Assessment of GHG emission reduction potential from food and yard waste management

Higher Educational Institution in Malaysia.

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Abstract

Rapid urbanization and increase in population have always led to the increment of GHG (greenhouse gas) emission from waste. The amount of waste discarded and fraction of degradable organic carbon would give impact on the volume of GHG generated. Therefore, it is crucial to control the GHG emission by waste reduction. This paper presented a real case study of food waste and green waste management at an on-site biological aerobic composting site in University of Malaya (UM). The case study was conducted based on the yearly waste generation and waste composition of UM campus in year 2012. The storage and transfer of waste within the campus was studied. The main objective of the study was to compare and evaluate the carbon emission performance of aerobic composting and the landfilling of food waste and garden waste in UM. The study further analyzed the emission reduction of GHGs with different case scenarios which represented the diversion of biomass from MSW for on-site biological aerobic composting. The emission inventory was quantified for 5 different scenario: (1) S0 denotes the
current waste management where 100% waste are landfilled; (2) S1 denotes diversion of 110 ton food waste and 110 ton yard waste to be composted within UM campus; (3) S2 denotes diversion of 219 ton food waste and 219 ton of yard waste to be composted; (4) S3 denotes diversion of 219 ton food waste and 460 ton yard waste for composting and (5) S4 denotes a diversion of 460 yard waste for on-site composting. From the baseline scenario (S0), a potential of 1,636.18 tCO\(_2\)e 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\(_2\)e. The net GHG emission for S1, S2, S3 and S4 were 1,399.52 tCO\(_2\)e, 1,161.29 tCO\(_2\)e, 857.70 tCO\(_2\)e and 1,060.48 tCO\(_2\)e 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 analyzed. 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\(_2\)O and CH\(_4\) from composting process is accounted for less than 5% of total carbon emission in all scenarios.

**Keywords:** GHG; food waste; yard waste; higher educational institute; waste management

**1.0 INTRODUCTION**
Waste sector which comprises of municipal solid waste (MSW) is deemed to be one of the major contributors of Greenhouse Gas (GHG) emission. The increasing amount of solid waste generated each year in many countries has raised concerns about the economic viability and environmental acceptability of the current waste-disposal approaches (Daskalopoulos, Badr, & Probert, 1998). Rapid urbanization and increase in population have caused the increment of GHG emission from waste (IPCC, 2007). In West Malaysia, the solid waste generated has increased from 16,200 tons per day in year 2001 to 19,100 tons per day in year 2005 (Tarmudi, Zamali and Abdullah, Mohd Lazim and Md. Tap, & Osman, 2009). This type of trend is foreseen to reach 31,000 tons of waste generation per day by year 2020 (Manaf, Samah, & Zukki, 2009). The waste sector has contributed to the GHG emission of 18.64% and 11.83% in year 1994 and 2000 respectively (Chua K.H., Endang Jati & Leong Y.P., 2011). The significance volume of GHG emitted necessitates the need to control the GHG emission by waste reduction. In Malaysia, waste has been discarded solely to landfill instead of being recycled every year (Omran, Mahmood, Abdul Aziz, & Robinson, 2009). In order to reduce the amount of waste produced, many recycling activities have been carried out throughout Malaysia. 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 by 25.5% in year 2020 (K.H. Chua, Endang Jati Mat Sahid, & Y. P. Leong, 2011). Besides, Prime Minister of Malaysia has also announced to cut down 40% of carbon dioxide (CO₂) by the year 2020 as compared to the year 2005 levels subject to assistance from developed countries (Bernama, 2009).
In view of the situation discussed earlier, it is particularly important to decrease the GHG emission before the GHG further contribute towards the climate change, which has raised the public concern over the years. The amount of waste discarded and fraction of degradable organic carbon would give impact on the generation of GHG, particularly methane gas (Barton, Issaias, & Stentiford, 2008). In line with the target set by the MHLG, a waste separation at site project has been initiated at Putrajaya in 2009 (Geetha Krishnan, 2009). The pilot project was aimed to lengthen the lifespan of landfill and at the same time turn organic waste into compost (Ali, 2009). It was proven that waste segregation can directly reduce 80% of the amount of waste to be incinerated for healthcare waste and further reduce emission factor of gaseous emission (Alvim-Ferraz & Afonso, 2005).

