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Mitigation of Greenhouse Gases Emission through Food Waste Composting and Replacement of Chemical Fertiliser

Jin Hong Wong[a], Chin Siong Ho[b],Nur Naha Abu Mansor[c], Chew Tin Lee[*a,b],

[a]Department of Bioprocess & Polymer Engineering, Faculty of Chemical & Energy Engineering, Universiti Teknologi Malaysia (UTM) Johor Bahru, 81310 Johor, Malaysia.
[b]Low Carbon Asia Research Center, Room 317, Block B-11, Faculty of Built Environment, Universiti Teknologi Malaysia (UTM) Johor Bahru, 81310 UTM Johor, Johor, Malaysia.
[c]Faculty of Management, Universiti Teknologi Malaysia (UTM) Johor Bahru, 81310 Johor, Malaysia.

ctlee@utm.my

A pilot scale composting plant has been established on-campus in Universiti Teknologi Malaysia (UTM) to achieve the goal as a sustainable campus. Portion of organic wastes were diverted from landfilling by converting it into compost (organic fertiliser) for reducing greenhouse gases (GHG) emission at the landfill and the dependency on inorganic fertiliser. Composting has been reported as a sustainable approach to reduce the footprint of GHG as compared to the waste disposal through landfilling. However, the amount of GHG emitted during composting can vary due to localised condition. The aim of this study was to assess the potential of composting in mitigating GHG emission compared to the current waste management employed in UTM (Landfilling). A business as usual (BAU) scenario represents the current organic waste management practice in UTM was established. Composting was proposed as an alternative scenario. The amount of GHG emitted or reduced from different sources including for transportation, waste processing, waste treatment as well as downstream activities such as carbon sequestration and inorganic fertiliser substitution was estimated based on lifecycle inventory analysis. The result indicated that composting scenario offer a GHG reduction of 66.72 % as compared to the BAU scenario. The fugitive emission from biodegradation of organic waste contributed significantly to the GHG emission for both scenarios whereas the GHG emission from the fossil fuel combustion was considered as not significant. The overall result suggested the potential of composting as a viable technology for sustainable organic waste management in UTM.

1. Introduction

The annual waste generation in Malaysia has exceeded 11 Mt but merely 5 % of wastes were being recycled whereby the remaining wastes were disposed to landfill (Agamuthu and Fauziah, 2011). This indicates a large room for improvement. Landfilling could minimises the opportunity for resources recovery, increase the contamination potential to soil and water source and serves as the largest source of greenhouse gases (GHG) in the waste sector. The selection of a new location for landfill construction also becomes more difficult as the demand of land was increased. Waste diversion strategies should be implemented to minimise the waste going into the landfill thereby lengthen the lifespan of the existing landfill site. Composting is a preferable option for Malaysia because solid wastes in Malaysia were characterised by high amount of putrescible waste and high moisture content (Wu et al., 2014).

To enhance the formation of ecological sound society, higher education institutes play crucial role to educate the young generation about the necessity of protecting environment and serve as a model for the society. A prototype of pilot scale food waste composting plant has been established in Universiti Teknologi Malaysia (UTM) to divert a portion of organic wastes from landfilling and reduce the dependency on chemical fertiliser through the utilisation of compost (end product of composting).The aim of this study was to evaluate the potential of GHG emission and reduction from composting scenario as compared to the current waste management practice (landfill) through GHG inventory analysis. This study focuses on global warming potential because GHG

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emission is one of the biggest environmental issues. The positive impact of organic waste composting in terms of the environmental perspective remains a topic of discussion notably regarding the carbon footprint as the amount of GHG emitted during composting might vary due to localised condition.

2. Methodology

The GHG inventory analysis was conducted by referring to the framework of lifecycle assessment (LCA) standardised by ISO 14040 (ISO, 2006) and other literature related to GHG inventory of waste management practice. Partial steps of the official LCA procedure, namely the goal and scope definition and the inventory analysis, were applied but the impact assessment was excluded due to the limited resource. The calculation was expressed in terms of kg CO_2-eq. and based on a timeframe of 100 y.

