Environmental and economic feasibility of an integrated community composting plant and organic farm in Malaysia

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Keywords: Food and vegetable waste, Composting, GHG mitigation, Cost and benefit analysis.

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Abstract

Waste prevention and management become the major issue worldwide to achieve sustainable development. Similar to many developing countries, Malaysia has faced serious problems in waste management due to its rapid economic growth and urbanisation. The municipal solid waste (MSW) production rate in Malaysia had increased significantly in a recent year, ranging from 0.8 – 1.25 kg/person·d. The wastes generated contain a high amount of organic portion and moisture content. Imperfect MSW management practice or delayed in waste collection and transportation can lead to severe health issues. This paper presents a case study in Johor Bahru, Malaysia in which a composting prototype is used as the waste management technology to recycle the food and vegetable wastes. The greenhouse gases (GHG) mitigation and economic feasibility of the integrated composting and organic farming in this study are reported. This study showed a reduction of 32% of GHG by diverting the food and vegetable wastes from landfilling to the composting plant. Higher reduction rate can be achieved with a better planning of waste collection route and applying the mitigation strategies during the composting process. High revenue can also be obtained from the sale of compost generated and vegetable. This study provides an insight of the feasibility and desirability to implement a pilot-scale composting for organic waste management to achieve the low carbon and self-sustain community.

1. Introduction

Municipal solid waste (MSW) is defined as the refuse or unwanted product that derived from human activities and discarded by the society. With the rapid population growth, urbanisation and industrialisation, the generation of the municipal solid waste (MSW) have increased over the years. According to the Department of Statistics (2016), Malaysian population reached 31.7M in 2016 with an annual growth rate of 1.5 % where 71 % of the total population has resided in the urban area in tandem with the rapid development. From 2012 to 2014, the MSW generation increased from 22 kt/d to 30-33 kt/d. Landfilling and open dumping remained the main disposal method; about 94.5 % of the collected wastes are disposed in the landfills or open dumpsites, with a recycling and composting rate of 5.5 and 1 % (Periathamby *et al.*, 2009), despite the fact that 57 % of the waste is made out of organic solid waste (Saeed *et al.*, 2009).

Solid waste management encompasses all the activities from generation to the final disposal. These include the control, generation, storage, collection, transfer and transportation, processing and disposal of solid waste consistent with the best practices of public health, economics, and finance, engineering, administration, legal and environmental considerations (Johari *et al.*, 2014). In developing country such as Malaysia, the over-reliance on landfilling and open dumping can lead to some severe issues, including the emission of greenhouse gases (GHG) from the site as well as the limited land area for waste disposal. It is essential to develop a more sustainable and effective MSW management in Malaysia.

Composting can be an alternative waste management strategy in overcoming this issue. Composting is a biological process which converts organic wastes into a stable organic product with high humic substances that last longer in soil (Wang *et al.*, 2016). It involves a relatively low processing cost and less complicated technology as compared to other MSW management technology. Composting transforms the organic wastes into compost that can be used to improve soil quality, minimise soil erosion, and promote plant growth. Compost without a detectable level of pathogens and heavy metals can act as a soil conditioner or organic fertiliser to plants. It also provides the soil with a large amount of organic matter and nutrients, improves the soil texture and chemical buffering, and water-holding capacity of the soil. With the presence of a high population of beneficial microorganisms in compost, the suppression of several plant diseases can be achieved with the application of compost. Composting has been widely practised in many developing countries. However, the replacement ratio of compost for chemical fertiliser is still low due to the inconsistency in the end quality of compost (Fan *et al.*, 2016), unclear definition of system boundaries, incomplete impact assessment and lack of sensitivity analysis (Laurent *et al.*, 2014).

