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Assessment of GHG Emission Reduction Potential from Source-separated Organic Waste (SOW) Management: Case Study in a Higher Educational Institution in Malaysia

(Penilaian Potensi Pengurangan Pelepasan GHG daripada Pengurusan Sumber Sisa Organik Dipisahkan (SOW): Kajian Kes di Institusi Pendidikan Tinggi di Malaysia)

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ABSTRACT

In Malaysia, the greenhouse gases (GHGs) emissions reduction via composting of source-separated organic waste (SOW) in municipal solid waste (MSW) has not been assessed. Assessment of GHG emissions reduction via composting of SOW is important as environmental impacts from waste management are waste-specific and local-specific. The study presents the case study for potential carbon reduction via composting of SOW in University of Malaya (UM). In this study, a series of calculations were used to evaluate the GHG emission of different SOW management scenarios. The calculations based on IPCC calculation methods (AM0025) include GHGs emissions from landfilling, fuel consumption in transportation and SOW composting activity. The methods were applied to assess the GHG emissions from five alternative SOW management scenarios in UM. From the baseline scenario (S0), a total of 1,636.18 tCO_{2e} was generated. In conjunction with target of 22% recycling rate, as shown in S1, 14% reduction in potential GHG emission can be achieved. The carbon reduction can be further enhanced by increasing the SOW composting capacity. The net GHG emission for S1, S2, S3 and S4 were 1,399.52, 1,161.29, 857.70 and 1,060.48 tCO_{2e}, respectively. In general, waste diversion for composting proved a significant net GHG emission reduction as shown in S3 (47%), S4 (35%) and S2 (29%). Despite the emission due to direct on-site activity, the significant reduction in methane generation at landfill has reduced the net GHG emission. The emission source of each scenario was studied and analysed.

Keywords: Composting; GHG; kitchen waste; SOW; university; waste management; yard waste

ABSTRAK

Di Malaysia, pengurangan pelepasan gas rumah hijau (GHG) melalui pengkomposan punca dipisahkan sumber organik (SOW) dalam sisa pepejal perbandaran (MSW) belum pernah dinilai. Penilaian pengurangan pelepasan GHG melalui kompos daripada SOW adalah penting kerana kesannya terhadap alam sekitar disebabkan daripada pengurusan sisa buangan adalah khusus-sisa buangan dan khusus-tempatan. Kertas ini membentangkan kajian kes bagi potensi pengurangan karbon melalui aktiviti pengkomposan SOW di Universiti Malaya (UM). Dalam kajian ini, satu siri pengiraan digunakan untuk menilai pelepasan GHG melalui pengurusan SOW berbeza. Pengiraan berdasarkan kaedah pengiraan IPCC (AM0025) adalah termasuk pelepasan GHG dari tapak pelupusan, penggunaan bahan api kenderaan dan aktiviti pengkomposan SOW. Kaedah ini digunakan untuk menilai pelepasan GHG daripada lima alternatif senario pengurusan SOW di UM. Daripada senario asas (S0), sejumlah 1636.18 tCO_{2e} telah dijana. Selaras dengan sasaran kadar kitar semula 22%, seperti yang ditunjukkan dalam S1, 14% potensi pengurangan dalam pelepasan GHG boleh dicapai. Pengurangan karbon boleh dipertingkatkan lagi dengan meningkatkan kapasiti pengkomposan SOW. Pelepasan bersih GHG untuk S1, S2, S3 dan S4, masing-masing adalah 1,399.52, 1,161.29, 857.70 dan 1,060.48 tCO_{2e}. Secara umum, sisa lencongan untuk pengkomposan terbukti bersih GHG mengurangkan pelepasan ketara secara signifikan seperti ditunjukkan dalam S3 (47%), S4 (35%) dan S2 (29%). Walaupun pelepasan adalah secara langsung disebabkan aktiviti di lokasi, penurunan ketara dalam penghasilan metana di tapak pelupusan sampah telah mengurangkan pelepasan bersih GHG. Sumber pelepasan setiap senario dikaji dan dianalisis.

