Greenhouse Gas Mitigation Potential in Waste Sector from Municipal Solid Waste Disposal in Metropolitan Bangkok

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Abstract

This study aims to evaluate greenhouse gas (GHG) emissions from municipal solid waste disposal in Metropolitan Bangkok and its mitigation potential from the perspective of the waste sector. The evaluation was performed by comparing GHG emissions in three scenarios: business-as-usual (BAU). implementation of the Bangkok solid waste management plan, and adoption of the national GHG mitigation policy proposed for the waste sector in Thailand. Estimation of GHG emissions was carried out following Intergovernmental Panel on Climate Change (IPCC) methodology. In 2019, GHG emissions from solid waste management in Metropolitan Bangkok under BAU were determined to be 1,067.66 $GgCO_2$-eq and they are expected to rise to an estimated 1,258.81 $GgCO_2$-eq in 2032 in the BAU scenario. The implementation of solid waste management following Bangkok's solid waste management plan would reduce the emissions to 863.01 $GgCO_2$-eq. Adoption of the national GHG mitigation policy in terms of increasing methane recovery from landfill disposal and increasing waste treatment through composting would yield total emissions of 633.01 $GgCO_2$-eq, a 49.7% reduction compared to the emissions in the BAU scenario in 2032.

Key words: Bangkok, greenhouse gas emissions, IPCC methodology, nationally determined contribution, waste disposal

1. Introduction

Proper management of municipal solid waste (MSW) is one of the challenges facing urban areas especially those situated in developing countries. Growing populations and changing lifestyles of the populations usually result in increasing amounts of MSW as well as greater complexity of its composition. These changes will require a more effective management strategy and facilities to handle the waste. In Thailand, there are approximately 27.35 million tons annually or about 75,000 tons per day of municipal solid waste generated (PCD, 2021) and this amount is forecasted to increase to 84,070–95,728 tons per day in 2030 (Pudcha *et al*., 2023).

MSW generation in Metropolitan Bangkok, the capital city of Thailand, has steadily increased due to development and urbanization. In 2020, there were 12,214 tons of MSW generated daily in Bangkok of which 3,564 tons were recycled and 8,650 tons were disposed of (PCD, 2021). The disposed MSW was managed in composting plants at 1,600 tons/day, incineration plants at 500 tons/day and mechanical biological treatment (MBT) facilities at 800 tons/day, with the remaining wastes taken to two sanitary landfill sites (BMA, 2022).

During MSW management, greenhouse gases (GHGs) can be generated by several management activities including composting, incineration and solid waste disposal on land using either open dumping or landfill methods. They are one of the major anthropogenic activities that contribute to the global climate change problem. In Thailand, GHGs generated from the waste sector accounted for about 4.3% of the national total in 2019 (MONRE, 2023). The majority of the emissions originated from the disposal of MSW on land either in

landfills or dumpsites, in which Metropolitan Bangkok had the highest emissions among all regions in the country (Chiemchaisri *et al*., 2007). Gradual improvement of disposal conditions of MSW from open dumpsites to sanitary landfills in light of a short-term national waste management strategy would increase overall GHG emissions but also provide the opportunity for landfill gas utilization as its mitigation measure (Chiemchaisri & Visvanathan, 2008). In 2015, Thailand submitted its nationally determined contribution aiming to reduce its GHG emissions by 20%–25% (ONEPP, 2021).

The Bangkok Metropolitan Administration (BMA) issued a development plan (20 years: 2013–2032) in 2014 targeting a reduction of the MSW amount disposed of by 20% and an increase in waste utilization by 40% from the base year (2013) to achieve sustainable MSW management while reducing impacts on the environment and climate change (BMA, 2014). Nevertheless, the extent of GHG mitigation to be achieved from the implementation of MSW management following the BMA development plan has not been evaluated.

Therefore, this research is aimed at determining GHG emissions from MSW management in Bangkok Metropolitan in three different scenarios: business as usual (BAU), Bangkok solid waste management plan (BMA plan), and national GHG mitigation policy (national plan) which include increased methane gas recovery from solid waste disposal sites, and increased waste treatment through composting and incineration.

