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Economical Smart Composting Machines to Manage Food Waste, Alleviate Environmental Degradation and Combat Climate Change on Penang Hill

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Penang Island, or Pulau Pinang, is one of the most urbanized and densely populated regions in Malaysia. It is undergoing rapid environmental degradation. Simultaneously, a significant culprit for soaring rates of deforestation and severe climate change is inefficient and unsustainable food waste management. Literature reviews have analysed the efficacy of various composting systems that divert food waste to be repurposed and transformed into a value-added soil enhancement. They reveal the superiority of an in-vessel Economic Smart Food Waste Composter. The ESFWC employs a plastic drum to turn compost materials, an automated programming system, and microbial solutions to accelerate the aerobic digestion of organic waste. The ESFWC requires minimal time, cost, labour and GHGs emissions. For this study interviews and questionnaires were conducted with stakeholders on Penang Hill, or Bukit Bendera. It

displays a need for an ESFWC, to reduce the detrimental environmental effects of food waste and also deliver health, economic, social, and environmental benefits for inhabitants of Penang Hill as well as other communities across the globe.

Key words: *Economical mechanized composting, Sustainability, Environment, Climate change, Food waste management.*

Introduction

Waste in Malaysia increased 1,900 tons per day from 2005 to 2009 when it reached 21,000 tons per day. It is expected to continue to rise to 31,000 tons per day by 2020. Ineffective waste management can result in the destruction of valuable resources, increased land costs, and long-term health and environmental problems. As of 2015, only 5.5% of municipal solid waste (MSW) is recycled, 1% is composted, and the remaining 94.5% of MSW is disposed of in landfill.

Food waste in particular impacts the environment, economy, and societal health detrimentally, and continues to be a source of grave environmental concern as the global population and its demand for food soars unrelentingly. Food waste is defined by Thi, Kumar, and Lin as "food losses occurring at the end of the food chain (retail and final consumption), which relates to retailers' and consumers' behaviour" (2015, 220). This can include any "animal and vegetable waste … from making, storing, selling, preparing, cooking, and serving food" (Priyambada and Wardana 2018, 158). Data reveals that "developed" countries with higher living standards generate more food waste than "developing" nations, which could speak to desires for higher quality and aesthetics of food products. However, "developing" countries, labelled as having lower living standards, often face greater challenges in managing food waste because of lack of resources and government intervention in environmental issues (Thi, Kumar, and Lin 2015). But social and economic advancement does not have to coincide with environmental degradation; employing sustainable policies and practices can mitigate the effects of food waste while still allowing living standards and development to prosper. Making up a staggering 50% of MSW in Malaysia, diverting food waste to compost can reduce up to half the amount of solid waste in the landfill (Kamyab et al. 2015; Ohimain & Izah 2015).

Composting is "a natural aerobic biochemical process in which thermophilic microorganisms transform organic materials into a stable, soil-like product" (Schaub and Leonard 1996, 263). Biological decomposition of organic waste has potential to "alleviate the pressure on urban waste management as well as to generate biogas for power generation" (127). Composting hereby solves problems of environmental damage and land scarcity resultant of outrageous

amounts of MSW dumped at landfills that are reaching their maximum capacity (Leung and Wang 2016). In addition, composting can eliminate up to 40% of the volume of organic by-products and create a profitable product (Schaub and Leonard 1996). This final product can also be used to improve soil texture and fertility, thereby terminating the use of synthetic fertilizers in the soil, and increase its carbon storage capacity, further reducing GHG emissions (Mu et al. 2017).

A traditional home composter bin for residential purposes has high risks of poor mixing and aeration because of the requirement of intense manual labour (Lundie and Peters 2005). For this reason, a comparison of the above two industrial composting methods was made to assess a suitable composting method to apply to Penang Hill. According to Waqas et al., a chosen composting method depends on the available manpower, amount and nature of the organic waste, and environmental and economic conditions (2018). In this case, the in-vessel composting system has revealed superiority to windrow systems by its shorter process duration, control of food waste-borne pathogens, and quality of final product for soil amendment (Pandey et al. 2016). However, a conventional industrial in-vessel composter still requires extensive initial investment and resources, and is typically used for much larger amounts of waste material.

