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Environmental Performance Evaluation on Potential Biological Treatment of Food Waste at Higher Educational Community, University of Malaya

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Abstract

Purpose - The purpose of this study is to evaluate the environmental impact of organic fraction municipal solid waste treatment techniques, namely composting and anaerobic digestion by using the Life Cycle Assessment approach

Design/methodology/approach – This study used Life Cycle Assessment approach concerning a facility located at Zero Waste Campaign, University Malaya for a period of one year in 2018. SimaPro 9 software was used to analyze the result from organic waste between anaerobic digestion using Cowtec machine and aerated static pile medium-scale composting. ReCiPe method was used as it implements both midpoint (problem oriented) and endpoint (damage oriented) impact categories.

Findings – Three main impact categories were found in anaerobic digestion that is acidification potential (7.83Ekg SO_2), climate change (2.79E+02kg CO_2), depletion of abiotic resources in fossil fuels (1.31E+04MJ). Whereas, for composting, the three main impact categories resulted were eutrophication potential (4.72Ekg PO_4), freshwater aquatic ecotoxicity (3.06E+06kg 1,4-dichlorobenzene), and marine aquatic ecotoxicity (11.95E+09kg 1,4-dichlorobenzene).

Research limitations/implications – The case study used a combination of Eco-Invent 3.2 Database and open literatures to fill the gap of inventory input of the method due to the limitation of inventory information on organic waste treatment in Malaysia.

Originality/value - The investigated research setting is considered unique as the results of this study act as a basis for policy-makers to highlight the importance of acquiring significant data on elementary flow of potential environmental impact. Moreover, this study would performed as indicator to fulfill the gap of knowledge on adapting integrated sustainable waste management that tackles the main four key pillars (social, economic, technology, decision-makers) to achieve environmental sustainability.

Keywords Food Waste, SDG 11.6, SDG 12.3, SDG 13 Climate Change Potential, Life Cycle Assessment, Anaerobic Digestion, Composting.

Introduction

Malaysia is prominent for its diverse culture and complex dishes that yields multitude of flavors. However, the abundance of different cuisines with each signifying Malaysians cultural identity served to many guests in celebrations and festivities leads to an ugly culture of food waste. With the ever-increasing population of 32 million in Malaysia, the total municipal solid waste amount generated were expected to increase at 31,000 tons daily with a generation yield range from 0.5-0.8kg/person/day to 1.7 kg/person/day in urban cities by the year 2020 (Kathirvale, et al., 2003; Manaf, et. al., 2009). The food leftovers contributes approximately 44.5% (37,890 tonnes) of solid waste composition in landfills which has detrimental effect towards environment, economic and even the religious implications as increased trends were recognized during the festive season ([1,2]SWCorp, 2019). It is widely known that the Food and Agriculture Organization (FAO) of the United Nations reported approximately 1.3 billion tones of food is either lost or wasted annually worldwide. This amount corresponds to a third of all food resources produced for human consumption. Sources of food waste could originate from household, commercial, industrial and agricultural residues, while the compositional food waste matrix varied broadly according to source and type (Xue et al., 2017). FAO defined food waste as "food losses of quality and quantity through the supply chain process taken place at production, post-harvest and processing stages".

The surplus amount of avoidable food waste can feed up to 12 million per person triple times each day, and it has been recorded that 4,600 tonnes of avoidable food waste recently recorded in Malaysia. A study conducted by SWCorp had investigated 8,861 kg of food leftovers in ten market bazaar involved during festive Ramadhan season ([3]SWCorp, 2019). A total of 170 waste disposal sites were recorded by the year 2016 and only 14 had the status of sanitary landfill in Malaysia (Agamuthu et al., 2012) and in 2000, US EPA had estimated the landfill emissions single-handedly contributed 36.7 million tons of anthropogenic emissions of methane (Ren et al., 2017). While the lack capacity in terms of costs, technology and energy was fully aware by the Malaysian authority, it was deemed difficult issues and challenges to completely address the environmental problems and forthcoming impact of natural calamities. Society must share an equal responsibility to tackle the issue and protect the environment, as the natural resources in the world are of limited supply (Li et al, 2019).

In a nutshell, most FW is being disposed of through landfilling, composting or fermentation. Although European Union guidelines had stated food waste should preferentially be used as an animal feed, it became illegal due to disease control concerns (Salemdeb et al., 2017; Cerda et al., 2018). Moreover, a study by Joshi and Visvanathan, 2019 had concluded between the five prevailing treatment in Asia, animal feeding, incineration and landfilling are deemed to be unsustainable due to hazardous threats to health and environment. It was further concluded that anaerobic digestion was more preferable than aerobic digestion (composting) considering the food waste characteristic in Asia including the underlying environmental and economical benefits. Furthermore, the society in Malaysia are prone to accept the decentralized, community-scale, anaerobic digestion system compared to centralized, large-scale system due to smaller energy footprint, simple operation, lesser resources necessity, smaller operation and maintenance costs, and better chance for public acceptance. In order to promote anaerobic digestion and sustainably manage food waste, a larger driving force in policy must be gained from the efforts to segregate food waste. Hence, the policies and technological drivers to manage food waste sustainably in Asia should shaped the commitment to national and international development goals, their socio-economic constraints, and their recognition of the potency to recover nutrients and energy from food waste. The streamline 3R concept (Reduce, reuse, and recycle) of the existing food waste management policies and scrutinize the gaps and challenges faced had led to most countries prioritize in food waste segregation and treatment instead of prevention at source by itself.

Figure 1 Sustainable Food Waste Management Practices in Asia

Sustainable Development Goals (SDGs) of United Nations

A total of 193 members in the United Nations (UN) were formalized in September 2015 that targets an ambitious agenda for 2030, which include the establishment of 17 sustainable development goals (SDGs) to achieve economic growth, social integration and environmental protection (UN Department of Economic and Social Affairs, 2015). There are a few SDGs target in relation with municipals solid waste, and exclusively affects indirectly to food waste. For Target 11.6 specifically addresses the issue on food waste challenges through stating that by 2030, the adverse per capita environmental impact of cities must be reduced, including by paying special attention to air quality, municipal and other waste management. In line with the above targets, it is necessary to provide cities and human settlements in Malaysia with adequate infrastructure, inclusive, safe, resilient and sustainable in the future acute challenges such as waste management to support booming growth populations, confront the environmental impact of urban sprawl and to reduce vulnerability from disasters. Besides that, under Goal 12, defined as 'Responsible Consumption and Production', and particularly target 12.3 also provides explicit concept of food loss and waste (FLW) management by 2030, "halving per capita global Food Waste at the retail and consumer levels and reduce Food Losses along production and supply chains (SC) including post-harvest losses" (UN Department of Economic and Social Affairs, 2015). For EU, the context under the Circular Economy Package, a programmes of zero waste was established in 2014 (European Commission, 2014), which in 2018, was followed up by revised EU Waste Legislation (European Union, 2018) and called upon its member states to pursue actively in monitor and reduce food waste at each supply chain stage.