In order to reduce the GHG emission in developing countries, composting is a favorable mitigation option for waste sector (Rogger, Beaurain, & Schmidt, 2011). Study by past researchers has found out that composting unit with frequent mixing would have higher emission factor in terms of GHG (Andersen, Boldrin, Christensen, & Scheutz, 2010). According to Barton et al (2008), composting would help in achieving carbon neutral condition while anaerobic digestion with energy production could achieve carbon negative condition, particularly in developing countries. In Africa, studies have revealed 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 recycling and composting should have more carbon emission reductions and would generate more CDM income than landfill gas combustion with energy recovery. 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, 2010). Furthermore, composting and anaerobic digestion are widely applied due to their environmentally friendly techniques (Cadena, Colón, Sánchez, Font, & Artola, 2009).

The main objective of the present study was to compare and evaluate the carbon emission performance of aerobic composting and the landfilling of food waste and garden waste in UM with the baseline scenario (direct landfilling of food waste and garden waste). The study further analyzed the emission reduction of GHGs (Greenhouse Gases) with different case scenarios which represented the diversion of biomass from MSW for on-site biological aerobic composting.

2.0 STUDY AREA

This paper presented a real case study of food waste and green waste management in University of Malaya (UM). UM has high number of staff and students in the region, and it is located in Kuala Lumpur, Malaysia. With student community over 32,018, including over 3,571 international students from over 100 different countries, the university has a global network alumni spanning 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 RM 240,000 per year on waste disposal. The generation of waste (number of trips) from UM in year 2011 was obtained from UM. 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. Garden waste and food waste generation were calculated based on the waste composition study in UM by Sharifuddin (2006). The residual waste generation was obtained by subtracting food waste and garden waste out from the total waste generated in UM. The total generation by weight for specific waste was calculated by assuming the transportation factor of 1 ton of garden waste/trip, 6 ton of food waste/trip and 1 ton of MSW/trip respectively. Waste Characterization study has revealed that compostable food waste contributes 40% by weight of the total MSW generated in UM. Hence, the annual generation of food waste, yard waste and landfilled waste are presented in Table 1.

Table 1: Generation of MSW from UM in year 2012

<table>
<thead>
<tr>
<th></th>
<th>To composting center</th>
<th>To landfill</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(flow 3)</td>
<td>(flow 4)</td>
</tr>
<tr>
<td>Separated yard</td>
<td>Separated food waste</td>
<td>Separated yard waste</td>
</tr>
<tr>
<td>waste</td>
<td></td>
<td>Separated food waste</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSW</td>
</tr>
<tr>
<td>By weight (t/y)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S0</td>
<td>460</td>
<td>219</td>
</tr>
<tr>
<td>S1 (22%)</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>S2 (45%)</td>
<td>219</td>
<td>219</td>
</tr>
<tr>
<td>S3 (65%)</td>
<td>460</td>
<td>-</td>
</tr>
<tr>
<td>S4 (45%)</td>
<td>460</td>
<td>219</td>
</tr>
</tbody>
</table>
Since September 2010, the first organic food waste composting site has been set up in the UM. The total land area of composting site was 72 m², which was located nearby Damansara Gate University of Malaya, Mukim Kuala Lumpur Wilayah Persekutuan Kuala Lumpur. Waste separation at source was the most crucial step in making this project a success. Before composting, the food waste were screened and shredded. Takakura composting method was applied where the food 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. The total waste volume generated in UM can be reduced through the implementation of this composting project in line with the enforcement of segregation of household waste in 2013 and the implementation of Solid Waste Management and Public Cleansing Act 2007 (Act 672)(Tamrin 2010).
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 compostable material from MSW namely food waste and yard waste was expended 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.

3.0 METHODOLOGY

The study presented a real case study of the food waste and yard waste management system in University of Malaya (UM). The waste generation in UM campus was determined and the types of waste to be analyzed are identified. The storage and transfer of waste within the campus was studied and documented in the paper.