Designed and created by members of Universiti Pendidikan Sultan Idris's (UPSI) Computing Department, the Economical Smart Food Waste Composter applies some of the concepts of mechanized in-vessel composting at a smaller, more manageable scale to create a machine that can efficiently and effectively convert food waste into high-quality compost.

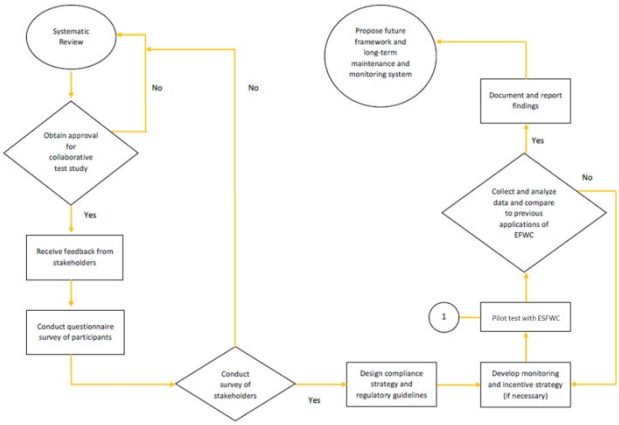
Figure 1. Image of ESFWC Model S1

The EFWC consists of a large plastic drum equipped with a mixer and fan for ventilation and aeration. The EFWC is a semi-automatic machine designed to facilitate and accelerate the composting process of food and plant waste into reusable biological material. Additionally, the machine minimizes energy needs in comparison to industrial composting methods, giving it an even lower ecological footprint. Without utilizing any incineration processes, the EFWC reduces carbon emissions which are characteristic of many industrial composters.

The EFWC appears to be a highly effective composting technology that is most suitable for installment on Penang Hill, to significantly reduce food waste disposal to the landfill, waste collection and management costs, and their urgent environmental consequences.

Methodology

Figure 2. Overview of Study Methodology Flowchart



A. Systematic review

Existing waste management methods

As described in Fig. 2, this study first involved a systematic review of existing waste management methods, and awareness of critical environmental concerns in Penang. The Pulau Burung Sanitary Landfill in Nibong Tebal, Penang has a total area of 62.4 hectares, 33 hectares of which are currently operational and receive roughly 1,800 tons of municipal and non-hazardous industrial solid waste daily. An average of 600 tons of MSW is sourced from Penang Island, with the difference coming from the mainland (Kamaruddin et al., 2016). Projected to last until 2018 before requiring an additional 28-hectare expansion to prolong its lifespan for another decade, a new solution must be found to manage MSW. Of the total MSW collected in Penang, 40-60% is food waste which can be redirected from the landfill to extend its life. Organic waste is also considered the biggest pollutant in landfills since it not only generates methane gas, a major GHG, but it also releases leachate (Khor 2015). A liquid that “passes through the waste refuse and water generated within the landfill site” (3); leachate contains many different pollutants that are toxic when untreated (Kamaruddin et al., 2016).

Waste source and composting site

A focus for the study was sought, a specific area that could be more easily isolated and measured. Penang Hill was proposed and assessed as a potential location, to conduct a pilot test of a mechanized composter's contribution to alleviating food waste. A site of both a biodiverse ecosystem flooded with native flora and fauna, and a bustling tourism and industrial development, Penang Hill, or Bukit Bendera, has undergone rapid change in recent years. The highest and most famous peak on the island at 833 meters tall, Penang Hill's natural water catchments that provide a water supply and prevent soil erosion and landslides are at risk from increasing human activities and development. And despite mitigation works in the past three years to improve the widespread deforestation for housing and infrastructure development, Penang Hill's condition has not seen significant improvement (Connolly 2019). It therefore serves as an optimal location for introducing composting, as an alternative waste management practice, to protect and restore the natural beauty of this landmark. The ability to localize the process from source to end-product further reduces environmental and economic costs. Managing food waste by treating it at the source is an enhanced sustainable approach by minimizing collection and transportation costs (Kamyab et al. 2015).