Food waste system also had taken effect on the climate change crisis, thus SDG 13 could assist the framework for climate change actions in the United Nation for Climate Change (UNFCC) negotiations (Porter et al., 2014; Vermeulen et al., 2012). By the year 2050, the world population is expected to grow to 9.7 billion; as a result, an increase in food demand to accommodate the population growth would aggravate the competition for natural resources, deforestation and land degradation. For this reason, achieving SDG 13 would require many actions for adaptation and mitigation in food waste systems since the global climate temperature had increased by 2°C. A major challenge is that food waste systems are linked to many SDGs and are likely to be trade-offs amongst SDGs through food system actions (Canavan et al., 2016; Doberman, A., 2016); with trade-offs specifically challenges in developing countries where climate change vulnerability would be highest.

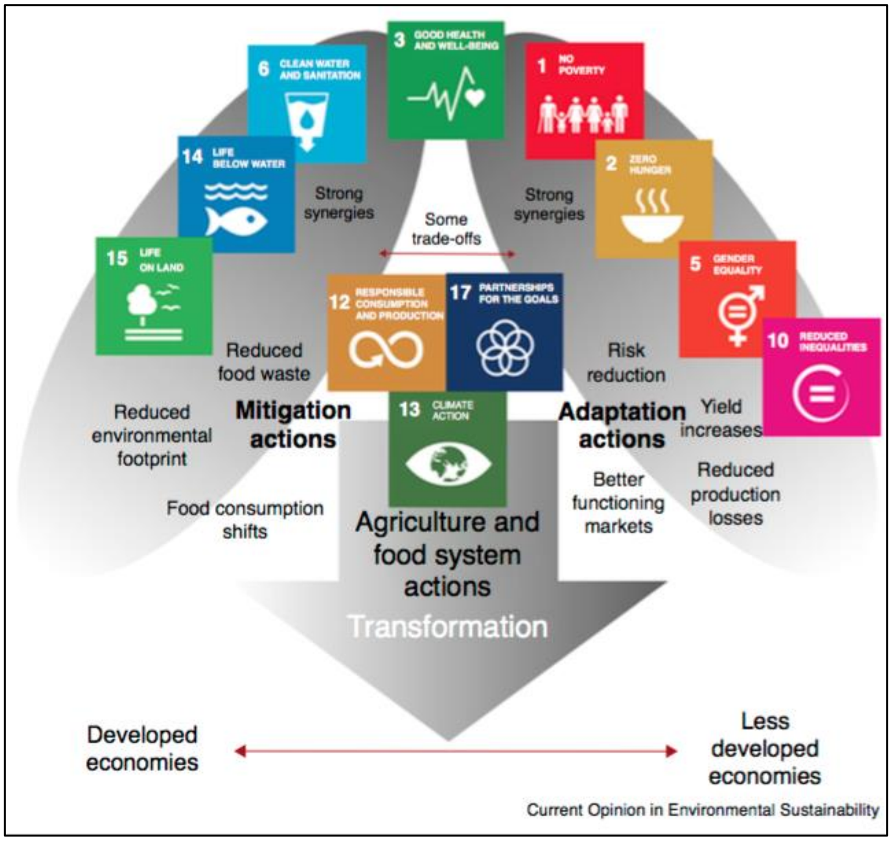


Figure 2 Relationships of Climate Change Actions in the Food Waste System to Sustainable Development Goals

The flourish numbers of academic literature also reflects the booming attention on food waste that evaluates the root causes, monitoring the performance and its management (Corrado and Sala, 2018, Schanes et al., 2018, Cristobal et al., 2018). Life Cycle Assessment (LCA) is one of the computer-based tool used in this study to estimate and compile the input, output and environmental impacts caused along the product's life cycle. LCA approach has been widely practiced in Asian and European countries, namely Italy (Arena et al., 2003; Cherubini et al., 2009, Cherubini, 2008), China (Hong et al., 2006; Zhao et al., 2009), India (Srevastava and Nema, 2011), Turkey (Banar et al., 2009; Cetinkaya et al., 2018), Thailand (Menikpura et al., 2013), Malaysia (Saheri et al., 2012) and even Singapore (Khoo, 2009). Studies employed in the economic literature on the short-run and medium-run for the quantitative impacts of food waste minimization, especially focuses on a system-wide macroeconomic simulation approach recognizes the direct impacts along different food chain stages and eventually results in the ripple effects for the wider macro-economy. Since food waste has the potential as a valuable resource if discarded properly, this means the treatment technology and the utilization of the recycled product based on sustainable criteria are vital.

Hence, this study would assist in the following objectives:

1. To gather the baseline data of information of the current practice of food waste management in higher educational community at University of Malaya.
2. To quantify and evaluate the environmental impact of food waste treatment in higher educational community at University of Malaya, namely anaerobic digestion and aerobic composting treatment using the Life Cycle Assessment (LCA) approach.
3. To formulate the policy framework for implementation of food waste treatment practice in higher educational community at University of Malaya.

Anaerobic Digestion

For anaerobic digestion treatment, it is related to a series of process in the absence of oxygen via breaking down the microorganisms of biodegradable material. It is commonly used either through managing of waste or producing energy for industrialized or domestic purpose.

The one-stage continuous anaerobic digestion system was used in Zero Waste Campaign (ZWC) site at University Malaya. For single-stage digesters, the simple built-in design and operation were inexpensive and most preferable technology for organic waste treatment accepted by the higher educational institution community of University Malaya. There were four degradation steps involved, namely hydrolysis, acidogenesis, acetogenesis and methanogenesis. The accurate microorganisms undertaking these processes have different necessities on ecological circumstances and cohabit in synergic concoctions. The rapid organic loading rate for single-stage digesters limited by methanogenic organism's ability to tolerate a sudden pH declined are convenient for the ZWC site selection. Moreover, anaerobic digestion process would produce digestate, as the nutrients quality is higher in digestate compared to an untreated organic waste. The nutrients (N-P-K) in liquid digestate are mineralized to allow the improvement of plant nutrient uptake and can be used to enhance the soil structure due to the organic matter's application, including minimizing the soil disturbance (Monnet, 2003).

