ASSESSMENT OF MUNICIPAL SOLID WASTE DISPOSAL OPTIONS USING ANALYTICAL HIERARCHY PROCESS AND LIFE CYCLE ANALYSIS

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To my beloved Family

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ABSTRACT

Disposal of municipal solid waste (MSW) generated in the city of Johor Bahru has been one of the challenges to the authorities and the public. Population sizes and MSW generation rates are increasing every year. The two existing landfills which are located at Seelong and Tanjung Langsat, can no longer cope with the amount of the MSW. This imposes more negative burden on the environment and public health; thus calling for better MSW disposal alternatives. However, local authorities are confronted with problems, protests and resistance as well as financial constraints in choosing and implementing waste disposals facilities. Solving the problem involves a complex evaluation procedure because compromises and tradeoffs among stakeholders and other interest groups are difficult to reach. In the current study, two concepts, analytical hierarchy process (AHP) and life cycle assessment (LCA) were used. The objectives are to identify stakeholders' opinion on MSW disposal (through visits, meetings, conferences and symposia sessions) and use AHP to structure those opinions in proposing disposal alternatives (landfilling, recycling, incineration, composting) along environmental, economic and social implications. LCA was finally conducted to assess environmental impacts of the disposals so that informed and sustained disposal decisions can be implemented. AHP results showed that habitat depletion, land use, stream ecology, air quality and flora & fauna dominated environmental concerns of the stakeholders. Capital cost, operation and maintenance cost, landfill capacity and regulation influence were the most critical criteria in economic factors. Concern for public health and safety, public awareness, cooperation among others were found to dominate the social factors. The four alternative disposal options (i.e. landfilling, recycling, incineration, composting) were assessed and ranked according to the preferences of the stakeholders. Incineration and composting were most preferred to landfilling and recycling. Landfilling was not preferred and was perceived to be most environmentally polluting, economically unsustainable and socially unacceptable by the stakeholders. LCA results showed that Landfill has the highest impacts among the selected environmental impact categories namely, global warming (992 kg Carbon dioxide eq), acidification (0.104 moles of Nitrogen or Sulphur-eq), photochemical ozone formation (0.686 kg Non-Methane Volatile Organic Compounds) (MNVOC) and eutrophication (0.104 moles of Nitrogen or Sulphur-eq); except for ozone depletion potential having the highest impacts (0.686 kg Chlorofluorocarbon 11-eq) in the incineration plan due to the presence of Chlorofluorocarbon-based chemicals utilized in flue gas purification. Incineration with energy recovery and composting with stable organic compost were found to have least environmental impacts. Finally, views of concerns of stakeholder on MSW disposal in Johor Bahru city were identified and modelled with AHP. Practical environmental performance of the disposal alternatives were demonstrated through the LCA. Combination of the concepts (i.e. AHP and LCA) revealled better information in sustainability of disposing MSW by incineration and composting. This can aid more guided information on selecting better MSW disposal alternatives. Thus it will be possible to avoid misunderstandings on MSW treatments e.g. incineration since the public are involved in the decision making processes.