3.1 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 waste diversion process, waste treatment alternative (on-site composting), waste transportation and landfilling of waste. The scope of the study is clearly illustrated in the conceptual map below (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 functional unit selected for the study was the management of total MSW generated in year 2012.
The boundary in this present case study was the site of the project activity where the biomass waste was recovered in UM and composted on-site. The project boundary included the facilities for composting the biomass, 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.

Table 2: Emissions included in the case study

<table>
<thead>
<tr>
<th>Carbon emission (tCO$_2$e)</th>
<th>Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfilling</td>
<td>Flow 7</td>
</tr>
<tr>
<td>Transportation</td>
<td>Flow 8</td>
</tr>
<tr>
<td>Composting site electricity consumption</td>
<td>Flow 5</td>
</tr>
<tr>
<td>Composting site fuel consumption</td>
<td>Flow 6</td>
</tr>
<tr>
<td>N$_2$O emission from composting</td>
<td>Flow 9</td>
</tr>
<tr>
<td>CH$_4$ emission from composting</td>
<td>Flow 10</td>
</tr>
</tbody>
</table>

The facilities for waste collection, sorting and transport 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.
3.2 Carbon Emission Calculation Method

The methodologies used to analyze the GHG emission for this case study in UM are accordance to CDM methodology AM0025, the emission reduction was calculated from the deduction of baseline emissions and project emissions. It was assessed based on four cases: S0 as the baseline scenario where all wastes were disposed at landfill; S1 where 22% of total waste generated (130 t/y food waste and 130 t/y yard waste) was sorted and composted on-site; S2 where 35% of total waste (204 t/y food waste and 204 t/y yard waste) was collected and composted on-site; S3 where 55% of total waste (204 t/y food 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.

### 3.2.1 Baseline Emission

The baseline scenario represented the disposal of the MSW in a landfill site without capturing landfill gas. The electricity was obtained from an existing fossil based power plant. The baseline emission in year “y”, BE$_y$, as in Eq (1) considers only the direct emission from landfill and the emission due to transportation of waste from UM to landfill.

$$\text{BE}_y = (\text{MB}_y - \text{MD}_{\text{reg},y}) \times \text{GWP}_{\text{CH4}} + \text{FE}_{\text{fuel},y} \quad \text{Eq (1)}$$

- MB$_y$ : Methane produced in the landfill in the absence of the project activity in year y (tCH$_4$)
- MD$_{\text{reg},y}$ : Methane that would be destroyed in the absence of the project activity in year y (tCH$_4$)
- GWP$_{\text{CH4}}$ : Global Warming Potential of methane (tCO$_2$/tCH$_4$)
- FE$_{\text{fuel},y}$ : Emission from fuel consumption in transportation of waste from UM to landfill in the absence of project

An accurate determination of methane produced from landfilled MSW required extensive studies showing the gas variation over long time interval or a simulation model calibrated for the specific conditions. However, in this present study, 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 food 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 the main Eqn (2). The method assumes that all the potential CH₄
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.

\[ M_e = \left[ (MSW_t)(MCF)(DOC)(DOC_f)(F)(16/12)-R \right](1-OX) \]  
\[ \text{Eq (2)} \]

\( M_e \): methane emission (t/year)

\( MSW_t \): total MSW disposed (t/year)

\( MCF \): methane correction factor (fraction)

\( DOC \): degradable organic carbon (fraction) (kg C/kg SW)

\( DOC_f \): fraction DOC dissimilated

\( F \): fraction of CH₄ in landfill gas

\( 16/12 \): conversion of C to CH₄

\( R \): recovered CH₄ (t/year)

\( OX \): oxidation factor (fraction)