Composting

Compost treatment process is the most natural way to biodegrade the organic waste such as food waste, leaves, grass trimmings and crop residue as they can naturally recycled by the Earth's soil (Aja & Al-Kayiem, 2014). On contrary to anaerobic digestion, composting is an aerobic treatment method where the compost product is decomposing the organic matter and being used as fertilizer and soil amendments in gardens, landscapes, horticulture and agriculture applications (ASABE & Home, 2013). The decomposition process in microorganism, for instance bacteria, fungi and actinomycetes can be described as the most decayed process taken place in the pile. In general, there are three methods of composting process, namely, windrow composting with turning, aerated static pile and in-vessel composting.

Windrow composting has been the reputable practice for a large scale composting worldwide and was implemented at ZWC site with the support of the University of Malaya top management and their operative staffs. It was carried out in piles with the following dimensions of three to five meters in width, two to three meters in height and up to hundred meters in length. These piles must be kept in high temperature to allow the oxygen flow to the core center. A unique manual-turn had made significant impact factor to heat release while exposing the anaerobic volumes to oxygen and are equipped with watering hose-attachments used to regulate the moisture levels. Advantage for this windrow composting is the low expenses compared to other technology which is practical to the higher educational institution of University of Malaya. The only main disadvantage is to control this specific difficult process and requires careful management. Effects can be the uncontrollable, undesirable emissions and odors.

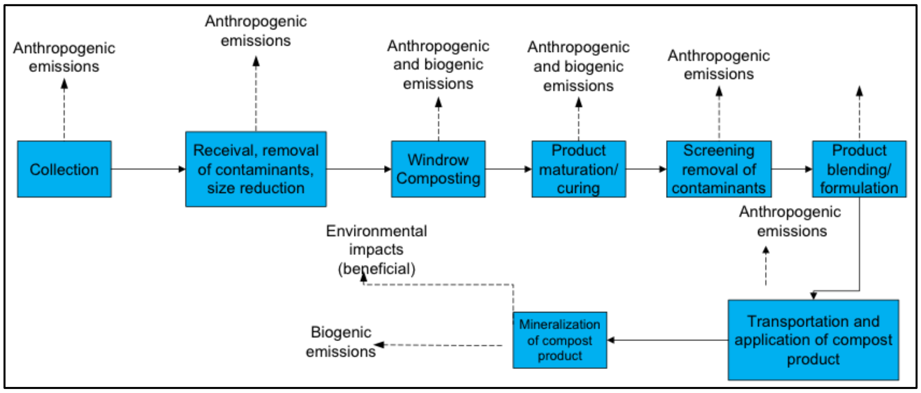


Figure 3 Windrow composting flow chart (Directive, 2011)

Methods And Materials

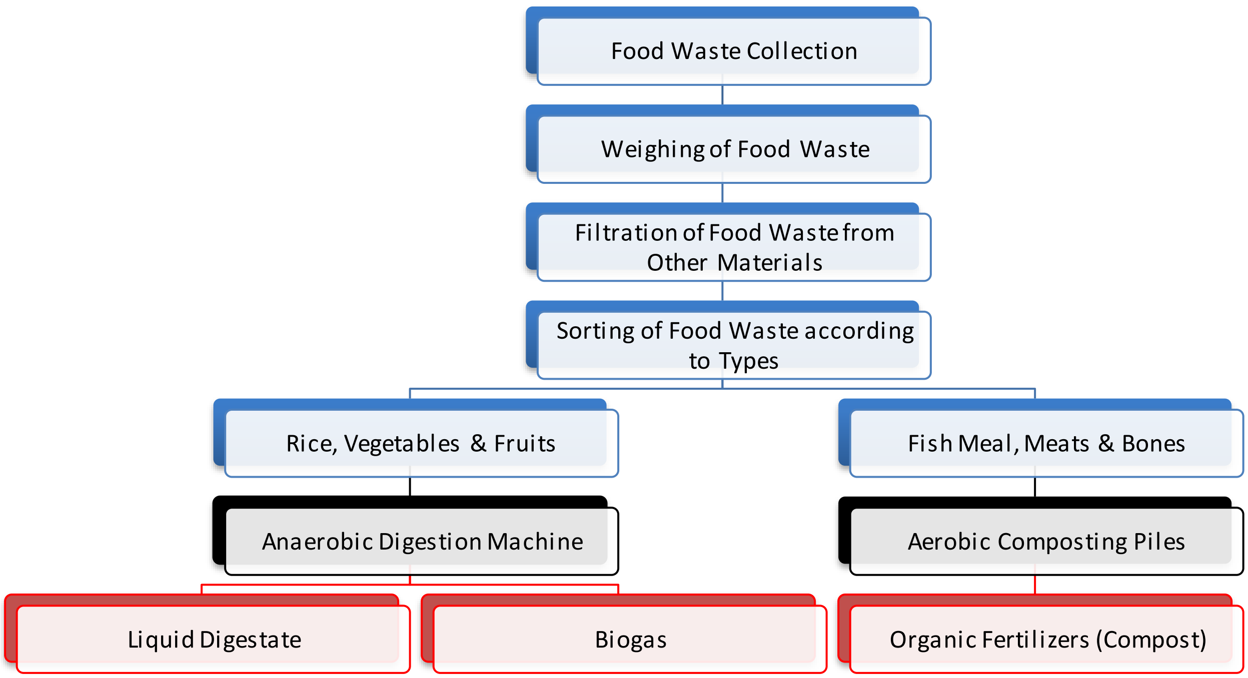
Conceptual Framework

There is a requirement to build a comprehensive detailed assessment to determine a feasible holistic approach in waste management especially for developing countries such as Malaysia. Most food waste focused LCA research has been performed in concentration under European settings (Laurent et al., 2014). As food waste prevention and treatment with technologies decrease the environmental impact are highly considered as means to achieve more sustainable global food and waste systems. Policies addresses the sustainable food waste management is being recommended and performed, especially in Malaysia.