Kata kunci: GHG; pengkomposan; pengurusan sisa; sisa dapur; sisa lapangan; SOW; universiti

INTRODUCTION

Waste sector which comprises of municipal solid waste (MSW) is deemed to be one of the major contributors of greenhouse gas (GHG) emission. Rapid urbanization and increase in population have caused the increment of GHG emission from waste disposal (Ngoc & Schnitzer 2009). In Peninsular Malaysia, the solid waste generated has increased from 16,200 tons per day in year 2001 to 19100 tons per day in year 2005 (Tarmudi et al. 2012). The waste generation is foreseen to reach 31000 tons of waste

generation per day by year 2020 (Manaf et al. 2009). The waste disposal in Malaysia has contributed to the national GHG emission of 18.64% and 11.83% in year 1994 and 2000, respectively (Chua et al. 2011). The significance volume of GHG emitted necessitates the need to control the GHG emission by waste reduction via alternative management strategy.

The amount of waste discarded and fraction of degradable organic waste would give impact on the generation of GHG. Studies by several researchers have found out that composting is a favourable mitigation option for GHG emissions in waste sector (Rogger et al. 2011). Composting would help in achieving carbon neutral condition while anaerobic digestion with energy production could achieve carbon negative condition, particularly in developing countries (Barton et al. 2008). In Africa, studies have shown that waste separation at source can reduce the carbon emission generated from municipal waste comprising averagely 56% of organic content (Couth & Trois 2010). Couth and Trois (2010) also discussed the strategies that have been carried out to promote emission reduction and mentioned that composting should have more carbon emission reductions and would generate more Clean Development Mechanism (CDM) income than landfill gas combustion with energy recovery. In China, biological recycling such as composting and anaerobic digestion was the most preferred technique applied to maximizing the material and energy recovery from organic waste (Zhang & Matsuto 2011). Furthermore, biological recycling of organic waste is widely applied due to their environmentally friendly techniques (Cadena et al. 2009).

In Malaysia, however, the GHG emissions reduction via composting of source separated organic waste (SOW) has not been assessed. There was a pilot project to turn SOW in municipal solid waste (MSW) into compost in Putrajaya, Malaysia. It was proven that recyling of SOW can directly reduce the amount of waste and lengthen the lifespan of landfill, but the potential of GHG emissions reduction was not accounted. The Ministry of Housing and Local Government (MHLG) has set the target to increase recycled waste from 5 to 20% by 2020. By increasing the recycling rate to 22% the GHG emission from waste sector can be reduced to 25.5% in year 2020 (Chua et al. 2011). However, the specific GHG emissions reduction from SOW recycling was not considered. Hence, assessment of GHG emissions reduction via composting of SOW is important as environmental impacts from waste management are waste-specific and local-specific.

Objective

The main objective of the present study was to investigate the carbon emission of MSW management in University of Malaya (UM). The hot spots for GHG emissions from the SOW management in the context of UM were identified. The study further evaluates the GHGs emissions reduction potential from diversion of SOW in MSW for compost production via aerobic fermentation process within the campus. The SOW refers to source-separated kitchen waste collected from canteens and source-separated yard waste collected by the UM landscape management team.

Study Area

This paper presented a real case study of MSW management in UM with high number of staff and students in the region and it is located in Kuala Lumpur, Malaysia. With student community over 32018, including over 3571 international students from over 100 different countries, the university has a global network alumni spanning of 78 countries (UM, 2011). It generated large volumes of waste from its residences, catering areas, laboratories, workshops and public area which has caused the management to spend over RM240000 per year on waste disposal. The MSW was collected on a daily basis and was disposed at a waste collection centre located inside the campus. The wastes were then transported out from campus and disposed at the nearest landfill.

