metal [i]	1.52	0.87	0.25	0.46	-
Organic waste	44.67	53.81	60.79	56.84	70.00
Rubber, leather	3.28	0.15	0.22	0.83	0.72
Textile	2.04	5.82	1.76	4.32	9.9
Wood	2.73	2.51	6.63	4.44	30.9
Glass	2.24	1.87	5.08	2.5	-
Ceramic	4.90	0.39	1.26	0.84	-
Inert	18.85	14.31	9.46	12.14	-
Hazardous waste	5.35	0.17	0.82	0.27	-
Amount (tons per day)	6500	3468	227	118	

[i] *Types of recycle waste in private business and recycling villages*

2.2. Methods

Waste material flow analysis

The study applied MFA approach which based on the law of the conservation of material to calculate the amount of waste recovered from landfills ($G_{tc\text{-}BCL}$), as following equations

$$G_{tc-BCL} = 650 - 10\% x G_{ktg} - \left[\sum_i G_{tc,i} - \left(\sum_i G_i^{NS} + \sum_i G_i^{XS} + \sum_i G_i^{KK}\right)\right] \text{ (t/d) .... (1)}$$

Where,

- G_{ktg}, the total amount of household waste was not collected *(t/d)*;
- $G_{tc,i}$, the total amount of recyclable waste generated

$$G_{tc,i} = r_i \times G$$ within the city, *(t/d)* .... (2)

+ r_i , the percent of recyclable waste i generated; meanwhile G is the total amount of waste generated in 2011, 6500 tons per day;
- 650 (t/d), the total amount of waste recycled of the city in 2011, accounted for 10% of the total generation (MONRE, 2011);
- $G_i^{NS,XS,KK}$, the amount of recyclable waste i transported to Nam Son, Xuan Son and Kieu Ki landfills,

$$G_i^{NS,XS,KK} = G_{CL}^{NS,XS,KK} \times r_i^{NS,XS,KK} \quad (t/d)$$

.... (3)

+ $G_{CL}^{NS,XS,KK}$, the total amount of waste transported to Nam Son, Xuan Son, Kieu Ki landfills;
+ $r_i^{NS,XS,KK}$, the percent of recyclable waste type i such as paper, metal, plastic… transported to Nam Son, Xuan Son, Kieu Ki landfills;

- the term

$$\left[\sum_i G_{tc,i} - \left(\sum_i G_i^{NS} + \sum_i G_i^{XS} + \sum_i G_i^{KK}\right)\right]$$

presented the amount of recyclable waste recovered outside landfills *(t/d)* ....(4)

The amount of recyclable waste type *i* landfilled was accounted as difference between amount of waste *i* transported to landfills and that of *i* recovered from landfills. Authors used an simple assumption that percentages of recyclable waste recovered from landfills including paper, metal, plastic and nylon are equal. The amount of other waste landfilled in 2011 was calculated by their percentages in table 2.

Estimation of GHG emission from landfills and composting facilities

Landfills

The study proposed to use 2006 IPCC guideline – model Tier 2 for estimating methane emission from landfills. The input data of composition of waste landfilled was used are the results from waste material flow analysis as well as some default parameters suggested by IPCC for (presented in Table 3). In order to calculate the direct CH_4 emitted from landfilling the amount of household solid waste in 2011, authors assumed that landfills in Hanoi operated within 1 year and closured in the end of 2011 when completed the treatment for the waste of 2011.

The CH_4 emissions from solid waste disposal for a single year can be estimated using the general Equations 5. Part of the CH_4 generated is oxidized in the cover layer, or can be recovered for energy or flaring. The CH_4 actually emitted from the landfill will hence be smaller than the amount generated (IPCC, 2006).

$$L = \left[\sum_i (CH_{4-gen,i,T} - R_T) \right] \times (1 - OX_T) \text{ (thousand tons)} \quad (5)$$

Where:

L, CH emitted in year T, *(thousand tons);*
R_T, recovered CH_4 in year T *(thousand tons);*
T, inventory year ;
OX_T, oxidation factor in year T, *(fraction);*

The coefficients of the 2006 IPCC model were chosen according to the 2006 IPCC guidelines mostly depend on the region and climate characteristics. The region of the city is Asia-southeast and the climate of Vietnam is moist and wet tropical. In addition, based on the features of landfills in Hanoi, authors used the methane correction factor of Semi-aerobic managed solid waste disposal sites. The table 4 presented values of all factors by IPCC used for the estimation model.

