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Cost-Benefit and Greenhouse-Gases Mitigation of Food Waste Composting: A Case Study in Malaysia

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Waste generation nowadays is rising in the world and it seems hard to prevent it. Municipal Solid Waste (MSW) has been a major problem worldwide, especially in the fast growing cities and towns in the developing countries. This study aims to estimate the cost benefit and mitigation of greenhouse gases (GHGs) by converting the on-campus food and green waste generated in Universiti Teknologi of Malaysia (UTM) campus to compost. This study calculated the costing which includes the transportation, operating and equipment costs if green and food waste were converted into compost. The analyses were made with the basis of the pilot scale operation in Phase I operation. Extrapolation was made to project the further four phases of composting with higher amount of waste to estimate the potential profit. The results obtained from this study indicated that composting has the potential to generate a significant profit of Malaysia Ringgit (MYR)1.6 M/y based on 2,700 t/y of food and green waste composted. At the same time, the total solid waste supposedly to be sent to the landfill can be reduced by at least 47 %. Moreover, this study revealed that the composting process is able to reduce the GHGs emission rate by 90 %, i.e. the GHGs produced by the composting process is shown to be only 10 % of the total GHGs produced by landfill dumping given the same amount of solid waste to be disposed at the landfill site.

1. Introduction

Municipal solid waste (MSW) management has become a major issue in the development plans worldwide, especially in rapidly developing cities. Malaysia is undergoing rapid industrialisation and urbanisation and this causes detrimental effects on the environment from the increase of waste generation (Abdullah, 1995). The daily waste generation has shown an upward trend. Waste generation was 16,200 t/d in year 2001. This amount increased to 19,100 t/d, in 2005 and 21,000 t/d in 2009 (Ahmad et. al., 2011) and is estimated to rise to 31,000 t/d by 2020 (Johari et. al., 2012).
The typical solid waste management system in the developing country causes such problems (Manaf, 2009): (i) low collection coverage and irregular collection services; (ii) crude open dumping and burning without air and water pollution control; and (iii) the breeding of vermin and flies.
The ultimate purpose of solid waste management is to cut down the production of solid waste and consequently reducing the disposal costs, the impact on the environment (Pitt and Smith, 2003), and the impact on human health (Agamuthu, 2009). Solid waste management (SWM) includes various

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technologies involving controlling waste generation, handling and storage, transportation, processing and fiech disposal. The hierarchy of SWM was formed since 1970s, one of those affordable hierarchies is suggested by Finnveden et al. (2005) in the order of reduction of waste amount, reuse, recycle, compost or recovery through incineration and finally landfill disposal. Other than that, energy and recyclable material can be retrieved as by-products to achieve sustainable waste management that is environmental friendly, economically reasonable and socially acceptable (Kamyab et al., 2015).

The current waste management methods practiced in Malaysia are highly dependent on landfill as only 5.5 % of the MSW is recycled and 1 % is composted, while the remaining 94.5 % of MSW is disposed on the landfill site (Periathamby et. al., 2009). Waste recycling is mainly performed by garbage scavengers at the landfill sites. Till date, SWM in Malaysia is at the stage of transition and planning towards sustainable and effective approaches. Sustainable and more efficient waste management strategies are needed to reduce the heavy reliance on landfills. Malaysia aims to establish a holistic framework that considers the trade-off involved in the segregation process and the economic performance of different MSW practices to achieve the national MSW recycling rate (22 % of the total MSW) by the year 2020 (Ministry of Housing and Local Government, 2005). It was also proposed that composting should be driven up to 8 % by the year 2020 in Malaysia (Agamuthu et al., 2009). Composting was also proposed as a potentially viable technology for MSW management in Malaysia (Tan et.al, 2014).

MSW in Malaysia consists of about 60 % organic and food waste (Kathirvale et. al, 2003). Conversion of food waste to compost can be an attractive solution for MSW management in Malaysia as the MSW has high moisture content (about 55 %) (Fauziah and Agamuthu, 2012). The 40-60 % moisture content in organic waste is generally considered ideal for microbial degradation via composting. The feasibility of composting is highly dependent on the costs of setting up and running the system. Normally the most expensive part of waste management is to set up advanced facility for recycling, recovery and safe disposal (Hamid et. al, 2012). The challenges in the developing countries for such effort are capital investment and technical know-how. Pricing is critical for compost feasibility as compost is sold from merely 150 MYR/t to even around or more than 1000 MYR/t depending on market demand and compost quality. Planning and design of low carbon product with reduced cost and CO2 emission can enhance the cost-effectiveness and marketability of the product. For instance Mohd Nawi et al. (2014) developed a graphical tool to show a potential reduction of 70.8 % carbon emissions as compared to the conventional palm oil supply chain carbon emission.