2.1 Goal and scope definition

The goal of this GHG inventory analysis was to evaluate the potential of GHG emission from the existing organic waste management practice and the suggested alternative (composting) for UTM campus. The functional unit for this GHG inventory analysis was 1 t of treated organic wastes, which includes 0.3 t of food waste and 0.7 t of green waste (dry leaves and the woodchip). The system boundaries include waste collection, transportation, waste treatment and disposal as well as land application of end product. All of the upstream activities such as production of materials would be excluded (zero burden assumption). Within system boundary, key assumptions and limitations applied in this study included: (1) CO_2, N_2O and CH_4 as major GHG; (2) GHG emission from all the upstream activities such as the provision of fossil fuel, provision of electricity, production of construction materials were excluded; (3) assuming the organic waste treated in both scenarios was 4.8 t food waste and 11.2 t green waste per month; (4) the biogenic CO_2 emitted during the degradation of organic waste was considered as neutral and excluded (IPCC, 2006); (5) the emission from water treatment was excluded; (6) the N_2O emission from the landfill was excluded since it was assumed as insignificant in the overall process (IPCC, 2006); (7) only the fossil CO_2 emission was considered from the fuel consumption, the CH_4 and N_2O only comprise 1 – 2 % of the overall GHG emission and were excluded (Kong et al., 2012); (8) assuming that all compost produced was safe to replace inorganic fertiliser.

2.1.1 Scenario description

Figure 1 shows the overall process flow of waste management in the business as usual (BAU) scenario within the boundary of the system (dash line).

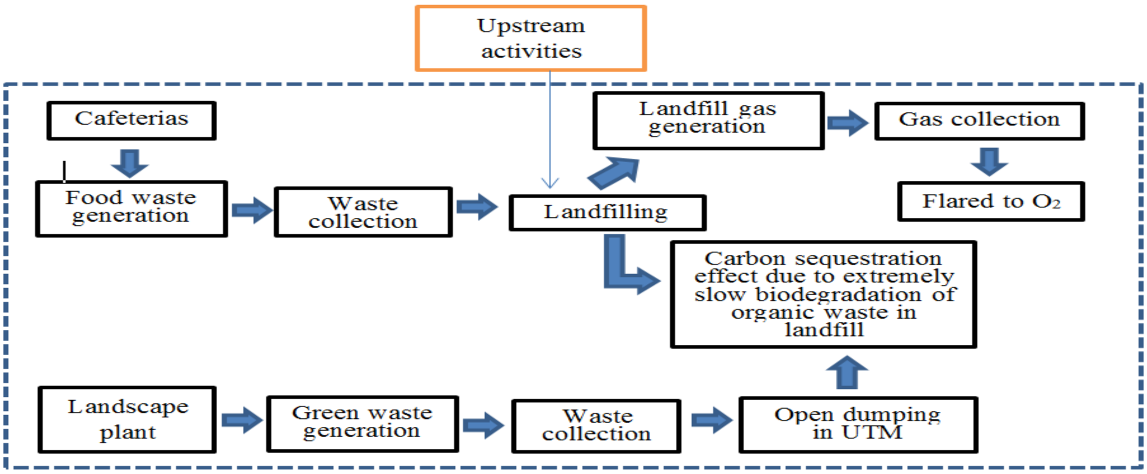

Figure 1: System boundaries for BAU scenario representing the current organic waste management in UTM.