LCA is a system assessment tools that quantifies the potential environmental exchanges and impacts of system processes. Outputs include indicators that simplify and organize inventory results as more comprehensible terms (Owens, 1999). Impact categories assessed were climate change, environmental eutrophication and acidification, resource depletion and stratospheric ozone depletion, which tackle the challenges in the SDG targets. Waste systems in LCAs would quantify impacts of interconnected waste management technologies, from generation to final disposal/treatment based on a specified waste composition, and so allow for comparisons between options (Manfredi and Pant, 2013). A normalized aggregated impact assessment was created to compare the treatments across categories.

Two alternatives were focused on this issue; namely, open aerated windrow composting and anaerobic digestion were studied. Hence, this paper aims to quantify the environmental impact of organic fraction in municipal solid waste treatment, particularly composting and anaerobic digestion of food waste in the higher institution using Life Cycle Assessment (LCA). Eco-Invent version 3.3 Database in SimaPro software version 9 was chosen to represent the plausible management practice in higher educational institution community at University of Malaya, Malaysia.

Figure 4 below would illustrate the overall food waste collection and treatment process at Zero Waste Campaign (ZWC) at University of Malaya producing three different states (Liquid, gas and solid) of by-products (Highlighted in red).



Nonetheless, there is a transparency in the study for criticism as there are reality simplifications. A few methodological options and several aspects may need to be improved in order for the holistic approach towards the best management practices implemented in Malaysia. It is vital to assess and benchmark information such as EU guidelines, open and grey literatures, any relevant environmental indicators and databases for waste sectors and easily available data in decision-making process for waste management policy.

Data Collection

University of Malaya is located at the heart of Kuala Lumpur and Zero Waste Campaign (ZWC) site was the food waste management center derived from the aforementioned higher educational institution in Malaysia. The emission data was majorly in the form of gaseous form and leachate collection. Water, electricity and fuels were used indirectly in composting treatment (operational activity such as cleaning, grinding and shredding). The input and output material were recorded to perform the LCA study. The Life Cycle Inventory (LCI) data covers all consumptions and emissions of environmental importance (Capp, 1988). For this study, only the direct emissions from anaerobic digestion and composting processes are taken. The given LCI form of constructs act as a basis for environmental assessment in these treatment process at the institutional level.

Each upstream impact in this LCA study was assumed to be of equal and excluded from analysis. The life cycle of food waste begins after disposed in trash bins and finally ends with the waste material decomposed or returned via treatment of composting and anaerobic digestion. The typical chemical elements in the organic municipal solid waste comprises of carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), and nitrogen oxide (N_2O). Pollutants evaluated were only as elementary chemical and considered as avoided or negligible emissions. Hence, the fate of the chemical compounds was excluded from this study.

In order to achieve the objective of this study, the organic municipal solid waste (OMSW) at University of Malaya (UM) comprised of food waste (FW) and yard waste (YW) only. All the food waste materials are collected from 15 different eating-places resides at UM, whereas, all yard waste materials are collected from the landscape excess primarily made up of dried leaves, small trunks, branches and grass clippings around the UM campus ground. After that, the yard waste was shredded using a shredder machine and mixed thoroughly in the composting pile. The sampling is then taken for elemental analysis (Guan, 2015). Other raw background data recorded such as electricity, fuel and water consumption used for shredder machine, grinder machine and cleaning respectively. The LCIA study from this food waste management at higher institution was lead to establish a site-specific data and background data. The functional unit for this study is within a period of one year of food waste generation at higher educational institution community of University of Malaya in 2018.

System Boundary

System boundary is a connected operation gathered together performing a definite function. In general, the main life cycle stages in typical LCA consist of raw material collection and process, product manufacturing, distribution, use, reuse and finally disposal. Each life cycle stages can be developed into sub-stages or sub-processes series and each breakdown level will alter the natures of available data. Ideally, the better the breakdown level is feasible, the better the transparency of study.

Figure 5 below shows the system boundary of anaerobic digestion treatment at Zero Waste Campaign (ZWC), University of Malaya

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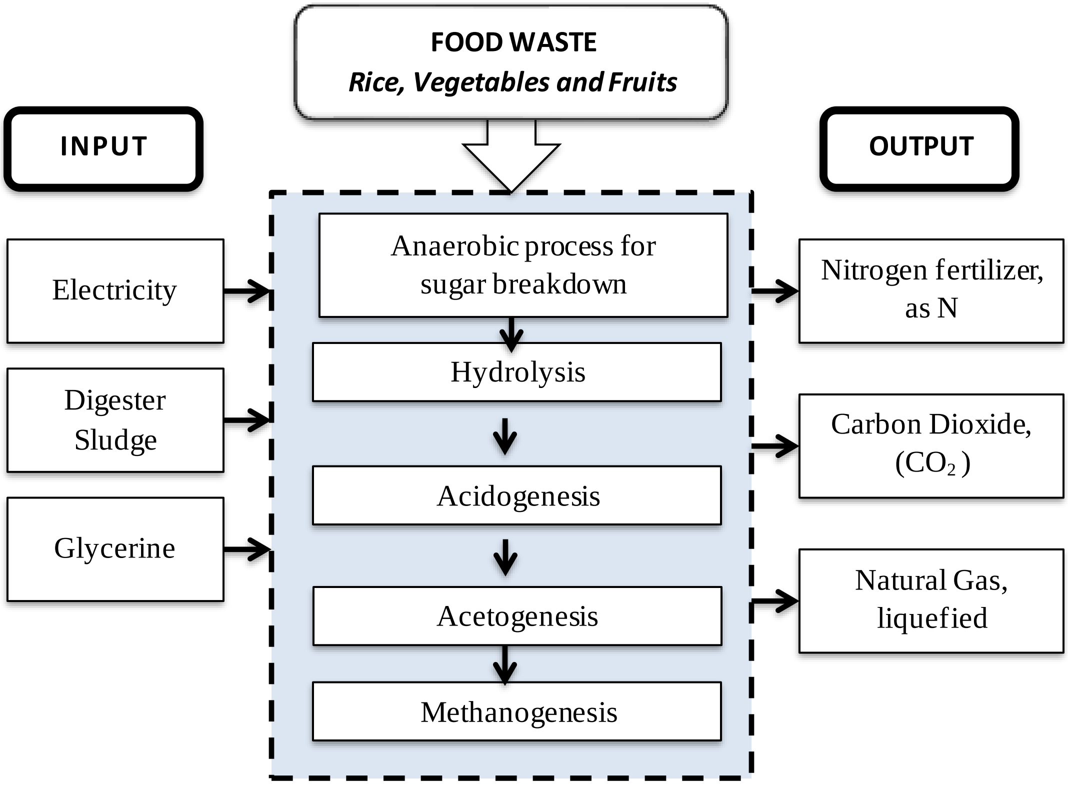

