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Research Paper

Evaluation of the alternative treatment methods for GHG emission mitigation from municipal solid waste management: case study of Ho Chi Minh City, Vietnam

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Abstract: Global warming has become a matter of increasing public concern over the last decade. In keeping with global efforts on greenhouse gas (GHG) reduction, municipal solid waste (MSW) is recognized as one of the major sources of anthropogenic emissions generated from human activities. In this paper, a system dynamics modelling approach has been used to quantify the collected waste from MSW disposal in Ho Chi Minh City (HCMC) in Vietnam. GHG emission and reduction rate have been calculated based on the International Panel on Climatic Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC) guides. The contribution of MSW treatment alternatives to mitigate methane emission has been investigated under various possible analysis scenarios. Based on the current waste management policies followed, the baseline methane emission is projected to reach 21,062 tonnes/year of CH_4 (442,312 tonnes/year of CO_2 eq.) by the year 2025. The study shows that MSW management, based on the different norms, can indicate different potential alternatives for reduction. The norms can be factors such as investment, benefits, energy production, GHG emission rates or GHG reduction rates, etc. This study emphasizes the importance of energy consumption, generation and recovery from various treatment and disposal methods that can also contribute indirectly to the reduction of the greenhouse effect by reducing the share of fossil fuels used in electricity production. In addition, the investigated waste treatment strategies with energy and material recovery can allow for the important benefit of GHG emission reduction.

Keywords: MSW, greenhouse gas, climate change, global warming, renewable energy, system dynamics modelling, Clean Development Mechanism, CDM

Introduction

Municipal Solid Waste (MSW) management continues to be an important environmental challenge facing the world because this waste sector is an important source of greenhouse gas (GHG) emissions. According to recent national estimates this sector produces on average 2 – 4% of national GHG emissions [1], with total emissions of approximately 1300 Mt CO_2 eq. in 2005 [2].

Gas emissions from MSW treatment methods are not only a result of the restricted availability of oxygen during the decomposition of the organic fraction of waste at the disposal site and treatment processing activities, but also includes the emissions created by energy consumption and production [3].

The threat of global climate change calls for international efforts to reduce emissions of GHG, mostly CO_2, CH_4 and N_2O. The extent to which the emissions of different GHGs contribute to global warming are calculated in CO_2 equivalent (CO_2eq.), using the global warming potential (GWP) of the different gases as proposed by the International Panel on Climatic Change [4, 5]. The GWP of CH_4 and N_2O (over a 100 year time horizon) is 21 and 310 times, respectively, greater than that of CO_2 [3]. The reduction of CH_4 emissions from alternative treatment methods for MSW could make a significant contribution to the mitigation of GHG stock.

Accurate prediction of MSW generation plays an important role in solid waste management (SWM) [6]. Conventional forecasting methods for solid waste generation frequently count for the demographic and socio-economic factors on a per-capita basis [7, 8]. The per-capita coefficients may be taken as fixed ones over time or they may be projected to change with time. Grossman *et al.* [9] extended such considerations by including the effects of population, income level and the household size in a linear regression model. Niessen [10] conducted a similar estimation by providing some other extensive variables characterizing waste generation. To implement those traditional statistical forecasting methods, however, it would be necessary to collect socio-economic and environmental information prior to analysis. In many cases, municipalities might not have sufficient budget and management capacity to maintain a complete database of solid waste quantity and quality in support of such needs on a long-term basis. For this reason, a new approach – system dynamic modelling – for the prediction of municipal solid waste generation in an urban area based on a set of limited samples has been presented by Dyson and Chang [6].

GHG emission from waste treatment activities has been thoroughly considered and calculated by the *IPCC Guidelines for National Greenhouse Gas Inventories* [4, 5, 11]. More recently, a new approach to promote GHG emission reduction has been introduced. This is the Clean Development Mechanism (CDM), an arrangement under the Kyoto Protocol allowing industrialized countries with a GHG reduction commitment (called Annex B countries) to invest in the projects that reduce GHG emissions in developing countries as an alternative to more expensive emission reductions in their own countries. The CDM is supervised by the CDM Executive Board (CDM EB) and is under the guidance of the Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC).

The range of the alternatives to mitigate GHG emissions is rather wide, yet several drawbacks should be noted. Therefore, this study analyzed the effect of MSW management options on GHG emissions. The purpose of this study is to predict and estimate the waste disposal and GHG emission reduction alternatives for MSW management. The scope of the study included all activities that play a role in MSW treatment. These activities include MSW composting, anaerobic digestion (with energy recovery), incineration (with energy recovery) and landfilling (with and without gas collection and energy recovery). The life-cycle environmental aspects of fuel, electricity consumption and production were also included, as well as the displacement of raw materials through recycling and the displacement of fossil fuel based electrical energy through energy recovery from MSW. The GHG emissions included in this study are CO_2, CH_4 and N_2O.

Municipal Solid Waste Generation Prediction

Methodology description

MSW generation is forecasted by the system dynamics method that uses a database on the population of the city, the collection efficiency and the per-capita waste generation rate. The quantity of waste generation and collection are calculated for three groups: the residents in rural areas, the residents in urban areas and non-residents. The available data for the model is shown in Table 1 and the flow diagram of the MSW management model is presented in Figures 1 & 2. In this study, the portion of non-residents is defined as those who do not register with the local government but who go and stay in Ho Chi Minh City (HCMC) for short periods of time. In HCMC, urbanization and industrialization have developed rapidly which has resulted in a population increase due to the influx of job seekers. It is assumed that the per-capita MSW generation rate will rise with a growth factor, depending on economic growth, urbanization rate and the quality of life of the residents. In this study, data used for prediction was taken from the Ministry of Construction's "Master Plan of MSWM of HCMC until 2025" [12], and is presented in Table 1.

Table 1 Available data for the prediction process [12].

Year	**Collection efficiency rate (%)**		**Population growth rate (%)**	**Kg/cap/day**	
	Urban	***Rural***		***Resident***	***Non resident***
1995	73	30	2.80	0.65	0.40
2000	75	40	2.75	0.74	0.45
2005	88	50	2.68	0.85	0.57
2010	93	60	2.60	1.0	0.62
2015	96	65	2.52	1.1	0.67
2020	100	70	2.85	1.2	0.72
2025	100	75	3.25	1.3	0.77

System dynamics modelling of MSWM

The methodology used in the development of the solid waste management model discussed in this paper is ''system dynamics''. SD is a computer-aided approach for studying, analyzing and solving complex problems. A detailed description of the methodology is given by Forrester [13] and Bala [14, 15].