It is assumed that there was no destruction of methane at the landfill site and hence MD_{reg.y} was
considered to be zero. 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. CO₂
emission from combustion or decomposition of biomass was not accounted as GHG emissions (UNFCCC 2011). The parameters with all the assumed values are shown in Table 3. The decay rate of the “other” waste (residual waste) was based on the decay rate of paper and textiles in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Food waste</th>
<th>Green waste</th>
<th>Residual waste</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Phi$</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>(IPCC 2006)</td>
</tr>
<tr>
<td>$OX$</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>(IPCC 2006)</td>
</tr>
<tr>
<td>$F$</td>
<td>0.54</td>
<td>0.54</td>
<td>0.54</td>
<td>(IPCC 2006)</td>
</tr>
<tr>
<td>$DOC_f$</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>(IPCC 2006)</td>
</tr>
<tr>
<td>$MCF$</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>(IPCC 2006)</td>
</tr>
<tr>
<td>$DOC$</td>
<td>0.15</td>
<td>0.20</td>
<td>0.4</td>
<td>(IPCC 2006)</td>
</tr>
<tr>
<td>$GWP_{CH4}$</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>(IPCC 2006)</td>
</tr>
<tr>
<td>$GWP_{N2O}$</td>
<td>310</td>
<td>310</td>
<td>310</td>
<td>(IPCC 2006)</td>
</tr>
</tbody>
</table>

The emission from fuel consumption in transportation of waste from UM to landfill is expressed in Eq (3). The total distance travelled per trip was 120 km and the fuel consumption per distance was 0.25 litre/km (SWD 2011). The methodological approach estimated emissions from road transport based on total fuel consumption. The calorific value of diesel was assumed to be 13.495 MJ/kg (Waldron C.D. 2006). 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 (European Commission 2007).
\[ \text{FE}_{\text{fuel}, y} = N_{\text{vehicles}, i, y} \times \text{km}_{i,y} \times \text{VF}_{\text{cons},I} \times \text{CV}_{\text{fuel}} \times \text{D}_{\text{fuel}} \times \text{EF}_{\text{fuel}} \quad \text{Eq (3)} \]

\text{NO}_{\text{vehicles}, i, y} : \text{Number of vehicles for transport with similar loading capacity}

\text{km}_{i,y} : \text{Average additional distance travelled by vehicle type I compared to baseline in year “y”}

\text{VF}_{\text{cons}} : \text{Vehicle fuel consumption in litres per kilometre of vehicle type I (l/km)}

\text{CV}_{\text{fuel}} : \text{Calorific value of fuel (MJ/kg)}

\text{D}_{\text{fuel}} : \text{Density of fuel (kg/l)}

\text{EF}_{\text{fuel}} : \text{Emission factor of fuel (tCO}_2\text{/MJ)}

### 3.2.2 Project emissions

The project emission within the project boundary in year \(y\) is expressed in Equation (4) which considered the emission of project electricity consumption, project fuel consumption, direct emission from composting process in term of N\(_2\)O and CH\(_4\), emission of CH\(_4\) from landfill with the presence of the project, and the emission from waste transportation from UM to landfill with the presence of the composting project.

\[ \text{PE}_y = \text{PE}_{\text{elec, } y} + \text{PE}_{\text{fuel, } y} + \text{PE}_{\text{c, N20, } y} + \text{PE}_{\text{c, CH4, } y} + \text{ME}_y + \text{FEP}_{\text{fuel, } y} \quad \text{Eq (4)} \]

\text{PE}_y : \text{Project emissions during the year } y \ (\text{tCO}_2\text{e})

\text{PE}_{\text{elec, } y} : \text{Emissions off-site from the electricity consumption on-site in year } y \ (\text{tCO}_2\text{e})
PE_{fuel, y} : Emissions on-site due to fuel consumption in year y (tCO_{2e})

PE_{c, N2O, y} : Emissions during the composting process due to N_{2}O production in year y (tCO_{2e})

PE_{c, CH4, y} : Emissions during the composting process due to CH_{4} production through anaerobic conditions in year y (tCO_{2e})

ME_{y} : Methane produced in the landfill in the presence of the project activity in year y (tCH_{4})

FEP_{fuel, y} : Emission from fuel consumption in transportation of waste from UM to landfill in the presence of project

The emission from project electricity consumption and project fuel consumption in year y are expressed in Equation (5) and Equation (6) 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 (Malaysia Energy Centre 2008). The yearly electricity consumption for UM composting site was 5564 kWh (Zero Trash Campaign 2012). The fuel consumption in the composting project was assumed as 4.63 litre/ton of waste composted (Zero Trash Campaign 2012) whereas the net caloric value and the emission factor of diesel were 38.592 MJ/litre and 7.42E-5 tCO_{2}/MJ respectively (Furuholt E. 1995). The fuel (diesel) was only used to power the grinding machine for the production of finished compost.