Figure 6 below shows the system boundary of aerobic static pile medium-composting treatment at Zero Waste Campaign (ZWC), University of Malaya

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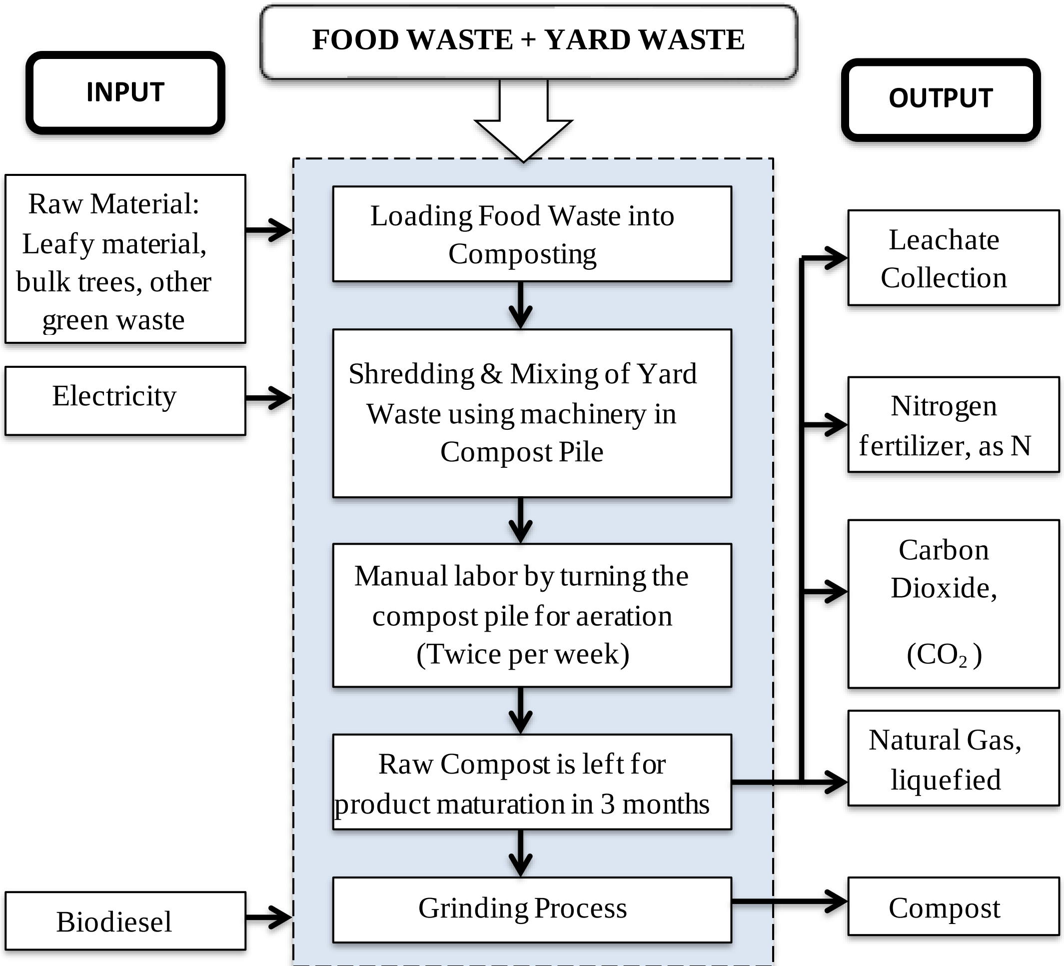


Life Cycle Inventory

A combination of primary and secondary data was used for the system's life cycle inventory (LCI). An energy and mass balance model (EMB) was developed to generate inventory data related to energy use and production, water use and GHG emissions during the AD and composting processes in the foreground system. Data used to develop this model was obtained from the thesis study done by Guan, 2015 and ZWC annual report data in 2018 for the higher institutional community-based composting system (corresponds to a functional unit of 1 kg FW collected and treated). The inputs were categorized according to the sub systems. Inputs to the composting system include energy, water, and auxiliary materials required throughout the scope of the study. The outputs quantified were associated to direct gaseous emissions mainly from the composting operation, diesel combustion used in the machinery as well as disposal of rejected solid waste from the composting system. Despite that, the vehicles transportation and facility construction were excluded.

i. Organic waste

Organic matter decomposition rates in AD and composting, and associated methane production and heat generation rates, were estimated from the carbon mineralization potential of food waste and green waste mixtures on a kg total solids basis ($C_{T,}$ g CO_2-C/kg TS). Carbon mineralization potential ranged from C_T=1100 g CO_2-C/kg TS for a feedstock consisting of food waste entirely to C_T= 200 g CO_2-C/kg TS for a green waste feedstock (Fernandez-Bayo et al., 2018). While AD facilities often report 100% capture rate for methane, since the reactor can be a sealed vessel, there is some uncertainty associated with this assumption. For this reason, fugitive emissions from the anaerobic digester were assumed to be 1.5% for the digester and gas processing (Lijo et al., 2014).

Data that were not generated in the EMB model for the background systems were derived from LCA databases, such as US Life Cycle Inventory (LCI) Database and previous studies (Wang, 2016; NREL, 2016). Biogenic carbon dioxide emissions due to biological respiration from the foreground system were tracked to monitor the influence of waste composition and AD time on emissions.

ii. Anaerobic Digestions

For material separation, it was assumed that organic waste was transported from the trucks to a RoRo bins where non-recyclable materials were removed from waste, and then ground prior to being sent to the AD process. LCI data for equipment operations emissions and energy use were selected from the GREET 2016 model (Table 1). The AD process of the facility consisted of one 120 m^3 (31700.6 gallon) in-ground reactor. Organic waste was anaerobically digested in mesophilic (35°C) and high solid conditions (Yazdani et al., 2012). This high solid conditions negates the energy-intensive wastewater treatment that would otherwise be required for a low-solids digester and provides lower moisture digestate more directly compatible with composting. The waste composition was comprised of food waste and green waste and was varied in the model based on food waste to green waste ratios from 100% green waste to 100% food waste. Water was added as needed, based on entering moisture content of the organic waste, as well as heat to the reactor to maintain mesophilic conditions. Primary data for the anaerobic digester process, including biogas production, were modeled with the EMB model and were dependent on the organic waste composition.

