SUSTAINABILITY PERFORMANCE ASSESSMENT OF MUNICIPAL SOLID WASTE MANAGEMENT UTILISING AGGREGATED INDICATORS APPROACH

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DEDICATION

I like to dedicate this thesis to my beloved family. Thank you for all the supports and encouragements invested in me along this journey. The amount of gratitude I felt towards your love and support cannot be put into words.

I love you.

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ABSTRACT

There is a need for effective and sustainable municipal solid waste (MSW) management system to be implemented in Malaysia, especially in the urban areas. Indicators have often been chosen as a tool to evaluate the performances of the current MSW management system in Malaysia. From the literature reviewed, no index was found to be similar with the one being proposed by this study. This study was conducted to produce a set of indicators that evaluate the MSW management system throughout the entire life cycle. The development of these indicators involved intensive literature reviews, discussion meetings with stakeholders, and workshop organisation with solid waste management experts. Weightage were assigned to the established indicators by using analytical hierarchy process, which were then incorporated into a performance index, known as municipal solid waste management performance index (MSWMPI). Data collection were done at five cities, which were Muar, Rembau, Putrajaya, Langkawi and Pekan. As a result, a total of nine indicators under four criteria, C1 (MSW Generation and Segregation), C2 (MSW Collection and Transportation), C3 (MSW Treatment) and C4 (MSW Disposal), were finalised. The weightage for the four criteria were found to be 32.17% for C1, 19.82% for C2, 25.41% for C3, and 22.60% for C4. Among the five cities, Pekan had the highest MSWMPI, with a value of 74.85 and was rated as performing good. On the other hand, the MSW management system in Muar had the lowest MSWMPI, with a value of 51.23. Langkawi had an MSWMPI of 59.89, which was followed behind closely by Rembau (58.12) and finally, Putrajaya had the MSWMPI value of 52.43. City profiling among the respective cities had also been done to identify the hotspots in the MSW management system. It was found that most cities performing well in C1 and C2, would not perform greatly in C3 and C4, and vice versa.

ABSTRAK

Terdapat keperluan untuk pelaksanaan sistem pengurusan sisa pepejal perbandaran (MSW) yang berkesan dan mampan di Malaysia, terutamanya di kawasan bandar. Penunjuk selalunya dipilih sebagai alat penilaian prestasi sistem pengurusan MSW terkini di Malaysia. Didapati bahawa tiada indeks yang sama dengan yang telah dicadangkan oleh kajian ini daripada kajian lepas. Kajian ini dijalankan untuk menghasilkan satu set penunjuk yang menilai sistem pengurusan MSW. Pembangunan penunjuk ini melibatkan tinjauan intensif kajian literatur, perbincangan dengan pihak berkepentingan, dan bengkel dengan pakar pengurusan sisa pepejal. Penetapan pemberat telah dijalankan melalui proses hierarki analitik yang seterusnya telah diguna-pakai dalam indeks prestasi dikenali sebagai indeks prestasi MSW (MSWMPI). Pengumpulan data dijalankan di lima bandar, Muar, Rembau, Putrajaya, Langkawi, dan Pekan. Hasilnya, sembilan penunjuk di bawah empat kriteria, C1 (penjanaan dan pengasingan MSW), C2 (pengutipan dan pengangkutan MSW), C3 (rawatan MSW), dan C4 (pelupusan MSW), telah dimuktamadkan. Pemberat bagi empat kriteria tersebut adalah 32.17% untuk C1, 19.82% untuk C2, 25.41% untuk C3, dan 22.60% untuk C4. Antara lima bandar, Pekan mempunyai MSWMPI yang tertinggi dengan markah 74.85 dan telah dinilai sebagai berprestasi baik. Sebaliknya, sistem pengurusan MSW di Muar mempunyai MSWMPI yang paling rendah, dengan markah 51.23. Langkawi mempunyai markah MSWMPI sebanyak 59.89, yang diikuti oleh Rembau (58.12), dan akhirnya Putrajaya mempunyai markah MSWMPI sebanyak 52.43. Pemprofilan bandar untuk kesemua lima bandar juga telah dibuat untuk mengenal pasti titik panas dalam setiap sistem pengurusan MSW. Didapati bahawa kebanyakan bandar yang berprestasi baik dalam C1 dan C2, mempunyai prestasi yang kurang memuaskan dalam C3 dan C4, dan sebaliknya.