\[ PE_{elec, y} = kWh_{ey} \times CEF_{elec} \quad \text{Eq (5)} \]
kWh\textsubscript{e,y} : Amount of electricity used for the composting process, measured using an electricity meter (MWh)

CEF\textsubscript{elec} : The carbon emissions factor for electricity (tCO2/MWh)

\[ PE_{\text{fuel}, y} = M\_y \times F_{\text{cons}, y} \times NCV\_\text{fuel} \times EF\_\text{fuel} \quad \text{Eq (6)} \]

\( M\_y \): Total waste composted in year \( y \) (ton)

\( F_{\text{cons}} \): Fuel consumption (l/ton)

\( NCV\_\text{fuel} \): Net caloric value of the fuel (MJ/l)

\( EF\_\text{fuel} \): CO\textsubscript{2} emissions factor of fuel (tCO2/MJ)

The direct emissions of N\textsubscript{2}O and CH\textsubscript{4} from composting activity are presented in Equation (7) and Equation (8) respectively. The emission factor for N\textsubscript{2}O emissions from composting process was taken as 4.3E-05 tN\textsubscript{2}O/t compost produced (UNFCCC 2011) whereas the final weight of compost produced is assumed to be 30% of the initial weight of waste input. The emission factor for CH\textsubscript{4} from composting process was assumed as 0.0019 tCH\textsubscript{4}/tOM of waste (Fukumoto Y. 2003). The emission factors for both N\textsubscript{2}O and CH\textsubscript{4} from composting process were 310 tCO\textsubscript{2}/tN\textsubscript{2}O and 21 tCO\textsubscript{2}/tCH\textsubscript{4} by considering time horizon of 100 years (UNFCCC 1995).

\[ PE_{\text{c,N2O}, y} = M_{\text{compost, y}} \times EF\_\text{c, N2O} \times GWP\_\text{N2O} \quad \text{Eq (7)} \]

\( M_{\text{compost, y}} \): Total quantity of compost produced in year \( y \) (ton)
EF$_{c,N2O}$ : Emission factor for N$_2$O emissions from the composting process (t N$_2$O/t compost)

GWP$_{N2O}$ : Global Warming Potential of nitrous oxide (tCO$_2$/tN$_2$O)

$\text{PE}_{c,CH4} = \text{EF}_{c,CH4} \times \text{GWP}_{CH4} \times \text{OM}$  Eq (8)

OM : Organic matter of the waste composted in year y (ton)

EF$_{c,CH4}$ : Emission factor for CH$_4$ emissions from the composting process (t CH$_4$/t OM)

GWP$_{CH4}$ : Global Warming Potential of methane (tCO$_2$/tCH$_4$)

3.2.3 Emission reduction

In order to calculate the emission reductions of the project activity, baseline emissions is expressed in Eq (1) and project emissions is expressed in Eq (4) were determined. The subtraction of baseline emissions from project emissions is the emission reductions in Eq (9).

$\text{ER}_y = \text{BE}_y - \text{PE}_y$  Eq (9)

BE$_y$: emissions in the baseline scenario in year y (tCO$_2$)

PE$_y$: emissions in the project scenario in year y (tCO$_2$)
4. Result and Discussion

The carbon emission of baseline emission and project emission of all the three scenarios were calculated. For the baseline emission, all the MSW generated in UM was disposed at Bukit Tagar Sanitary Landfill, which was about 60km from UM. Total distance of 120km 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 N₂O and CH₄ 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.

4.1 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 CH₄ was included as the source of carbon emission. From the baseline scenario (S0), a total of 1,636.18 tCO₂e was generated of which 98% of the total emission was direct emission from landfill whereas the emission from transportation contributed 20.54 tCO₂e. Hence, the carbon emission for UM in waste management for studied period can be expressed as 1.623 tCO₂e/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 (Table 3). The second source of carbon emission was the transportation to landfill. The
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 4.