Hence it is highly desirable to propose a composting process that is of lower cost, generating co-benefits yet give high impact of environmental protections. This paper aims to conduct a simple cost analysis for the conversion of food and green waste into compost. The potential of GHGs mitigation was calculated based on a GHG estimator as developed. The study also proves the concept of food waste composting choosing the campus of UTM as a test bed.

2. Materials and Methods

The campus of UTM was chosen as a test bed to implement a pilot scale food waste composting plant. The costing of compost production and GHG estimation were conducted. The research process is as follow:

Data collection: the basic food and green waste generation data was collected from the Office of Asset and Development in UTM. Two major potential savings harnessed by the composting project were considered, i.e. the cost spent for waste disposal services and the cost spent for chemical fertilizer for maintaining the landscape plants in UTM were recorded.

A composting site was constructed for the composting work. A simple concrete floor of 10 m x 20 m with leachate collection drainage system was constructed. Open pile composting was selected due to low cost and simplicity. Three piles of composts were made each day, each pile of compost was made up of 100 kg of segregated and shredded food waste and 300 kg of shredded green waste. The equipment used for this study included a food waste shredder (capacity of about 250 kg/h), an in-house modified green waste shredder (about 300 kg/h), and simple composting tools such as spades, bins, trolley. Waste shredding, mixing and piling of compost piles were conducted manually by the workers. Food waste collection and segregation were conducted by a private collector and green waste was collected by the Office of Asset and Development, UTM.

Monitoring of composting: basic parameters such as moisture content, pH, temperature and conductivity were monitored up to 12 weeks. The final compost was analysed for the C/N ratio, basic nutrients (nitrogen (N), phosphorus (P), potassium (K)) and germination tests.

Estimation of cost benefits of composting: Five phases of composting scenarios were analysed. Phase I pilot scale composting with a composting capacity of 1,200 kg waste/d (ratio of 1:4 for food : green waste)

was conducted for 6 months; the costing of higher capacity of composting was extrapolated for Phase II till V where all food and green waste generated in UTM campus would be composted completely.
A GHG estimator, developed based on Microsoft Excel spread-sheet, inserted with the corresponding mathematical equation(s) and constant(s) selected from the literature, is presented in Section 2.1 to estimate GHGs emission for the composting process.

2.1 GHG Estimator

A GHG estimator was developed to calculate the GHGs emission during the food and green waste composting in this study based on the model developed by Grant et.al (1999). A few equations were selected as follow.
Eq(1) in the model calculates the emissions based on diesel production:

$$\text{Production emissions (kg)} = \text{fuel usage (kg)} \times [\text{kg } CO_2 / \text{kg fuel}] \times E_{CO2} \quad (1)$$

Eq(2) calculates the emissions due to diesel combustion (Recycled Organic Unit, 2001):

$$\text{Emission}_{\text{combustion}} \text{ (kg)} = \text{fuel usage (kg)} / (19.04 \text{ kg diesel /kg fuel}) \times (62.5 \text{ kg } CO_2 \text{ /kg fuel}) \times E_{CO2} \quad (2)$$

To simplify the calculation, an assumption was made for fuel consumption for transportations that uses petrol of 0.12 L/km. It was estimated that 2.45 kg carbon dioxide is released per kg of petrol (production and combustion combined). All emission estimates were converted to tones.
Emissions from the transportation used such as transporting raw materials to the composting site are based on the mode of transportation, capacity, and distance travelled. Due to the infinite types of transportations, only two truck sizes (15 t and 28 t) were used to estimate emissions for simplification purpose based on Eq(3) as follow:

$$\text{Emissions}_{\text{transporation}} \text{ (kg)} = \text{Distance travelled (km)} \times [CO_2 \text{ (kg)} \times E_{CO2} + N_2O \text{ (kg)} \times E_{N2O} + CH_4 \text{ (kg)} \times E_{CH4}] \quad (3)$$

