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Climate Benefit of Recovering Biodegradable Municipal Solid Waste: A Case Study in Kuala Lumpur, Malaysia

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Abstract: Excessive emission of methane (CH_4) released by waste sector accounts for 3-4% of the total annual anthropogenic Greenhouse Gases (GHGs) emission. Malaysia's GHGs inventory in 1994 has shown that waste sector had emitted 1, 043 Gigagrams (Gg) of CH_4 from landfills and was expected to increase driven by excessive waste generation. There is a need to determine GHGs emission from waste sector in order to determine the importance and involvement in climate change mitigation. In this study, the potential emission trends for four inventory years from the disposal of Biodegradable Municipal Solid Waste (BMSW) in disposal sites were estimated. To determine emission at city level, the urban city of Kuala Lumpur, Malaysia was chosen. It was observed that BMSW generated in 1985 had potential to emit 0.22 $MtCO_2$ eq year^{-1} of GHGs emission and in 2000 it was projected to emit at a rate 0.31 $MtCO_2$ eq year^{-1}, throughout the whole decay process of the fraction. To reduce the amount of BMSW transferred to landfill, resource recovery action was proposed. Findings had shown that if 20% of degradable solid waste generated in 2000 were recovered as resource through composting and anaerobic digestion, GHGs emission rate for each treatment would be 584.6 and 146.1 tCO_2 eq year^{-1}, respectively.

Key words: Methane emission, landfill treatment, biological treatment, composting, anaerobic digestion, mass balance approach

INTRODUCTION

Borderless impact of climate change has caused deterioration of ecosystem. Excessive emission of Greenhouse Gases (GHGs); incinerator Carbon dioxide (CO_2), landfill methane (CH_4) and wastewater methane (CH_4) and Nitrous Oxide (N_2O) released by waste sector has caused climate change impact and lead to serious environmental problems. According to recent national estimation, total methane (CH_4) that released by waste sector was accounts for 3-4% of the total annual anthropogenic GHGs emission (Intergovernmental Panel on Climate Change, 2006). It was reported by the Intergovernmental Panel on Climate Change (IPCC, 2001) in 2001 that atmospheric CH_4 concentration has increased from about 700-1, 745 ppbv over the same period and is increasing at the rate of 7 ppbv year^{-1}. Emission Annex 1 are expected to reduce slightly from 24 Mt in 1990 to 23Mt in 2010 due to reducing organic waste landfilling and methane collection system (USEPA, 1999). In contrast, increase of GHGs emission pattern from waste sector is expected to be seen among developing countries driven by population growth and continuing dependency on landfill as a final treatment option. In 1995, methane emissions per capita in Thailand, Indonesia and Malaysia were recorded at high of 9.4, 6.5 and 6.1 kg/capita/day, respectively and projected to increase to 13.6, 9.0 and 11.1 kg/capita/day in 2025 (Bengtsson and Sang-Arun, 2008). Thus, efforts to involve active participation from developing countries to mitigate GHGs from waste sector have become more important.

In developing countries however, the priority was improving local development to meet basic needs rather than reducing climate change emission. Combining these two conflicting agendas might enhance the effectiveness of local development in one hand and contribute to mitigate emission at an international level in another. Climate benefit approach offers combined benefit in response to local needs in environmental pollution control obligations and to contribute to global climate change mitigation. Development benefit can be gained from the social, economic and environment benefits that result from climate action in mitigating GHGs while contributing to sustainable development. On the other hand, climate benefit can be gained from development actions that contribute to GHGs mitigation or climate-resilient development (Zusman, 2008).

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Resource recovery at waste treatment level can be performed to promote combined development and climate benefit approach in waste sectors. There are various technological options to recover BMSW at middle treatment stage such as composting, anaerobic digestion, effective microorganism, soil mulching, pyrolysis and briquette. Considering the rapid economic growth in Asia, Environmentally Sound Technology (EST) will be needed in reducing growing greenhouse gas emissions (Muzones, 2008). Bengtsson and Sang-Arun (2008) had stated that biological treatment methods, composting and anaerobic digestion have the advantage of drastically reducing GHGs emission.

This study was conducted with the main objective to assess the potential for reduction in CH_4 emission rate from waste sectors by recovering BMSW as a resource. To begin with current climate change impact and municipal waste management in Kuala Lumpur was elaborated. In order to assess a trend of possible emission from waste sector, estimation of landfill CH_4 emissions in 4 inventory years were conducted. Furthermore to assess the reduction possibilities from resource recovery, estimation of potential emission from composting and anaerobic digestion treatment were conducted. To enhance implementation of resource recovery action, climate benefit approach was suggested to obtain combined benefits of Municipal Solid Waste (MSW) development at local level and climate mitigation at global level.