B. Approval

Approval was obtained from participating parties, such as the PHC and THF, to conduct an initial assessment of waste collection and management on Penang Hill. It was hoped that the ESFWC machine could be implemented subsequently, to manage food waste generated by constituents of the Cliff Cafe.

C. Preliminary community engagement assessment

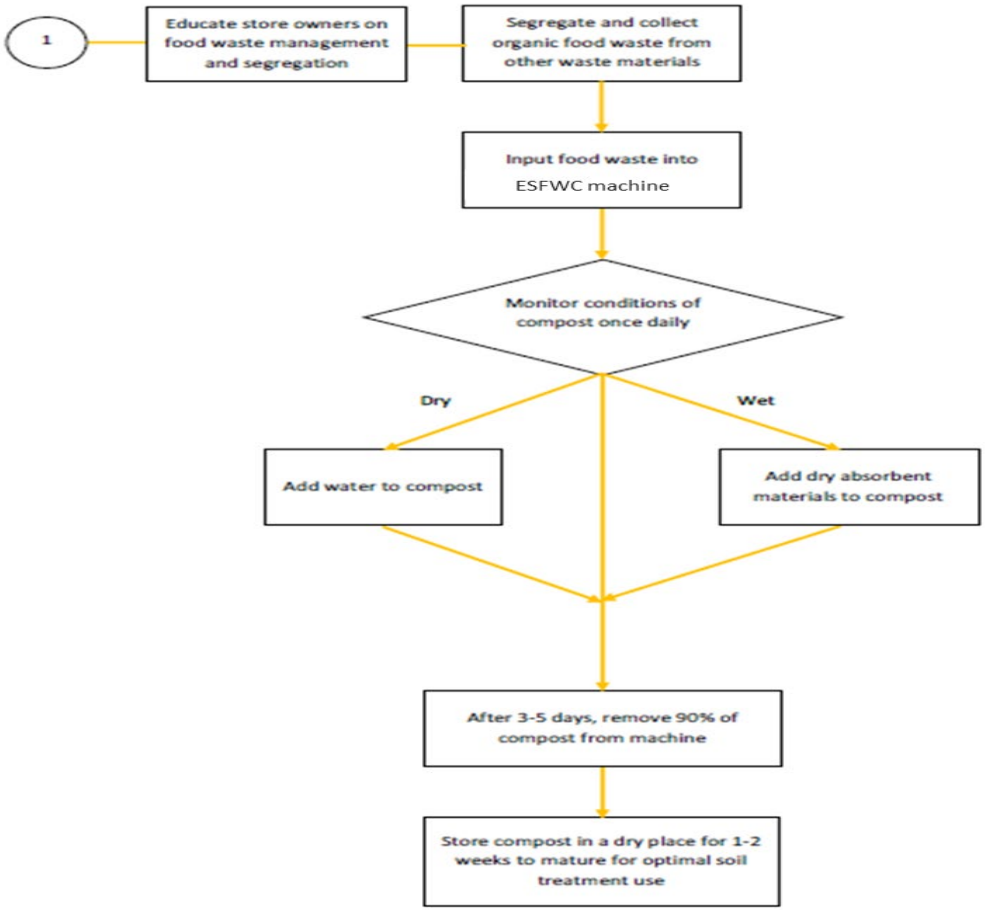
Surveys and interviews were conducted with members of David Brown's Restaurant, the Bellevue Hotel, The Habitat Penang Hill (THPH), PHC, and MBPP as stakeholders of Penang Hill. That determined actionable steps taken to reduce food waste and practice sustainable efforts, if any, and the prospect of implementing the ESFWC. Subsequently, a questionnaire was administered to management of the Astaka Bukit Bendera, to assess their awareness of composting and waste management, as well as their willingness to participate in this pilot test of mechanized composting in this location on Penang Hill. Based on the feedback from these questionnaires and surveys, specific guidelines will instruct participants in the pilot test composting process. A monitoring schedule will require a member of THF to supervise the ESFWC machine and its progress, in decomposing waste during the pilot test. And if overwhelming responses of unwillingness to separate food waste and cooperate in the study are received, an incentive system will be designed to encourage store-owners. The details for the pilot test are described below in Fig. 3.