iii. Composting

For the downstream processing of digestate, the solids were composted on site using an aerated static pile. The pile was supplied with airflow using per standard composting practices to maintain temperatures between 50°C-70°C. Composting time was determined by completing compost to maturity and pathogen reduction based on temperature and respiration data, where temperature was maintained at 55°C for a minimum of three days and respiration was less than 100 mg O_2/kg TS-hr (CA Regulations Title 14, Division 7, Chapter 3.1). The model estimated water loss and the water additions needed to maintain optimal moisture content in the compost (50-60% moisture content, wet basis). For composting, a well-managed site and well-aerated compost pile were assumed, thus there were no emission to water or air that would be of concern, which included NO_x, N_2O and VOCs (Horwath et al., 2015).

iv. Credits for excess electricity and compost

Electricity generated from the biogas during AD and compost generated were treated as co-products from the system and were assessed using system expansion (Heimersson et al., 2017). System expansion assumes co-products generated from the system will displace other substitutable products in the market and avoid their respective environmental impacts (Weidema, 2000). Compost was assumed to displace synthetic fertilizers and surplus electricity generated was assumed to displace electricity from the California grid mix. The electricity displacement calculation was simplified to replace an equal amount of electricity from California's energy grid, based on GREET 2016, rather than displacing energy or electricity from a specific source, for instance, natural gas from fossil sources, since California's energy grid is a mixture of renewable and non-renewable energy sources. This was done because the captured biogas was converted into electricity and heat on-site before introduced to the grid, rather than simply used as natural gas for heating or other purposes. Fertilizer displacement by compost production was calculated on a per plant available nitrogen basis to compare compost as a fertilizer with ammonium-nitrate commercial fertilizer, based on GREET 2016, and nitrogen compositions of composted digestate were based on prior literature (Wang, 2016; Rigby and Smith, 2011).

Impact Assessment

To evaluate the environmental burden and benefits, the impact assessment was carried out using the LCA software SimaPro version 9 and ReCiPe 2016 Midpoint (H) was used. The basis for comparison of AD and composting management practices and feedstock compositions included three impact categories: GWP based on IPCC AR5 characterization factors over 100 years, primary energy use (PEU) (non-renewable), and water use impact (stressed water use, SWU) determined using the mass balance based (MBB) water use impact assessment method previously developed (Pace, 2017; IPCC, Climate Change, 2014; Huijbregts *et al*, 2010). Ultimately, the biogenic CO_2 emissions were given a characterization factor of 0 for GWP, and thus had no influence on the impact category. Characterization factors for impact categories are shown in Table 2 below.

Table 2 Characterization factors for impact categories evaluated in the study

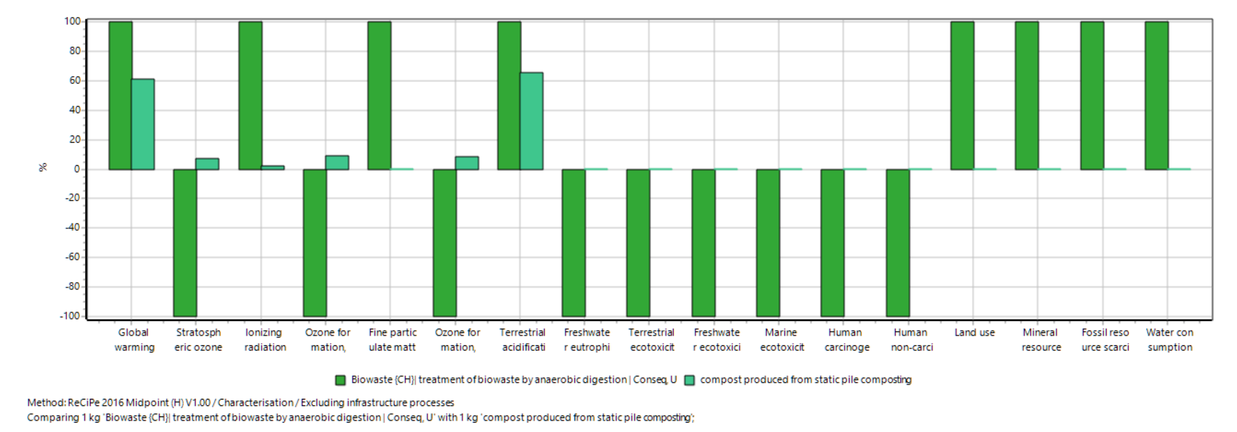
Input	Impact Category	Characterization Factor	Source
Biogenic, CO_2	GWP	0 kg $CO_2{}^e$	IPCC AR5
Fossil, CO_2	GWP	1 kg $CO_2{}^e$	IPCC AR5
Biogenic, CH_4	GWP	28 kg $CO_2{}^e$	IPCC AR5
Fossil Methane	GWP	30 kg $CO_2{}^e$	IPCC AR5
N_2O	GWP	265 kg $CO_2{}^e$	IPCC AR5
Water use	SWU	0.998 $m^3 sw_e/m^3$ water use	MBB Method, ZWC facility
Coal brown, in ground	PEU	9.9 MJ/kg	Ecoinvent v.3.3
Coal, hard, in ground	PEU	19 MJ/kg	Ecoinvent v.3.3
Gas, natural, in ground	PEU	39 MJ/Nm^3	Ecoinvent v.3.3
Crude oil, in ground	PEU	46 MJ/kg	Ecoinvent v.3.3
Biomass feedstock	PEU	1 MJ/MJ	Ecoinvent v.3.3
Geothermal Energy	PEU	1 MJ/MJ	Ecoinvent v.3.3
Hydropower Energy	PEU	1 MJ/MJ	Ecoinvent v.3.3

Sensitivity analysis identifies the sensitive parameters of whether a minor variation in a parameter would induce a surge in the environmental impact category. Here, the input parameter for sensitivity analysis focuses on the change in the rate of recycling (Song et al., 2013).

Results And Discussions

Potential Environmental Impact Assessment between Anaerobic Digestion and Composting

Figure below represents 17 impact categories resides in two organic waste treatments at Zero Waste Campaign (ZWC) site, University of Malaya. The significant positive environmental impact results presented in the figure below which highlighted about global warming potential (GWP), ionizing radiation, free particulate matter, terrestrial acidification, land use application, mineral resource, fossil resource scarcity and water consumption are the positive environmental impact. However, the stratospheric ozone, ozone formations, freshwater eutrophication, ecotoxicity (terrestrial, freshwater, marine), human carcinogenic and non-carcinogenic showed the significant negative environmental impact that indicates benefits towards the environment.