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LIST OF ABBREVIATIONS

AHP	–	Analytical Hierarchy Process
LCT	–	Lifecycle Thinking
MSWMPI	–	Municipal Solid Waste Management Performance Index
PTT	–	Proximity-to-Target
MCDM	–	Multi-Criteria Decision Making
MPRRP	–	Maximum Practicable Recycling Rate Provision
MSW	–	Municipal Solid Waste
RCE	–	Resource Conservation Efficiency
ZWI	–	Zero Waste Index
SWCorp	–	Solid Waste and Public Cleansing Management \ Corporation
FT	–	Federal Territory
NGOs	–	Non-governmental organizations
PPSPPA	–	Perbadanan Pengurusan Sisa Pepejal dan Pembersihan Awam
CBA	–	Cost – Benefit Analysis
CEA	–	Cost Effectiveness Analysis
Eco-Eff	–	Eco-Efficiency Analysis
EA	–	Emergy Analysis
EIA	–	Environmental Impact Assessment
LCA	–	Life Cycle Assessment
LCC	–	Life Cycle Cost
RA	–	Risk Assessment
SEA	–	Strategic Environmental Assessment
WTT	–	Waste Treatment Technique
C&D	–	Construction and demolition
EU SDS	–	European Union Sustainable Development Strategy

UNCSD	–	United Nations Commission on Sustainable Development
SDI	–	Sustainable Development Indicators
OECD	–	Organisation for Economic Co-operation and Development
DSR	–	Driving Force, State and Response
SWM	–	Solid Waste Management
EPI	–	Environmental Performance Index
ISWM	–	Integrated and Sustainable Waste Management
DPSIR	–	Driving Force-Pressure-State-Impact-Response
GHG	–	Greenhouse gas
CTI	–	Cleaner Treatment Index
NRI	–	Net Recovery Index
RCE	–	Resource Conservation Efficiency
SC%	–	Percentage of Separate Waste Collection
ZWI	–	Zero Waste Index
MRI	–	Material Recovery Indicator
ERI	–	Energy Recovery Indicator
CI	–	Costs Indicator
MAU	–	Multi-Attribute Utility
MAUT	–	Multi-Attribute Utility Theory
ELECTRE	–	*Élimination Et Choix Traduisant la Réalité*
PROMETHEE	–	Preference Ranking Organization Method for Enrichment Evaluations
TOPSIS	–	Technique for Order Preference by similarity to Ideal Solution
GMM	–	Geometric Means
WAMM	–	Weighted Arithmetic Means
CR	–	Consistency Ratio
RI	–	Random Index
CI	–	Consistency Index
MCF	–	Methane Correction Factor
RM	–	Ringgit Malaysia

LIST OF SYMBOLS

CO_2	–	Carbon Dioxide
CH_4	–	Methane
N_2O	–	Nitrous Oxide
kg	–	Kilogram
$\sum$	–	Sum
$\prod$	–	Product
λ_{max}	–	Largest eigenvalue
MSW_x	–	Mass of solid waste sent to landfill in inventory year
L_o	–	Methane generation potential
f_{rec}	–	Fraction of methane recovered at landfill (flared or energy recovery)
OX	–	Oxidation factor
DOC	–	Degradable organic carbon in year of deposition
DOC_F	–	Fraction of DOC that is ultimately degraded
F	–	Fraction of methane in landfill gas

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Under this chapter, introduction towards this study were made. Firstly, the background of study was shared to give a general idea where the study focusing on. Then, the problem that this study focusing on were highlighted and discussed. With that, the research objectives of this study were identified. The scope of this study was discussed to show the boundary of this study. Furthermore, the significance of this study was discussed to show the importance and contribution of this study to society. The layout of this thesis was explained at the end of the chapter.

1.2 Background of Study

Municipal solid waste (MSW) is commonly understood as waste that is generated from residential and commercial areas, that excludes those from hazardous properties that are generated from industrial premises and construction areas (Environmental Protection Agency, 2003). Environmental Protection Agency (2010) explained materials like construction and demolition debris, municipal waste water treatment sludge and non-hazardous industrial waste are not classified as MSW, although these materials are most likely to be disposed to landfills.

Globalization, industrialization, rapid social and economic development has started a disturbing trend of solid waste generation in many countries (Chang, 2015; Jayasinghe *et al.*, 2013; Jin and Lin, 2012). Breaking the historical link between wealth creation and waste creation remains as one of the tough challenge for every country (Hester and Harrison, 2002; Islam, 2017). As the status of a country increases, incomes and living standards of the citizens increases, which then leads to more consumption of goods and services. This increases the rate of waste generation in the country as its citizens afford to spend more money for a more comfortable living (Hoornweg and Bhada-Tata, 2012).

