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Potential of Greenhouse Gas Emissions Reduction Associated with Municipal Solid Waste Management in Hanoi City, Vietnam

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Authors' contributions

This work was carried out in collaboration between all authors. Author HTT initiated the research, conducted it, and wrote the first draft of the manuscript. Author HY supervised the research and reviewed the manuscript drafts. Authors YH and TM supervised and participated in the result discussion of the research. All authors read and approved the final manuscript.

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ABSTRACT

Vietnam is considered to be one of the most potentially affected countries by the effects of climate change due to its topography and socio-economic properties. In order to contribute to the global efforts in climate change mitigation the government has recently announced to strive for a low-carbon economy. Greenhouse gas (GHG) emissions associated with municipal solid waste (MSW) management system are one of the critical concerns in this regard. This study applied Life Cycle

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Assessment (LCA) approach to estimate the total amount of emissions from current MSW management in the capital city of Vietnam; and explored the potential of reduction through various possible scenarios of MSW management system. All scenarios studied presented high potential for emission reduction through improving composting, anaerobic digestion (biogas production), installing landfill gas capture system; and reducing amount of waste disposed in landfill. Particularly, the integrated MSW management consisting different technology options has the greatest potential of reduction, and landfill gas recovery system has significant effective impacts on mitigating GHG emissions from waste sector. This study therefore suggests feasible alternatives to achieve targets of emission reduction in the waste sector for the city studied.

Keywords: Greenhouse gas emissions; municipal solid waste; LCA; scenarios; potential.

1. INTRODUCTION

Municipal solid waste is generally disposed in open dumping sites and small amount of waste is treated in sanitary landfill in developing countries. As a consequence, waste management sector contributes significantly to GHG emissions. From climate change concern, municipal solid waste management is also considered a global issue because alternatives and decisions of MSW management by local governments can affect the release of GHG emissions globally [1]. The IPCC reports that waste sector have contributed 2.8% of the total global GHG emissions from anthropogenic sources [2]. However, MSW management presents the potential for GHG reduction and has links to other sectors (e.g., energy, industrial processes, forestry and transportation) with further GHG reduction opportunities [3].

In waste management sector, land filling is critically concerned with its environmental implications, GHG emissions in particular. Landfill emission is the main source of GHG, consisting approximately 50% CH_4, 50% CO_2 and trace amounts of non-methane organic compounds produced by decomposition of organic waste [4]. Emissions associated with MSW management have been estimated for most developed countries, for instance in the United States, landfill is the second largest anthropogenic emission of methane. It contributed approximately 22% of the total anthropogenic sources of methane in 2008 [5]. Furthermore, the US EPA estimated CO_2e for various MSW management systems and the results indicate approximately 2.4 kg CO_2e was emitted from one kg of MSW [6]. While, it was estimated that the average of CH_4 generation was 74.0 kg per ton of waste landfilled in Canada [7].

In developing countries and emerging economies, GHG emissions from solid waste are considerable because of the high percentage of biodegradable waste that is disposed in landfills without landfill gas (LFG) collection system. Spies et al. [8] pointed out that developing countries have potential to mitigate national emissions by around 5% and eventually up to 10% when integrated municipal solid waste management is implemented. However, there have not been such specific studies on emissions from waste management sector in Vietnam. This lack of appropriate research projects has led to difficulties in establishing the targets of GHG reduction (e.g. targets of GHG reduction for Nationally Appropriate Mitigation Actions (NAMAs)) in the waste sector. Therefore, this study aims to estimate emissions; and investigate potentials of reduction from MSW management in the biggest city of Vietnam as a typical case study for country.

2. MATERIALS AND METHODS

2.1 Municipal Solid Waste Management in Hanoi Capital

Hanoi, the capital city of Vietnam, is located in the north of the country. It covers an area of 3,324.92 km^2 (Fig. 1). It situates in the typical tropical monsoon climate characterized by high temperature (annual average 26.6ºC) and rainfall (annual average 1,800 mm). The city had a population of 6,725,500 persons in 2011 and the population growth rate was about 1.1% per year [9].