Since September 2010, the SOW composting site has been in operation, located next to waste collection centre within UM. Before composting, the SOW were screened and shredded. Takakura composting method was applied where the kitchen waste was mixed with seed compost which was rich in effective microorganism (EM). The compost piles were turned everyday by the site operator to allow aerobic reaction to happen throughout 1-2 months before it became mature and stored. After that, the compost is ready to be used as soil conditioner.

METHODS

SYSTEM BOUNDARY AND EMISSION SOURCES OF THE STUDY

The system of the study started with the temporary storage of the MSW in UM and followed by SOW diversion process, waste treatment alternative (on-site composting), waste transportation and landfilling of waste. The scope of the study was clearly shown in Figure 1. Components outside the dash dotted lines were not in the boundaries of this study although they were recognized to have some impacts on the environment. The total number of trips from UM (with full waste cargo) made to disposal sites in year 2012 were summarized in Table 1. Waste generation in UM shows variation by month. MSW generation was relative higher during academic months (September-December and February-Jun). A total of 825 collection trips were recorded for MSW in 2012. The transportation factor of 1 ton of yard waste/trip and 1.5 ton of MSW/trip, respectively, were assumed for estimated waste generation in UM. The estimated weight of kitchen waste was 219 ton, taking into consideration that 40% of total MSW collected which was made up of kitchen waste. The functional unit selected for the study was the management of 1,007.5 ton MSW, comprising of 679 ton SOW (total of yard waste and

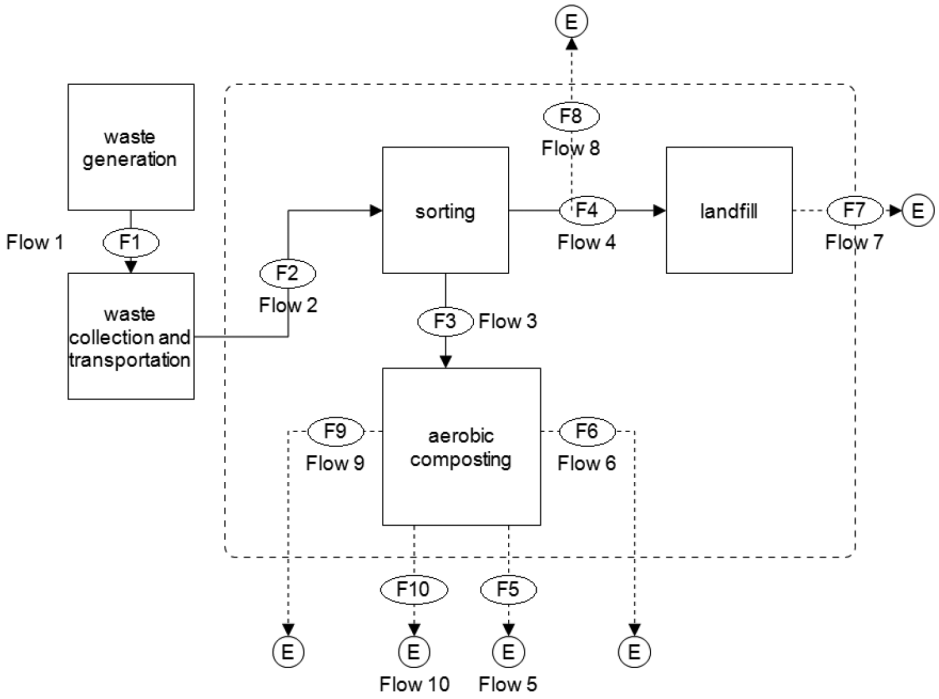

FIGURE 1. System boundaries of composting and landfilling project

TABLE 1. Number of UM waste collection by trip for disposal by external waste company in 2012

Month	Yard waste	Municipal waste	Total
January	31	22	53
February	32	26	58
March	31	31	62
April	36	24	60
May	42	20	62
Jun	38	35	73
July	63	20	83
August	41	9	50
September	51	48	99
October	36	61	97
November	20	25	45
December	39	44	83
Total by trip	460	365	825
Total by weight (ton)	460	547.5	1007.5

Source: (UM 2012)

kitchen waste) where the remaining was the mixed residual waste (UM 2012).