MATERIALS AND METHODS

Background in study area: Kuala Lumpur is the capital city of Malaysia. Since, the 1970s, Kuala Lumpur has undergone a period of mass urbanization. It is located at longitudes 102°42'E and latitudes 3°8'N with a 242.3 km^2 landmass area. As of 2005, the population was 1.6 million with density of 6840 person km^{-2}. With a tropical climate, Kuala Lumpur has monthly temperature ranged from 22.1-33.1°C with hot and humid weather throughout the year with over 2,000 mm in annual precipitation. Southwest monsoon (April-September) and northeast monsoon (November-February) bring rainfall all year around especially during transition period in March. Analysis on need for climate change mitigation action and municipal solid waste management in Kuala Lumpur is based on various sources of published information, particularly from government reports, technical journals and conference proceedings. Further investigation was done on literature sources to identify current trends in practice and future management needs. Confirmation on landfill operation conditions were obtained from interviews with the respective government offices.

Method and assumptions of CH_4 emission estimation: Based on published data of waste generation amount and composition of BMSW in Kuala Lumpur's waste stream, this study has estimated CH_4 baseline emission for 4 inventory years of 1985, 1990, 1995 and 2000. The Biodegradable Municipal Solid Waste (BMSW) is defined as collected paper, textile, organic (leftover food) and wood fraction generated by domestic and commercial sector in Kuala Lumpur. Mass balance approach which has been proposed in 1996 (NGGIP, 1996) IPCC Guidelines was applied based on localy available activity data while taking into consideration the mixed municipal waste in final stream. However, for study which can provide long term activity data and able to determine country-specific parameter, it is recommended to apply First Order Decay (FOD) method for more accurate degradation process delayed over time period as proposed in 2006 IPCC guidelines. Implementing the selected mass balance approach, the researchers intend to obtain total mass of degradable waste throughout the whole decay process of the fraction, evaluated in inventory year at the time of disposal. The given equation is as follows:

$$\begin{aligned}&CH_4 \text{ emission potential } (t\ CH_4\ year^{-1}) = \\ &(MSW(T) \,.\, MSW(F) \,.\, MCF \,.\, DOC. \\ &DOC(F) \,.\, F \,.\, 16/12\text{-}R) \times (1\text{-}OX)\end{aligned} \quad (1)$$

Where:

MSW (T)	=	Total MSW generated (Ton $year^{-1}$)
MSW (F)	=	Fraction of MSW disposed to solid waste disposal sites
MCF	=	Methane Correction (Fraction)
DOC	=	Degradable Organic Carbon (fraction)
DOC (F)	=	Fraction DOC disimilated
F	=	Fraction of CH_4 in landfill gas
R	=	Recovered CH_4
OX	=	Oxidation factor

Default data was given in 2006 IPCC Guidelines in order to assist countries conducting emission inventory. For more accurate estimation however, priority should be given to country specific value of activity data and parameters. Fraction of MSW disposed to solid waste disposal sites was set as 0.75, considering 75% of collected waste were landfilled, 20% illigelly disposed and 5% recycled (Periathamby *et al.*, 2009). As for Methane

Correction Factor (MCF), value 0.60 was used. Malaysia used this figure in reporting GHGs inventories of waste sector for Second National Communication. Determination for other parameters were based on default value, 0.5 as the dissimilated fraction of DOC, 0.5 as the fraction of CH_4 in landfill gas (F), 0 as the recovered CH_4 and 0 as the Oxidation factor (OX). To evaluate GHGs impact of the emitted landfill methane, CH_4 emission rates was converted to Carbon dioxide equivalent (CO_2e) using equation:

$$CH_4 \text{ emission} (\text{Mt} CO_2 \text{e year}^{-1}) = GWPCH_4 . CH_4 \text{ emission} (\text{t} CH_4 \text{ year}^{-1}) \quad (2)$$

Where, $GWPCH_4$ is 100 year global warming potential of methane = 21 (1996 IPCC value).