2. Methodology

The quantities of municipal solid waste generated during 2000–2018 were obtained from BMA statistics. All general waste collected from 50 districts in Metropolitan Bangkok is transported to three transfer stations, namely the On-nut, Nongkhaem and Saimai stations, with the total weights received being recorded daily. The collected waste is then treated in composting facilities located at On-nut station and incineration facilities located at Nongkhaem station, while the majority of the waste is transported from the transfer stations to their final disposal in landfills. The composting facilities have total capacities of 1,600 tons/day (1,000 and 600 tons/day units). The incineration facilities, with an initial capacity of 500 tons/day, started operating in 2016. They have recently upgraded their capacity to 1,500 tons/day with the construction of a new 1,000 tons/day unit following the BMA plan, which was set to be completed in 2022. The waste composition at each transfer station has been determined and recorded annually.

GHG emissions were estimated following guidelines proposed by the Intergovernmental Panel on Climate Change (IPCC). The most updated methodologies include the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) and 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019). According to the IPCC Guidelines, GHG emissions from the following solid waste management activities are considered.

1) MSW landfills: This waste disposal method generates CH_4 from the anaerobic decomposition of organic waste in landfill cells. To estimate CH_4 emissions from landfills, the activity data used are historical data on the waste deposited in the landfills from a starting year of 2000, the amount of waste received during the year of calculation, and degradable waste composition categorized into food waste, paper, textile and wood types. The emission factors used in the calculation include degradable organic carbon (DOC), the fraction of biodegraded degradable organic carbon (DOC_f), and the CH_4 generation rate constant (k) for each waste type, which are applied specifically to the waste composition of Metropolitan Bangkok.

2) Organic waste (food and yard) composting: This biological treatment produces fugitive CH_4 and nitrous oxide (N_2O) emissions in some oxygen-depleted zones of the aerobic reactors used for converting organic wastes into compost. In the calculation, the activity data consisted of the amount of waste treated in the compost plant, whereas for CH_4 and N_2O emissions, IPCC default factors were used.

3) MSW Incineration: This thermal treatment can produce carbon dioxide (CO_2) through fossil carbon combustion., but other biomass-based waste compositions are considered carbon-neutral. The emissions were estimated using actual activity data in terms of the amount of MSW incinerated, fossil carbon (plastic) composition, and dry matter content in the wastes. For continuous-feed-stoker type incinerators, the IPCC default emission factors in terms of total and fossil carbon content in MSW and the oxidation factor were applied. Following the IPCC's national GHG inventory methodology, the emissions from waste incineration in the waste sector will not be considered if the incinerator is equipped with an energy recovery unit, as the emissions will be considered as part of the energy sector in national GHG inventories. Thus, the conversion of waste management from landfilling to incineration is considered an effective mitigation measure for reducing GHG emissions in the waste sector, but those emissions from waste incineration wind up considered in the inventory account of the energy sector instead.

Following the estimation of GHGs including CO_2, CH_4 and N_2O from all activities, overall GHG emissions were determined by converting them into CO_2-equivalent units (CO_2-eq) using global warming potentials of 25 for CH_4 and 298 for N_2O (IPCC, 2007).

Three different scenarios were considered for comparing GHG emissions from the current year (2019) to the end of the BMA plan period (2032), as follows.

1) The "BAU" scenario: This scenario considered the

current MSW management of BMA using existing facilities (as of 2019). It included the operation of composting and incineration facilities at their current capacities of 1,600 tons/day and 500 tons/day, respectively. The remaining waste was to be sent to final disposal in two landfills. Only 12.5% of landfill gas was being recovered at one landfill.

2) The "BMA plan" scenario: This scenario was developed based on Bangkok's 20-year plan (2013–2032) to adopt the "Green City Policy" targeting reduction of waste to be disposed of by 20% in 2032 and increase waste utilization by 40% from 2013 onwards. To achieve this target, the BMA planned to increase the capacity of composting facilities to 2,400 tons/day and incineration facilities to 3,500 tons/day by 2032. To determine the potential mitigation of GHG emissions from this BMA plan, a linear increase of organic waste (food and yard wastes) being diverted from landfills to composting facilities during 2019–2032 and incineration facilities during 2022–2032 were assumed after their construction has been completed.

3) The "National plan" scenario: This scenario considers the mitigation strategy proposed for the solid waste sector at the national level. The key GHG mitigation measures include recovery of landfill gas for electricity production, targeted at a maximum potential recovery rate set at 43% of total gas production through optimization of gas collection planning, following the study of Menikpura *et al*. (2013); increased utilization of organic waste through composting, to be 2,400 tons/day (similar to the BMA plan), and increased waste incineration for electricity production to be 3,500 tons/day (similar to the BMA plan). The implementation of all measures was assumed to increase linearly to its maximum potential during the planning period (2019–2032). The effect of GHG mitigation from all mitigation measures was determined. It should be noted that some other mitigation measures proposed in the national plan such as waste reduction have already been fully implemented in Bangkok and are considered part of BAU, while other technologies, such as anaerobic digestion of source-separated organic waste, production of refuse-derived fuel (RDF) from MSW and semi-aerobic landfills have not been considered, as those facilities are not in operation in Metropolitan Bangkok.