Malaysia, as one of the developing countries located in South East Asia, faces the same fate. The country is separated into two regions by the South China Sea, which are West Malaysia and East Malaysia. The capital city Kuala Lumpur, while Putrajaya is set as the administrative centre of the federal government. As explained by Abu Eusuf *et al.* (2011) and Johari *et al.* (2014), the management of solid waste process usually involves the generation, storage, collection and transport, processing and disposal of solid waste. In Malaysia, the management of MSW in certain regions has been outsourced by the government to private waste consortia, while the remaining-are under the responsibility of its own local municipality respectively (Abdul Manaf *et al.*, 2009; Johari *et al.*, 2014). There are four (4) private waste consortia currently collecting, transporting and disposing the generated MSW, which are: Alam Flora Sdn. Bhd., SWM Environment Sdn. Bhd., E – Idaman Sdn. Bhd. and Eastern Waste Management Sdn. Bhd. (Johari *et al.*, 2014). Each of the waste consortia is responsible for its own region and has its own operation coverage (Johari *et al.*, 2014). However, it is reported that about 70 – 76% of MSW generated is successfully collected by waste consortia (Abdul Manaf *et al.*, 2009; Johari *et al.*, 2014), and about 95% of the collected MSW are send to disposal. The most common MSW disposal being practiced in Malaysia landfilling. With the increasing population and rocketing generation of MSW along with time, concerns arise on the issue whether land filling will be sufficient to tackle and receive the disposed MSW or not (Abu Eusuf *et al.*, 2011).

Budhiarta *et al.* (2012) found that the main source that contributes to MSW generation in Malaysia is household, instead of commercial and industrial premises. It is found that the waste composition among the household waste is of food waste and its mixture (74%), plastics (21%), others (2%) and mixed organic and wood (1%). Food waste can be reused as composting while plastic waste can be easily recycled, however, they are found to be the largest components among the household waste generated. It is brought to light that only less than 5% of waste are separated and recycled in reality, though the amount of waste conceivably be recycled is massive (Abdul Jalil, 2010; Hassan *et al.*, 2000; Isa *et al.*, 2005; Omran *et al.*, 2009; Periathamby *et al.*, 2009). This shows that until today, not only the awareness on waste reduction among the public is still low since more than a decade ago, the practices and behaviour towards waste reduction are still poor as well.

Many studies (Abdul Manaf *et al.*, 2009; Ahmed *et al.*, 2013; Johari *et al.*, 2014; Tarmudi *et al.*, 2009) have been conducted by various researches in Malaysia over the years to further investigate the factors contributing and promoting the generation of MSW. All authors in unison concluded that, rapid economic and population growth, changing lifestyle and rural-urban migration are the four (4) main factors that contributes to the increasing generation of MSW. Tarmudi *et al.* (2009) has also discovered that multi-racial community in Malaysia plays a role in the increasing generation of MSW. Since there are different cultures and beliefs, there are various festivities along the year to be celebrated among the community as well. With these celebrations, there is no doubt that the generation of MSW would then be multiplied.

Ineffective and inefficient solid waste management will cause degradation and harm towards the environment (Kurniawan, 2010), this is a fact that everybody is aware of. Open dumpsites bring severe environmental issues to a country, which includes contamination of surface water, ground water and solid through direct contact of waste or leachate (Zurbrugg, 2002). This not only affects the health of humans and animals, but it also causes serious losses to the country's economy and other welfare. Emissions of greenhouse gases from waste stream, contributes to climate change and global warming (Environmental Protection Agency, 2002; Kurniawan, 2010), too

cannot be ignored. Calabro (2009) highlighted in his study that waste management practices have directly emitted greenhouse gases such as: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) into our atmosphere. Chua *et al.* (2011) agreed and further explained that landfills and various practices of waste water treatments released greenhouse gases, where the common greenhouse gases produced by landfills are CH_4, wastewater treatment commonly produced CH_4 and N_2O, and lastly burning of wastes that contained carbon would produce CO_2.

