SUSTAINABILITY EVALUATION FRAMEWORK FOR FOOD WASTE COMPOSTING

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DEDICATION

This thesis is dedicated to my parents, who have always loved me unconditionally and whose good examples have taught me to work hard for the things that I aspire to achieve.

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ABSTRACT

The high rate of population growth and industrial development have led to a significant increase in the production of municipal solid waste (MSW) worldwide. The authorities have been facing significant challenges to materialise a sustainable framework of solid waste management, especially for food waste (FW). This study aims to develop a sustainability evaluation framework for FW composting. A case study of an existing FW composting plant in Minhang District, Shanghai, China was used as the basis for the framework development and evaluation of its potential impacts from environmental and economic perspectives. The environmental impact focuses on the greenhouse gas (GHG) emissions that were analysed through life-cycle inventory methodology in terms of carbon dioxide equivalent (CO_2-eq.) while the economic feasibility (EF) is evaluated using cost-benefit analysis (CBA). The sensitivity analysis for composting was also conducted to determine the critical economic factors that will impact the EF of the composting process. Based on the evaluated framework, the results showed that the FW management contributed to 32,988 kg CO_2-eq. of GHG emissions from the overall composting operation. The composting operation also provided -7,962 kg CO_2-eq. of GHG reduction from compost application on farmland, although insufficient to offset the overall GHG emissions. The CBA showed that the plant is financially viable, with net present worth of, in Chinese yuan, CNY 362,204,575 due to optimum compost selling price to generate profit. The sensitivity analysis revealed that the compost selling price significantly affected economic performance among other economic factors, such as labour, fuel price, and subsidy. The sustainability evaluation framework for FW composting was proposed to show how it can be considered as a guideline for the policymakers and local government to improve FW management via composting in the developing countries, especially Malaysia.

ABSTRAK

Kadar peningkatan penduduk dan pembangunan perindustrian yang tinggi telah menyebabkan peningkatan penghasilan sisa pepejal perbandaran (MSW) yang ketara di seluruh dunia. Pihak berkuasa telah menghadapi cabaran besar untuk mewujudkan rangka kerja pengurusan sisa pepejal, terutamanya untuk sisa makanan (FW). Kajian ini bertujuan untuk membangunkan rangka kerja penilaian kelestarian bagi pengkomposan FW. Kajian kes kilang pengkomposan FW yang beroperasi di daerah Minhang, Shanghai, China telah digunakan sebagai asas untuk pembangunan rangka kerja dan penilaian potensi-potensi impaknya dari perspektif alam sekitar dan ekonomi. Impak alam sekitar ditumpu kepada pelepasan gas rumah hijau (GHG) yang dikaji melalui kaedah inventori kitaran hayat dari segi karbon dioksida setara (CO_2-eq.) manakala prestasi ekonomi (EF) dinilai menggunakan analisis kos-faedah (CBA). Analisis kepekaan untuk pengkomposan juga dijalankan bagi menentukan faktor-faktor kritikal ekonomi yang akan memberi kesan kepada EF proses pengkomposan. Berdasarkan rangka kerja yang dinilai, keputusan menunjukkan bahawa pengurusan FW tersebut menyumbang kepada pelepasan GHG sebanyak 32,988 kg CO_2-eq. daripada proses keseluruhan pengkomposan. Proses pengkomposan juga memberi pengurangan GHG sebanyak -7,962 kg CO_2-eq. melalui penggunaan kompos di ladang, walaupun tidak mencukupi untuk mengatasi keseluruhan pelepasan GHG. Keputusan CBA menunjukkan bahawa kilang tersebut berdaya maju dari segi ekonomi, dengan nilai bersih kini, dalam yuan China, sebanyak CNY 362,204,575 kerana harga jualan kompos yang optimum untuk menjana keuntungan. Analisis kepekaan mendedahkan bahawa harga jualan kompos mempengaruhi prestasi ekonomi di antara faktor ekonomi yang lain, seperti buruh, harga minyak dan subsidi. Rangka kerja penilaian kelestarian untuk pengkomposan FW dicadangkan bagi menunjukkan bagaimana rangka kerja tersebut dapat digunakan sebagai panduan oleh penggubal dasar dan kerajaan tempatan untuk menambah baik proses pengurusan FW melalui pengkomposan di negara-negara membangun, terutamanya Malaysia.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AD	-	Anaerobic digestion
BAU	-	Business-as-usual
BCR	-	Benefit-cost ratio
BGB	-	Beijing Goldenway Bio-Tech Co., Ltd.
C	-	Carbon
CBA	-	Cost-benefit analysis
CDM	-	Clean Development Mechanism
CH_4	-	Methane
CNY	-	Chinese yuan
CO_2	-	Carbon dioxide
CO_2-eq.	-	Carbon dioxide equivalent
EF	-	Economic feasibility
FAO	-	Food and Agriculture Organisation
FW	-	Food waste
GHG	-	Greenhouse gas
GPS	-	Global Positioning System
GWP	-	Global warming potential
HIC	-	High-income countries
IPCC	-	Intergovernmental Panel on Climate Change
ISO	-	International Organisation for Standardisation
LCA	-	Life-cycle assessment
LCI	-	Life-cycle analysis
LIC	-	Low-income countries
MIC	-	Middle-income countries
MYR	-	Malaysian Ringgit
MSW	-	Municipal solid waste
N_2O	-	Nitrogen oxide
NCV	-	Net-calorific value
NPK	-	Nitrogen (N), phosphorus (P), and potassium (K)
NPW	-	Net present worth