3. Results and Discussion

3.1 Amount of MSW Managed by the BMA

Table 1 shows the annual quantity of MSW received at the BMA's three transfer stations and two landfill sites during 2000–2018. Based on those statistics, the total amount of waste collected at transfer stations has been increasing from 3.29 million tons in 2000 to 4.51 million tons in 2018, whereas the amount disposed of in landfills has also increased from 3.29 million tons to 4.08 million tons during the same period. During 2000–2005, all of the collected waste was disposed of in landfills, as composting and incineration facilities were not yet in operation. As the composting facilities started operating in 2006 followed by incineration facilities in 2016, the amount of collected waste sent to landfills was reduced to about 80% of its prior level in 2016–2017 but increased again to 90% in 2018 due to the temporary shutdown of composting facilities.

The per capita amount of waste managed by the BMA was determined from the recorded registered population of the area under the BMA's jurisdiction. That population stayed relatively constant during 2000–2018, being lowest, at 5,634,132, in 2004 and highest, at 5,844,607, in 2003. The amount of waste collected per registered resident was gradually increasing as shown in Fig. 1. Its growth trend can be described using a linear expression as follows.

Table 1 Statistics on MSW quantity (tons) collected and disposed of by BMA.

Year	On-nut		Nongkhaem		Saimai	Phanomsarakham	Kamphaengsan
	composting	landfilling	Incineration	landfilling	landfilling	landfilling	landfilling
2000	-	1,305,970	-	1,085,448	900,172	1,305,970	1,985,620
2001	-	1,314,000	-	1,186,405	865,050	1,314,000	2,051,455
2002	-	1,294,290	-	1,300,628	878,332	1,294,290	2,178,960
2003	-	1,306,700	-	1,229,124	839,020	1,306,700	2,068,144
2004	-	1,326,410	-	1,308,132	779,688	1,326,410	2,087,820
2005	-	897,170	-	1,291,506	903,375	897,170	2,194,881
2006	319,375	833,660	-	1,230,987	681,408	1,153,035	1,912,395
2007	404,055	813,585	-	1,242,075	758,212	1,217,640	2,000,287
2008	394,565	819,060	-	1,215,330	764,036	1,213,625	1,979,366
2009	389,090	818,330	-	1,224,666	1,223,480	1,207,420	2,448,146
2010	169,360	1,059,040	-	1,224,087	812,803	1,175,300	2,036,890
2011	151,840	1,177,490	-	1,257,046	784,896	1,329,330	2,041,942
2012	438,000	693,500	-	1,288,718	861,291	1,131,500	2,150,009
2013	396,857	1,087,963	-	1,288,106	863,469	1,484,820	2,151,575
2014	438,000	985,500	-	1,350,340	813,717	1,423,500	2,164,057
2015	397,310	1,044,805	-	1,350,762	917,963	1,442,115	2,268,725
2016	591,665	1,002,290	366,645	1,152,501	987,721	1,593,955	2,140,222
2017	584,000	958,490	169,717	1,419,498	965,294	958,490	2,384,792
2018	246,141	1,420,814	176,189	1,459,599	956,893	1,666,955	2,416,492

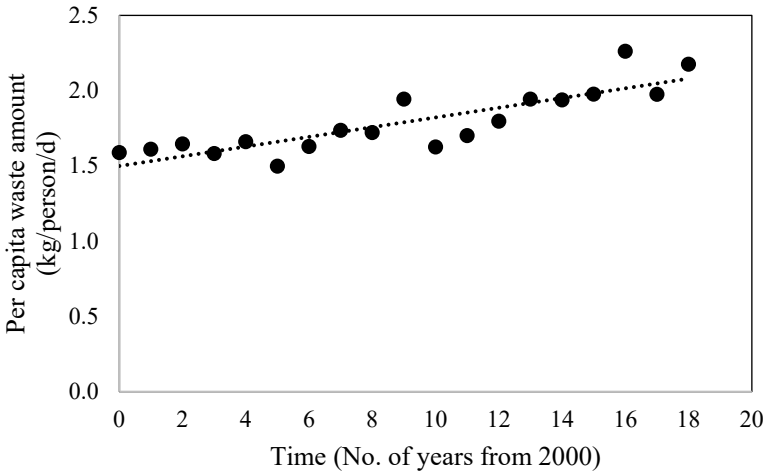

Fig. 1 Trend of per capita waste generation managed by the BMA during 2000–2018.