D. Data collection, analysis, and future directions

Following the conclusion of the pilot test, there will be a data comparison. The data obtained on the efficacy of the ESFWC machine, to reduce food waste disposal and generate usable compost materials for soil treatment locally on Penang Hill, will be compared to data collected from previous implementations of the ESFWC at SMK Jalan Damai and in the Taman Pandan community. Analysis of these measurements will enable the determination of the promise of the ESFWC. That promise is to meet needs, to reduce the environmental effects of existing waste management methods such as landfill disposal or incineration, as well as the efficacy and superiority of mechanized composting over other composting methods. These conclusions may provide pivotal insights and invite future studies to continue research and technological development to progress Penang and greater Malaysia towards adopting sustainable practices as conventional.

E. Penang Hill pilot test

Figure 3. EFWC Implementation on Penang Hill Pilot Study Methodology Flowchart



Prepare participants and food waste

Store-owners within the food court on Penang Hill will be educated on the imperative of improved food waste management and waste material separation procedures, based on the results from the preliminary questionnaire. Once a waste collection system is in place, food waste will begin to be diverted to the ESFWC machine as the main input substances of the composting process.

ESFWC process

An updated custom ESFWC Model S3 with a larger capacity of 50kg of input material, an industrial plastic drum, and enhanced specifications will be installed on Penang Hill. The automatically programmed composting process proceeds for 3 to 5 days, during which the machine turns and aerates the waste materials to expedite decomposition. Further facilitating organic waste decomposition, microbes are added to the waste materials for aerobic digestion to proceed. However, this ESFWC model still requires some human intervention, in manual input of raw materials and monitoring once per day of the composition of the output compost, to ensure an optimal final product for soil enhancement.

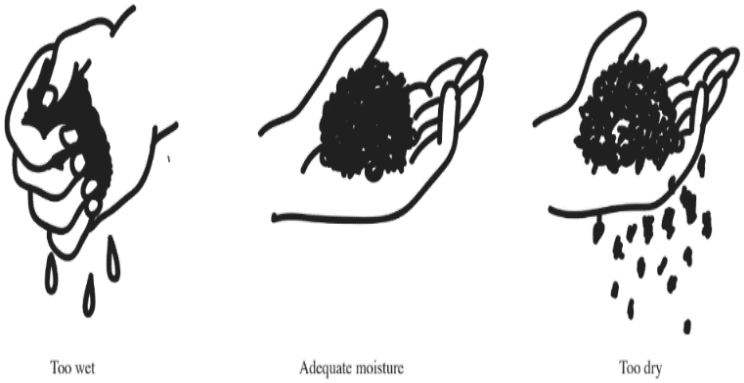
Achieving optimal compost and applications

Although the ESFWC aids in generating productive compost yields, the composition of the waste input still greatly affects the quality of the output (Azim et al. 2017). High-quality compost requires proper control and management, including removing non-organic components in the food waste that result in impurities in the final compost product as well as maintaining a certain pH, carbon to nitrogen ratio (C:N), moisture content, aeration rate, particle size, and porosity (Cerda et al. 2018). The most important factor in composting being maintenance of an oxygen supply, consistent and adequate aeration is key to efficient microbial activity. Aeration is important for both promoting microbial growth and minimizing gas emissions (Li et al. 2013). Aeration occurs naturally at higher temperatures that ease warm air leaving and cooler air entering the compost, but it can also be facilitated by turning the material to provide sufficient oxygen through reversing the air flow into the compost pile (Priyambada and Wardana 2018).