Method and assumptions of biological treatment emission estimation: The CH_4 emission from composting and anaerobic digestion was calculated using method proposed in 2006 IPCC Guidelines using below equations:

$$CH_4 \text{ emission potential } (\text{t}CH_4 \text{ year}^{-1}) = \sum (\text{Mi x EFi}) \times 10^{-3} - R \quad (3)$$

Where:

CH_4 emission	=	Total CH_4 emission in inventory year, t CH_4
Mi	=	Mass of organic waste treated by i, t year^{-1}
EF	=	Emission factor for treatment I, gCH_4 kg^{-1} waste treated
I	=	Composting or anaerobic digestion
R	=	Total amount of CH_4 recovered

As for Emission Factor (EF) value, IPCC default value on a wet weight basis, 4 g CH_4 kg^{-1} waste treated was used for composting and 1 g CH_4 kg^{-1} waste treated was used for anaerobic digestion. As for the recovered CH_4 amount (R), value 0 was used. Furthermore, GHGs impact from CH_4 emission was converted to CO_2eq using Eq. 2 before.

RESULTS

The need for climate change mitigation action: The global warming trend in Peninsular Malaysia is illustrated by a significant increase of the mean annual temperature, ranging from 0.99-2.69°C per 100 year and Kuala Lumpur has the highest warming trend of 2.69°C per 100 year observed (Ng *et al*., 2005). It has been reported that temperature's have risen at 0.18°C per decade for over 40 years while a rise in sea level was recorded in the southern coastal area of Peninsular Malaysia at 1.25 mm annually (INC, 2000; UTM, 2007). As shown in Table 1 is GHGs inventory in 1994 as reported in Initial Communication Malaysia submitted to United Nations Framework Convention on Climate Change (UNFCCC). In term of CO_2 equivalent, 67.5% GHGs emission was accounted for CO_2, 32.4% of CH_4 and 0.1% of N_2O. From total, 18.7% was from waste sector and landfill CH_4 was the main source of generation.

Table 1: Greenhouse gases for each sector in Malaysia, 1994

	CO_2 equivalent (Gg)			Total emission only (1994)	
Sectors	CO_2	CH_4	N_2O	CO_2e (Gg)	%
Energy	84, 415.00	13,335.00	102.00	97, 852	67.8
Industrial	4, 973.00	-	-	4, 973	3.4
Agriculture	-	6, 909.00	16.00	6, 925	4.8
LULCF	7, 636.00	3.00	0.00	7, 639	5.3
Waste	318.00	26, 607.00	-	26, 925	18.7
Total emission	97, 342.00	46, 854.00	118.00	144, 314	
Percentage	67.50	32.50	0.10	-	-
Total sink	-	-	-	-68, 717	-
Net total	-	-	-	75, 597	-

Ministry of Science, Technology and The Environment Malaysia (INC, 2000)

Climate change concerns under context of sustainable development have indirectly been addressed in past and existing national policies. The initiative has been taken to develop national policy and strategies on climate change in fostering sustainable development in Malaysia to meet Malaysia's need and to respond to UNFCCC (Tan *et al*., 2009).

Municipal solid waste management: Waste generation rate in Kuala Lumpur has been increasing parallel with its population (Fig. 1). Kathirvale *et al*. (2003) reported the average amount of MSW generated in Kuala Lumpur had reached 1.7 kg/person/day which is a significantly higher than the national average of 0.5-0.8 kg/person/day. Current study by Saeed *et al*. (2009) had estimated that MSW generation of Kuala Lumpur is predicted to escalate to 2.23 kg/capita/day by 2024 (Table 2).

There are high percentage of organic fraction contains in the waste stream. In contrast with the composition of national trends, organic waste percentage in Kuala Lumpur continually increases every year.

In the year 2000 degradable wastes comprise of organic (leftover food), paper, textile and wood fraction had total up to 77.3% (Nasir, 2007). With this high percentage, degradable fraction in Kuala Lumpur's MSW

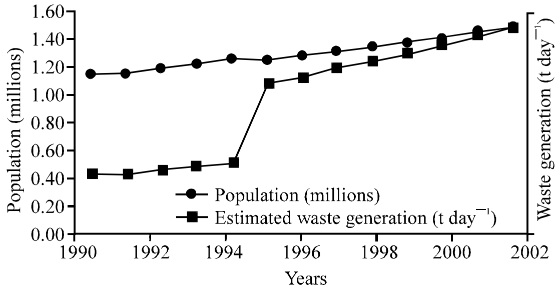

Fig. 1: Kuala Lumpur waste generation trend, 1990-2002 (Yahaya, 2003)

Table 2: Estimation of daily waste generation in Kuala Lumpur

Years	Estimation daily waste generation Domestic waste (t day^{-1})	Commercial waste (t day^{-1})	Total (t year^{-1})
1985	573	459	376, 680
1990	750	552	475, 230
1995	934	662	582, 540
2000	1185	817	730, 730

Table 3: Trend of solid waste composition in Kuala Lumpur, 1975-2000, unit (%)