Table 2 Estimated emissions ($GgCO_2$-eq) from MSW management in BAU and BMA plan scenarios.

Year	BAU				BMA plan			
	composting	incineration	landfilling	total*	composting	incineration	landfilling	total*
2019	82.96	98.99	984.70	1,067.66	82.96	98.99	984.70	1,067.66
2020	82.96	98.99	1,001.65	1,084.61	89.34	98.99	988.03	1,077.37
2021	82.96	98.99	1,017.11	1,100.07	95.72	98.99	1,004.13	1,099.85
2022	82.96	98.99	1,031.99	1,114.95	102.10	296.97	898.95	1,001.05
2023	82.96	98.99	1,046.64	1,129.60	108.48	336.57	878.76	987.24
2024	82.96	98.99	1,061.18	1,144.14	114.86	376.17	858.58	973.44
2025	82.96	98.99	1,075.65	1,158.61	121.25	415.76	838.39	959.64
2026	82.96	98.99	1,090.06	1,173.02	127.63	455.36	818.21	945.83
2027	82.96	98.99	1,104.43	1,187.39	134.01	494.96	798.02	932.03
2028	82.96	98.99	1,118.77	1,201.73	140.39	534.55	777.84	918.23
2029	82.96	98.99	1,133.07	1,216.03	146.77	574.15	757.65	904.43
2030	82.96	98.99	1,147.35	1,230.31	153.15	613.74	737.47	890.62
2031	82.96	98.99	1,161.61	1,244.57	159.53	653.34	717.28	876.82
2032	82.96	98.99	1,175.85	1,258.81	165.91	692.94	697.10	863.01

Remark: * Emissions from incineration (waste to energy plant) not accounted for in total emissions.

$$Y = 1.4992 + 0.0322\ x \quad (1)$$

Where Y = amount of waste collected per registered resident (kg/person/day) and x is the corresponding year from 2000 onwards (x = 0 for the year 2000). Based on this equation, it is suggested that the amount of waste managed by the BMA gradually increased from 1.4992 kg/person/day in 2000 at a rate of 2.15% per year. It should be noted that this waste generation rate was determined based only on the registered population; thus the actual waste generation rate would be much lower if it were determined based on both the registered and non-registered populations. Currently, it is estimated that about 4 million people are residing in the BMA area as non-registered residents.

The amount of MSW to be managed by the BMA during 2019–2032 was then predicted through extrapolation of its preceding trend. The quantity of waste is expected to increase from 3.87 million tons in 2019 to an estimated 4.35 million tons in 2032.

The major waste composition recorded by the BMA during 2008–2017 is described as follows: food waste 41.92–51.52% (45.22% on average), yard waste 5.26%–8.07% (6.05%), paper 6.25%–12.43% (9.71%), plastic 13.33%–21.54% (19.55%), leather/rubber 0.76%–1.95% (1.39%), textile 2.33–5.52% (4.13%) foam 1.22%–1.92% (1.53%), glass 1.01–3.33% (2.59%), metal 1.15%–1.95% (1.50%), and other minor components. There was no clear trend in the waste composition change except a notable decrease in plastic components during 2015–2017 (13.33%–18.86%) compared to those in the previous years (19.18%–21.54%). Therefore, the average waste composition was used in the forecast of the quantity of each waste component to be managed during 2019–2032. It should also be pointed out that the information on waste composition was collected before the COVID-19 pandemic; therefore the waste composition would represent the typical MSW of Metropolitan Bangkok during normal times.

3.2 GHG Emissions in the BAU Scenario

GHG emissions from MSW management by the BMA in 2000 (base year) with 3.29 million tons disposed of in landfills was determined to be 671.7 $GgCO_2$-eq. Even though the operation of composting and incineration facilities was introduced in 2006 and 2016, the amount of waste disposed in landfills did not decrease because an increasing amount of waste was collected during 2000–2018. Therefore, there was a trend toward increased emissions during this period. Table 2 presents the

Table 3 Estimated emissions ($GgCO_2$-eq) from MSW management in the national plan scenario.