To avoid strong odours and achieve optimal compost, a high carbon to nitrogen ratio (C:N) of roughly 30:1 to 40:1 is sought. The ratio is generally most effective in providing microbes with enough carbon for energy and nitrogen, for protein synthesis during the degradation of organic waste. Additionally, consistent temperatures within 30-60 °C must be maintained and monitored (Priyambada and Wardana 2018), and optimal decomposition by microbial activity occurs at a moisture content of about 55% (Jouhara et al. 2017). Particle size and porosity are

also important and interdependent: reducing particle size increases the surface area available for microbes to decompose, and creates sufficiently sized pores to permit air and water to spread evenly throughout the compost, accelerating the aeration and overall composting process (Priyambada and Wardana 2018).

Figure 4. Illustration of compost product consistencies



Determining compost consistency during daily monitoring can inform both the progress of the decomposition and the need to add supplements to the compost. Illustrated in Fig. 4, if the substance feels wet to the touch and excretes strong odours and liquid when lightly squeezed, dry absorbent materials such as dry leaves and trimmings must be added to the compost. On the other hand, if the substance feels dry and crumbles easily in the hand, water is needed to moisten the compost to be able to mould and stick together.

After compost consistency is optimized, roughly 90% of the substance will be removed from the ESFWC to be stored for further maturation. It can be a natural soil fertilizer within The Habitat Penang Hill's nature walk, and in various other green spaces on Penang Hill. Compost could also be supplied to the Penang Hill Middle Station farming community, to support their food production. The 10% of compost remaining in the ESFWC will then be used in the next cycle to stimulate decomposition of the new organic waste. From this, the composting system can continue to convert food waste into soil fertilizer in a natural recycling process.

Results

A. Penang Hill Corporation

The Penang Hill Corporation oversees all development on Penang Hill, to maintain and evolve the hill to be a world-renowned eco-tourism site. With this role, the PHC strives to improve and innovate Penang Hill to not only sustain visitors and residents, but to also sustain the natural environment of the hill itself and its habitat for native flora and fauna. The PHC has therefore noticed that as Penang Hill attracts more tourists over the years, it has simultaneously invited more waste production: what used to be a few garbage bags per day of waste that was burned has increased to one pick-up truck per day. Now, two full-sized lorries must drive up and down the hill to collect and transport waste per day.

B. Majlis Bandaraya Pulau Pinang

This is an admirable approach to managing and recycling food waste into compost. However, it is not the most efficient, effective, or longstanding food waste management method. In particular, the amounts of waste that will need to be handled in the present and in future years will only increase. A critical part of optimizing the collection of food waste by MBPP would also require accurate waste segregation at the source. This would enable food waste to be simply and quickly diverted for repurposing into compost and recyclable plastic, aluminium, glass, and other materials to be directed to recycling centres rather than general waste disposal sites.

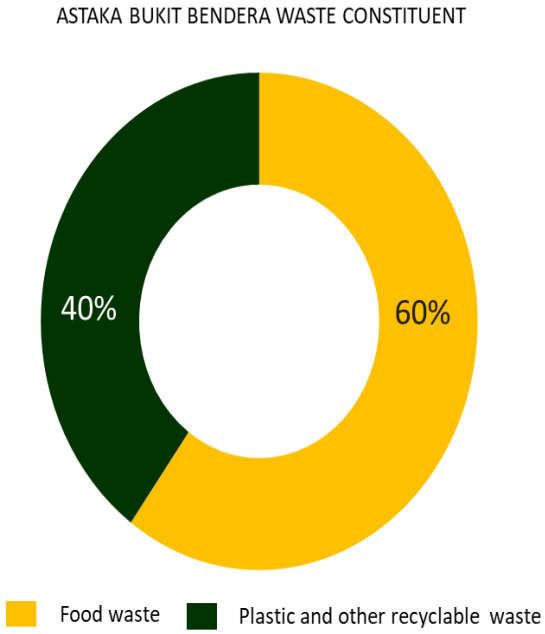
C. Food waste generation on Penang Hill

The Bellevue Hotel separates and recycles their waste materials, which largely consist of food waste and plastics. Kitchen food waste is either composted or fed to the animals that reside at the hotel or at their estate in Balik Pulau. Another significant portion of waste collected at the hotel is made up of dry leaves, which are reused in the soil of the hotel's garden spaces. Manually composting food waste at the Bellevue Hotel has also been met with challenges as stray dogs and cats are attracted to general garbage waste, and the smell of decomposing food waste. So despite well-intentioned attempts to recycle and compost food waste, these open-air processes do not have the protection and monitoring required to maintain them, forcing the Bellevue staff to avoid leaving compost piles to sit overnight.