The policy makers and researchers have extensively used the SD approach for every type of complex and dynamic environmental system such as global environmental sustainability [16, 17], global warming and greenhouse gas emissions [18, 19] and solid waste management [20, 21. 22, 23]. Within the solid waste management sector, Talyan *et al*. [24] applied the SD approach to assess the MSWM focus on the waste generation, collection and recycling system in Delhi city. Dyson and Chang [6] also presented this approach for predicting solid waste generation in a fast-growing urban area.

Figure 1 shows the causal loop diagram developed by incorporating the essential elements of MSWM system. The diagram, consisting of elements and arrows, explains the existing feedback mechanism among the interrelated elements of the MSWM system. The arrows, referred to as the causal links, include a sign (either + or −) on each link, indicating the effect of one element on the other. The link will be considered positive (+) if an increase or decrease in one element causes a change in the same direction in the other element, or negative (−) if an increase or decrease in one element causes a change in the opposite direction. These linkages complete small negative and positive feedback loops to represent the dynamic structure of the complete system. The polarity of the loop is the product of sums of its links.

To develop a quantitative model, the causal loop diagram is converted to a stock flow diagram (Figure 2), which explains the physical as well as the information flows among various elements of the MSWM model. The main building blocks of the stock flow diagram consist of three variables: stock, flow and converter. Stock variable, is an accumulation of resulted processes in the system. The flow variable represents the activities responsible for the rate change in physical and information flows to and from the stocks. The third variable called as converter, is for transformation of the information from stock variable to the flow variable. This is an intermediate variable used for miscellaneous calculations. The switch control is to change the initial values of the constants, converter and stock variables to select the alternative strategies. The single arrow represents the cause and effect links within the model structure.

In the this study, the dynamic models present simulation of municipal solid waste generation that is predicated on the contributing factors of population growth rate, per-capita-waste generation rate, area characteristic (rural or urban) and population status (resident/non-resident) via the use of software package Stella®.

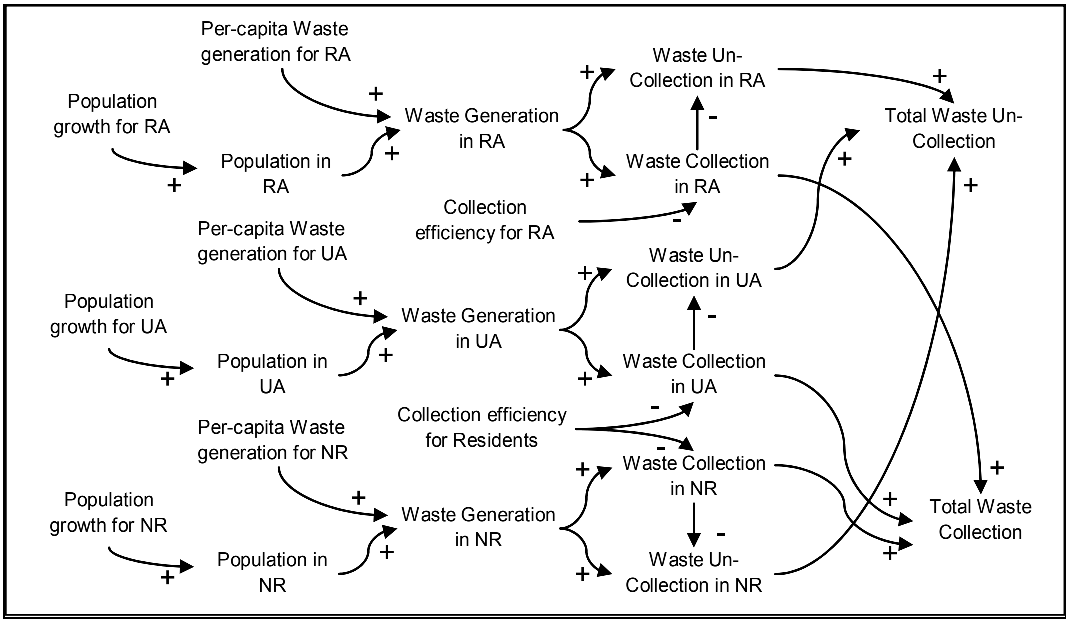

Figure 1 Causal loop diagram of MSWM model.
UA: Urban Area, RA: Rural Area, NR: Non-Residual