Year/Composition	1975	1980	1990	1995	2000
Organic	63.7	78.1	40.8	61.8	68.7
Paper	11.7	11.5	30.0	12.2	6.4
Textiles	1.3	3.2	2.5	2.8	1.5
Woods	6.5	2.6	3.2	0.0	0.7
Plastic	7.0	0.6	9.8	5.3	11.5
Glass	2.5	0.6	3.0	5.3	1.4
Metals	6.4	3.2	4.6	6.9	2.7
Others	0.9	0.4	6.1	5.8	7.1

Sivalapan *et al.* (2002)

stream should be put in focus to recover it as resource instead of treating it as waste. However, the absence of formal waste separation practices in Kuala Lumpur will be a major constraint to face before being able to carry out resource recovery practice efficiently. This also had caused high moisture contents with 55% wet weight and 240 kg m^{-3} bulk density (Kathirvale *et al.*, 2003). Furthermore, mixed MSW that has been collected had limited the available technological options for middle and final treatments. The current waste treatment option available in Malaysia is mainly focused on the end of pipe solution (Table 3).

Landfilling is the main method used for treatment with approximately 75% disposed in this fashion, 20% burned or illegally dumped into rivers while only 5% is recycled (Periathamby *et al.*, 2009).

As of April 2007, there are 150 operating landfill sites in Malaysia and only 10 of them categorized as sanitary landfill (Nasir, 2007). There are no operational dumping sites in Kuala Lumpur territory at present but under

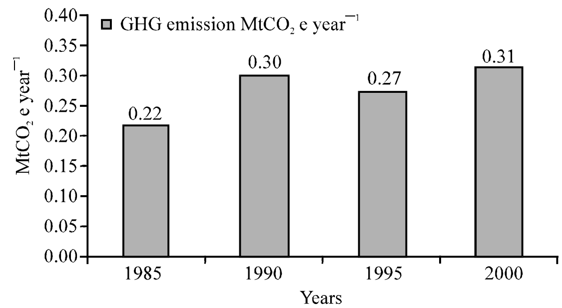

Fig. 2: Landfill methane emission from 4 inventory years

The 9th Malaysia plan, Kuala Lumpur was provided with a transfer station located in Taman Beringin which has capacity to handle 1,700 tons of waste per day (EPU, 2006). The high urbanization rate however has generated vast amount of waste and has transported more waste to landfill and shorten its lifespan, forcing the need for alternative cost-effective treatment option that best suit local conditions.

Enforcement of the 3R's has been raised in newly enacted Solid Waste and Public Cleansing Management (SWPCM) Bill. Practice enforcement has been elaborated covering the implementation requirement, take back and deposit refund system, compound on implementation failure and prescribe regulation (SWPCM, 2007). Under the bill, waste separation is made compulsory in line with endorsement of National Strategic Plan for Solid Waste Management in Malaysia (NSP). Its target was to minimize waste through recycling at 22% by year 2020. Unfortunately, recycling target for specific waste stream had excluded leftover food (organic) recycling in the strategy comprehensive approach.

It has been estimated that from MSW recyclable of Kuala Lumpur, food waste has 57% of recyclable potential with 155,041 t year^{-1} recycling rate (Saeed *et al.*, 2009). Considering low recycling rate in Kuala Lumpur, expanding the recyclable option to BMSW should be highly recommended for efficient resource recovery action.

Potential of CH_4 emission from current landfill waste treatment: Based on waste composition data, DOC value for each inventory year was calculated. Using DOC values for each inventory year, potential emission from generated BMSW in 4 inventory years was estimated as shown in Fig. 2. Result show that BMSW generated in 1985 had the potential to emit 0.22 $MtCO_2$ eq of GHGs emission and BMSW generated in 2000 was projected to emit GHGs emission at rate 0.31 $MtCO_2$ eq throughout whole decay

Table 4: Potential of CH_4 emission in 2000 (unit: t CO_2e $year^{-1}$)

100% landfill	80% landfill	20% compost	20% anaerobic digestion
311, 514	249, 211	584.6	146.1

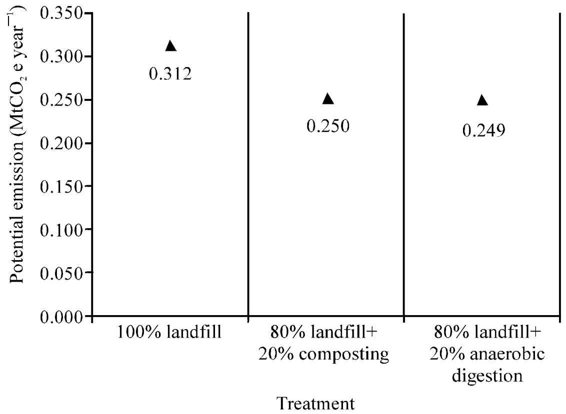

Fig. 3: GHGs emissions saving from resource recovery

process of the fraction. Potential of high emission rate can be observed from BMSW generated in 1990 and it is believed that it is due to high percentage of paper waste composition. From estimated results, it is predicted that there will be continuous increment in CH_4 emission density generated by waste sector.