In recent decades the city has experienced rapid economic growth and urbanization. As a result, increase of municipal solid waste in Hanoi is clearly seen. The city generated about 6,500 tons/day (2,372,500 tons/year) in 2011 [10]. It was estimated equal to 11% of total MSW generation in Vietnam. Waste collection efficiency was different between areas, in which 95% and 60% of waste was collected in urban districts and suburban areas, respectively. Only 85% of waste generation was collected in Hanoi in 2011. Therefore, around 975 tons/day of MSW was not properly collected and treated. This uncollected waste was scattered on roadsides, lakes and open dumps. The city uses a collection system but there is not any source separation strategy.

Solid waste in Hanoi consists of high organic component, followed by plastic and paper [11]. The detail of MSW composition is presented in Table 1. Remarkable, MSW generation is projected to increase by 15% yearly due to economic development, urbanization and population growth [12]. Most of waste is currently disposed in landfill sites while only 15% of the waste is treated by other technologies (Table 2).

Table 1. Composition of municipal solid waste in Hanoi

No	Type of waste	Rate (%)
1	Organic waste	70.9
2	Paper	3.8
3	Plastic	9.0
4	Textile	1.6
5	Glass	1.3
6	Metal	0.4
7	Wood	1.3
8	Leather and rubber	0.7
9	Others	11

(Source: [11])

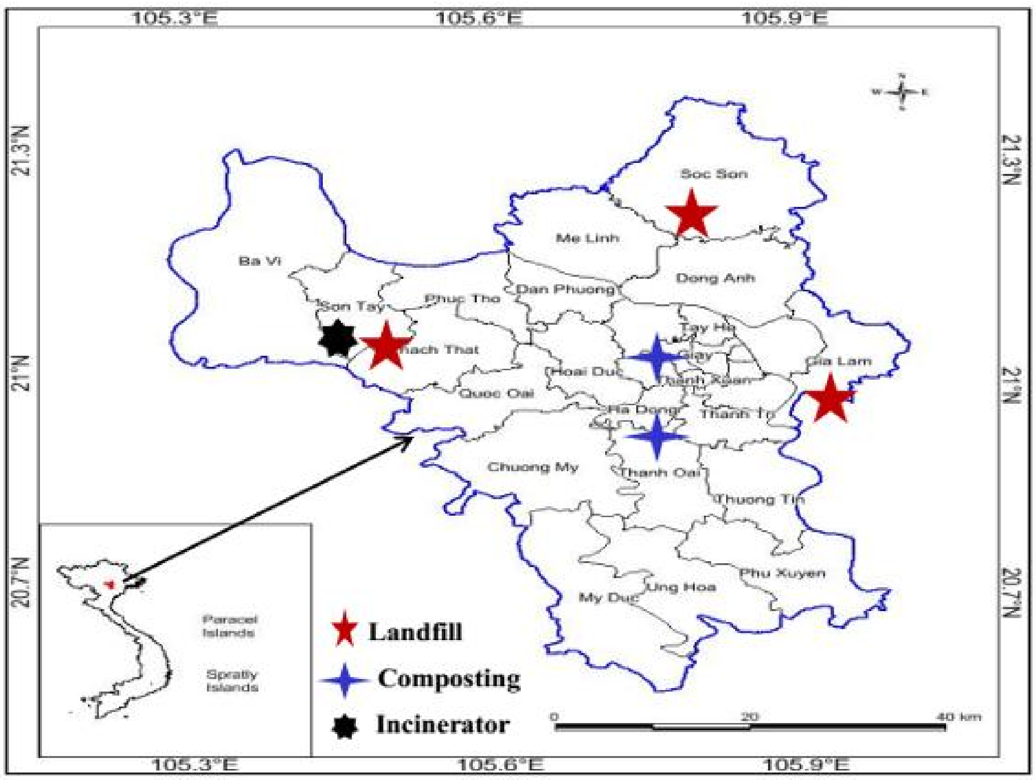

Fig. 1. Location of solid waste treatment facilities in Hanoi city

Table 2. MSW generation and treatment in Hanoi, 2011

Waste generation (tons/day)	Collected waste (tons/day)	Treatment methods							
		Landfill		Composting		Recycling		Incineration	
		(tons/day)	%	(tons/day)	%	(tons/day)	%	(tons/day)	%
6,500	5,525	4,662	84.4	110	2	453	8.2	300	5.4