This study presented an interesting case study at Johor Bahru, Malaysia. The pilot-scale composting plant is integrated with the concept of community farming to enable self-sustaining. The compost produced is being used directly on the family farm. The economic analysis demonstrated a potential high-return of this community-composting model that is a determinant factor to sustain the composting site. There have been several studies reported on the environmental and economic analysis of industrial composting plant. However, application of such a community composting model has not been addressed in details (Lim *et al.*, 2016). The main objective of this study is to quantify the cost and benefit analysis (CBA) and the GHG emission regarding kg CO_2-eq through inventory analysis of a community composting prototype located in Johor, Malaysia. The analyses are conducted based on two scenarios. Scenario 1 comprises the baseline scenario where the waste is sent to open dumping (OD); Scenario 2 represents the waste treatment in the community composting plant (CCP). This paper fills in the gap in the feasibility studies of a novel community-composting model.

2. Method

2.1 Community-composting site and waste sources

Study site comprises of a composting facility and an organic farm. The composting plant is currently handling around 2.5 to 3 t/d of food and vegetable waste. It is a community farm preaches to produce healthy and organic crops to close to 70 families who support the farm.

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2.2 Scenario analysis

2.2.1 Scenario 1: Baseline scenario – open dumping (OD)

Scenario 1 represents the current waste management practice where the food waste is collected and disposed at a landfill around Kulai, Johor. A total of 288 t/y of food waste (FW) on the generation rate of 24 t/mth is disposed to the landfill. As for the fruit and vegetable retail market, the vegetable waste is currently sent to the open dumpsite in a farm located at Ulu Tiram, Johor.

2.2.2 Scenario 2: Community-composting plant (CCP)

Scenario 2 represents the current pilot-scale composting being operated by the organic farm. Different types of waste are collected using a 2t-truck and transported to the farm. A total of 84.6 t/d of waste is composted with a production of 32 t/mth of compost.

2.3 Environmental assessment – GHG Inventory analysis

The life-cycle inventory analysis for scenarios 1 and 2 was conducted for the estimation of GHGs emission regarding kgCO_2-eq. This analysis aims to identify and quantify the environmental performance related to the system through the inputs and outputs of the two scenarios within the system boundary.

The system boundary of this study included the transport of waste to the disposal area, process emission from the decomposition of organic waste during the treatment and replacement of chemical fertiliser as well as carbon sequestration through compost application. The functional unit (f.u.) is defined as 1 t of waste entering the treatment facility.

2.3.1 Scenario 1

The GHG emission factor for landfilling and open dumping is calculated based on the non-sanitary landfill emission from IPCC model (2006). The GHG emission only considered the fuel consumption for the transportation of the wastes from the hotel and the fruit and vegetable retail to the open dumpsite, as well as the emission from the anaerobic digestion of waste at the open dumpsite. The CH_4 generation potential from landfill (IPCC, 2006) was calculated using Eq. (1):

$$L_0 = MCF \times DOC \times DOC_f \times F \times SF \quad (1)$$

where L_0 is the methane generation potential (t CH_4/t waste), MCF is the methane correction factor (fraction), DOC is the fraction of degradable organic carbon of the waste (weight fraction), F is the fraction of methane in landfill gas, SF is the stoichiometric factor.

The CO_2 emission from diesel combustion is calculated using Eq. (2) (U.S. EPA, 2016):

$$E_{CO2} = EF \times \text{volume of diesel consumed} \quad (2)$$

where E_{CO2} is the CO_2 generation potential, EF is the emission factor for diesel combustion which is 2.70 kg CO_2/ L diesel.

2.3.2 Scenario 2

The GHG inventory in Scenario 2 accounted for the emission of CH_4 and N_2O from the composting process, GHG emission from the diesel consumption for biomass transportation, shredding, mixing and screening of materials. The processes that contributed to carbon savings included the substitution of chemical fertiliser, carbon storage factor from compost to soil and carbon sequestration. The key assumptions made included:

- The biogenic CO_2 emissions from the composting process are considered to be carbon neutral, but the emission from CH_4 and N_2O were included with 21 times and 310 times higher GWP than CO_2 based on 100-year time horizon.
- The GHG emissions from the operation of on-site machinery included CO_2, CH_4, and N_2O.
- the input data is a mixture of on-site data and literature data from other similar studies
- the total FW and VW generated was 24 t/mth and 54 t/mth
- the GHG savings from the compost production was based on the amount of compost produced

The following limitations were applied:

- The application of compost was equivalent to the chemical fertiliser but excluded the potential N_2O emission from the compost application in soil.
- The emission from water usage and in the form of leachate was excluded.
- The emissions from the waste materials other than food and vegetable wastes were excluded.