This result supports the statement released by IPCC (2000) indicating that CH_4 emissions from developing countries are expected to increase with key factors being population growth, additional waste generation associated with economic development and the continuing priority of many developing countries to reduce unmanaged dumping and develop larger solid waste disposal sites where have commonly higher CH_4 emission.

Potential of CH_4 emission from biological treatment: Even though landfill management will help to reduce emission levels the most efficient option should be taken that is reducing waste sent to landfill. To evaluate mitigation potential from resource recovery action in Kuala Lumpur context, the year 2000 was set as baseline year. Potential of CH_4 emission from composting and anaerobic digestion as option for resource recovery treatment were considered. It is shown in Table 4 and Fig. 3 if 20% of DMWS generated in 2000 is recovered through biological treatment, it is estimated that composting has potential to emit 584 tCO_2eq $year^{-1}$ while anaerobic digestion has potential to emit at 146.1 tCO_2 eq GHGs emission, respectively. Furthermore, resource recovery of 146,146 tons of BMSW had potential to provide direct benefit in waste sector by reducing the burden on landfill. At the same time, offer mitigation benefit in climate sector with potential to avoid 61,718-62,157 t CO_2 e $year^{-1}$ through biological treatment, compared to current landfilling method.

DISCUSSION

Borderless impact of climate change has caused the deterioration of ecosystem resources. The negative impact can be seen especially in developing countries that still search for suitable approach in managing solid waste management effectively. GHGs emission from MSW sector in developing countries is expected to increase due to high dependency on landfilling method as final treatment option. Given the above fact of climate change impact and current MSW management status, Kuala Lumpur has a local obligation to improve urban solid waste management while taking part in mitigating climate change impacts.

Looking at the whole decay process of degradable fraction from MSW generated in 1985, 1990, 1995 and 2000, the emission trend will lead to increase in CH_4 density if there is no optional treatment taken to handle waste along the resource life cycle route. Recovering waste as a feedstock resource for biological treatment apperars to be a beneficial tool in improving management in waste sector by reducing waste transport to landfill. Based on National Strategic Plan for Solid Waste Management in Malaysia the target to minimize waste through recycling at 22% by year 2020, possible GHGs emission reduction of 20% recovery has been estimated. Findings showed that with low emission rate, both composting and anaerobic digestion treatment have potential to reduce emission compared to landfill treatment.

This study recommended resource recovery action as a tool to absorb various stakeholders' participation in these two conflicting agendas of waste management and climate change mitigation. Resource recovery action offer development benefits; material recovery which can be obtained from extension of product lifecycle route, minimization in waste generation and reduced dependency on landfill as final waste treatment option. Indirectly, by-product of composting provide nutrient recovery benefits while anaerobic digestion offers energy recovery benefits. Furthermore, resource recovery actions will also provide climate benefits. Methane emission from waste sector can be mitigated directly through reduction in landfilling of degradable organic waste. Indirectly, emissions from other sectors have the possibility to reduce with utilization of recovered material as substitute to virgin material. Meanwhile, soil carbon storage can be increased through nutrient recovery from organic fertilizer usage. Therefore, improving resource and waste management will benefit waste sector in reducing waste generation at final waste stream and at the same time contributing in mitigation GHGs emission from waste sectors as well as other sectors.

CONCLUSION

Increase trend of total waste generation and changing in waste composition of BMSW in Kuala Lumpur has caused on increase in CH_4 density and will continue to increase if no optional treatment is undertaken to handle waste along the resource lifecycle route. This study has estimated the potential CH_4 emission from degradable MSW fraction in Kuala Lumpur and potential of emission reduction between current waste treatment condition with alternative treatment of composting and anaerobic digestion for resource recovery.

It is expected that result and discussion performed through this study will enhance stakeholder's involvement in handling waste management and climate change issue more efficiently.

For possible future research to improve findings of this study, it is recommended for extension effort in determining local parameters for more accurate value in estimating GHGs emission from waste sector at local level.

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