David Brown's Restaurant, on the other hand, has a well-established traditional composting system. It consists of a few compost piles that utilize egg shells, coffee grounds, fruit and vegetable skins and scraps, grass, and leaves to produce fertilizer that is used on site. These compost piles are likely safe from the animals that threaten the Bellevue Hotel, because David Brown's sits on an elevated tip of Penang Hill that is less accessible to roaming strays. This has enabled the success of their composting system. But this manual process still requires that the waste materials rest for at least six months, during which the compost is manually turned once every two weeks to mature, and to produce usable soil fertilizer.

On the other hand, The Habitat Penang Hill employs other sustainable practices to manage their waste, which consists almost entirely of dry leaves from the park. Coinciding with THPH's mission of promoting biodiversity and environmental conservation, every morning the nature trail is blown. Leaves are collected and stored for approximately one month until they are subsequently shredded, to accelerate their biological degradation, before being spread onto the soil as a natural mulching layer. Additional waste produced by THPH consists of coffee grounds, residual food waste, and recyclable materials at The Habitat's food and beverage cafe. The coffee grounds are often provided to the landscapers of THPH to use with the dried leaves in the soil at the park.

Figure 5. Pie chart illustrating the major constituents of waste generated by the Astaka Bukit Bendera



Finally, the Astaka Bukit Bendera management has observed high amounts of food waste. Penang Hill only continues to grow as a tourism hub, welcoming both local and foreign visitors alike who consume food from these stalls and discard much food that is wasted. It was also reported that the food complex produces up to twenty bin bags of waste per day, comprising approximately 60% food waste, as described in Fig. 5 above. Additionally, although there are recycling bins on the hill, most recyclable materials, especially plastics, are combined in general waste disposal bins rather than separated.

Discussion

With the goal of encouraging more tourism, the caretakers of Penang Hill cannot control or restrict food waste at the individual consumer level. Instead, waste must be monitored and organized by management, to ensure participation in a structured waste collection and composting system.

It is a positive sign that composting methods have already been employed at multiple locations on the hill. However, sustainability in the long-term could also be impeded because of an insufficient workforce and space, to manage the amounts of food waste collected on the hill, given that the manual composting process can take up to a year to complete. The shortcomings and problems encountered by the Bellevue Hotel, David Brown's Restaurant, and the pre-existing community composting site, reveal the need for a contained and accelerated composting system to more quickly and effectively transform waste on Penang Hill. This reveals the promise of a mechanized composter to consolidate the space, resources, and labour required to produce compost from food waste in a minimal amount of time, to maximize the turn-over rate of the entire waste collection and composting process.

Furthermore, the rich stabilized organic matter in compost improves plant growth through soil fertilization compost. Other benefits of compost for the soil are the compost's water holding capacity that can increase soil moisture content, and its ability to lower the soil pH, partaking in making required nutrients available for plant uptake, and acting as a biopesticide by inhibiting plant and soil diseases and pathogens (Waqas et al., 2018).

Conclusion

Food waste is a pressing worldwide concern that has often been regulated by various composting systems as alternative waste management methods. Mechanized in-vessel composting in the form of the Malaysian-invented and designed ESFWC machine has proven to be a successful economical and sustainable composting system. It reduces costs, GHG emissions, energy, resources, and labour, while still generating a value-added product that further facilitates the environmentally sustainable growth of urban green spaces. For these reasons and the success of past implementation of the ESFWC in significantly contributing to reducing food waste and returning balanced organic content and moisture compost, the ESFWC is proposed as a matchless addition to Penang Hill, which is open to such a solution, to locally manage food waste and conserve the beauty, history, and natural environment of this iconic Malaysian treasure.

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