1.3 Problem Statement

Along with the development of the nation, waste generation has been one of the critical issues that need immediate attention in Malaysia. It has been well established by many studies that urbanization rate and economic development increases along with waste generation (Budhiarta *et al.*, 2012; Guerrero *et al.*, 2013; Hoornweg and Bhada-Tata, 2012; Hoornweg *et al.*, 2015). From a MSW generation rate of 0.5 – 0.8 kg per capita per day recorded at year 2003, it has increased to 0.5 – 2.5 kg per capita per day recently, as highlighted by Johari *et al.* (2014). Ninth Malaysia Plan (2006 – 2010) had published that in year 2001, a rate of 16,200 tonnes per day of waste were generated in Peninsular Malaysia (Government of Malaysia, 2006). This means that, an amount of 5.91 million tonnes of MSW were generated in that year. Government of Malaysia (2006) has also stated that in year 2005, MSW generation rate had reached an amount of 19,100 tonnes per day. On the other hand, Fauziah *et al.* (2004) had estimated that the local authorities and waste management consortia in Malaysia have to handle approximately 17,000 tonnes of MSW generated daily throughout the country. In short, the MSW generation in Malaysia has escalated steadily with time from the past decade, where Periathamby *et al.* (2009) highlighted that the escalation was more than 91%. Furthermore, Mohamad Taha (2016) has made a worrisome statement, where Malaysia is estimated to generate an approximate amount of 16.76 million tonnes of MSW at year 2020.

In Malaysia, the enforcement of managing and minimizing MSW is a shared responsibility not only among local authorities, but also federal government agencies like: Ministry of Housing and Local Government, Ministry of Environment, Ministry of Health and many more (Sreenivasan *et al.*, 2012). This hinders and challenges the management of MSW in Malaysia (Abdul Manaf *et al.*, 2009; Ogawa, 2008; Tarmudi *et al.*, 2009). Besides that, hitherto there is no way for us to ensure, or even assess the performance of the existing MSW management system in Malaysia. With this overwhelming situation of MSW escalation happening in Malaysia, it portrays an urgent need for a holistic approach on the management of MSW to ensure its efficiency and effectiveness. Duraiappah (1996) highlighted that in order to provide the service of waste disposal for the increased waste generation, or even improve the solid waste management, it would be costly and results in allocating more money by government on existing waste management system. Collapse of the MSW management system would give rise to extravagant operation cost and environment degradation, as discussed earlier (Kurniawan, 2010; Periathamby, 2001; Sreenivasan *et al.*, 2012; United Nations Development Programme Malaysia, 2008; Weitz *et al.*, 2002).

There are few methods being used to assess the performance of waste management system (Coelho *et al.*, 2012), which includes benchmarking, lifecycle assessment, multi-criteria decision making and many more. Indicators are chosen to be used as a tool that would altogether assess and ensure the performance of the existing MSW management system. This is because the utilisation of indicators not only reflect the current conditions of the existing waste management system, it can also help to monitor for future trend as well (Lockerbie *et al.*, 2016; Visvanathan, 2012). However, the development of useful sustainable indicators is not easy. It requires not only an understanding of concepts and definitions, but also a good knowledge of environmental policy, fiscal instruments and social needs. Indicators, which are derived from data, are commonly the first and most basic tools for analysing change in society. Zabaleta (2008) mentioned that although accessibility towards data on social, economic and physical environment are expanded due to rapid development in information technology, usable information produced from these data ~~was~~ are at a slower rate, and thus unable to meet the increasing demand for information of environmental issue.

From the literatures reviewed, there is no index similar to the one that is being proposed in this study. This study aims to develop an index, known as "Municipal Solid Waste Management Performance Index (MSWMPI)", where this index was interpreted from an established set of indicators that assess the environmental and socio-economic performances of the current MSW management system in Malaysia. This index represents the overall performance of MSW management system through aggregation of the established indicators. The challenge of this study is to define a simple but comprehensive set of indicators that cover all aspects of sustainability, and also to be able to be calculated by local administrators, as well as managers of the MSW management system and not only by scientists or academic experts. Nevertheless, the developed index will have the following main characteristics:

- It will evaluate the performance of an entire integrated waste management system (and not just of some of its components);
- It will focus on MSW (and not just one of its fractions);
- It will evaluate both the environmental and socio-economic performances of the system.

1.4 Research Objectives

The research objectives of this study are as follows:

1. To establish a set of indicators that covers all the sustainability aspects throughout the entire lifecycle of MSW management process.

2. To assign weightage to the established set of indicators using Analytical Hierarchy Process (AHP).

3. To develop a performance index that evaluate the performance of MSW management system in Malaysia by aggregating the established set of indicators.

4. To validate the developed performance index by conducting case studies.

5. To identify the hotspot in the MSW management system through the developed performance index.

1.5 Scope

- This study focused mainly on the MSW only, where mostly the waste generated are from residential and commercial areas.