Year	MSW (tons)	National plan			
		composting	incineration	landfilling	total*
2019	3,867,095	82.96	98.99	932.50	1,015.46
2020	3,904,327	89.34	98.99	914.42	1,003.76
2021	3,941,560	95.72	98.99	899.83	995.55
2022	3,978,792	102.10	296.97	712.87	814.97
2023	4,016,025	108.48	336.57	679.72	788.20
2024	4,053,257	114.86	376.17	652.89	767.75
2025	4,090,490	121.25	415.76	628.14	749.38
2026	4,127,722	127.63	455.36	604.18	731.80
2027	4,164,955	134.01	494.96	580.61	714.62
2028	4,202,187	140.39	534.55	557.32	697.71
2029	4,239,420	146.77	574.15	534.31	681.08
2030	4,276,652	153.15	613.74	511.59	664.75
2031	4,313,885	159.53	653.34	489.18	648.71
2032	4,351,117	165.91	692.94	467.10	633.01

Remark: * Emissions from incineration (waste to energy plant) not accounted for in total emissions.

estimated GHG emissions arising from MSW management by the BMA during 2019–2032 in the BAU scenario. The emissions are expected to increase from 1,067.67 $GgCO_2$-eq in 2019 to an estimated 1,258.81 $GgCO_2$-eq, up 18%, in 2032. Among other sources, the emissions were mainly attributable to MSW disposal in landfills (984.70–1,175.85 $GgCO_2$-eq) while the emissions from composting and incineration facilities stayed constant at 82.96 and 98.99 $GgCO_2$-eq as they were already operating at their full capacities before 2019, except for in 2018 when the facilities were shut down occasionally.

3.3 GHG Emissions in the BMA Plan Scenario

GHG emissions from MSW management, with the implementation of composting and incineration facilities with increased capacities following the BMA plan, are also presented in Table 2. The emissions in this scenario gradually decrease from 1,067.67 $GgCO_2$-eq in 2019 to 863.01 $GgCO_2$-eq, or a 19.2% reduction, in 2032. The decrease in emissions is mainly attributable to increased diversion of organic wastes from landfill disposal, which reduces landfill emissions from 984.70 to 697.10 $GgCO_2$-eq. Despite the emissions from composting and incineration increasing to 165.91 and 692.94 $GgCO_2$-eq respectively, the emissions from incineration have not been accounted for in the total emissions of the waste sector, as the BMA's incinerator utilizes energy recovery following the IPCC's national GHG inventory methodology. This increase in GHG emissions of about 600 $GgCO_2$-eq needs to be considered as a part of emissions from renewable energy sources in the energy sector. According to Misila *et al*. (2020), Thailand set a target for renewable energy at 30% in 2036 and this will result in GHG emissions of 122,386 $GgCO_2$-eq from this source.

3.4 GHG Emissions in the National Plan Scenario

Table 3 presents estimated GHG emissions when landfill gas recovery and the operation of composting and incineration facilities rise to their potential, following implementation of the BMA plan. In 2019, emissions were expected to decrease due to landfill gas recovery measures, which helped reduce emissions from landfill disposal from 984.70 to 932.50 $GgCO_2$-eq, resulting in total emissions of 1,015.46 $GgCO_2$-eq or a further reduction of 5% from the BMA plan. During the period of the plan, the landfill and total emissions gradually decrease to 467.10 and 633.01 $GgCO_2$-eq, respectively, in 2032. Implementation of this scenario would reduce the emissions by 49.7% from those in the BAU scenario in 2032, meeting the national target of a 20%–25% reduction.

Table 4 Summary of GHG emissions and their mitigation under different scenarios.

Scenario	Total emissions in 2032 ($GgCO_2$-eq)	Emission reduction in waste sector (%)
BAU	1,258.81	-
BMA plan	863.01	31.4
National plan	633.01	49.7

4. Conclusions

Following a trend of increasing MSW generation in Bangkok, GHG emissions from MSW management are anticipated to rise from 671.7 $GgCO_2$-eq to 1,258.81 $GgCO_2$-eq, or an 87% increase by 2032. Implementation of the BMA's waste management plan by increasing Bangkok's composting and incineration facilities by 2032 would help reduce the emissions by 395.8 $GgCO_2$-eq or 31% from the anticipated emissions in the BAU scenario. Further incorporation of landfill gas recovery for GHG mitigation following the national plan, in addition to those measures implemented in the BMA plan, would increase the emission reduction to 49.7% from the BAU scenario by 2032, as summarized in Table 4. Thus, implementation of MSW management by the BMA following the national GHG mitigation plan would help meet the nationally

determined contribution, aiming to reduce GHG emissions by 20%–25%.

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