BAU represents the existing organic waste management in UTM. Under BAU, food and mixed wastes in campus were collected by waste management company twice a week and travel 24.5 km to the Seelong sanitary landfill (Johor, Malaysia) for final waste disposal. Seelong landfill was proper waste disposal site with landfill gas recovery system, gas pumping and treatment system and has been involved in the clean development mechanism (CDM) project since year 2007. The green waste was collected by the contractor and open dumped in the campus. The distance travelled for each trip was approximately 6.4 km for the dry leaves and 1.7 km for the wood chip. Contractor travel 5 trips for dry leaves and 7 trips for woodchip for each month. In this scenario, fossil fuel combustion from different kind of machinery and anaerobic biodegradation of buried organic wastes in both landfill and open dumpsite were major sources of GHG emission. In contrast, landfill gas recovery and gas treatment in Seelong sanitary landfill was served as source of GHG avoidance. Landfill gas recovered was treated by flare and information about gas collection efficiency and flare efficiency as well as landfill condition were referring to CDM monitoring report (CDM, 2012). Carbon sequestration effect in landfill also important because contribute significantly in GHG avoidance (Kong et al., 2012). The main concept was due to existing of portion of organic wastes occupied in region that unfavourable for biodegradation. As long as these portion organic wastes in landfill cell were not exposed to favourable condition for microbial activities, it would remain intact and excluded from carbon cycle. Organic carbon that was not degraded nor leached in the form of leachate for 100 y could consider as carbon sequestrated.

Scenario 2 represents the composting scenario where the organic wastes were treated in the pilot scale composting plant as shown in Figure 2. Both food waste and green waste were collected and transferred to the composting plant with distance travelled, 7.9 km and 4.8 km (3.1 km for dry leaves and 1.7 km for wood chips), respectively. The overall composting process was conducted in an open environment with compost turning manually once a week. The plant currently processes 4.2 t food waste and 11.2 t green waste (4.48 t dry leaves and 6.72 t of wood chip) per month. In this scenario, GHG could emit from fossil fuel combustion when wastes/compost transportation and waste processing in composting site, during composting process and after compost applied to land. In term of GHG avoidance, stable organic carbon in compost that would not degraded or degraded extremely slow for 100 y could serve as carbon sequestrated. Application of high quality compost with sufficient fertilising capacity could displace certain amount of inorganic fertiliser, which avoids GHG emission from inorganic fertiliser production process.

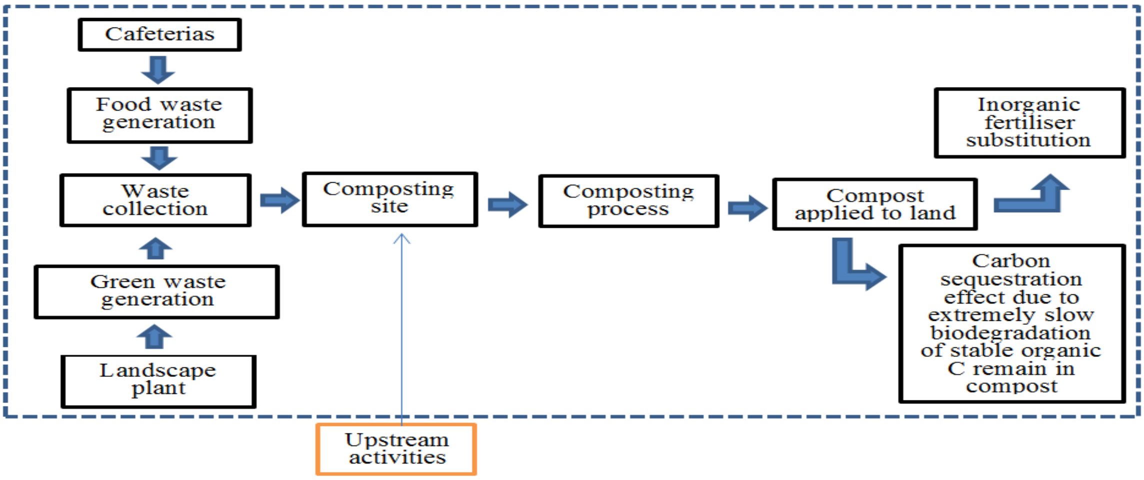

Figure 2: System boundaries for composting scenario representing as alternative to manage organic waste in UTM.

The characteristics of the initial and final compost were listed in Table 1. The elemental analysis (C/N ratio) was conducted using the CHNS elemental analyser (vario MICRO cube, Elementar, Germany) while the total phosphorus (P) and potassium (K) content were analysed using the Spectroquant test kits (MERCK, Germany).