The duration and type of transportation or vehicle were the two main parameters used to calculate the emissions for the application of compost as end product. Due to the large number of available transportations and vehicle models available in the market today, only two generic tractor engine sizes (145 and 280 kW) and two manure spreader engine sizes (250 and 700 kW) were taken into consideration.
The electricity used by the composting site and electrical equipment (e.g pumps) was considered in the GHGs estimator model. The GHGs emissions from the production of the electricity were determined from the inventory data by Grant et al. (1999). The emission was determined using Eq(4):

$$\text{Emission (kg) from electricity use} = \text{MJ electricity} \times [CO_2 \text{ (kg)} \times ECO_2 + N_2O \text{ (kg)} \times EN_2O + CH_4 \text{ (kg)} \times ECH_4] \quad (4)$$

Three essential parameters were considered in the GHGs estimator mainly involved the emission during the decomposition of compostable organics, fuel usage from transportation and equipment, as well as electricity usage. During the construction of the GHG estimator, a large amount of data sources are used, hence some constraints are presented as follow:

a. Inventory data is collected based on estimated industry averages for energy usage, and in some cases the estimates are based on various sources and numerous journals read;
b. Emissions from the green waste were excluded due to the lack of adequate information;
c. Other benefits of compost applications to soil were excluded due to time constrain to observe and analyse the effect of compost

Emissions relating to the decomposition of feedstock during composting were determined. Carbon losses were based on the results from studies of Jackson and Line (1997) and Jakobsen (1994).
The contributing factors of the increasing GHGs are mainly the carbon dioxide and methane gases, along with several other gaseous components. In the Intergovernmental Panel on Climate Change (IPCC) model to calculate GHG emission from landfills, only methane is taken into account for the estimation of GHG emissions from landfills and carbon dioxide emission is negligible despite its global warming potential (GWP) upon release (IPCC, 2007). This is due to the generic agreement that carbon dioxide from waste decomposition is of biogenic origin and hence does not add to the overall GHG emissions that contribute to global warming (IPCC, 2007).
Organic waste are the wastes that purely contributes to the emission of GHG and different types of organic waste have their own associated degradable organic carbon (DOC) and rate constants which affect the

total amount of emission, and the rate at which it is generated (IPCC, 2007). The rate of emissions can be controlled with strategies such as waste compaction, leachate recirculation (Raimondi, 2014) and even aerobic landfilling (Rusli et al., 2014). A conventional landfill from MSW, from Australian default values, is approximately 1.287 t CO_2/t of waste. Emissions are a result of transportation, excavation, compaction and soil spreading. As opposed to landfill dumping, composting produces approximately 0.0768 tCO_2/t of waste. A fuel consumption of 1,036 L/t waste landfilled for a conventional landfill while WARM, designed by the USEPA (2015) estimated 0.72 t CO_2e/t waste landfilled. McDougall et al. (2001) provided a fuel consumption estimate of 0.6 L/m^3 of void space. In the case of composting, only 36 L/t fuel waste was used due to the short distance between the composting site, waste collection areas and application areas. Hence, it is suggested to build a composting site to be near to the waste collection area, as well as the application areas.
Eq(1) to Eq(4) were then incorporated in the Microsoft Excel 2010 for further computations. The model is built, in the excel-spread sheet to estimate the outputs of the studies including the process costing and GHG emission, in the user-friendly format to facilitate data entry and analyses. Five scenarios were analyses for increased food waste collection within UTM campus, there are termed as Phase I to Phase V.

3. Results and Discussion

3.1 Cost benefit analysis of composting

This study analyses and calculates the costing that includes the transportation, operating, and equipment costs if green and food waste were converted into recyclable materials through composting. The total cost and potential savings for Phase I to V are presented in Figure 1.