The boundary in this present case study was the site of the project activity where the SOW was recovered in UM and composted on-site. The project boundary included the facilities for composting, on-site electricity consumption, on-site fuel consumption, fuel consumption of waste transportation from UM to landfill, direct emission from composting process and direct emission from landfill. The emissions included in the study are summarized in Table 2.

The facilities for waste collection and transportation to the composting site were excluded from the study. The application of compost as soil conditioner for landscaping was excluded as well due to its insignificant amount in association to the replacement of chemical fertilizer. The summary of the methodology flow is shown in Figure 2.

SCENARIO SET-UP

It was assessed based on four scenario cases: S0 as the baseline scenario where all wastes were disposed at landfill; S1 where 22% of total waste generated (130 t/y kitchen waste and 130 t/y yard waste) was sorted and composted on-site; S2 where 35% of total waste (204 t/y kitchen waste and 204 t/y yard waste) was collected and composted on-

TABLE 2. Emissions included in the case study

Carbon emission (tCO_{2e})	Flow
Landfilling	Flow 7
Transportation	Flow 8
Composting site electricity consumption	Flow 5
Composting site fuel consumption	Flow 6
N_2O emission from composting	Flow 9
CH_4 emission from composting	Flow 10

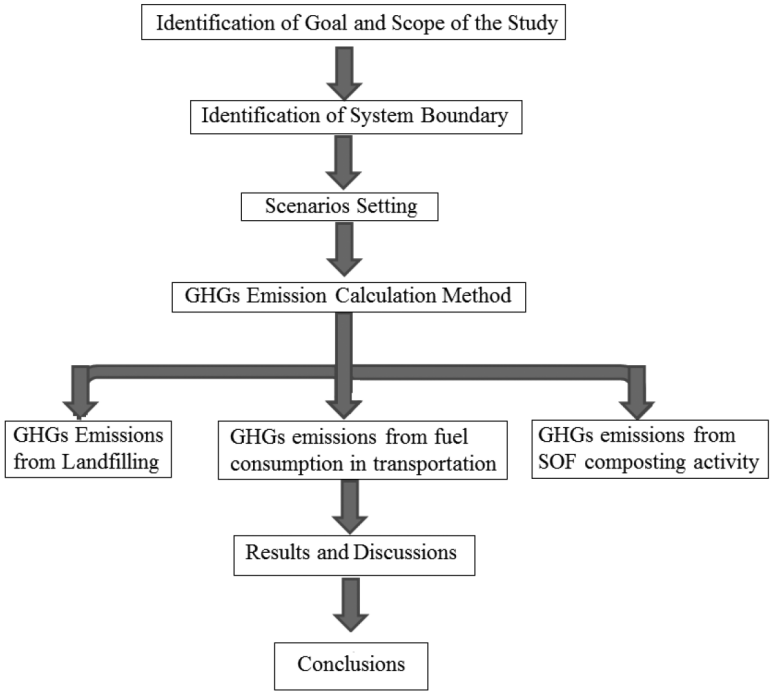

FIGURE 2. The flow of methods

site; S3 where 55% of total waste (204 t/y kitchen waste and 460 t/y yard waste) were collected and composted on-site and S4 where a total of 460 t/y of yard waste was collected and composted on-site while the rest was disposed of in landfill without energy recovery.

Scenarios were proposed in line with the national target to achieve recycling rate of 22% of total waste generated (as shown in S1). The diversion of SOW from MSW was expended gradually through S2 (35%) and S3 (55%). S4 considers the possible immediate diversion of yard waste alone due to its current availability of separated collection in UM campus. The summary of the scenario for alternative SOW management is shown in Table 3.

CARBON EMISSION CALCULATION METHOD

The methods used to analyze the GHG emission for this case study in UM are in accordance to CDM methodology AM0025 (UNFCCC 2008). The emission reduction was calculated from the deduction of baseline emissions and project emissions.