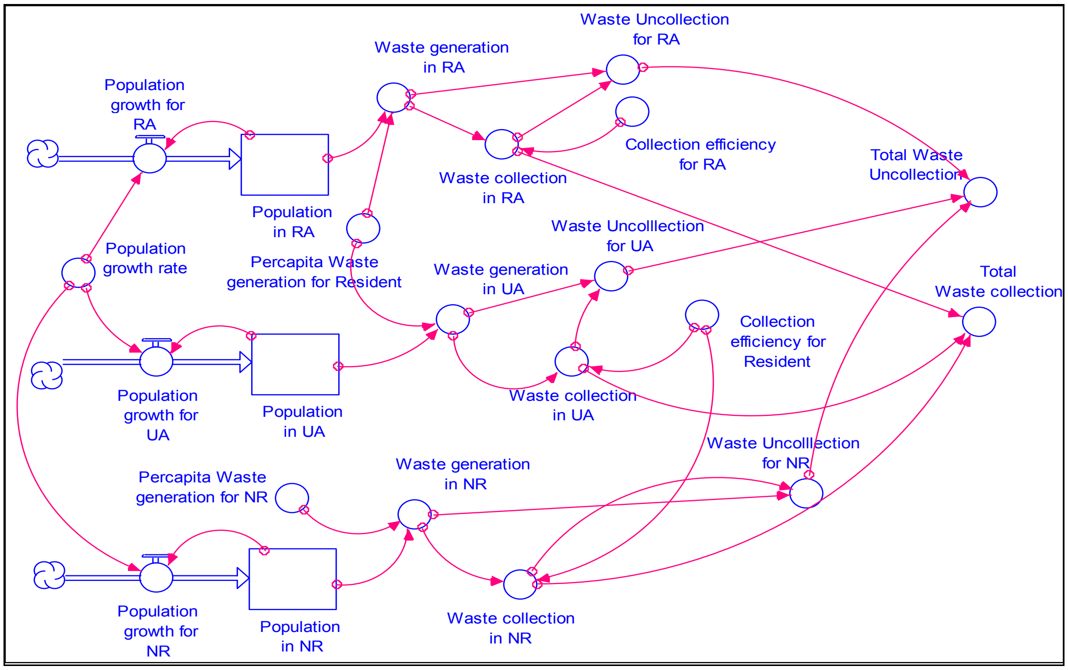

Figure 2 Stock flow diagram of MSWM model.
UA: Urban Area, RA: Rural Area, NR: Non-Residual

Table 2 Composition of MSW in HCMC [33].

Composition	Food	Garden	Textile	Wood	Plastic	Paper	Metal	Others
(%)	58	11	9	3	10	3	0	6

GHG Emission Reduction Estimation

Baseline emission

Baseline emission is from waste in cases where there is an absence of project activities associated with disposal at a solid waste disposal site. Baseline emission is calculated by the first order decay (FOD) model, considered in two parameters, as well as landfill gas (LFG) generation rate and methane (CH_4) emission rate. These parameters are used to calculate for the reduction of GHG emissions in the CDM waste management projects guided by UNFCCC.

Baseline emission is the amount of methane, calculated in tonnes of carbon dioxide equivalent (tCO_2 eq.) that would, in the absence of the project activity, be generated from disposal of waste at the solid waste disposal site. Baseline emission is determined through "*Tool to determine methane emissions avoided from dumping waste at a solid waste disposal site*" [3] or according to the "*2006 IPCC Guidelines for National Greenhouse Gas Inventories"* [11]. For a simple purpose calculation and prediction of the baseline emission from solid waste disposal site, a spreadsheet model for *Estimating Methane Emissions from Solid Waste Disposal Sites* (*IPCC Waste Model*) that has been developed by the IPCC to assist countries in implementing the FOD [11] was used. For the present study using 2006 IPCC tier 1 approach [11], emissions were calculated using the defualt emission factor in the guideline and waste composition application as in the Table 2.

GHG emission and reduction

GHG emission reduction is the decrease of GHG emission within project activities to compare baseline emissions [3, 25, 26]. Generally, emission reduction in the year y is calculated according to the following equations:

$$ER_y = BE_y - PE_y \pm L_y \quad \text{(Eq. 1)}$$

$$PE_y = PE_{pro,y} + PE_{energy\ cons,y} - PE_{energy\ gene,\ y} \quad \text{(Eq. 2)}$$

Where ER_y is the emission reduction in the year y; BE_y is the baseline emission in the years; PE_y is the project emission in year y; and L_y is the leakage emission in year y. The emission was considered within the project boundary as defined in the Glossary of CDM terms version 01 [27]. The project emission (PE_y) in this study was defined to include emissions from energy consumption ($PE_{energy\ cons,y}$), energy generation ($PE_{energy\ gene,y}$); and the emissions from processing of project activities ($PE_{pro,y}$). These are expressed in the equation 2.

GHG emissions from processing

The quantity of emissions (including CH_4 and N_2O) from composting, anaerobic digestion in biogas facilities and incineration will depend on the amount of waste treated and the related emissions [11]. For landfill treatment, the GHG emission is dependent on the LFG collection efficiency and the conversion efficiency of the gas engine. In this study, it was assumed that the GHG emission from the gas engine was also calculated by using the Tier 1 emission estimates for the source categoriser of 2006 IPCC [11]. Emission factors are in units of kg CO_2 eq./TJ on a net calorific value basis. The methane emission factor for the elctricity genaration engine of LFG is calculated on CO_2, CH_4 and N_2O as 54600, 1 and 0.1 kg CO_2 eq./TJ, respectively. These factors were also applied to calculate the GHG emission of anaerobic digestion in biogas facilities where biogas was collected and recovered by electricity engine.

For the calculation purpose of biogas generation from anaerobic digestion method, the previous study shows that the substrate material mechanically generated 130–160 m^3 of biogas per tonne [28]. In this study, the default value of emission factor of MSW generating 100 m^3 of biogas per tonne [29] was used.

GHG emission of energy consumption and generation

The GHG emission from energy consumption of project activities ($PE_{energy\ cons,y}$) was calculated based on the used energy source, quantity of energy consumption and appropriate emission factor defaults [11]. For example, diesel fuel with density of 0.85 kg/L generates energy of 43 TJ/Gg by combustion process and releases LFG on CO_2, CH_4 and N_2O as 74100, 3.9 and 3.9 kg CO_2 eq./TJ, respectively.

For project activities involving electricity consumption generated in an on-site fossil fuel power plant or drawn from the electricity grid, the GHG emission is determined using the *default emission factor* in tCO_2 eq./MWh, that is also used to calculate GHG reduction by electricity generation from project activities. In cases where electricity is generated in an on-site fossil fuel fired power plant, the *default emission factor* for a diesel generator with a capacity of more than 200 kW for small-scale project activities is 0.8 tCO_2/MWh (see *AMS-I.D* version 13) [30]. Another case, where electricity is purchased from the grid, the *emission factor* should be calculated according to the "*Tool to calculate the emission factor for an electricity system*" [31]. This tool is also applied to calculate the GHG emission reduction in the cases where alternative methods are used to generate electricity, such as LFG recovery, incinerator combining thermal power and anearobic digestion with biogas utilization. Their GHG emission reduction by energy generation ($PE_{energy\ gene,y}$) is calculated as the GHG emission that is created when the correlative amount of electricity is generated by national electricity system.

Tuyen *et al.* [32], reported that the baseline emission factor for the electricity system in Vietnam was 0.515 and 0.585 tCO_2/MWh by 2007 and 2008, respectively. In this study, it is assumed that electricity consumption is imported from the grid and electricity generation is also exported to the grid. The baseline emission factor of 0.585 tCO_2/MWh (as of 2008) was used for calculation.