Table 4. Default parameters used in IPCC model

Parameter	IPCC default	Average
DOC (% wet waste)		
Organic waste	0.08-0.20	0.15
Paper	0.36-0.45	0.4
Wood	0.39-0.46	0.43
Textile	0.20-0.40	0.24
DOC_f (%)		0.5
k ($Year^{-1}$)		
Organic waste	0.17–0.7	0.4
Paper	0.06–0.085	0.07
Wood	0.03–0.05	0.035
Slowly degrading organic waste	0.15–0.2	0.17
Delay time (month)		6
F		0.5
Oxidation factor		0
MCF		0.6

Composting

Composting is an aerobic process and a large fraction of the degradable organic carbon (DOC) in the waste material is converted into CO_2. CH_4 is formed in anaerobic sections of the compost, but it is oxidized to a large extent in the aerobic sections of the compost. This process also emitted N_2O and acounted for about from 0,5% (Beck-Friis, Smars, Jönsson, & Kirchmann, 2001) to 5% of total nitrogen in solid waste.Thus, according to 2006 IPCC guidelines, the study used default CH_4 and N_2O emission factor at about 4gCH_4 per 1 kg waste and 0,3gN_2O per 1 kg waste respectively.

The Global warming potential (GWP) provides a metric for evaluating and comparing the potential climate change associated with emissions of different GHGs (Scheutz, Kjeldsen, & Gentil, 2009). The IPCC provides the GWP for a time horizon of 20, 100 and 500 years, but a time horizon of 100 years is employed most commonly (Forster, 2007). According to Fuglestvedt et al. (2001) the choice of time horizon depends on the policy objective. This study adopted the 100 years horizon with GWP of CH_4 and N_2O equal to 25 and 298 respectively suggested by Forster (2007) in order to determine the maximum change in climate.

Energy generation

Energy generation from landfill gas can involve either heating applications (steam raising via boilers, kiln firing or space heating), or power generation systems. For the purposes of this study, it will be assumed that where energy recovery occurs it involves the burning of landfill gas in a gas engine to generate electricity, which is then exported into the grid. Power generation systems can involve spark-ignition or dual-fuel diesel engines, or gas turbines (in increasing order of generation capacity). Before the landfill gas is burned in these engines it is normally compressed and dewatered, which also removes most of the trace contaminants to protect the engines from acid gases and particulate matter. Tuyen and Michaelowa (2004) reported that the baseline emission factor for the Vietnam electricity system was 585 tCO_{2-eq}/GWh by 2008. According to F.R. McDougall (2001), a conversion efficiency of 30% will be assumed and an electrical energy recovery of 1.5 kWh per Nm^3 (Normal metric cubed) of landfill gas collected.

3. Results

3.1. Waste material flow analysis

The amount of recyclable waste recovered outside landfills is determined by the equation 4 was 256 tons per day, where 780 is amount of recyclable waste transported to landfills (in equation 3). Thus, the amount of recyclable waste recovered from landfills, determined by equation 1 is 277.5 tons per day.

Within landfills in Hanoi city, activities of waste recovery of waste pickers and junk-mans contributed an amount of 277.5 tons recyclable waste a day. In addition, debris material released from composting plants and recycle village of about 55.55 (35% mass of organic waste input) and 65 tons per day (10% mass of recycle waste input) respectively (MONRE, 2011), was landfilled likewise. Thus the actual total amount of waste landfilled daily was 3656 tons and the percentages of recycled paper, plastic and nylon, metal in Hanoi in 2011 was 36%, 53% and 79.64%. Eventually, the total amount of household solid waste untreated was 2155.5 tons per day. Table 5 describes the waste material flow in 2011 of Hanoi for current status as well as comparative scenarios.