Table 1: The characteristics of compost

	Mass (kg w/w)	C %	N%	C (kg)	N (kg)	C/N ratio	P %	P (kg)	K %	K (kg)
Initial	400	41.33	1.32	165.32	5.28	34.64				
Final	172	34.85	2.45	59.94	4.214	14.36	0.17	0.292	0.42	0.722

2.2 Inventory analysis

2.2.1 BAU scenario

Relevant data for the BAU scenario were collected based on the Seelong sanitary landfill CDM project report and existing literatures. The background emission data were based on IPCC (2006) and Manfredi et al. (2009). In this scenario, GHG could emit when combustion of fossil fuel during transportation of wastes and landfill operation as well as fugitive emission during biodegradation of organic wastes from landfill site. Carbon sequestration effect generally considered as source of GHG avoidance.

The fossil CO_2 emission for fossil fuel combustion was estimated by multiplying the amount of fossil fuel consumed with the emission factor of a particular fossil fuel. For the emission caused by transportation, all wastes were assumed to be transferred by the medium size truck with emission factor of 0.16 L diesel/km travelled (Saari et al., 2007). Quantity of fossil fuel consumed during the landfill operation was assumed as 1 to 3 L. t^{-1} waste deposited during the entire lifecycle of the landfill (Manfredi et al., 2009) and higher value was applied for the calculation. Emission factor for diesel combustion applied in this study was 2.7 kg CO_2-eq. L^{-1} diesel (Fruergaard et al., 2009).

Poor aeration in landfill cell was common phenomena caused by waste compaction, water content of wastes and configuration of landfill site. This condition favours the production of CH_4 during the anaerobic biodegradation of the organic wastes. The estimation of CH_4 emitted in landfill was based on the IPCC method (IPCC, 2006) as shown in Eq(1).

$$CH_{4,Landfill} = [(W*MCF * DOC * DOC_f *F * 16/12) - (W*MCF * DOC* DOC_f*F * 16/12 * CE * OE] * (1 - OX) \quad (1)$$

where $CH_{4,Landfill}$ is the emission of CH_4 gas, W is the waste input in kg, MCF is the methane correction factor, DOC is degradable organic carbon in the particular waste type, DOC_f is the fraction of DOC that can be decomposed, F is the fraction of CH_4 in the landfill gas, CE is the landfill gas collection efficiency, OE is the flare efficiency and OX the oxidation factor. For food waste, MCF and DOC_f have been modified to deal with specific condition in Seelong sanitary landfill, which MCF assumed as 0.9 and DOC_f assumed as 0.75. CE and OE also assumed as 65 % and 99 % (CDM, 2012). Open dumping of green waste would refer to general condition of uncontrolled landfill in IPCC model.

In the landfill cell, some region might be unfavourable for organic waste decomposition. These unbiodegradation portions might remain unchanged. It is assumed organic carbon not degraded nor forming as leachate for more than 100 y would be considered as carbon sequestrated (C_{left}) and calculated by Eq(2).

$$C_{left} = - W*DOC*(1 - DOC_f)* (1 - D_{leachate})*MCF*44/12 \quad (2)$$

where C_{left} is carbon sequestrated, $D_{leachate}$ is the dissimilation factors of the organic carbon as leachate. $D_{leachate}$ for proper landfill site and open dump site were assumed as 0.02 and 0.04, respectively (Manfredi et al., 2009).

2.2.2 Composting scenario

In composting scenario, GHG could emit when combustion of the fossil fuel during the transport of the waste/compost and during waste processing, fugitive emission during composting process and emission from land after compost application. In terms of GHG avoidance, application of compost can substitute a fraction of inorganic fertiliser, which provides GHG reduction by avoiding the GHG emission during production of inorganic fertiliser. A portion of the carbon in compost that remains stable for more than 100 y after compost application is considered as carbon sequestrated.