METHANE EMISSION FROM LANDFILL

A simple mass balance approach (default IPCC method) was used to estimate the total generation of methane gas from waste disposed in landfill. This method is suggested due to the intention to compare maximum GHG generation potential from different scenarios of kitchen waste and yard waste management. It does not reflect the generation of GHG over time, which is beyond the intention of the present paper. IPCC default method is based on (1). The method assumes that all the potential CH_4 emissions are released during the same year the waste is disposed of. The method is simple and emission calculations require only input of a limited set of parameters.

$$\mathrm{Me,y} = \left(\mathrm{MSWt} * \mathrm{MCF} * \mathrm{DOC} * \mathrm{DOCf} * \mathrm{F} * \left(\tfrac{16}{12}\right) - \mathrm{R}\right) * (1 - \mathrm{OX}), \quad (1)$$

where $Me_{.y}$ is the methane emission in year "y" (t/year); MSW_t is the total MSW disposed in year "y" (t/year); MCF is the methane correction factor (fraction); DOC is the

TABLE 3. Scenario setting for alternative SOW recovery in UM

	To composting center (flow 3)		To landfill (flow 4)		
	Separated yard waste	Separated kitchen waste	Separated yard waste	Separated kitchen waste	MSW
By weight (t/y)					
S0			460	219	329
S1 (22%)	110	110	350	109	329
S2 (45%)	219	219	241	-	329
S3 (65%)	460	219	-	-	329
S4 (45%)	460	-	-	219	329
By trips					
S0			460	36	329
S1 (22%)	110	18	350	18	329
S2 (40%)	219	36	241	-	329
S3 (55%)	460	36	-	-	329
S4 (40%)	460	-	-	36	329

Source: (UM 2012)

degradable organic carbon (fraction) (kg C/kg SW); DOC_f is the fraction DOC dissimilated; F is the fraction of CH_4 in landfill gas; 16/12 is the conversion of C to CH_4; R is the recovered CH_4 (t/year); and OX is the oxidation factor (fraction).

Electricity consumption was excluded in the assessment as there was no significant reduction of electricity consumption with the diversion of biomass out of landfill. Moreover, we assumed that no landfill gas was collected for flaring or power generation (F=0), thus emission from thermal energy generation was not included in the assessment as well. CO_2 emission from combustion or decomposition of biomass was not accounted as GHG emissions (IPCC 2006). The parameters with all the assumed values are shown in Table 4. The decay rate of the 'other' waste (residual waste) was based on the decay rate of paper and textiles in the Revised 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

TRANSPORTATION TO LANDFILL (FUEL CONSUMPTION)

The emission from fuel consumption in transportation of waste from UM to landfill is stated in (2). The total distance travelled per trip was 120 km and the fuel consumption per distance was 0.25 L/km (Zamri 2011). The methods approach estimated emissions from road transport based on total fuel consumption. The calorific value of diesel was assumed to be 13.495 MJ/kg (Raheman & Phadatare 2004). The emission factor of diesel was assumed to be 73.9E-06 tCO_2/MJ (Herold 2003) while the density of diesel was taken as 0.832 kg/litre (Alptekin & Canakci 2008)

$$FEfuel, y = N, i, y * D * VF * CV * \partial * EF, \quad (2)$$

where *FEfuel, y* is the total GHG emissions from fuel consumption in transportation in year "y" (tCO_2); N,i,y is the number of vehicles for transport with similar loading capacity, i in year "y"; D is the average distance travelled by vehicle type i in year "y"; VF is the vehicle fuel consumption in litres per kilometre of vehicle type i (L/km); CV is the Calorific value of fuel (MJ/kg); ∂ is the Density of fuel (kg/l); and EF is the Emission factor of fuel (tCO_2/MJ).