CH_4 and N_2O emissions from composting may be calculated using the total mass of waste composted and the emission factors (U.S. EPA, 2011) as listed in Eq. (3) and (4):

$$E_{CH4} = EF_{compost,\ CH4} \times M_{compost} \quad (3)$$

$$E_{N2O} = EF_{compost,\ N2O} \times M_{compost} \quad (4)$$

E_{CH4} and E_{N2O} are the CH_4 and N_2O generation potential, $EF_{compost,\ CH4}$ and $EF_{compost,\ N2O}$ is the emission factor for CH_4 and N_2O, $M_{compost}$ is the mass of material added or fed to the composting process (wet weight basis) (t/mth). The $EF_{compost,\ CH4}$ and $EF_{compost,\ N2O}$ are 4 kg CH_4/t waste and 0.3 kg N_2O/t waste.

CH_4 and N_2O emissions from the nonroad vehicle (agricultural equipment) are calculated using Eq. (5) and (6) (U.S. EPA, 2016):

$$E_{CH4} = EF_{diesel,\ CH4} \times \text{volume of diesel consumed} \quad (5)$$

$$E_{N2O} = EF_{diesel,\ N2O} \times \text{volume of diesel consumed} \quad (6)$$

E_{CH4} and E_{N2O} are the CH_4 and N_2O generation potential, $EF_{diesel,\ CH4}$ and $EF_{diesel,\ N2O}$ is the emission factor for CH_4 and N_2O, which are 0.00038 kg CH_4/L diesel and 0.00033 kg N_2O/L diesel.

2.4 Cost and benefit analysis (CBA)

The CBA assessed the economic feasibility for the two scenarios studied. Such analysis provides useful information to the local authorities or other investors to set up a community composting plant.

2.4.1 Scenario 1

The major cost for Scenario 1 is the diesel consumption for waste collection and transportation to the landfill and open dumpsite.

2.4.1 Scenario 2

On-site data collection was conducted to conduct the CBA for Scenario 2. The costing in this scenario includes the infrastructure and site construction, equipment purchase, diesel consumption for waste collection and on-site operation, workforce, sample analysis, and utility cost. The cost benefits of this scenario included the saving from the compost utilisation (replacement of chemical fertiliser) and the selling of vegetables. **Figure 1** shows a common system to calculate the cost to produce 1 kg of compost for the community composting plant (CCP).

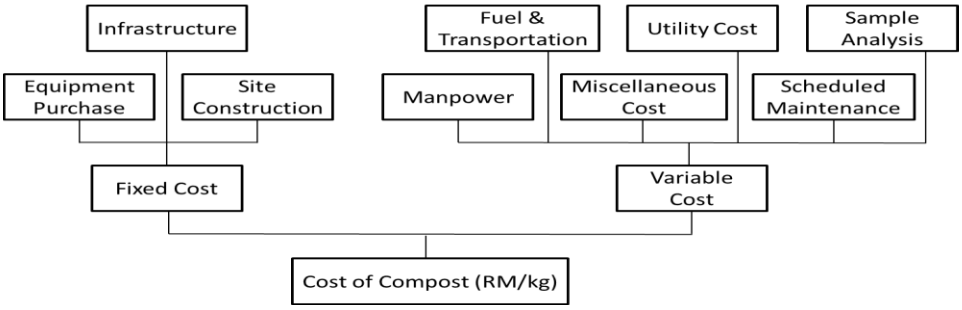

Figure 1 Key data to compute the cost of the community composting plant (CCP) for Scenario 2.

3. Results and Discussions

3.1 GHG Inventory analysis

The environmental impacts of the two scenarios by evaluating the GHG emissions by kg CO_2-eq for both scenarios are presented in **Table 1** and **2**.