O_2	-	Oxygen
OFMSW	-	Organic fraction of municipal solid waste
OM	-	Organic matter
PLC	-	Programmable logic controller
SJTU	-	Shanghai Jiao Tong University
SWB	-	Shanghai Wenxin Bio-Tech Co., Ltd.
TWD	-	Taiwan dollar
UNFCC	-	United Nations Framework Convention on Climate Change
USD	-	US Dollar
UTM	-	Universiti Teknologi Malaysia

LIST OF SYMBOLS

⌀	-	diameter (symbol used in engineering)
%	-	percent
10^9	-	billion
ca	-	capita
cfu	-	colonial forming unit
d	-	day
h	-	hour
J	-	Joule
k	-	kilo
L	-	litre
M	-	million
MW	-	Megawatt
t	-	tonne
T	-	Tera
W	-	watt
w/w	-	weight by weight
y	-	year

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

The expanding world population is one of the factors that influence the principle of sustainable development. United Nations (2017) reported that the world population reached approximately 7.6 x 10^9 people in 2017. It is estimated to reach 8.6 x 10^9 in 2030 and will sum to 9.8 x 10^9 in 2050 and 11.2 x 10^9 by 2100 due to immense economic growth, rapid urbanisation and industrial development.

The rapid economic transition and increasing of the urban population have led to higher production of municipal solid waste (MSW) annually. As countries urbanise and prosper, living standards and income level also increase and resulting in higher consumption of goods and services, thereby producing a larger amount of solid waste (Kaza *et al.*, 2018). An efficient and sustainable MSW management remains a significant challenge to be implemented by municipalities around the world, especially in the fast-growing cities in developing countries.

A report by The World Bank stated that the world cities produced about 2.01 x 10^9 t of MSW in 2016, and this value is expected to reach 3.40 x 10^9 t by 2050 under a business-as-usual (BAU) scenario (Kaza *et al.*, 2018). Hoornweg and Bhada-Tata (2012) reported the cost of solid waste management around the world in 2012 is USD 205.4 x 10^9 annually and will increase to about USD 375.5 x 10^9 in 2025. The increasing MSW generation and poor management of MSW may inflict a higher budget for municipalities in the developing countries to manage and dispose of them. Inefficient MSW management may also cause depletion of invaluable land resources, risks to human health and long-term environmental impacts. It is vital to implement a sustainable and efficient MSW management strategy to balance the demand for development, the quality of human life, and the safety of the environment.