Table 4: The summary of carbon emission from different sources

<table>
<thead>
<tr>
<th>Carbon emission (tCO$_2$e)</th>
<th>S0</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfilling (flow 7)</td>
<td>1,615.64</td>
<td>1,373.09</td>
<td>1,132.74</td>
<td>829.08</td>
<td>1036.04</td>
</tr>
<tr>
<td>Transportation (flow 8)</td>
<td>20.54</td>
<td>17.35</td>
<td>14.19</td>
<td>8.19</td>
<td>9.09</td>
</tr>
<tr>
<td>Composting site electricity consumption (flow 5)</td>
<td>-</td>
<td>3.74</td>
<td>3.74</td>
<td>3.74</td>
<td>3.74</td>
</tr>
<tr>
<td>Composting site fuel (diesel) consumption (flow 6)</td>
<td>-</td>
<td>2.92</td>
<td>5.81</td>
<td>9.00</td>
<td>6.10</td>
</tr>
<tr>
<td>N$_2$O emission from composting (flow 9)</td>
<td>-</td>
<td>0.88</td>
<td>1.75</td>
<td>2.71</td>
<td>1.84</td>
</tr>
<tr>
<td>CH$_4$ emission from composting (flow 10)</td>
<td>-</td>
<td>1.54</td>
<td>3.06</td>
<td>4.98</td>
<td>3.67</td>
</tr>
<tr>
<td>Total CO$_2$ emission</td>
<td>1,636.18</td>
<td>1,399.52</td>
<td>1,161.29</td>
<td>857.70</td>
<td>1,060.48</td>
</tr>
</tbody>
</table>
Figure 2: The net carbon reduction of each scenarios as compared to S0 by percentage

4.2 Project emission

In project emission, 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$_2$O and CH$_4$) emission from composting process. Besides, the carbon emission from 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 Y. 2003; UNFCCC, 2011).
In overall, on-site composting project in UM exhibits total carbon emission reduction in waste management, as shown in the result presented in Figure 2. S3 shows highest net carbon emission reduction (47%), followed by S4 (35%), S2 (29%) and S1 (14%). Net carbon emission for each scenario is mainly contributed by the methane emission from landfills. Methane emission from landfill is accounted for over 96% of total emission in waste management as shown in Table 3. This results were in accordance with (USEPA 2006) 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, carbon emission from landfilling decreases with the amount of waste disposed of. S3 (829.08 tCO$_2$e) recorded the lowest carbon emission from landfill, followed by S4 (1,036.04 tCO$_2$e) and S2 (1,132.74 tCO$_2$e). S3 exhibits the lowest carbon 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 term 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 food waste.

The carbon 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 carbon 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 green waste and grinding of finished compost. The N$_2$O emission from composting was based on the production of finished compost. For green
waste the compost to feedstock ratio by weight was 0.3 while for food 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.

**5.0 Conclusion**

Waste sector has been associated with climate change and the environmental performance of SWM can be evaluated by its carbon 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 resource allocation. This paper presented the climate change benefits from waste prevention strategies through case study in UM, Malaysia. In conclusion, waste 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$_2$e/ton of waste generated.

From the baseline scenario (S0), a potential of 1,636.18 tCO$_2$e 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$_2$e. The net GHG emission for S1, S2, S3 and S4 were 1,399.52 tCO$_2$e, 1,161.29 tCO$_2$e, 857.70 tCO$_2$e and 1,060.48 tCO$_2$e 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 analyzed. 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 N₂O and CH₄ from composting process is accounted for less than 5% of total carbon emission in all scenarios.

The study presents the case study for potential carbon reduction via composting of food waste and yard waste in UM. In conjunction with target of 22% recycling rate, as shown in S1, 14% reduction in potential carbon emission can be achieved. The carbon reduction can be further enhanced by increasing the food waste and yard waste composting capacity. In this study, a series of methodologies were used to evaluate the carbon emission of different food and yard waste management scenarios. After careful screening, IPCC default method (simple mass balance approach) was selected to quantify the maximum potential carbon emission from landfill. Methane is assumed to be emitted in the year of disposal, which is accordance to the functional unit of the present study (waste generated in year 2012). In this comprehensive case study, the methods were applied to rank five different waste management scenarios. The methods serve well as decision support instruments in waste management.

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Reference