Impact category	Unit	Biowaste {CH}| treatment of biowaste by anaerobic digestion | Conseq, U	Compost produced from Aerated static pile composting
Ecosystem			
Global warming	kg CO_2 eq	0.387419322	0.235817023
Stratospheric ozone depletion	kg CFC11 eq	-2.28202E-05	1.66995E-06
Ozone formation, Terrestrial ecosystems	kg NOx eq	-0.002839196	0.000245283
Terrestrial ecotoxicity	kg 1,4-DCB e	-7.88788E-05	2.00601E-07
Freshwater ecotoxicity	kg 1,4-DCB e	-0.603487479	1.23271E-05
Marine ecotoxicity	kg 1,4-DBC e	-0.791061525	1.72295E-05
Terrestrial acidification potential	kg SO_2 eq	0.001719952	0.001124122
Freshwater eutrophication	kg PO_4^{3-} eq	-0.004814095	4.31145E-07
Human Health			

Fine particulate matter formation	kg PM2.5 eq	0.003085035	3.45134E-07
Human carcinogenic toxicity	kg 1,4-DBC e	-0.313875746	2.27178E-05
Resource Surplus Cost			
Mineral resource scarcity	kg Cu eq	0.000856169	2.26465E-06
Fossil resource scarcity	kg oil eq	0.191451469	0.000165423
Water consumption	M^3	0.049469225	4.36028E-05

i. Global Warming Potential

Global warming is the result of increasing temperature due to emissions of GHGs, such as CO_2, CH_4, N_2O and CFC. Generally, MSW treatment generates both biogenic and fossil CO_2, where the biogenic CO_2 is produced due to the degradation of a biodegradable fraction of MSW, whereas fossil CO_2 is produced by burning non-biodegradable materials, such as plastic, textiles, and leather (Sharma and Chandel, 2015). However, the biogenic CO_2 has zero impact factor and does not contribute to global warming (Edwards et al., 2017; IPCC, 2008). The baseline scenario for anaerobic digestion has the most GHG emissions (0.3874 kg CO_2 eq) due to the high fossil CO_2 and CH_4 emissions, no segregation of waste and no LFG control system, but it can be reduced considerably when used as a cooking oil in biogas form or electricity generation. For passive aerated static pile composting, the GWP showed 0.2358 kg CO_2 eq.

ii. Ozone depletion

The characterization factor for ozone layer depletion accounts for destruction of the stratospheric ozone layer by anthropogenic emissions of ozone depleting substances. AD could bring forth the environmental benefit that is -2.28202E-05 kg CFC-11eq, whereas composting would bring environmental burden of 1.66995E-06 kg CFC-11eq.

iii. Terrestrial Acidification Potential

Acidification is caused due to the release of acidifying substances such as Nox and Sox, where the acidification effect by NOx is comparatively higher than SOx. Anaerobic digestion had higher acidification impact (0.001720 kg SO_2 eq) owing to the emission of SOx and NOx in substantial amount during the energy generation from biogas. The passive aerated static pile composting only had 0.001124 kg SO_2 eq.

iv. Freshwater Eutrophication Potential

Eutrophication is triggered by the release of phosphate, nitrogen oxide and ammonia. Nitrogen oxide released from scenario passive aerated static pile composting 4.31145E-07 kg PO_4^{3-} eq has more eutrophication impact compared to anaerobic digestion owing to the heavy release of nitrogen oxides from the AD process.

iv. Human Toxicity and Ecotoxicity Potential

The characterization of human toxicity and ecotoxicity accounts for the environmental persistence (fate) and accumulation in the human food chain (exposure) and toxicity (effect) of a chemical. Human toxicity is caused by the emission of pollutants like PM, SOx, NOx, and heavy metals. The composting treatment posesses the environmental benefits [(Terrestrial: -7.88788E-05; Freshwater: -0.603487479; Marine: -0.791061525; Human: 2.27178E-05) kg 1,4-DBC e] due to high emissions of SOx and NOx. AD has brought some environmental burden and hence the total impact of this scenario is relatively less than for AD treatment [(Terrestrial: 2.00601E-07; Freshwater: 1.23271E-05; Marine: 1.72295E-05; Human: -0.313875746) kg 1,4-DBC e].

v. Photocemical ozone formation

Ozone in the lower levels of the atmosphere is created owing to various chemical reactions between NOx and VOCs in the presence of sunlight. The presence of ozone at a low level can result in asthma and other respiratory problem. The anaerobic digestion poses the maximum photochemical oxidation potential (-0.002839196 kg NOx eq) compared to composting with 0.000245283 kg NOx eq), where diesel usage and NOx emissions are the major contributors.

vi. Mineral and Fossil Resources Scarcity

The characterization factor of fossil depletion is the amount of extracted fossil duels extracted, based on the lower heating value. The unit of 1 kg of oil is equivalent of a lower heating value of 42 MJ, whereas for mineral depletion characterization factor is the decrease in grade. The AD had the value of 0.191451469 kg oil eq, whereas composting had the lower value of 0.000165423 kg oil eq., both had the difference due to the usage of diesel consumption and materials to build the AD machinery.

vii. Water Consumption

Water consumption used initially in AD (0.049469225 m^3) is completely minimal compared to composting (4.36028E-05 m^3) . However, it can still be considered as a negligible biogenic emission.

viii. Sensitivity Analysis

This section describes the outcome of the sensitivity analysis based on the increment of the recycling rate in the MRF process ranging from 20% to 100%. This analysis also indicated that as the recycling proportions of MSW range from 20% to 100% MSW for the landfill would vary from 44.4% to 14.4%, while the MSW proportion of the biological treatment (compost and anaerobic digestion will remain the same (48.1%).

Implementations of Organic Waste Treatment Scenarios in terms of Environmental Policy and its Contribution towards SDGs

It can be understood based on the effects on considered impact categories and the result of sensitivity analysis that the potential impacts of the present scenario can be reduced when proper sorting and material recovery is done along with composting of biodegradable waste and landfilling of the residues which is also corroborated by the studies carried out by Ghinea et al., (2014) in Romania, Mali and Patil (2016) in India, Ogundipe and Jimoh (2015) in Nigeria, Yadav and Samadder (2018) in India and Yay (2015) in Turkey. Also sensitivity analysis results indicated that the environmental burden decreases with an increase in the recycling rate, and hence the implementation of MRF would increase the total environmental benefits.