Table 1 Input data for GHG calculation in Scenario 1 landfilling/ open dumping.

Item	Value	Reference
Methane correction factor, MCF	0.6	IPCC (2006)
Degradable organic carbon (fraction), DOC	0.15	IPCC (2006)
Fraction of DOC decomposed (fraction), DOC_f	0.5	Food waste (IPC C, 2006)
Fraction by volume of CH_4 in landfill gas, F	0.5	Food waste (IPCC, 2006)
Stoichiometric actor, SF	16/12	Food waste (IPCC, 2006)
Methane generation potential, L_0	30 (kg CH_4/t waste)	Calculated from Eq. (1)

Table 2 GHG inventory for Scenarios 1 and 2.

Input	Scenarios		Remark
	1	2	
I) Feedstock and compost (t/mth)			
FW to open dumpsite	24	0	
VW to open dumpsite	54	0	
FW to composting site	0	24	
VW to composting site	0	54	
Onion and garlic waste to composting site	0	6	
Fishery waste to composting site	0	0.6	
Compost produced	0	32	
II) GHG calculation (kg CO_2-eq) for both scenarios			
A) CO_2 generation potential based on the feedstock input (kg CO_2-eq/t material)			
CO_2 generation potential from FW and VW	630	0	
CO_2 generation potential from co-composting of FW and VW	0	177	U.S. EPA (2010)
Total A: total CO_2 generation potential for feedstock	**630**	**177**	

treatment			
B) CO_2 generation potential based on diesel consumption (kg CO_2-eq/t material)			
CO_2 generation potential from transportation	1,334.77	1,157.14	
CO_2 generation potential from machinery at composting site	0	267.62	
Total B: total CO_2 generation potential for diesel consumption (kg CO_2-eq/t material)	**1,334.77**	**1,424.76**	
C) GHG saving from compost utilisation (kg CO_2-eq/t compost)			
i. Replacement of chemical fertiliser			
N fertiliser avoided	0	-224.66	Chiew and Shimada (2013); Boldrin *et al.* (2009)
P fertiliser avoided	0	-12.8	
K fertiliser avoided	0	-18.6	
ii. Carbon sequestration	0	-4	Boldrin *et al.* (2009)
Total C: total CO_2 saving from the reduction of chemical fertiliser production and carbon sequestration (kg CO_2-eq/t compost)	**0**	**-260.06**	
Total CO_2 potential from composting (emission – saving) (kg CO_2-eq/t waste)			
Total emission (A + B)	1,964.77	1,601.76	
Total saving of carbon emission (C)	0	-260.06	
Total D (final)	**1,964.77**	**1,341.70**	**32 % GHG Saving**

The results from **Table 2** shows that composting (Scenario 2) provides a promising outcome in GHG saving with approximately 32% of GHG mitigation compared to the open dumping (Scenario 1). Seng *et al.* (2013) and Bong *et al.* (2016a) also observed the similar finding (over 60 % saving of GHG) when composting was used as waste treatment compared to landfilling.

For both scenarios, the diesel consumption for waste collection and transportation contributed significantly to the GHG emissions among all inventory items. A more efficient wastes collection flow is required to reduce the GHG emissions. The current wastes collection flow is not efficient, it is time and diesel-consuming and leading to high GHG emission. This can be improved by combining several trips and reduced the trip frequency between the waste source and the farm. For the vegetable waste collection, instead of going twice per day, the two trips can be combined and collected only in the afternoon. This re-planning of the waste collection route is dependence on the maximum capacity of the truck. This issue highlights the importance of optimising the location of the composting site that could minimise the transportation distance and the GHG emissions to the composting facility (Seng *et al.*, 2013) and more recently (Bong et al., 2016a).