Fossil CO_2 emission from combustion of fossil fuel was calculated based on those used in the BAU scenario, i.e. based on the amount of fossil fuel consumed and multiply by the emission factor of the fossil fuel. The data for the diesel and petrol consumption (within the composting plant and transfer of the waste/compost) was collected by interviewing the staff who managed the plant. Emission factor applied were 2.31 kg CO_2-eq. L^{-1} petrol combustion (Putri et al., 2012) and 2.7 kg CO_2-eq. L^{-1} diesel combustion (Fruergaard et al., 2009).

For GHG emission during composting process, CH_4 and N_2O released ($CH_{4,release}$, and $N_2O_{release}$) were calculated based on the mass balance of C and N analyses using Eq(3) and (4) (Boldrin et al., 2009). Data from Table 1 was used to determine the mass balance of C and N for this study.

$$CH_{4,release} = C_{release}*CH_{4,emitted} * (1 - \eta) *16/12 \quad (3)$$

$$N_2O_{release} = N_{release}*N_2O_{emitted} *(1 - \eta) * 44/28 \quad (4)$$

where $C_{release}$ is the C emitted to the atmosphere (kg), $CH_{4,emitted}$ is the C loss as CH_4 (%) and η is the efficiency of the biofilter; while $N_{release}$ is the N emitted to the atmosphere (kg) and $N_2O_{emitted}$ is the nitrogen loss as N_2O (%). $CH_{4,emitted}$ and $N_2O_{emitted}$ for this study were assumed as 2.5 % and 0.7 % (Boldrin et al., 2009).

The amount of CO_2 reduction ($CO_{2,bind}$, kg) through carbon sequestration was calculated using Eq(5).

$$CO_{2,bind} = - C_{compost}*C_{bind}* 44/12 \quad (5)$$

where $C_{compost}$ is the amount of C content in compost (kg) and C_{bind} is the C content bound to soil as carbon sink (%). C_{bind} for this study was assumed as 2 % (Boldrin et al., 2009).

The amount of inorganic fertiliser displaced by the compost ($Mass_{disp}$) was estimated by Eq(6).

$$Mass_{disp} = - Input_{nutrient} \times Subs_{eff} \quad (6)$$

where $Input_{nutrient}$ is the nutrient content in the compost applied (kg) and $Subs_{eff}$ is the substitution efficiency (%). The substitute ratio was assumed as 20 – 60 % for nitrogen (N), 90 – 100 % for phosphorus (P) and 100 % for potassium (K) (Boldrin et al., 2009). Emission factor for inorganic fertiliser production were assumed as 4.7–13.0 kg CO_2-eq. kg N^{-1} for N fertiliser, 0.5–3.1 kg CO_2-eq. kg P^{-1} for P fertiliser and 0.4–1.5 kg CO_2-eq. kg K^{-1} for K fertiliser (Boldrin et al., 2009).
The compost applied on land might also induce emission of N_2O emission from soil. The N_2O emitted from compost application ($N_2O_{application}$) (kg) was calculated by Eq(7).

$$N_2O_{application}=N_{compost}*N_2O_{\%N} * 44/28 \quad (7)$$

where $N_{compost}$ is the N content in compost (kg) and $N_2O_{\%N}$ is the N content that would convert to N_2O (%). $N_2O_{\%N}$ was assumed as 2.2 % (Boldrin et al., 2009).