Sustainable development has been defined in numerous ways, but often the definition is quoted from the book 'Our Common Future', also known as the Brundtland Report. It is defined as the development that meets current needs without compromising future generations' ability to meet their own needs (World Commission on Environment and Development, 1987).

Elsaid and Aghezzaf (2015) described sustainable solid waste management system as economically viable, environmentally effective and socially acceptable. Viability means that the cost of having a clean environment is accepted by all sectors of the population, while environmentally effective implies that the environmental conservation policy and hierarchy are adopted in the waste management system. Meanwhile, the system is socially acceptable by the population when the service provided meets their needs. Hence, it is essential to identify social drivers and incorporate them into the solid waste management framework to realise a model that is economically and environmentally optimised as well as sustainable.

The increasing waste generation around the world has urged local governments to consider sustainable development to achieve a better and more sustainable future. The development of sustainable solid waste management, especially on food waste (FW), can help to reduce the dependence on landfill. FW streams from MSW can be diverted from large-scale landfilling through composting. In the developed countries, such as Germany, Italy, Denmark, and France, large-scale FW composting may be a good business case due to established MSW legislations and progressive policies, specifically on FW recycling (European Compost Network, 2019). The development of quality standards for organic waste treatment and compost production in the organic waste recycling sector has also generated a bio-based economy in these countries. These factors further become the essentials to develop a sustainable framework for FW composting to ensure the feasibility of the FW management industry in the long term.

In contrast with developed countries, several factors such as weak enforcement, lack of technology, and ineffective policy implementation make the MSW management in the developing countries inefficient with a very low possibility of improvement. Being a rapidly developing country, Malaysia faces similar problems: technologies and facilities are insufficient to cope with the ever-increasing rate of MSW generation, especially FW. Implementing sustainable FW management framework through composting that can produce valuable organic fertilisers is still a significant challenge in this country.

Several possible factors are impeding the framework development of FW recycling industry. FW composting plants in Malaysia, especially at large scale, generally have not been widely constructed and operated due to lack of finance, expertise and know-how of technology, which cause the plant to be financially and economically unattractive. Some operating large-scale composting plants are using agricultural waste and animal manure. The compost from these plants are of higher quality, thereby sold at a higher price, compared to compost from FW derived from MSW-based sources.

There are several manufacturers of organic fertilisers operating at different scales using agricultural-based materials as feedstock in Malaysia. Legenda Madu Sdn. Bhd. (www.lmorganicfertilizer.com), Green Plant Organic Fertilizer Sdn. Bhd. (www.greenplant.com.my) and Global Green Synergy Sdn. Bhd. (www.ggs.my) are among manufacturers of organic fertilisers using biomass from the oil palm industry to produce organic fertilisers. Most of these manufacturers use relatively more consistent agricultural waste as feedstock; thus, the quality control of the end products is more consistent compared to using FW.

FW composting uses FW that varies in content, thereby posing difficulties in controlling the amount of nutrients in the final product. Maintaining minimum percentages of nutrient content in compost produced from FW to meet Malaysian quality standard of organic fertiliser is hard from batch to batch, and may require other additional feedstock that is rich in nitrogen, phosphorus, and potassium (NPK) content to supplement the compost quality. Manufacturers of organic fertilisers using FW as feedstock are not many in Malaysia, especially at large-scale operation. To date, Mentari Alam Eko (M) Sdn. Bhd. (www.maeko.com.my) that sells in-vessel composting machines and Promise Earth (M) Sdn. Bhd. (www.biomate.com.my) that also sells in-vessel composters, as well as organic fertilisers made from FW, are among the few companies that promote FW composting.

Taking examples in Johor state alone, two operating companies producing organic fertilisers are All Cosmos Industries Sdn. Bhd. (www.allcosmos.com) and Sarjani (M) Sdn. Bhd. (www.sarjani-malaysia.com.my). All Cosmos Industries Sdn. Bhd., which is based in Pasir Gudang and founded in 1999, is a Malaysia-based investment holding company established by Taiwanese investors that focuses on the production and marketing of high grade bio-chemical and bio-organic fertilisers, as well as agriculture-related activities. The company uses biomass from cocoa and palm oil industry as a feedstock for the production of organic fertilisers. Being a 100 % subsidiary under All Cosmos Bio-Tech, the company spent a total capital cost of MYR 50 M for its setup. All Cosmos Industries Sdn. Bhd. is one of the biggest fertiliser manufacturers in Asia, with an annual production capacity of around 300 kt of fertilisers.