GHG emission of leakage

The sources of leakage considered using the methodology of UNFCCC [27] are CO_2 emission from increased transport and the residual waste from treatment processes (such as anaerobic digester, gasifier, combustion processing, stabilized biomass, etc. in case it is disposed of at the landfill site). In this study, the GHG emission of leakage was considered as uncollected GHG that is released from project activities. For example, the treatment method of sanitary landfill within collection efficiency was about 75% of LFG and 25% of LFG collection was emission as leakage.

Energy consumption and generation

For composting treatment, McDougall *et al.* [29] mentioned that composting involves a net consumption of energy, consuming process energy and not producing any energy in a usable form and they suggested that the energy requirement is a range of 18–50 kWh (electrical) per tonne of waste input. For the purposes of the general estimation, a default energy consumption of 30 kWh of electrical energy per tonne of waste input to the composting plant was assumed. Biogasification involves both consumption of energy during processing, plus the production of useful energy as biogas that contains 50 – 75% of methane. Since biogas can be burned to produce steam to heat the digester, and more can be burned in a gas engine to produce electricity, the energy requirement for the process can be met from within the biogas produced. Electrical energy requirement for biogasification has been reported as 50 kWh per input tonne, which represents around 32–35% of the gross electricity produced by the plant. The default value of energy production is 190 kWh/input tone [29]. In the composting process, the mass loss due to evaporation and biodegradation of the organic fraction; the final compost accounts for 50% of the input to the composting process (i.e. after any pre-sorting) and for biogasification, an average figure of 70% is used [29]. For the present study, it was assumed that MSW contains 69% organic waste (see Table 2) and biogas was combusted in an engine to generate electricity with a conversion efficiency of 30%.

The thermal treatment process, as well as liberating energy from the feedstock, also consumes energy. Energy released during incineration may be used for several purposes (heat and steam production, electricity generation), each with its own conversion rate for the amount of useful energy produced. For the purposes of the assessment modelling it was assumed that the thermal treatment process consumes around 70 kWh per tonne incinerated, with the gross electricity production efficiency of up to 23%, as has been recommended for MSW incinerators recovering electricity. This generates a gross power production of 520 kWh per tonne of waste [29].

The landfilling process will also consume energy for waste landfilled, such as fuel and electricity in the operation of the site itself. No data were available on the energy consumption of transfer stations, while it has been suggested that the fuel consumption for the landfilling process was around 0.6 litres of diesel per cubic metre of void space filled [29]. The United States Environmental Protection Agency (U.S. EPA) sets requirements for the emissions released from municipal solid waste landfills, using a default assumption of 75% LFG efficiency according to what has been reported in the EPA AP-42 documentation. Additionally, LFG in landfills systems can recover only 40–90% of the emitted gas [29]. In this study for the purposes of predicted modelling, therefore, it was assumed that LFG was burnt in a gas engine with a conversion efficiency of 40% LFG burnt; the energy conversion efficiency of the process would be 30% LFG emitted. LFG has an energy content of 15–21 MJ/Nm^3 (depending on methane content) of LFG [29]. Assuming that heat content of 18 MJ/N m^3 of LFG, on the combustion in a gas engine with a conversion efficiency of 30% (representation of 75%*40%), the energy would be an electrical energy recovery of 1.5 kWh per Nm^3 of LFG collected.

Economic Evaluation of GHG Reduction Methods and Alternatives Assessment

There is a need to assess the environmental, economic and social aspects of the alternatives to manage waste in order to abate GHG emissions. The assessment will not concentrate solely on the amount of CO_2 eq. mitigated, but also on other conditions such as requirement of land, feasibility of implementation of each alternative, cost and benefit, energy generation etc.

For the economic benefits of a project, calculation is based on the amount of useful products, such as electricity generation from landfill gas recovery, anaerobic digester with biogas utilizable activities, incinerators with thermal power, composting products from composting plants or GHG reduction credits. Systems containing energy recovery devices are credited for selling energy to save money, with the price of selling electricity of 0.04 US$/kWh at present [33] and the system composting production such as fertilizer for soil improvement. Good quality fertilizer is approximately 30% of final composting product and if it includes the appropriate nutrient components it can sell in the market for as much as 30 US$/tonne [33].

The reduction of GHG emissions from alternatives is eligible to receive "carbon credits" or "Certified Emission Reductions (CERs)", issued by the CDM - Executive Board - UNFCCC. These credits can be sold in international markets to developed countries. The trading price for carbon credit units (US$/tonne CO_2 eq.) is dependent on the world market, which will increase when the demand for buying "carbon credits" of developed countries increases. In this study, the trading price of "carbon credits" uses the current market price in Vietnam, 5-8 US$/tonne CO_2eq. and the price of 6 US$/tonne CO_2 eq. was used as an estimation [33].

For the investment cost of each alternative, in order to appraise the abatement costs of GHG emissions, the investment cost of each alternative is evaluated. Operating and maintenance (O&M) costs are not included in this valuation because they are site specific, highly variable and a function of factors such as salaries, transportation, insurance rates, taxes and prices obtained for recyclables or energy sales, etc. [34]. It should be noted that there is a rough correlation between investment costs and O&M costs. O&M represents approximately 40% of the costs of landfilling and 35%–40% of incineration costs (excluding revenues from energy sales) [35]. The investment to reduce one tonne of CO_2 eq. by alternatives was summarized in Table 3 using the investment costs for each alternative (given as US$ of investment) by Ayalon *et al*. [34].

From Table 3, the investment to reduce one tonne of CO_2 eq. by collecting and burning the LFG in landfills is about US$45; the incineration of MSW is the most effective technology but the investment is the highest (US$194). Another potential energy recovery system is anaerobic digestion producing biogas, which is rather low (US\$39) and the method of aerobic composting using the windrow technology, is the lowest (US\$9), but the efficiency of this method to reduce GHG emission is not so high (see Figure 9). Therefore, the lowest investment cost alternative to mitigate GHG emissions from the waste sector is construction of composting plants. Table 3 also shows that the annual abatement costs of CO_2 eq. emissions are largely a difficult value. This presentation emphasizes the fact that proper waste treatment can be the most significant means to abate GHG emissions in the short term, and another suitable treatment method for the long term.