(Source: [10])

Table 3. Distances travelled and fuel consumption by waste collection vehicles in Hanoi city, 2011

Waste collected and transported	The number of 10-ton trucks/trips daily (unit)	Distances travelled from collecting point (km)	Fuel consumption of truck per km travelled (litter)
Mix waste (sent to landfill)	466	50	1.62
Recyclable materials	46	60	1.62
Composting materials	11	20	1.62
Incinerated waste	30	60	1.62

(Source: [10])

The city has three engineered landfills without LFG capture system operated in 2011 (Fig. 1). These landfills received 84.4% of the total collected MSW, which accounted for 1,701,630 tons/year. Nam Son is the biggest landfill with an area of 236ha and receives more than 4,400 tons of MSW/day. Kieu Ky landfill receives 150 tons of MSW/day, however it is expected to be closed within few years latter because of overload. Xuan Son landfill receives 100 tons of MSW/day. These landfills are located in suburban and rural areas of Hanoi within distances of 50 to 60 km from the city center [10]. It is noticed that the space for MSW landfill will further become scarce because of urbanization and economic development [13]. Therefore, it is urgent to introduce strategies to divert waste from landfills through, reducing, reusing and recycling.

There are two composting facilities being operated in Hanoi city. However, their capacity is very low compared to the amount of organic waste generation. Cau Dien composting facility received only 50 tons of organic waste/day in 2011. It is located in a suburban area less than 20 km from the center of Hanoi. Seraphin composting facility is operated by a private company and receives only 60 tons of organic waste/day [10]. It is about 25 km far away from city center. All composted products are sold to farming and plantation enterprises.

Recyclable wastes such as paper, plastic, metals and glasses were treated in recycling facilities. The amount of MSW recycling accounted for 8.2% of the total collected waste [11]. On the other hand, waste incineration has been undertaken recently in Hanoi. There is only one incineration facility with a capacity of 300 tons/day. However, it is open burning technology without any energy recovery system or electricity conversion system [12].

The city has used the 10-ton trucks to transport waste from collecting points to treatment facilities and final disposal sites. Above Table 3 shows the statistical data related to fuel consumption of collection and transportation.

2.2 Methods

2.2.1 Life cycle assessment of municipal solid waste management

This study used Life Cycle Assessment (LCA) to estimate potential GHG emissions associated with all stages MSW management including collection and transportation, composting, material recycling, incineration and final disposal. LCA is a suitable methodology for evaluating the possibility of environmental impact mitigations in the waste management. It is a system analysis tool that is currently being used in many countries to evaluate the impacts of different integrated MSW management alternatives [14]. In the waste management sector, LCA commonly works at one-year time period. It can presents a long journey of product from "cradle to grave".

It has been recognized that there are several connections between waste management and LCA [15]. Waste is often generated with production, processing, manufacture and disposal. LCA estimates the potential environmental impacts associated with products or services such as waste management systems. In addition, it helps to determine the "hot spots" in the whole system of waste management through quantifying emissions and environmental impacts of each activity. The LCA application in waste management field differs slightly compared to the product approach [15]. For instance, LCA starts when waste is generated and emissions (GHG emissions) are counted from the point that solid waste reaches the collection bin. However, application of LCA in waste management is not affected by differences but require modification for different aspects of system analysis [16].

Recently, a number of studies have applied LCA with regard to GHG emissions from MSW system. LCA has been applied to assist decision making in the field of MSW management and planning for both developed and developing countries [1,17,18]. Weitz et al. [1] applied LCA and found that MSW strategy reduced 52 million tons of CO_2e thanks to improvement of integrated solid waste management in the United States during the period of 1974-1997. Mohared et al. [16] used LCA tool to calculate GHG from MSW management in Ottawa city, Canada. The study pointed out the best options for reducing emission along with local government's strategy on MSW management. Similarly, Zhao et al. [19] figured out emissions from solid waste management in Tianjin city, China. The results obtained have led to conclusion that LCA can properly support decision making with regard to the GHG emissions in waste management in developing countries.

2.2.2 System boundary

LCA is based on material and energy flows through system boundary, therefore it is absolutely necessary to define a practical system [15]. This study analyses the MSW management system from a life cycle perspective, hence all processes associated with solid waste management are included and evaluated (Fig. 2).