GHG EMISSIONS FROM SOW COMPOSTING ACTIVITY

The SOW composting emission within the project boundary in year "y" is shown in (3) which considered the emission of electricity consumption, fuel consumption, direct emission from composting process in term of N_2O and CH_4.

$$PE, y = PEelec, y + PEfuel, y + PEn20, y + PEch4, y, \quad (3)$$

where $PE_{, y}$ is the total composting emissions during the year "y" (tCO_2e); $PE_{elec, y}$ is the emissions off-site from the electricity consumption on-site in year "y" (tCO_2e); $PE_{fuel, y}$ is the emissions on-site due to fuel consumption in year "y" (tCO_2e); $PE_{n2o, y}$ is the emissions during the composting process due to N_2O production in year "y" (tCO_2e); and $PE_{ch4, y}$ is the emissions during the composting process due to CH_4 production through anaerobic conditions in year "y" (tCO_2e).

The emission from project electricity consumption and project fuel consumption in year "y" are shown in (4) and (5), respectively. The composting activity involved on-site electricity consumption which was connected to the national grid. The emission factor from electricity consumption was 0.672 tCO_2/MWh (Rahman Mohamed & Lee 2006). The yearly electricity consumption for UM composting site was 5564 kWh (UM 2012). The fuel consumption in the composting project was assumed as 4.63 L/ton of waste composted (UM 2011) whereas the net

TABLE 4. Parameters for carbon emission calculation and their values

Parameters	Kitchen waste	Yard waste	Residual waste
Φ	0.9	0.9	0.9
OX	0.1	0.1	0.1
F	0.54	0.54	0.54
DOC_f	0.5	0.5	0.5
MCF	1.0	1.0	1.0
DOC	0.15	0.20	0.4
GWP_{CH4}	21	21	21
GWP_{N20}	310	310	310

caloric value and the emission factor of diesel were 38.592 MJ/L and 7.42E-5 tCO_2/MJ, respectively (Furuholt 1995). The fuel (diesel) was only used to power the grinding machine for the production of finished compost.

$$PEelec, y = kWh, y * CEFelec, \quad (4)$$

where $kWh_{,y}$ is the amount of electricity used for the composting process, measured using an electricity meter (MWh); and CEF_{elec} is the carbon emissions factor for electricity (tCO_2/MWh).

$$PEfuel, y = M, y * Fc * NCV * EF, \quad (5)$$

where $M_{,y}$ is the total waste composted in year y (ton); Fc is the fuel consumption (L/ton); NCVis the net caloric value of the fuel (MJ/L); and EF is the CO_2 emissions factor of fuel (tCO_2/MJ).

The direct emissions of N_2O and CH_4 from composting activity are presented in (6) and (7), respectively. The emission factor for N_2O emissions from the composting process was taken as 4.3E-05 tN_2O/t compost produced (UNFCCC 2008) whereas the final weight of compost produced is assumed to be 30% of the initial weight of waste input. The emission factor for CH_4 from composting process was assumed as 0.0019 tCH_4/tOM of waste (Fukumoto et al. 2003). The emission factors for both N_2O and CH_4 from composting process were 310 tCO_2/tN_2O and 21 tCO_2/tCH_4 , respectively, by considering the time horizon of 100 years (UNFCCC 2008).

$$PEn20, y = Mcompost, y * EFn20 * GWPn20, \quad (6)$$

where $M_{compost,y}$ is the total quantity of compost produced in year y (ton); $EF_{,n2O}$ is the emission factor for N_2O emissions from the composting process (t N_2O/t compost); and GWP_{n2O} is the global warming potential of nitrous oxide (tCO_2/tN_2O).

$$PEch4 = EFch4 * GWPch4 * OM, y, \quad (7)$$

OM, y is the organic matter of the waste composted in year "y" (ton); $EF_{,ch4}$ is the emission factor for CH_4 emissions from the composting process (t CH_4/t OM); and GWP_{ch4} is the global warming potential of methane (tCO_2/tCH_4).