Table 5. Waste material flow analysis of Hanoi in for different scenarios

Scenarios	**Compost (tons/day)**	**Landfill (tons/day)**	**Percentage of different waste landfilled**					**Recycle (tons/day)**	**Untreated (tons/day)**
			Organic	Paper	Textile	Wood	Others		
HT	159	3656	56,65%	4,32%	5,77%	2,94%	30,32%	650	2155,5
S1	2903	3141	0	1,57%	4,23%	5,65%	88,5%	829	0
S2	2903	3141	0	1,57%	4,23%	5,65%	88,5%	829	0

3.2. GHG emission from treatment facilities.

CH_4 emission from landfills

Organic the waste, paper, wood and textile are the main sources of CH_4 emission in landfills. The Fig. 1 illustrated the potential quatity of CH_4 emission of above types of waste. Results showed that the capacity of CH_4 emission are different from various waste and organic waste contributed the largest propotion of 70%, followed by paper with the percentage of approximately 17%. The smallest contributer in landfill is wood accounted for about 14% of total CH_4 emitted from landfills.

The CH_4 emission factor waste presents the amount of CH_4 released per 1 ton of that kind of waste landfilled. That of textile and paper waste was very high at around 90 kg CH_4 per tom of waste treated. On the other hand, the CH_4 emission factor of organic waste was smallest though that is the largest source of CH_4 emission from landfills.

The amount of CH_4 generated from landfill in Scenario S1 and S2 would be 8.33 thousand tons. Therefore, the total volume of LFG emission doubled the total volume of CH_4 emission, in scenario S1 and S2 that would be 245 Mm^3. Thus, if upgrading current landfills technology to landfill with active LFG recovery system of and a gas-fired power plant, the electrical energy recovery would be approximately 367.5 gigawatthour (GWh).

GHGs emission from composting plants

Results of CH_4 and N_2O emission from composting facilities and there GWP_{100} were summarized in the Table 6. The result of this study also certified the importance of available recycling practices, especially composting in order to avoiding landfilling organic waste. In scenarios S1 and S2, the amount of organic waste to landfill equals to 0 meanwhile there was 1059.6 thousand tons composted. Hargreaves, Adl, and Warman (2008) reported that organic waste composting had a potential as a beneficial recycling tool for waste management and treatment. Furthermore, this method reduced the volume of waste which goes to landfill and the production appropriated for applying agriculture fields as safety fertilizer as well as avoiding biogenic CO2 emission by long time C storage in soil (Boldrin, Andersen, Møller, Christensen, & Favoino, 2009)

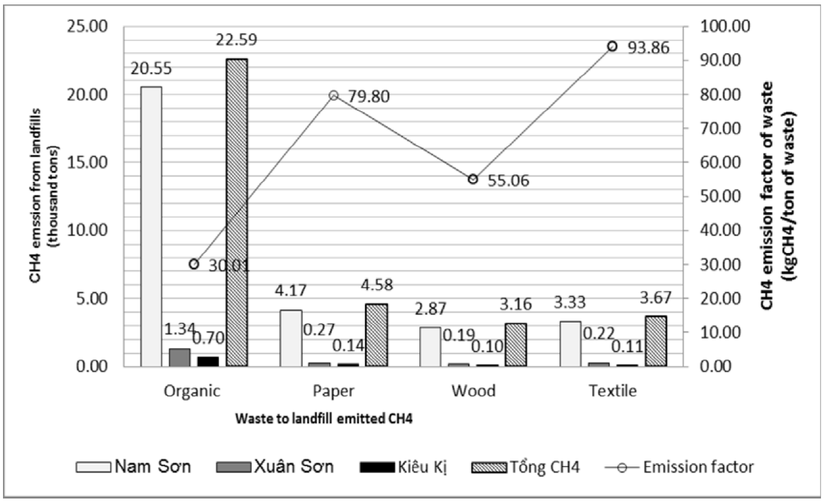

Figure 1. CH_4 emission from current landfill in Hanoi with different materials

Table 6. Quantity of GHG emission from composting with different scenarios

	GHG	Total organic waste, 2011	Emission factor	Amount	GWP_{100}
		thousand tons	g/kg	Thousand tons	thousand tons CO_{2-eq}
HT	**CH_4**	58,04	4	0,232	5,803
	N_2O	58,04	0,3	0,01741	5,188
				Total	**10, 991**
S1 and S2	**CH_4**	1059,60	4	4,238	105, 96
	N_2O	1059,60	0,3	0,318	94,73
				Total	**200,69**