The upstream boundary does not include emissions from manufacturing of products because those emissions are calculated in other industrial processes. This is to avoid double counting of emissions. The downstream boundary consists all stages of MSW management such as collection, transportation, treatment and disposal. This approach allows to calculate both direct and indirect emissions associated with MSW management.

2.2.3 Integrated waste management model

With regard to GHG emissions from waste management, there have been several models developed within the discipline of life cycle assessment. This study used the Integrated Waste Management model, version 2.5 (IWM-2) developed by Andrew J.D. Richmond. It was developed from IWM-1 (1994) produced by McDougall, White, and Hindle. The IWM model bases on life cycle inventory of municipal solid waste [20]. The model allows development of new scenarios and modification of existing scenarios when data update is necessary.

The IWM is able to model and evaluate the potentials of GHG reduction from the whole process of MSW management. It is a spreadsheet-based model with several input screens relevant to MSW management system. Each screen contains several aspects of MSW management such as collection, transportation, landfill, recycling, biological treatment, incineration, etc. The model's outputs are presented in form of Excel spread-sheet that summarize input data, outputs with total life cycle emissions of GHGs by gas and emission source. Therefore outputs are comparable among the five different scenarios studied.

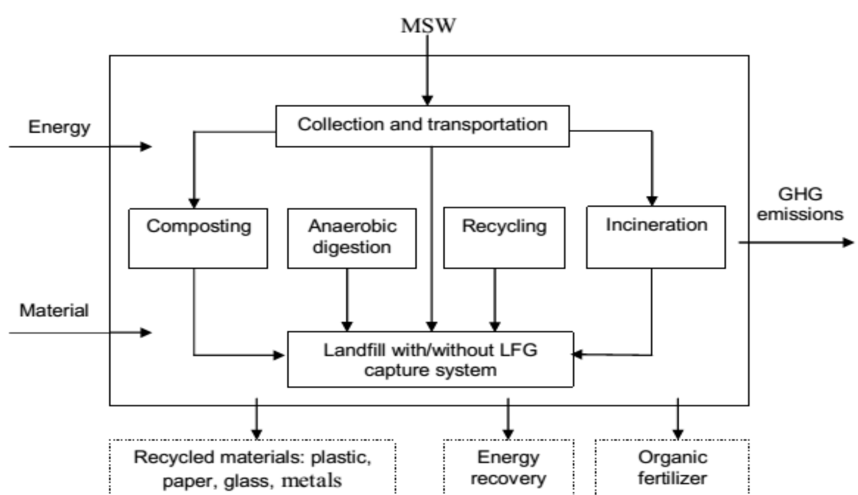

Fig. 2. System boundary in MSW management

2.2.4 Scenarios design

Scenarios will help to evaluate and compare the potential of different waste management options. This study proposes five scenarios that consider the current MSW management, existing treatment facilities, national policies and feasible alternatives for Hanoi. Systematically, we propose scenarios that present single improvement of technology prior to applying the integrated management. This aims to compare efficiency among technologies. The scenarios use the same amount of waste and include the same waste characterization data, therefore the results obtained are comparable among scenarios studied.

2.2.4.1 S0 – Baseline

This scenario is based on the current MSW management in Hanoi: no separation at source; 2% of the waste treated through composting, 8.2% of waste recycled, 5.4% of waste incinerated and 84.4% waste landfilled, no energy recovery system; and no LFG capture system.

2.2.4.2 S1 - Composting system upgrade

In this scenario we assume composting of 30% of total collected waste, The scenario also assumes that the compost is used as fertilizer. Source separation applied for organic waste. The other parameters are the same as S0.

2.2.4.3 S2 - Anaerobic digestion system upgrade

It describes 30% of total collected sent for anaerobic digestion; and biogas generated is used to produce electricity; source separation applied; composting rate: 2%; recycling rate: 8.2%; incineration rate: 5.4%; landfill rate: 54.4%; no energy recovery system and; no LFG capture system.

2.2.4.4 S3 - LFG capture system upgrade

This scenarios is based on S0; landfills in Hanoi are installed LFG capture system and LFG capture efficiency is 90%; collected CH_4 is flared without energy recovery.