RESULTS AND DISCUSSION

The carbon equivalent emission of all scenarios was calculated. For the baseline emission, all MSW generated in UM was disposed at Bukit Tagar Sanitary Landfill, which was about 60 km from UM. Total distance of 120 km was taken into calculation by considering the return trip of the disposal transportation. The emissions for the baseline were basically the methane emission from landfill and the fuel consumption during transportation. For the project emission, the emission sources namely the on-site electricity consumption, the on-site fuel consumption and the N_2O and CH_4 emission from composting itself were identified. Several limitations such as the unknown or data that required further experiment in the analysis were overcome with sufficient references.

BASELINE EMISSION

The baseline emission was referred as the emission arise from disposal of all waste from UM to sanitary landfill, as well as the emission from transportation of waste to the landfill. In the baseline calculation, only CH_4 was included as the source of carbon emission. From the baseline scenario (S0), a total of 1,636.18 tCO_{2e} was generated of which 98% of the total emission was direct emission from landfill whereas the emission from transportation contributed 20.54 tCO_{2e}. Hence, the carbon emission for UM in waste management for studied period can be expressed as 1.623 tCO_{2e}/ton of waste disposed. The amount of methane gas that was released as GHG was determined and the carbon emission equivalent was calculated based on standard conversion. The second source of carbon emission was the transportation to landfill. The combustion of diesel fuel was included as the source of emission for transportation to disposal. The total carbon emission from transportation in Year 2011 is shown in Table 5.

EMISSIONS FROM SOW COMPOSTING ACTIVITY

In SOW composting activity, there were essentially four sources of carbon emissions: CO_2 from on-site electricity consumption, CO_2 from on-site fuel consumption and GHGs (N_2O and CH_4) emission from composting process. Besides, the carbon emission from the transportation of MSW from UM to landfill disposal was included in the analysis as the non-compostable MSW, is disposed of in

landfill despite the establishment of on-site composting project. For transportation, the calculation for project was similar with the baseline transportation calculation. For the on-site electricity and fuel (diesel) consumption, the data was obtained from the real consumption in UM composting center. The GHGs emission from composting was calculated based on references from several sources (Fukumoto et al. 2003; UNFCCC 2008).

Overall, the on-site composting project in UM exhibits total GHG emission reduction in waste management, as shown in the result presented in Figure 3. S3 shows highest net GHG emission reduction (47%), followed by S4 (35%), S2 (29%) and S1 (14%). Net GHG emission for each scenario is mainly contributed by the methane emission from landfills. Methane emission (in CO_2eq) from landfill is accounted for over 96% of total emission in waste management as shown in Table 3. This results were in accordance with literature (Chen & Lin 2008; Weitz et al. 2002) which has found out that, the net GHG emissions for a given material was the lowest for source reduction and the highest for landfilling. Hence, the authors wish to present the significance of the methane emission from landfill and thus promote diversion of compostable material from the waste stream. Generally, GHG emission from landfilling decreases with the amount of waste disposed S3 (829.08 tCO_{2e}) recorded the lowest carbon emission from landfill, followed by S4 (1,036.04 tCO_{2e}) and S2 (1,132.74 tCO_{2e}). S3 exhibits the lowest GHG emission in transportation fuels with the reduction of the number of hauling trips. It is interesting to bring the attention upon S4 and S2 in terms of transportation emission. Despite the equal weight of compostable material being composted, lower number of hauling trip is anticipated in S4 due to lower bulk density of yard waste as compared to kitchen waste.

The GHG emission from on-site electricity consumption was assumed to be the same for all scenarios as the static pile composting mechanism did not require electricity supply. The aeration of composting was done by manual turning. The GHG emission from on-site fuel consumption was based on the tonnage of organic waste composted. The fuel consumption included the diesel or petrol used for the shredding and chipping for yard waste and grinding of finished compost. The N_2O emission from composting was based on the production of finished compost. For yard waste the compost to feedstock ratio by weight was 0.3 while for kitchen waste was 0.15, based on the operation in UM campus. For CH_4 emission from composting, the emission factor of 0.0019 tCH_4 per ton of organic matter was used.