Apart of emission due to waste transportation, the emission from the waste degradation can be critical if the pile is not well managed. CH_4 and N_2O are emitted during composting. Both GHG contributes 21 times and 310 times higher global warming potential (GWP) than CO_2 based on the 100 y time horizon. Failure of monitoring the composting process can cause a higher emission of these GHG compared to landfilling and open dumping. The mitigation of GHG emission from composting process can be achieved by applying different amendment strategies (Bong *et al.* (2016b). The GHG emission from the composting process could be measured directly from the pile to show the real GHG emissions of the compost piles. The GHG emission from the process ranges within 4 to 8,000 kg CO_2-eq/t wastes when different composting approaches were applied (Bong *et al.*, 2016a; Lim *et al.*, 2016). Amendment made during composting can improve the compost quality as a high nutrient soil-enhancer. The GHG calculation for machinery on composting site was calculated based on the diesel consumption from all the on-site activities. Due to the lack of data availability, the electricity consumption is not included in this study for GHG emission.

The greatest GHG saving recorded for Scenario 2 came from the avoided GHG emission from the production of N fertiliser, followed by the avoidance of K and P fertilisers production (**Table 2**). The application of compost also resulted in the GHG savings from soil carbon sequestration, a process that retains and increases the carbon storage in soil. As mentioned in **Section 2.1**, the compost produced in this study is consumed locally; the avoidance of the transportation to and from the farm site can significantly contribute to the GHG savings.

3.2 Cost and benefit analysis (CBA)

Table 3 shows the cost and benefit analysis (CBA) of the two scenarios. In this section, the total costs of the two scenarios on a yearly basis were calculated with the capital cost being normalised into 10 y. All the costs were reported in MYR/mth unless otherwise stated.

Table 3 Costing breakdowns, saving, and revenue gained from the two scenarios.

Item	Scenarios		Remark
	1	2	
I) Cost breakdown and compost revenue (MYR/mth)			
A) Capital cost			
Site construction	0	450,000	Accommodation for workers, workshop and seedling area; farming area; composting site with leachate collection
Infrastructure	0	98,700	Site with water and electricity supply
Tractor		70,000	2-t truck
Screener	0	20,000	
Shredder	0	2,500	
Bobcat	0	40,000	Model: S175 from Teck Soon Sdn Bhd
Waste collection bin	0	16,000	MYR 160 × 100 units
Chimney system	0	1,000	
Tilling machine	0	1,800	Model: VMT500
Total A	**0**	**700,000**	
B) Operational cost			
i. Labour cost			
Composting process monitoring	0	2,000	1 worker × MYR 2,000/mth
Farming	0	8,000	4 worker × MYR 2,000/mth
Total	**0**	**10,000**	
ii. Fuel cost			
Transportation (diesel, L/mth)	1,040	900	
On-site machinery (diesel, L/mth)	0	200	
Total	**1,038**	**1,100**	Diesel cost = MYR 2.10/L
iii. Miscellaneous cost			
Laboratory analysis	0	1,050	
Other	0	2,000	Utility cost (electricity and water bill and maintenance fee)
Total	**0**	**3,050**	
Total B (MYR/mth)	**1,038**	**14,150**	
C) Saving from compost utilisation			
Chemical fertiliser	0	-139.8	MYR 120/ 50 kg fertiliser
Pesticide & Herbicide	0	-300.00	MYR 100/ 100 cc pesticide & herbicide
Total C (MYR/mth)		**-339.80**	
D) Revenue			
Membership	0	-27,000	Membership = MYR 2,000/ 6 mth·family
Total D (MYR/mth)	**0**	**-27,000**	
II) Final costings (MYR/yr)			
Total cost A	0	+100,000	Normalised for 10 years
Total cost B	+12,456	+169,800	
Total cost C	0	-4,077.60	
Total cost D	0	-320,000	
Total D (final) (MYR/mth)	**+12,456**	**-54,277.60**	

As reported in **Table 3**, the investment for a composting facility (Scenario 2) offers good return potential with the incorporation of community agriculture, especially with the adaptation of the membership concept. Although composting had a relatively low investment and capital cost, it brought a lesser revenue and a longer payback period compares to other waste management technologies (Blumenstein *et al.*, 2012; Bong *et al.*, 2016a; Yoshizaki *et al.*, 2012). The membership subscription concept plays a critical role in this case study in maintaining a substantial cash flow. This liquidity allows the purchase and upgrading of the on-site facilities to improve the composting process further. It is expected that a minimum of 100 families is required to sustain the operation of this composting side. Current subscription capacity is limited by the crop yield which is not enough to provide sufficient crops to 100 families. This limitation is expected to me solved in another few years' time when the soil gets more fertile over the years.