2.2.4.5 S4 - Integrated MSW management

Targets are based on existing infrastructures, governmental plan and applicable management: source separation; 20% of total collected waste is composted and product is used as fertilizer; 10% of total collected waste is used in biogas production and biogas generated is used to produce electricity; incineration rate: 10%; recycling rate: 10%; landfill rate: 50%; energy recovery system.

3. RESULTS AND DISCUSSION

3.1 Waste Flows of Scenarios Studied

The waste flows of the proposed scenarios are shown in Table 4. This study assumed the amount and waste composition as the baseline of year 2011 to facilitate the comparison of scenarios. Current situation - S0 and LFG capture system upgrade - S3 present the highest amount of waste sent to landfill followed by S1. Meanwhile, integrated waste management - S4 has the smallest amount of waste sent to landfill.

3.2 GHG Emissions Associated with MSW Management in Hanoi

This study considered the three main GHGs (CO_2, CH_4 and N_2O) and their global warming potential (GWP). Based on the IPCC's report, the GWP for 100 - year time horizon of CO_2, CH_4 and N_2O are 1, 21 and 310, respectively [21].

Table 4. Waste flow of scenarios studied in Hanoi, 2011

Scenario	Waste input (collected waste)	Treatment methods				
		Composting	Biogas	Recycling	Incineration	Landfill
S0	2,016,625	40,150	0	165,345	109,500	1,701,630
S1		604,987.5	0	165,345	109,500	1,136,792.5
S2		40,150	604,987.5	165,345	109,500	1,096,642.5
S3		40,150	0	165,345	109,500	1,701,630
S4		403,325	201,662.5	201,662.5	201,662.5	1,008,312.5

(Unit: tons/year)

The final results were calculated in terms of carbon dioxide equivalent (CO2e) by multiplying amount of each gas with its associated GWP. The results of GHG emissions from five scenarios studied are displayed in Figs. 3, 4 and 5.

Fig. 3 shows emissions by greenhouse gas from each scenario. The results show that CH4 is the main gas emitted for most scenarios, except scenario S3. Current practice contributes the highest amount of CH_4 accounting for 2,702,973 tons CO_2e, followed by S1 and S2 scenarios. When landfill gas is collected, methane emission decreases significantly. In this case (S3), emission of CH_4 is only 270,585 tons CO_2e. Scenario S4 - integrated management scenario emits more CH_4 than S3 because it was assumed that LFG capture efficiency just reaches 50%, however, S4 is the smallest contributor of total emission among five scenarios. This figure illustrates the high potential of reduction through collecting CH_4 in landfill. For CO_2 emission, scenario S3 generates higher amount of CO_2 than those emitted from others. This is because methane from landfill collected and flared. While all scenarios present very low N_2O emission. It is noted that scenarios S1, S2 and S4 could save N_2O emission by 4,340 and 8,370 tons CO_2e thank to biological treatment improvement.

Fig. 4 displays GHG emissions by source from each scenario. It is remarked that landfill contributes more than 90% of total emissions, where as the recycling could save emissions in all scenarios. It is because recycling produces secondary materials that can be used to replace the virgin raw material production. Therefore, the emissions from raw material extraction would be avoided.

The net GHG emissions in the five proposed scenarios are presented in Fig. 5. The amount of emissions decrease along with amount of waste diverted from landfill in each scenario. Current practice generates the highest amount of GHG emissions, while integrated waste management has the lowest amount. In the biological treatment options, emissions from composting and biogas production are almost the same. LFG collection system demonstrates the high potential for mitigating emissions.

To get insight of emissions from each scenario, details are analyzed as follow.

3.2.1 S0 - Baseline

This scenario illustrates emissions associated with current MSW management in Hanoi city in 2011. The total amount of emissions was 3,034,128 tons CO_2e, and landfill contributed up to 98% in this case. It is because a huge amount of collected waste (84.4%) sent to landfill was organic waste; and LFG capture system was not applied. Emissions from other sources (collection, biological treatment, recycling and incineration) accounted about 2% of total emissions. Remarkably, recycling could be able to save 102,679 tons CO_2e that would have been emitted through exploitation and production of virgin resources. The average emission from current practice was 1.5 tons CO_2e/ton of waste.