Table 3 Investment cost and benefits estimation for GHG mitigation from MSW [34]

Alternative	Size of typical plant (tonne/day)	Plants needs	Efficiency of CH_4 reduction (%)	Investment cost of reduction (US\$/tonne CO_2eq.)	Annualized cost (US\$/tonne CO2eq.) (15 yrs)
Landfill with energy recovery	400	7	50	45	3.02
Incineration	500	6	100	194	12.94
Aerobic	250	12	90	9	0.58
Anaerobic	500	6	100	39	2.59

Case study

Overview of the study area

HCMC is the largest city in Vietnam; it covers an area of 2,095 km². The base population in HCMC for the year 1997 was 6,352,300 people, which included residents of 4,852,300 people (urban area of 4,028,800 people and rural area of 823,500 people) and 1,500,000 non-residents. The average population growth rate for 1997–2025 is shown in the Table 1 [33].

The per-capita waste generation was taken as 0.65 and 0.40 kg/day of resident and non-resident area, respectively, by the year 1997 [12] and will increase with a growth factor depending on the future development status (such as economic growth, urbanization rate and the living standard of the residents, etc.). The collection efficiency is dependent on collection area such as rural or urban area. All available data for calculating the waste generation prediction is expressed in Table 1. The components of solid waste at the disposal site are presented in general terms such as biodegradable waste of about 69%, reusable/recyclable waste is 13% and un-recyclable is 18% (see Table 2).

Scenario description

Classification scenarios are categorized by MSW treatment technologies that mitigate GHG emissions from MSW. For the purpose of GHG emission estimation, scenarios assume that they consider in simple definition within specific boundaries and technologies, as presented in Table 4.

The study considers the MSW generation and related environmental effects in the period of 2007-2025 for all of the alternative scenarios, excepting the baseline and sanitary landfill scenario which was considered until the year 2040. Because the UNFCCC has given the guideline that CDM projects are developed by every 7 years, it is assumed that the present study considers the GHG emission in two shifts of CDM project. It was thus estimated for the next fourteen years (2 x 7 years) by the year 2026-2040.

Results and discussion

Sensitivity analysis

Sensitivity analysis is used to determine the sensitive capacity of a model, consider the changes in the value of the parameters of the model and in the structure of the model. For this study, parameter sensitivity test is performed to ensure the roughness of model as well as to understand the dynamics of the system. As discussed in a previous section, the methane emission is affected by mainly basic factors such as the population, the efficiency of MSW management and the quantity of MSW going to landfills. For the purpose of sensitivity analysis using the SD approach, the comparison between actual data and model data is presented in Figure 3, based on the population rate and waste collected rate. The actual data available is only 10 years (1997-2007) and the model data is forecasted from the real data on 1997 and the predicting database in Table 1 by SD approach. The result shows that model simulation is very nearly the actually aspect, and the confidence of the model is accepted.

Table 4 Scenario Description.

Scenarios	Description	Definition/Boundary
Baseline	*Open dumping landfill (LFG is not collected and treated) – baseline emission*	*100% of amount of waste was dumped by landfill as an open dumping in natural condition.*
Sanitary landfill	*Sanitary landfill combined with LFG recovery*	*100% of amount of waste was dumped by sanitary landfill within LFG collection, treatment and energy recovery.*
Composting	*Composting plant*	*69% of waste (organic waste) was treated by composting plant with technology of Aerobic compost, 31% residual was dumped by landfill (assume that no GHG emit from this part)*
Anaerobic digestion	*Anaerobic digestion as Bio-gasification (biogas recovery)*	*69% of waste (organic waste) was treated by Anaerobic digestion with biogas recovery system, 31% residual was dumped by landfill (assume that no GHG emit from this part)*
Incineration	*Incineration within thermal power recovery*	*100% of waste was treated by incinerator with technology of Semi-continuous (fluidised bed) combined thermal power system, 10% residual material was dumped by landfill (assume that no GHG emit from this part)*

Baseline emission

Figure 4 shows the baseline emission of the project in the period 1997-2025 for waste disposal, and until the year of 2040 for pollution emission only of residual waste at site. The baseline emission is presented in the amount of landfill gas and greenhouse gas as CO_2 and CH_4. Most of these show the same linear trend. Emissions also gradually increase following the time and amount of waste disposal. It accumulates to reach the maximum at the end of the waste disposal period of 2025, and it is reduced in a gradual slope in the next period.

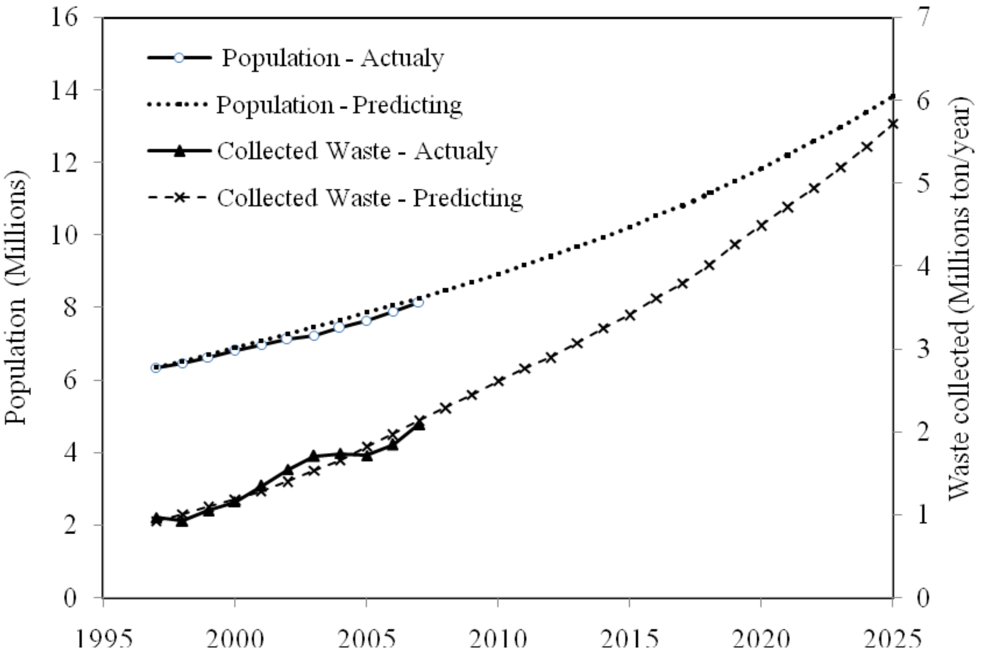

Figure 3 Comparison of actual vs. predicted population data.