On the other hand, Sarjani (M) Sdn. Bhd. is a Malaysian bumiputra-owned company founded in 2007 that manufactures organic fertilisers using manure from livestock farm as feedstock and supplies them to local farmers and municipalities for agricultural and landscaping purposes. The company has a monthly production capacity of 80 to 100 t (around 960 to 1,200 t/y) to meet the demand for organic fertilisers. The total capital cost is not stated on the website.

Despite having many organic fertiliser companies using agricultural waste as feedstock for composting in Malaysia, the development of a large-scale FW composting plant to produce organic fertiliser is still entirely new and requires a comprehensive framework to be feasible prior implementation. Most of the FW composting operations existing nowadays are only on-site composting facilities operated at small to medium scale by local community or municipality. This scenario may due to unclear profitability, thereby regarded as a non-sustainable business. FW composting faces a range of complex issues, including lack of waste segregation at source, cost of waste collection, and negative perceptions about the varied quality of the end compost produced from FW due to the inconsistent composition of the daily

FW generated. These challenges pose difficulties in making the FW composting a business case to generate significant profit and may require external intervention such as government subsidies to sustain the operations.

In the fast-developing countries such as Malaysia, municipalities are on the lookout for practical solutions to improve their solid waste management, primarily on FW at large scale. The establishment of a comprehensive framework that can be used as a guide or a set of benchmark indicators for FW management to ensure its sustainability is vital. In Malaysia, there are not many feasibility studies have been reported on large-scale FW composting. Learning the steps involved and replicating an existing sustainable FW composting framework from other developing countries are crucial to realise a similar waste treatment plant in the developing countries, including Malaysia. Such a framework is essential to guide the proper steps, minimise the risk of failure and to attract the interests of various stakeholders, including the investors and policymakers.

China, being one of the largest generators of solid waste among countries around the world, manages to deal with its solid waste disposal efficiently and this could serve as an excellent example for other developing countries to follow the steps in tackling solid waste problems. Due to the high generation of MSW compared to other Asian countries, China contributes to 70 % of the total waste generated in East Asia and the Pacific region (Hoornweg and Bhada-Tata, 2012). The FW dominates its MSW composition at about 55.86 % (Mian *et al.*, 2017), which is identical to most of the fast-developing countries. Hence, the case study from China is suitable for other developing countries to benchmark.

This study examines the FW management system of urban China, using Minhang District, Shanghai as a case study, and identifies the major steps involved to make the system feasible that other growing cities can learn from, particularly for cities in Malaysia. The study also evaluates the environmental and economic impacts of the existing system in the case study. Through these processes, the study proposes a sustainability evaluation framework for FW management that can be used as a guideline and put forward for consideration by stakeholders from the private, public, academic, and non-profit sectors in Malaysia. The framework intends to provide valuable inputs for developing policy on FW management industry via large-scale composting in the country.

To build a comprehensive framework for feasible FW management, the engagement between specific stakeholders such as the government, industry and community needs to be well-developed. Understanding the crucial steps involved, such as the engagement between stakeholders, waste collection and treatment processes, as well as the environmental and economic impact assessments, are vital as these building blocks are involved in developing the sustainability evaluation framework. The three essential pillars of sustainability are environmental, economic, and social. In this study, the environmental sustainability evaluation was based on the inventory of greenhouse gas (GHG) emissions from the composting operation as this is the most common method used. The sustainability evaluation for the economic aspect used cost-benefit analysis (CBA) to assess the economic feasibility (EF) of the large-scale FW composting operation to ensure if the proposed process could generate profit to sustain its operation in the long run. However, this study did not assess sustainability in terms of the social aspect and may be considered in future work.