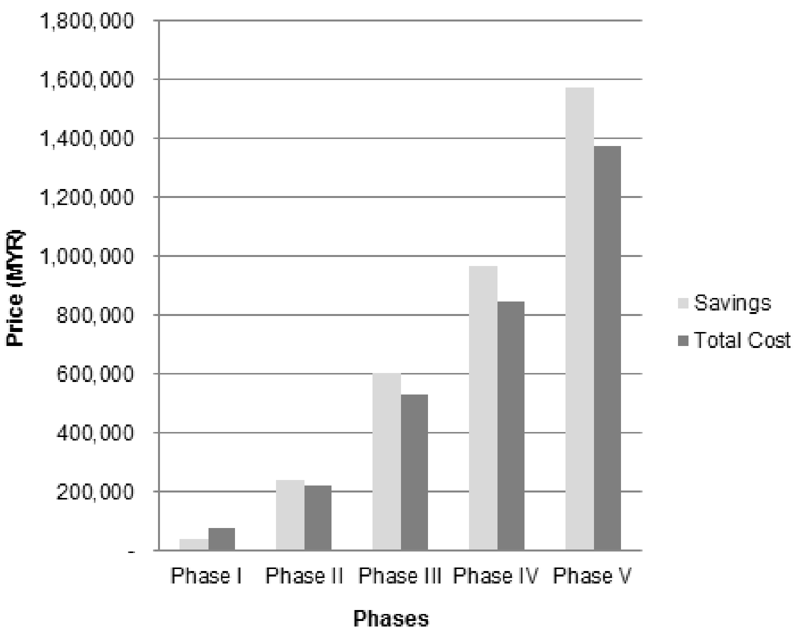

Figure 1: Total savings and cost for the composting for Phase I to V

Based on Figure 1, it can be seen that compost production is able to generate profit after the saving overtakes the total cost needed from Phase III onwards, a benefit harnessed by process-scale economy. This is because most of the raw materials of compost (food and green wastes) are readily available from the campus; the costs of transportation of food and green waste to the site were also low as the costs were co-shared with the existing transportation means to remove other recyclable wastes.
Figure 2 shows the increase trend of potential net profits to be harnessed from different scales of composting from Phase I till V. Savings of chemical fertilizer and the tipping cost contributed significantly to the net profit. For Phase I operation (1,200 kg food and green waste/d), a minimum set-up cost of MYR75,000 was spent to start up the composting project in UTM campus, the cost included site construction, labor costs for daily composting work, fuel for equipment, compost analyses and a site

manager to govern the composting process. Basic analysis on the end compost product indicated that the compost has met the basic quality to serve as a fertilizer for landscape.

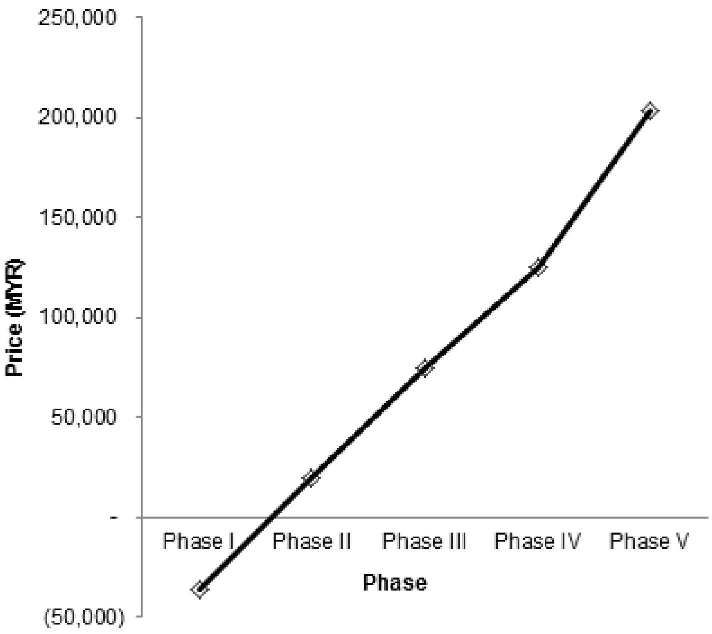

Figure 2: Estimation of the net profit (in MYR) of the composting process for Phase I to V

3.2 Co-benefit of GHGs mitigation of the composting

Based on the in-house GHGs Estimator as developed based on the model described earlier, it was found that the composting process could mitigate up to 90 % of the GHGs emission should all the waste was sent to the landfill site under the business as usual practice. This result strongly supports composting as a green initiative to mitigate GHGs emission at the landfill site and to minimize the environmental pollutions notably underground water contamination due to non-sanitary landfills practices.

4. Conclusion

In summary, this study concludes that conversion of food and green waste on-campus has a good potential to provide net profit by reducing the existing operation costs hence savings for waste disposal and fertilization of the landscape. The revenue is proportional to the scale of composting due to economy scale.

A GHG estimator was developed to calculate the mitigation of GHGs through food and green waste composting against the business as usual practices where all wastes were sent to the landfills. The GHGs estimator considered the emissions from diesel production and combustion, petrol production and combustion, transportation to composting site, application of composted end product, and electricity usage. A saving of 90 % GHGs emission was computed based on the current pilot composting project in UTM campus. This study serves as a pilot case study to promote composting as a green and viable technology for solving the issue of solid waste management in Malaysia.

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