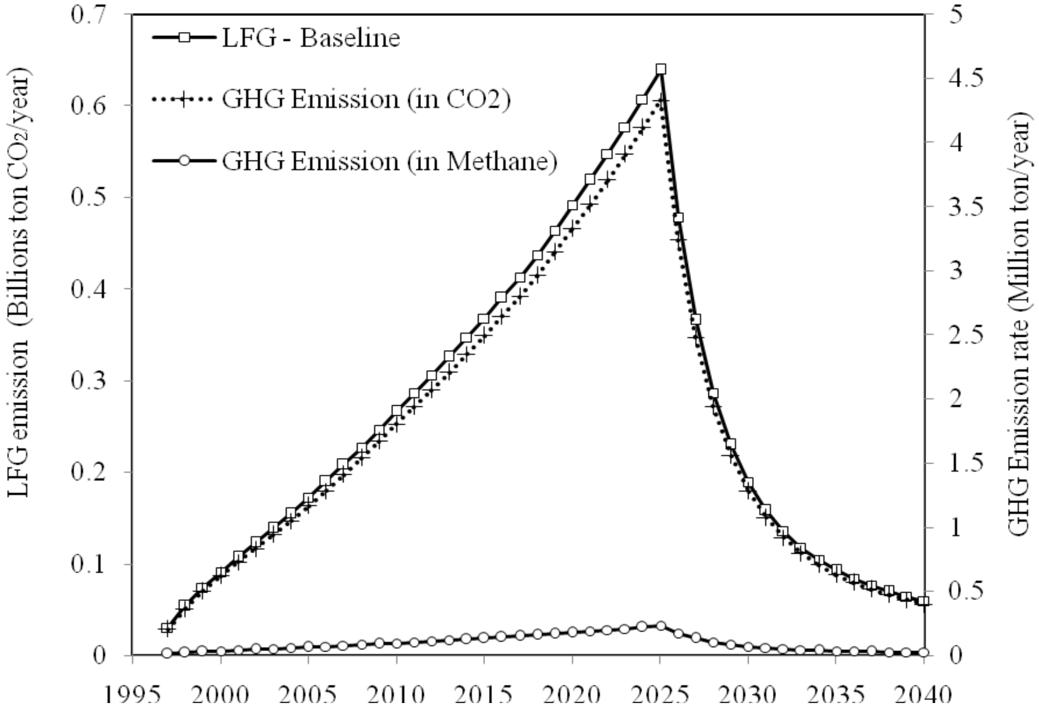

Figure 4 Baseline emission of project.

The amount of emissions is mainly defined by waste composition, as is illustrated in Figure 5. Food component is a high portion of waste (58%) as more baseline emission content. The important GHG emissions from waste disposal are caused by the organic component. MSW with a higher organic waste content will have higher baseline emissions. To compare with others, the baseline emission of the food component quickly drops drown after stopping waste disposal, indicating that the food component's emissions occur in the short time period after waste disposal.

Energy consumption and generation

For each alternative treatment option the total amount of energy exported to the grid is electricity generation excluding energy recovery. It means that the energy consumption is the amount energy recovered. The energy content of the by-products (biogas, LFG and thermal) and the conversion efficiency of the process are used to calculate the electricity generation. Figure 6 shows the quantity of electricity export rate per year of each scenario. The quantity of incineration scenario is the highest energy export potential, next is the sanitary landfill scenario and the anaerobic digestion scenario. This result conforms with the findings of McDougall *et al*. [29], and IPCC [11]. The composting scenario is lowest energy export potential and a minus value. The cause of this case is the energy consumption is more than energy generation that is zero for electricity generation by composting method.

GHG emission and reduction

In this study, the GHG emission of each alternative scenario was considered into two cases as (i) without energy consumption and generation consideration (Figure 7), and (ii) within energy consumption and generation consideration (Figure 8) for total GHG emission calculation from the project. In two cases, the baseline emission is the same and is not dependent on energy consumption and production. Although the operation of each alternative in two cases is the same, the order of alternative scenarios regarding GHG emission is quite different, with the exception of the sanitary landfill scenario that has the highest emission in all two cases, and it still emits the GHG after stopping waste disposal. In general, the amount of GHG emission of each scenario in the case of without energy consumption/generation consideration is more than the case, respectively.

For first case, without GHG emission from energy consumption and generation consideration, sanitary landfill scenario is the highest emission; next is the composting scenario, incineration scenario; and the smallest emission is anaerobic digestion scenario. As the first case, the highest GHG emission of the second case is sanitary landfill scenario, next is composting scenario, respectively. However, incineration scenario is the smallest GHG emission, and the emission of this scenario and anaerobic digestion scenario is minus value. This result shows that these two scenarios were contributing to GHG emissions and, on the contrary, they were a GHG emission reduction factor. Figure 9 expresses the GHG emission reduction of each scenario. Iit is known that if the emission reduction is compared by baseline emission, sanitary landfill scenario is the lowest emission reduction, next is composting scenario. The emission reduction of incineration and anaerobic digestion scenario are higher than baseline emission. This point shows that these scenarios not only reduce the baseline GHG emission from the project, but there is also a GHG reduction factor.

Considering the GHG emission within the emissions from energy consumption and generation is widely used for calculation of GHG emission and reduction, especially in CDM projects, guided by UNFCCC. For this approach, the sanitary landfill scenario is the highest GHG emission method while the incineration scenario is the highest GHG emission reduction method.