There was a booming existence in the current food waste treatment capacity in China with 19.5% and is concentrated in regions with high GDP cities such as Beijing and Shanghai. Anaerobic digestion is the most prevalent of the current food waste pilot projects with the value of 76.1% and strategies to improve the food waste treatment capacity and efficiency are suggested (Li et al., 2019). At community level, it is necessary to re-establish a social contract between the waste processors, the communities, the residence and the states. Massive investment is necessary in the waste management processing so that the government, the business and the civil society level would lead a political will to develop the awareness dissemination campaign quickly.

Waste-to-energy and waste-to-wealth has become the main focus in developed and developing country such as incineration that generates electricity with high amount of calorific value are recycled in waste. In some countries, waste is considered as a commodity, a product that can be sell or buy as other energy to reduce the environmental impact. Many countries in Asia and the Pacific have strengthened SCP policies, comprising issues such as cleaner production, renewable energy, waste management, consumer information and many others. Since the formulation of the Paris Agreement and SDGs, there have been policy trend to emphasize decoupling between the consumption of non-renewable, natural resources, and the welfare and wellbeing of society as a whole. SCP is no longer limited to environmental policy domains such as pollution control, waste management and recycling, or green consumerism, instead expanding socio-economic technology areas such as infrastructure building and capital information, including social welfare, business development, local development and innovation.

Transition to SCP at the local level by accepting these two alternative organic waste treatment is possible by identifying and nurturing bottom-up initiatives. It should be linked to solutions of local life concerns. There exist huge gaps between international and national agendas (long-term and mid-term goals) as well as local concerns. To address this gap, it is more effective to build linkages between different local initiatives, including through a promotion of localized networks focusing on logistics, information, financial, and material resource utilizing advanced information technologies, as opposed to simply up-scaling successful initiatives. For stronger policy supports, this bottom up approaches reflecting local concerns should be prioritized to better shape the waste management facility in this country.

The concept of circular economy involves material selection that makes little or no distinction between primary materials and secondary (recycled) materials. Moreover, it promotes improvement in the quality of secondary materials, components and products by means such as RRRDR (Remanufacturing, Refurbishment, Repair and Direct Reuse). Value chain management seeks to enhance product designs to better suit consumer lifestyles while enhancing overall environmental efficiency across the lifecycle. The implementation of this environmentally friendly technique depends widely on a political framework that creates and provides an economically attractive incentive for running AD plants. Dutch renewables policy has been widely criticized for having been too unstable to provide sufficient incentives for investments in renewable energy technologies (Rooijen and Wees, 2006). The uncertainty in receiving subsidies makes a highly cost-efficient system important, thus to recommend the biogas plants to be profitable without subsidy is to look for alternative revenues, for instance, from digestate and heat or savings in feedstock costs by making a contract with arable farms to supply with reverse osmosis (RO) concentrate in return for less expensive energy crops. Given the uncertainty of RO treatment regulations and the currently low values of digestate and heat, high investment and operating costs limit the feasibility of AD of wastes of farm origin and other co-substrates unless subsidies are provided (Gebrezgabher et al., 2010).

Promoting non-materialistic consumption can thus have benefits both in terms of human happiness and environmental sustainability which is in line with the traditional Asian way of life that aspire for a better life. Simple information provision alone has limited power to change consumer behaviors. Recent developments in behavioral economics have emphasized new and various ways to provide information and influence consumer choice. Such insights include tailoring environmental information to guide consumer's decisions can be utilized in SCP policies to make them more effective.

To conclude in terms of economical perspective, UM ZWC has successfully produced commercialized own-research product by transforming food and organic waste generated in University of Malaya into a self-sustaining resource in the form of organic compost. Not only it has reduced the collection cost, tipping fees and greenhouse gases, but it also contributes to the income-growth revenue for the university. This contribution in turn would support the SDG targets that eventually achieve the three key pillars of sustainability, namely economy, social, and environment.

Research study limitation

There might be flaws and implications due to the access granted by the zero waste management might not be accurate even if the small amount of changes can be negligible. However, the small amount of change might still be considered as a direct impact towards climate change if it is produced in bulk volume of food waste. Another possible flaw to this paper is due to the limitation of study from the South East Asian region, as there are possibilities that through comparison with the European studies on food waste management, certain hindsight still need to be considered. For instance, the behavior of respondent on food waste would affect the volume of food waste amount generated. The economical and purchasing decision of communities in UM might still bring forth impact to the food waste amount. Besides that, the lifestyle and diet of the community itself within the higher institution campus might have linked on the food waste volume and the composition of carbon-nitrogen compound in organic municipal solid waste composition in landfill. Every aspect of the situation is tied together with the future environmental, economy and health impact category.

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Conclusion

Potential use of organic waste treatment in terms of anaerobic digestion and composting could reduce resource use and environmental impacts. There is a significant reduction in eutrophication potential, acidification potential, ecotoxicity potential and global warming potential that contributes to climate change crisis worldwide in both treatments.

Overall, few conclusions can be derived based on the findings of this study:

- Anaerobic Digestion Treatment and Composting aids a perfect climate change solution in the field of waste management as they help to reduce the environmental burden for organic waste treatment in landfills. Reducing the global warming potential, acidification potential and eutrophication in the local environment could tackle the climate change crisis happening around the world.
- Promotes further supporting evidence for being the sustainable food waste management practices in local municipal waste management and replicate to other cities in developing countries as the food waste characteristics in Malaysia brought perfect condition for agricultural production and food demand.
- All SDG 11.6, 12.3 and 13 are interconnected with each other and even spearhead the circular economical package that highlights the global climate crisis.

Use of environmental impact assessment software and databases specific to the area being analyzed seems to guarantee obtaining more accurate and reliable data. In the case of LCA, taking into account the entire life cycle of food waste treatment and using large amounts of data, quality and quantity of inventory information is of particular importance. In the case of the analyses carried out in anaerobic digestion and composting treatment, specific method of calculation option in the impact assessment and sensitivity analysis must be crucially considered in the waste management. The study of LCA is essential part for a conscious decision-making process to be used with the knowledge of the environmental, economic and social consequences that could support the Sustainable Development Goals in future agendas, in particular waste management field.

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