3.2.2 S1 - Composting system upgrade and S2 - anaerobic digestion system upgrade

These two scenarios present potential reduction when the city improves organic waste treatment through biological options. They used same amount of organic waste sent to composting and anaerobic digestion facilities. The amount of GHG emissions from S1 and S2 are almost same, in which S1 generated 1,759,709 tons CO_2e and S2 emitted 1,689,385 tons CO_2e. These amounts are 44% and 42% lower compared to S0 respectively. Notably, the anaerobic digestion (S2) did not reduce much lower emission than the composting (S1), although methane generated was used for electricity production. Theoretically, the emission from anaerobic digestion should be much lower than that from composting because it can both reduce CH_4 emission from landfill and save emissions associated with the production of virgin raw material for electricity production. Average units generated are 0.87 tons CO_2e per ton of waste from S1 and 0.83 tons CO_2e per ton of waste from S2.

3.2.3 S3 - LFG capture system application

As landfill gas capture system was applied, total emission decreased significantly by 920,250 tons CO_2e or 70% lower than that from current situation. It is clearly seen that the LFG capture system is one of the most important factors to reduce GHG emissions from waste management. The LFG capture system application produced only 0.45 tons CO_2e per ton of waste. It presents a high potential of reduction in waste management.

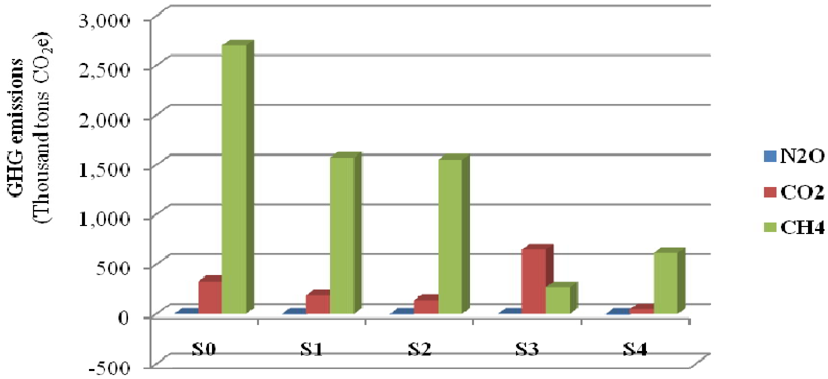

Fig. 3. Emissions from Hanoi's waste sector for the scenarios by greenhouse gas

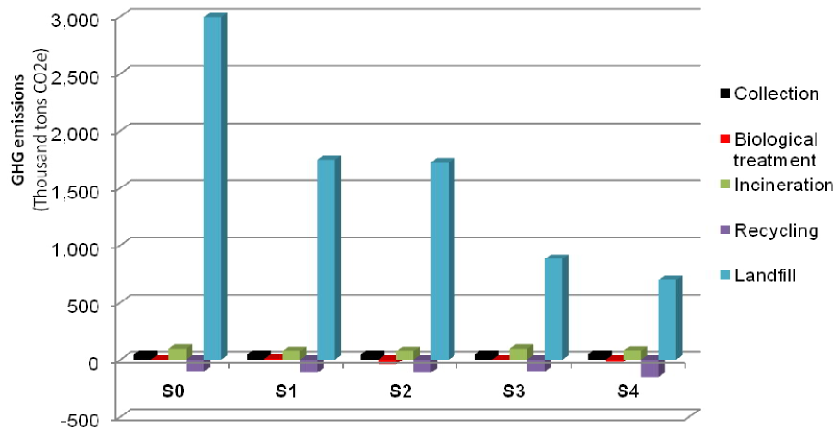

Fig. 4. Emissions from Hanoi's waste sector for the scenarios by emission source

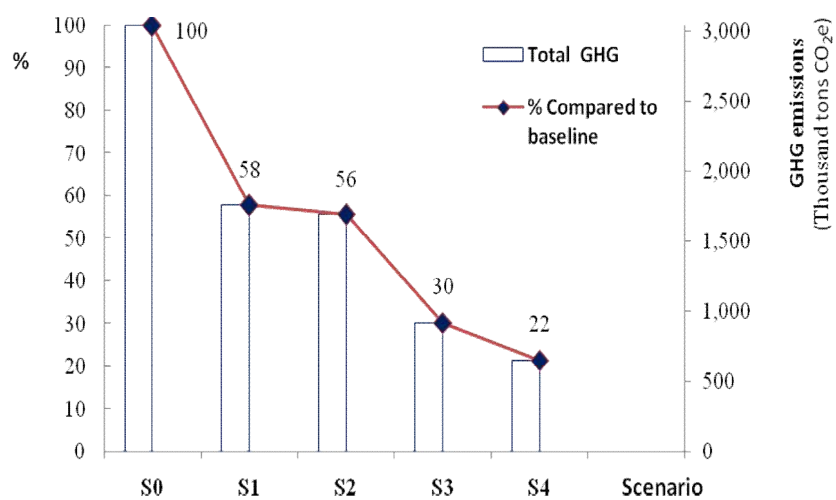

Fig. 5. Net GHG emissions MSW management in Hanoi

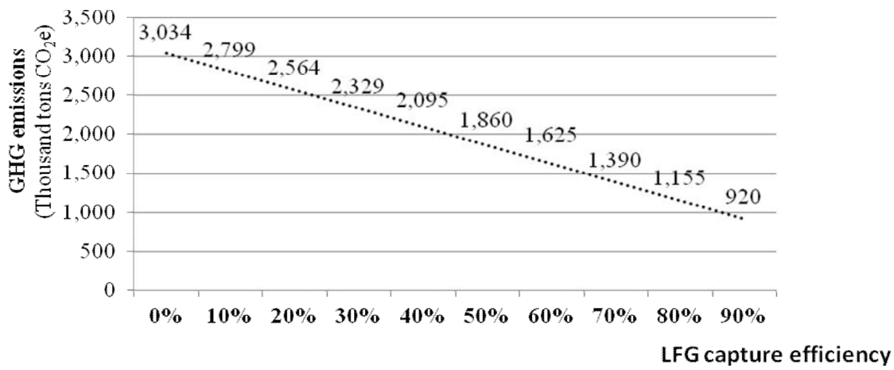

Fig. 6. Sensitivity analysis for LFG capture efficiency on GHG emissions

3.2.4 S4 - Integrated MSW management