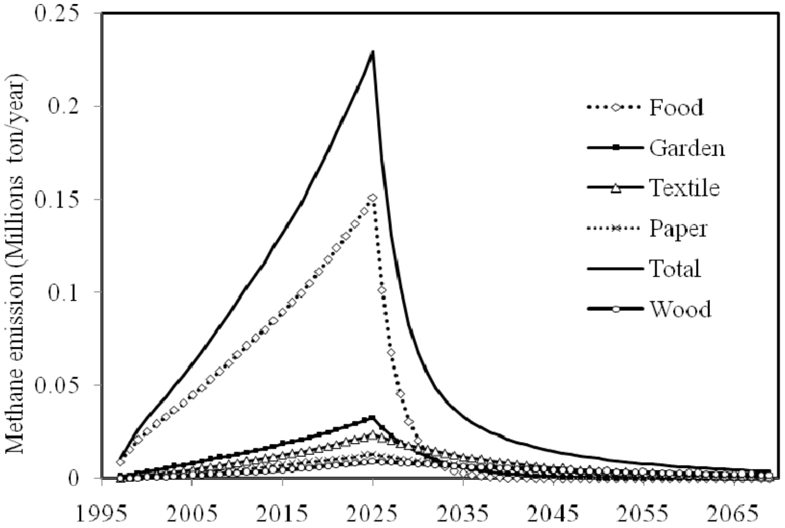

Figure 5 Methane emission of each composition.

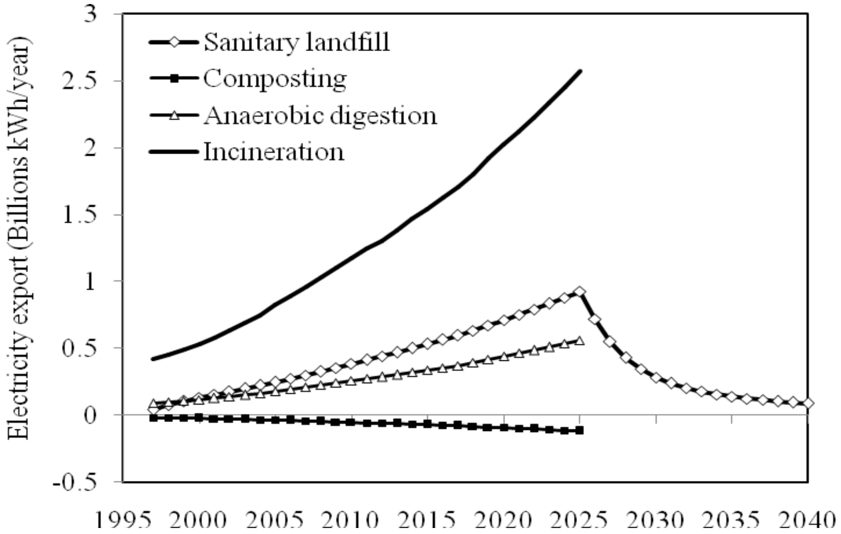

Figure 6 Energy export from each scenario

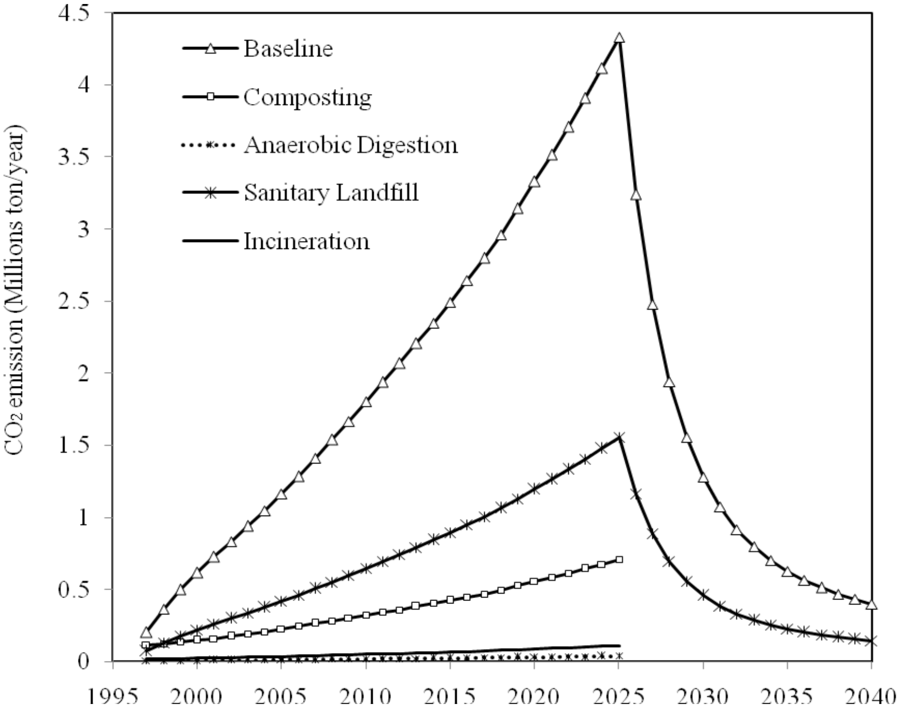

Figure 7 CO_2 emission of each scenario.

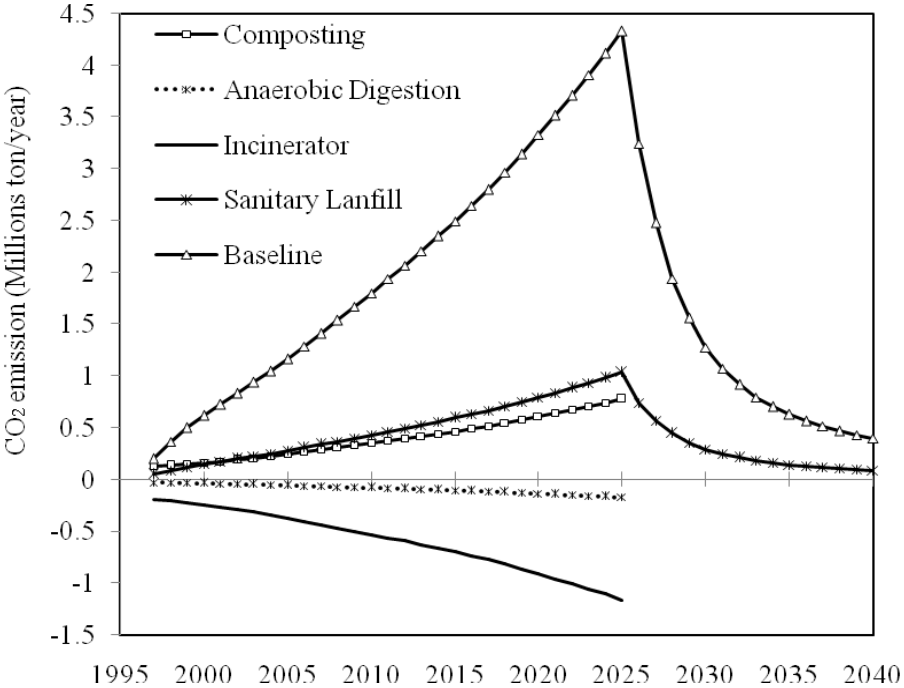

Figure 8 CO_2 emission of each scenario.