As reported by Galgani *et al.* (2014), in Northern Ghana, composting was not viable without external subsidies, although some successful cases in Bangladesh and Indonesia were recorded in which subsidies was not required in running the composting project. The economic viability of a composting project is hard to be estimated since it can be affected by many factors. Including the capital cost, the technology selected, the scale of the project, the supply and demand chain of the wastes and the mature compost, available facilities and equipment, and the composting site selection. In this study, besides the membership concept, the family-run business model also allow the early payback of this project, where big support has been provided during the early set up of the composting facility. These included the land, free supply of wastes, volunteer of dump-site and bobcat drivers, and on-site operator. To facilitate more ventures in the composting business, the government would need to provide financial incentives to overcome the financial barrier, most notably the setup cost which was reported to be nearly MYR 700,000 (**Table 3**). The cost will be higher if either the purchasing or rental cost of the land is included. Some mechanisms include soft loan, green technology scheme, tax exemption for imported machinery, buy-back mechanism from local council (i.e. to be used for landscaping), quality assurance for safe utilisation, and technical assistance to produce good quality compost should be considered by the local government to relieve the financial and technological barrier of the investors.

As recorded by the Food and Agriculture Organization (2016), world fertiliser consumption rate had increased from 98.7 to 119.9 kg/ha of arable land from the year 2002 to 2013. In the same period, the statistic rose from 1,177.0 to 1,726.6 kg/ha of arable land in Malaysia. This can be reduced with the performing of composting and through compost utilisation. The organic farm farm had demonstrated a successful composting-economic model while other composting facilities could have limited land and workforce to run an organic farm. A joint effort between compost facilities and farmers should be established, especially with the help of the government unit.

4. Conclusion

This study showed a community composting project as a viable waste management technology to reduce the amount of organic waste to the landfill. The pilot scale composting facility presented by the organic farm was capable of reducing up to 32% of GHG and able to generate revenue compared to open dumping. Most of the GHG emissions from composting were recorded to be contributed by diesel consumption from transportation and the on-site operation of composting process (including the emission from diesel consumption for on-site machinery and the composting process alone. However, the GHG emission can also reduce by a better planning of waste collection route where the later can be improved by implementing some mitigation strategies such as improve aeration, the addition of a bulking agent, cover with mature compost, and the addition of microbial inoculants. The composting-economic model demonstrated by the organic farm can be applied as a successful strategy with the adaptation of membership concept. More families can be fed through the up-scaling of the composting facility and the expanding of the agricultural land. Income can also be generated by the mature compost sale. Further investigation is needed for better understanding the supply-demand chain of wastes and mature compost to minimise the GHG emission during the process as well as amplify the revenue from running a composting facility.

As a conclusion, composting is proof to be a cleaner and sustainable technology compared to open dumping that reuses the organic wastes to produce bio-fertiliser for agricultural purposes. The relatively low investment cost and simple technology in composting also allow the better development of the composting project in developing country.

Acknowledgment

The authors acknowledge research grants received from the Ministry of Higher Education (MOHE) Malaysia (grant no. 7301.4B145 and 2546.15H25); and Universiti Teknologi Malaysia (grant no. 2546.14H65). The authors also acknowledge the funding and support from JICA-JST-SATREPS project entitled "Development of Low Carbon Scenarios in Asian Region" and by EU project Sustainable Process Integration Laboratory – SPIL, funded as project No. CZ.02.1.01/0.0/0.0/15_ 003/0000456, by Czech Republic Operational Programme Research, Development and Education, Priority 1: Strengthening capacity for quality research.

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