Emissions from the integrated MSW management is shown in scenarios S4. This scenario considered the improvement of all potential treatment options including composting, anaerobic digestion, recycling, incineration and landfill. The LFG capture system was also applied but capture efficiency assumed only 50%. The results shows the lowest emission among the five scenarios studied. It produces 654,376 ton CO_2e and could potentially reduce 78% of total emission compared to the current situation. It indicates that combination of different technologies could reduce GHG emissions significantly in waste sector.

3.3 Sensitivity Analysis for LFG Capture Efficiency

As analyzed in the previous sections, most of GHG emissions is produced in landfill. Therefore, it is reasonable to assess the effect of LFG capture efficiency on GHG emissions. This section presents the sensitivity of LFG capture efficiency at different rates ranging from 0% to 90%. It sets GHG emissions as the dependent variable and LFG capture efficiency as the independent variable. The LFG capture efficiency is increased gradually by each 10% interval (above Fig. 6). The results show that the amount of total GHG emissions have a strong inverse relation with LFG capture efficiency with coefficient of the determination R^2 = 0.960.

4. CONCLUSION

In this study, we have figured out the amount of GHG emissions associated with the current MSW management in the capital city of Vietnam. Currently, a significant amount of GHGs is emitted due to the improper management of solid waste. Estimation of GHG emissions shows that landfill is the biggest contributor among emission sources of waste management. From the climate change mitigation concern, every technology improvement in waste management in Hanoi has positive impacts on emission reduction. Based on proposed scenarios, it is suggested that integrated waste management is the best options to reduce emissions in waste sector in Hanoi.

Sensitivity analysis of LFG capture efficiency shows that recovery of methane produced in landfill is priority to achieve the targets of GHG reduction from MSW management system. However, for sustainable waste management the other alternatives such as organic waste recovery (composting and biogas production) are acceptable because of environmental advantages and economic benefits they may bring to society.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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