Conclusion

Waste sector has been associated with climate change and the environmental performance of waste management can be evaluated by its GHG emissions. Waste prevention was considered as one of the critical success factors in integrated solid waste management hierarchy. However, it often received less priority in term of SOW diversion and treatment. This paper presented the climate change benefits from waste prevention strategies through SOW composting

TABLE 5. The summary of carbon emission from different sources

Carbon emission (tCO_{2e})	S0	S1	S2	S3	S4
Landfilling (flow 7)	1,615.64	1,373.09	1,132.74	829.08	1036.04
Transportation (flow 8)	20.54	17.35	14.19	8.19	9.09
Composting site electricity consumption (flow 5)	-	3.74	3.74	3.74	3.74
Composting site fuel (diesel) consumption (flow 6)	-	2.92	5.81	9.00	6.10
N_2O emission from composting (flow 9)	-	0.88	1.75	2.71	1.84
CH_4 emission from composting (flow 10)	-	1.54	3.06	4.98	3.67
Total CO_2 emission	1,636.18	1,399.52	1,161.29	857.70	1,060.48

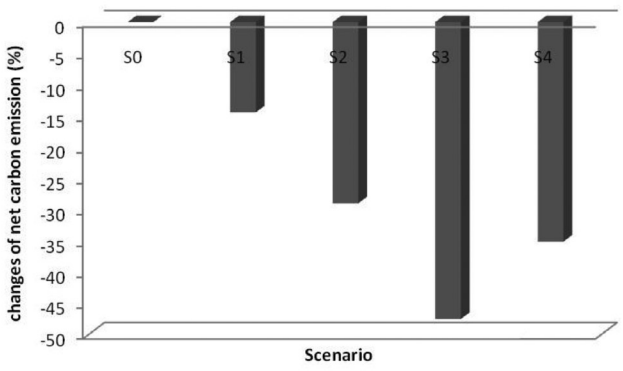

FIGURE 3. The net carbon reduction of each scenarios as compared to S0 by percentage

case study in UM, Malaysia. In conclusion, SOW diversion from disposal in UM created climate change benefits in term of net GHG emissions reduction derived from life cycle of waste management. The current carbon emission in association to waste management in UM is 1.623 tCO_{2e}/ ton of waste generated.

From the baseline scenario (S0), a potential of 1,636.18 tCO_{2e} was anticipated by UM waste generated in year 2012 of which 98% of the total emission was direct emission from landfill whereas the emission from transportation contributed 24.569 tCO_{2e}. The net GHG emission for S1, S2, S3 and S4 were 1,399.52, 1,161.29, 857.70 and 1,060.48 tCO_{2e}, respectively. In general, waste diversion for composting proved a significant net GHG emission reduction as shown in S3 (47%), S4 (35%) and S2 (29%). Despite the emission due to direct on-site activity, the significant reduction in methane generation at landfill has reduced the net GHG emission. The emission source of each scenario was studied and analysed. The study showed that landfill methane gas emission contributed to the largest share of emission among all scenarios. The second largest emission contributor was the emission from transportation of waste to disposal (1%~1.2%) followed by the emission diesel consumption in composting site (3~9%). Direct emission of N_2O and CH_4 from composting process is accounted for less than 5% of total GHG emissions in all scenarios.

Chua et al. (2011) advocates that GHG emission can be reduced by 25.5% from Malaysia waste by increasing the recycling rate to 22%. This is still less than the target committed by the Malaysian government, which is to reduce its GHG emission by 40% in year 2020. The current study supports an additional of 14% GHG emissions reduction including the recycling of SOW via composting by 22%. Higher Education Institutions in Malaysia thus play an important role in national GHG emissions reduction strategy, through on-site SOW composting activities. The present paper is significant in showcasing the possibility of GHG emission reduction through on-site SOW composting and thus contribute to future research in modeling GHG emission reduction from all higher educational institutions in Malaysia.

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