Hence, it is of great interest to evaluate the existing framework of a large-scale FW composting system along with its GHG emissions and EF from a case study as a referral for Malaysia. The large-scale FW composting (200 t/d) implemented in Minhang District, Shanghai, China is selected as the case study.

1.2 Problem Statement

Malaysia is one of the many developing countries that face a challenging task to materialise sustainable MSW management. Currently, under the framework for sustainable solid waste management, Malaysia has targeted 18 % of waste treatment and 22 % of recycling rate to divert 40 % of waste from landfill by 2020 (Ministry of Urban Wellbeing, Housing and Local Government Malaysia, 2015). Despite the creation of the National Solid Waste Management Policy in 2007 to standardise and improve waste management nationwide, the deployment efforts were confronted by a limited budget, short of staff's technical capacity, and uncertainty in the policy's guidelines (Wee *et al.*, 2017). The implementation of the framework and other supporting policies are, however, still weak and challenging in this country. Malaysia almost reaches its target year, but the progress of developing the composting sector as a feasible industry to treat waste is still unclear. There is still limited FW composting plant operated at large scale (> 100 t/d) in Malaysia. Such a processing plant is currently viewed as not economically feasible due to tedious work for waste segregation at source and high cost for frequent waste collection daily; otherwise it would contribute to odour and public health problem.

In Malaysia, there is a limited number of feasibility studies reported on large-scale FW composting, especially on the sustainable framework or detailed analysis reporting on the impacts of large-scale FW composting in terms of environmental and economic aspects. Those available studies did not address either the critical factors or key drivers, causing the success or failure of the composting facilities. A sustainability evaluation framework is required to achieve good feasibility.

Hence, this study aims to develop a sustainability evaluation framework based on an existing large-scale composting plant (200 t/d) in Minhang District, Shanghai, China. This case study can become a benchmark for other developing countries, including Malaysia, to replicate a similar framework for FW management. The proposed sustainability evaluation framework serves as a basic structure underlying a feasible and sustainable FW management system and serves as general guidelines to operate the process flows to be replicated in Malaysia.

1.3 Research Objectives

The objectives of the research are:

(a) To develop a sustainability evaluation framework for food waste (FW) composting.

(b) To analyse the greenhouse gas (GHG) emissions of FW composting for the sustainability evaluation framework.

(c) To evaluate the economic feasibility (EF) of FW composting for the sustainability evaluation framework.

1.4 Scope of Study

The scopes of this research are:

(a) To develop the sustainability evaluation framework for FW composting using a case study in Minhang District, Shanghai, China. The study evaluates the upstream, bio-waste management, and downstream level involved in the FW management along with the strategies implemented to make the system feasible and sustainable. The sustainability evaluation is conducted based on the assessment of environmental and economic impacts of the FW management system.

(b) The evaluation of GHG emissions of FW composting based on the developed sustainability evaluation framework in terms of carbon dioxide equivalent (CO_2-eq.) and global warming potential (GWP) per ton of compost produced to analyse its environmental impact. A streamline of life-cycle inventory (LCI) analysis is conducted using the case study. The system boundaries for this assessment include waste collection and transportation, pre-treatment, waste treatment, as well as product distribution and application on farmland, based on the developed sustainability evaluation framework.

(c) The EF analysis of the FW composting plant using cost-benefit analysis (CBA), which involve net present worth (NPW) analysis, benefit-cost ratio (BCR) and payback period to evaluate its profitability and self-sustainability. The cost efficiency is analysed based on the estimated capital expenditure, operation expenditure and revenue generated. Sensitivity analysis is also conducted to assess the influence of several economic factors on the EF of the case study.

1.5 Significant of Study

The significant of the research are:

(a) The development of a sustainability evaluation framework for FW composting involving public-private-community partnership.

(b) The evaluation of the environmental and economic impacts of FW composting using the case study to show the applicability of FW composting as an alternative technology for FW management in Malaysia.

(c) The outcome presented through the sustainability evaluation framework can be a valuable input for developing policy on FW management industry and composting sector in Malaysia.

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