3. Results and Discussion

The GHG inventory analysis for two distinct waste management scenarios were conducted based on the localised condition in UTM. According to Figure 3, total GHG emission from the BAU scenario based on the existing organic waste management practice in UTM was 961 kg CO_2-eq. t^{-1} waste treated. In contrast, the total GHG emission from the composting scenario was 320 kg CO_2-eq. t^{-1} waste treated. The composting scenario offers a saving of 66.72 % (641.08 kg CO_2-eq. t^{-1} waste treated) GHG emission as compared to the BAU scenario. This result indicated that composting offers positive environmental impacts for the organic waste management in UTM. Based on the inventory analysis, it was found out that the greatest GHG emission was from the direct emission of the organic waste. Direct emission has accounted for > 99 % and 71.4 % of the total GHG emission for the BAU and composting scenario. Direct emission during composting was mainly caused by the CH_4 and N_2O emitted from the anaerobic biodegradation of organic waste. CH_4 and N_2O each has the global warming potential (GWP) 21 and 298 times higher than CO_2. These GHG emissions have over shadowed the benefits brought by the carbon sequestration following compost application on land. GHG emission from other sources considered minor especially for fossil fuel combustion which only 7 kg CO_2 t^{-1} waste treated for BAU scenario and 15.28 kg CO_2 t^{-1} waste treated for composting scenario. This could be due to short distance between waste source and waste treatment facilities as well as scale of composting plant (In this case study, small amount of wastes being managed make composting operation rely more on manpower whereas involvement of large machinery that consume high amount of fossil fuel was inevitable for larger scale composting plant).
The composting technique employed in this composting plant was quite basic. Further mitigation strategies of GHG emissions such as CH_4 and N_2O should be implemented. These include the installation of biofilter, introduction of better aeration system, the use of bulking agent and better compost management system such as frequent turning and better control of moisture content (Bong et al., 2016). Besides, more effort should be made to produce high quality compost because production of high quality of compost is an important criterion as it decides the amount of compost to be applied on land and the mitigation potential of GHG in soil.

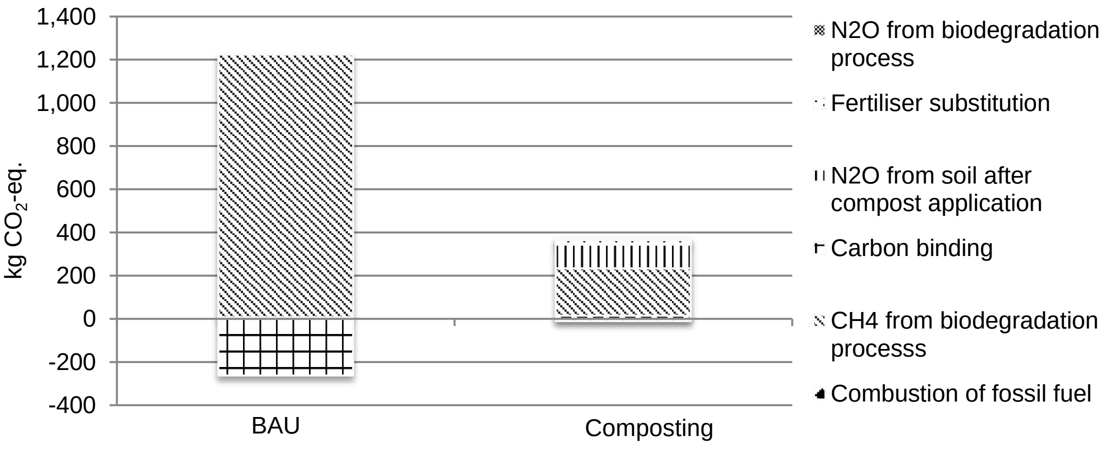

Figure 3: Greenhouse gas emission and avoidance among BAU scenario and Composting scenario.

4. Conclusions

In this study, the GHG inventory analysis has been conducted using the lifecycle approach to evaluate the potential of GHG mitigation from composting as compared to the existing waste management in UTM. The GHG emission from the composting scenario was 319.92 kg CO_2-eq. t^{-1} organic waste treated, which was 66.72 % lower than the BAU scenario (961 kg CO_2-eq. t^{-1} organic waste treated). The GHG emitted from the fossil fuel consumption was insignificant as compared to the total GHG emission of the system for both scenarios. CH_4 and N_2O emitted during the degradation of organic carbon were the main contributors of GHG emission, which has accounted for > 99 % emission for the BAU scenario and 71.41 % for the composting scenario. It is likely that the quality of compost would significantly influence the GHG mitigation potential for the composting scenario, as most of the GHG avoidance comes from compost application. This study concluded that composting is a more environmental friendly technology to manage organic waste in UTM from the view of global warming potential.

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