- Lifecycle Thinking (LCT) approach is adopted so that the evaluation of the current MSW management system performance covered the entire lifecycle of the MSW management process.

- Comprehensive literature surveys and reviews are conducted to produce an extensive list of potential indicators. A finalised set of indicators suitable and applicable for Malaysia are established by conducting numerous discussion meetings and a workshop with relevant stakeholders. Besides that, it is made certain that the established set of indicators are readily available and accessible

data that are provided by SW Corp Malaysia. Survey questionnaire was used to obtain data for one of the established indicators, where the target respondents are of the community living in the selected cities.

- Analytical Hierarchy Process (AHP) was adopted to assign weightage to the criteria of the study. Therefore, another set of survey questionnaire specifically for AHP weightage assignment was designed and developed. The target respondents for this AHP questionnaire were solid waste management experts. In this study, the solid waste management experts are defined as those who have knowledge and experiences in the solid waste management in Malaysia, including government officers, researchers, academicians, officers of private waste consortia and many more.

- The performance index, which is also known as MSW Management Performance Index (MSWMPI) is determined through aggregation of the criteria score with its respective criteria weight age. Consequently, the criteria score was then being determined through aggregation of the Proximity-to-Target (PTT) score of the established indicators and its indicator weightage.

- It should be noted that in this study, the weightage of one (1) criteria is being equally distributed among the indicators established under that respective criteria. In other words, one (1) criteria weight age equals to the sum of all indicator weight age under that respective criteria.

- MSWMPI is then validated through end-user approach at five (5) selected cities, which are: Langkawi, Muar, Pekan, Putrajaya and Rembau. Data collection in these five (5) cities were conducted, where it took approximately one (1) month to finish collecting all the necessary data. The collected data were then being fed into the established indicators, where MSWMPI for each selected city was determined. Lastly, the interpretation of results given by the MSWMPI were carried out to identify the areas for improvements for each city.

1.6 Significance of Study

Since currently there is no way for the policy makers and society to know the performance of the existing MSW management system in Malaysia, MSWMPI is able to provide insights on the current performance of MSW management system in Malaysia. With these insights, evaluation on the performance and identification of potential problems in the current MSW management system can be carried out.

Besides that, since MSWMPI covers the entire lifecycle of MSW management system, the weaknesses and strength of the current MSW management system can be clearly highlighted. This provides reliable information for policy making, thus helps in decision making among the policy makers. Unnecessary and avoidable costs along the current MSW management system can be successfully identified and thus, save governmental expenditures on MSW management.

Most importantly, the framework of developing MSWMPI is flexible and adaptable with time. Not only MSWMPI monitors the performance of MSW management system from time to time, the indicators established for the development of MSWMPI can be replaced. This is to ensure MSWMPI adequately reflects the latest MSW management scenario in Malaysia. In short, MSWMPI is a useful tool for the policy makers to continuously measure and monitor the performance of the current MSW management system in Malaysia entirely.

1.7 Thesis Layout

Chapter 1 discussed about the background and problem statements of this study. Research objectives of the study were identified and listed as well. The scope and significance of this study were also discussed in Chapter 1.

Chapter 2 discusses all the relevant literatures that are included in this study. Under this chapter, solid waste, municipal solid waste (MSW), MSW management, assessment methods with respect to solid waste management, indicators and data aggregation are discussed. Lastly, multi-criteria decision making (MCDM) were discussed as well.

Chapter 3 discusses the research methodology of this study. The research background of this study was discussed, along with the methodological flow chart. Besides that, the establishment of the indicators and framework structure, and also the adoption of Proximity-to-Target (PTT) method were discussed. Weightage assignment through Analytical Hierarchy Process (AHP) and data collection for each indicator were explained as well. The raw data suitable for the indicators were explained clearly in this chapter. Lastly, the aggregation of indicators to form MSWMPI were also described.

As for Chapter 4, the results and outcomes of the study were conferred. Under this chapter, the development of study framework, along with the description of each established indicator. The results obtained from AHP were showed and discussed too. The type, target and low benchmark on each established indicator are discussed lastly.

Chapter 5 further discusses the MSWMPI for the five (5) involved cities, where the weaknesses and strengths of the MSW management of each cities are identified and discussed. This is carried out through creating a profile for each involved city. Strategical enhancements based on the MSWMPI result were proposed for each city respectively.

Lastly, with the results obtained from the study, conclusions, recommendations for future study and limitation of study were made and discussed in Chapter 6.

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