(Without GHG emission from energy consumption and generation consideration)

Benefit estimation

As discussed above, some of the alternatives for waste management can generate energy while some alternatives can create products such as compost fertilizer for sale. In addition, GHG emission reduction can be converted to CERs and be credited for trading. In the present study, the price factor per each unit for sale used the basic price mentioned above. Figure 10 shows the benefit estimation for each scenario, with incineration the most beneficial alternative, next is sanitary landfill, anaerobic digestion and the least one is composting scenario. The incineration scenario achieves the higher benefit than the others because of the high energy generation rate, however, the investment cost of this alternative is very high as mentioned in Table 3.

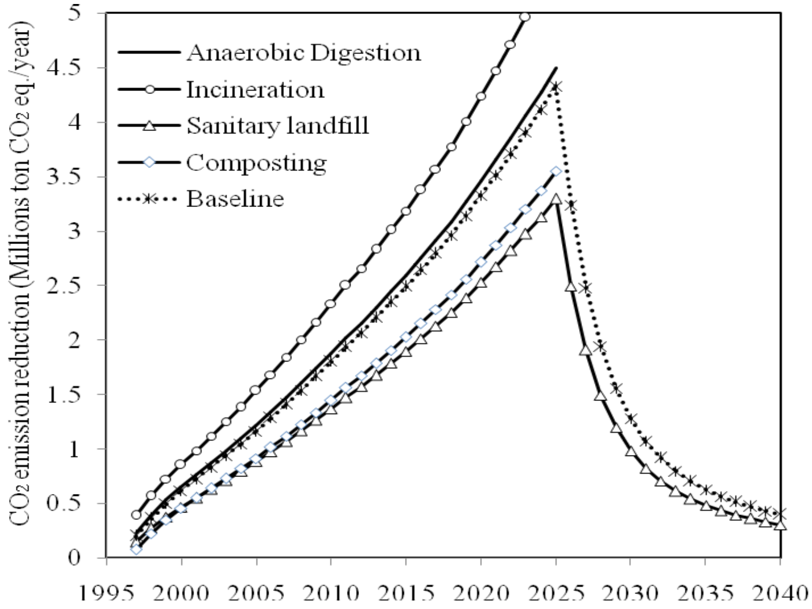

Figure 9 CO_2 emission reduction of each scenario.

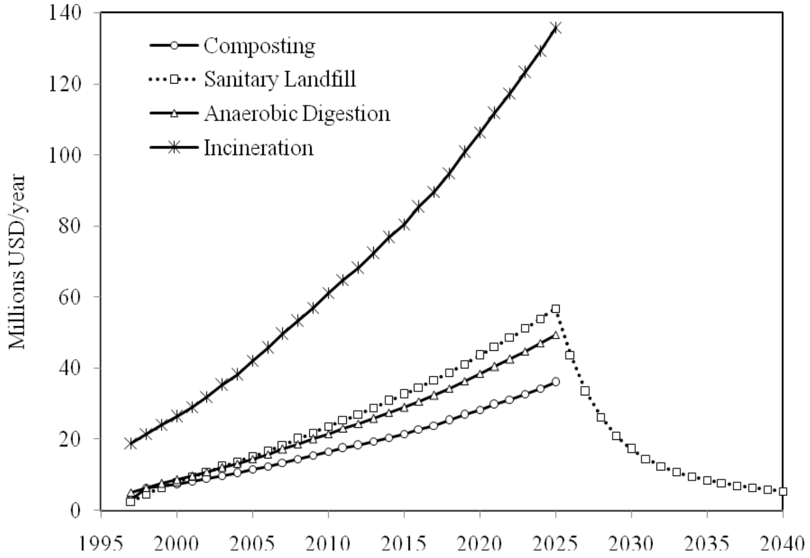

Figure 10 Benefit estimation of each scenario.

Conclusion

In this paper, methane emission and methane emission reduction are quantified for MSW management system of the HCMC case for the period of 2007–2025. System dynamics modelling approach was applied to develop a model for predicting the collected waste rate that would go to the treatment/disposal site. GHG emission rate and GHG emission reduction rate was calculated based on IPCC and UNFCCC guides. The alternative treatment method options proposed in waste management are analyzed under various possible scenarios. The results for baseline scenario show that by the year 2025, HCMC will discard about 21,062 tonnes/year of CH_4 (442,312 tonnes/year of CO_2 eq.). The implementation of proposed options such as the quantity of waste collected, treatment capacity and GHG emission enhancement by introducing different available technologies such as anaerobic digestion, composting, incineration and the replacement of traditional open landfill by sanitary landfill having the facility to capture the landfill gas are considered. The study also estimates the methane emission reduction within the cases of energy consumption and energy generation considered for each alternative. The results show that composting is the lowest investment alternative, although it results in high GHG emissions, the least benefit by itself and no energy generation alternative. On the contrary, while the investment is very high, the incineration scenario achieves the most benefit and energy production and has the additional benefit that it is not only a no GHG emission alternative, but it can also be a GHG reduction factor. Another case, the sanitary landfill scenario, gives the highest GHG emissions and long-term period emissions. However, it is a low investment and high energy benefit alternative. Furthermore, the study shows the important role of electricity production from different treatment options that would also reduce the burden on conventional sources like fossil fuel and would indirectly reduce the emission of other greenhouse gases.

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