Potential GHG emission and mitigation

As a result, the potential the total amount of GHG emission from treatment facilities in Hanoi was approximately 860 thousand tons CO_{2-eq}, landfills accounted for 99% and made a contribution of 850 thousand tons CO_{2-eq}.

Appearently, the amount of GHG emission from composting in both comperative scenarios increased as a result of increase in composting technology but the total amount of GHG emission in both was enormously reduced to 410 and 230 thousand tons CO_{2-eq}. The eletrical energy recovery from LFG application in S2 leads to only 30 thousand tons GHG emitted from landfills. Moreover, energy recovery from LFG could contribute to save of about 180 thousand tons CO_{2-eq} in energy sector. The Fig. 2 illustrated the GHG emission of scenarios.

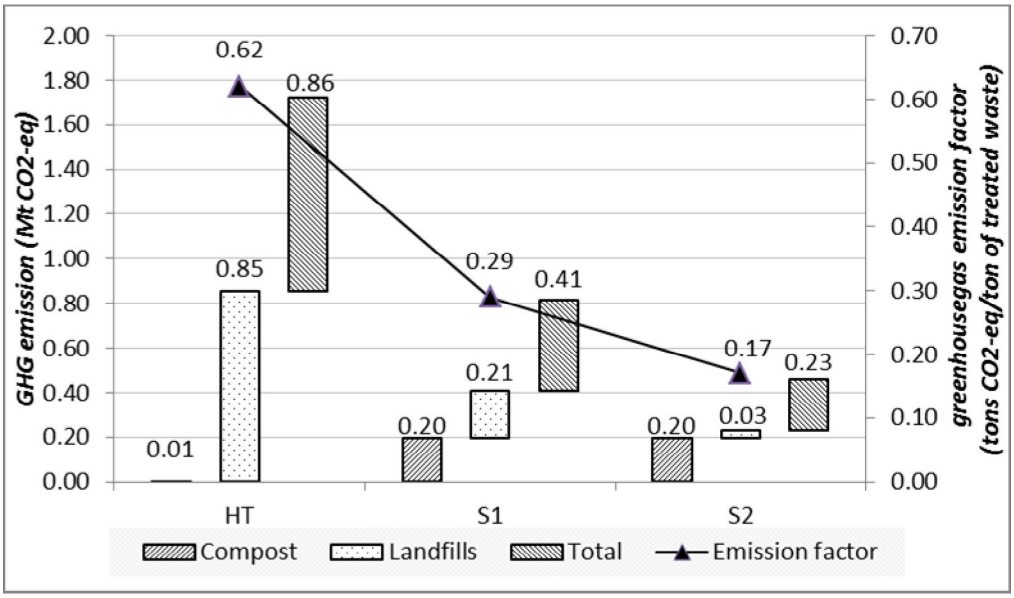

Figure 2. GHG emission of scenarios

4. Conclusions

Result of waste flow analysis in 2011 of Hanoi showed that there was a great amount of waste untreated, up to 2155 tons per day. That reflected accurately the improperly solid waste collection system of the city. The calculation showed that GHG emission reduction can reach up to about 53% and 73% when use scenarios S1 or S2. In addition, the scenario S2 was the most GHG emission mitigation practice due to applying LFG recovery technology to available landfills. The result of the study indicated that available solid waste treatment technologies in Vietnam such as landfills and composting could be wedges of GHG mitigation in waste sector because of their potential to recover material and energy. However, waste management system need to be improved with priority of separation at source and thorough collection.

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