ABSTRAK

Pelupusan sisa pepejal perbandaran (MSW) yang dihasilkan di bandar Johor Bahru merupakan satu cabaran pada pihak berkuasa dan orang ramai. Saiz penduduk dan kadar penghasilan sisa pepejal didapati semakin meningkat setiap tahun. Tapak pelupusan sedia ada iaitu Seelong dan Tanjung Langsat tidak dapat menampung jumlah sisa pepejal yang semakin meningkat. Ini mengakibatkan kesan negatif terhadap alam sekitar dan kesihatan awam. Oleh itu, alternatif untuk pelupusan sisa pepejal amat diperlukan. Namun, pihak berkuasa tempatan berhadapan dengan masalah, bantahan dan tentangan serta kekangan kewangan dalam memilih dan melaksanakan kemudahan pelupusan sisa pepejal. Penyelesaian kepada masalah ini melibatkan prosedur penilaian yang rumit kerana kesukaran untuk mencapai kata sepakat di kalangan pihak berkepentingan dan badan-badan lain yang berkaitan. Oleh itu, dalam kajian ini, dua konsep iaitu proses hierarki analitikal (AHP) dan penilaian kitaran hayat (LCA) telah digunakan. Objektif kajian ini adalah untuk mengenal pasti pendapat pihak berkepentingan mengenai pelupusan sisa pepejal (melalui pelbagai kaedah interaksi seperti lawatan, mesyuarat, persidangan dan sesi simposium) dan menggunakan AHP untuk menstrukturkan pendapat tersebut dalam mencadangkan alternatif untuk pelupusan sisa pepejal (penimbusan, kitar semula, pembakaran penunuan, pengkomposan) bersama dengan implikasi alam sekitar, ekonomi dan sosial. Akhir sekali, LCA digunakan untuk menilai impak alam sekitar dari pelupusan sisa pepejal agar penyelesaian yang mampan boleh dilaksanakan. Keputusan AHP menunjukkan masalah alam sekitar yang membelenggu pihak berkepentingan merangkumi kekurangan habitat, penggunaan tanah, ekologi sungai, kualiti udara dan flora serta fauna. Manakala, dari sudut ekonomi, kos modal, kos operasi dan penyelenggaraan, kapasiti tapak pelupusan dan peraturan alam sekitar merupakan kriteria yang paling kritikal. Antara faktor sosial adalah seperti keprihatinan terhadap kesihatan dan keselamatan awam, kesedaran awam dan kerjasama awam. Empat alternatif untuk pelupusan sisa pepejal telah dinilai dan disenaraikan mengikut kecenderungan pihak berkepentingan. Keputusan penilaian menunjukkan pembakaran penunuan dan pengkomposan lebih digemari berbanding penimbusan dan kitar semula. Penimbusan tidak digemari dan dilihat sebagai paling mencemarkan alam, tidak mampan dari segi ekonomi dan tidak boleh diterima secara sosial oleh pihak berkepentingan. Justeru itu, LCA telah dijalankan untuk penimbusan, pembakaran penunuan dan pengkomposan. Tapak pelupusan mempunyai impak tertinggi di kalangan kategori impak berpotensi yang telah dipilih iaitu pemanasan global (992 kg karbon dioksida), pengasidan (0.104 mol Nitrogen atau Sulfur), pembentukan ozon fotokimia (0.686 kg bukan-metana kompaun organik meruap (NMVOC)) dan eutrofikasi (0.104 mol Nitrogen atau Sulfur). Manakala pembakaran penunuan paling berpotensi mengakibatkan penipisan ozon dengan impak tertinggi (0.686 kg klorofluorokarbon 11) yang disebabkan oleh kehadiran bahan kimia berasaskan klorofluorokarbon yang digunakan dalam pembersihan gas serombong. pembakaran penunuan berserta pemerolehan semula tenaga dan pengkomposan berserta baja organik yang stabil didapati mempunyai impak alam sekitar yang paling rendah Akhir sekali, kebimbangan pihak berkepentingan terhadap pelupusan sisa pepejal di Johor Bahru telah dikenal pasti dan dimodelkan menggunakan AHP. Prestasi alam sekitar untuk alternatif MSW yang praktikal telah ditunjukkan melalui LCA. Gabungan konsep AHP dan LCA membantu memberi maklumat yang lebih baik mengenai kemampanan melupuskan sisa pepejal melalui pembakaran penunuan dan pengkomposan, seterusnya membantu untuk memilih alternatif untuk MSW yang lebih baik. Justeru itu, terdapat kemungkinan untuk mengurangkan salah faham mengenai rawatan MSW seperti pembakaran penunuan kerana orang awam terlibat dalam proses membuat keputusan.

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LIST OF ABBREVIATIONS

AD	-	Aerobic Digestion
AHP	-	Analytical Hierarchy Process
AP	-	Acidification Potential
APC	-	Air Pollution Control
CBA	-	Cost Benefit Analysis
CHP	-	Combined Heat and Power
CI	-	Consistency Index
CML	-	Centre of Environmental Science, University of Leiden, the Netherlands
CR	-	Consistency Ratio
DOE	-	Department of Environment
EIA	-	Environmental Impact Assessment
ELECTRE	-	Electionet Choix Traduisant La Réalité
EP	-	Eutrophication Potential
FU	-	Functional Unit
GFI	-	Grate Firing Incineration
GHG	-	Greenhouse Gases
GIS	-	Geographic Information System
GMM	-	Geometric Arithmetic Mean
GWP	-	Global Warming Potential
HHV	-	Input-Output Analysis
IPCC	-	Intergovernmental Panel on Climate Change
IRDA	-	Iskandar Malaysia Development Authority
ISO	-	International Standard Organization
LCA	-	Life Cycle Assessment

LCI	-	Life Cycle Inventory
LCIA	-	Life Cycle Inventory Assessment
MBT	-	Mechanical Biological Treatment
MCA	-	Multi-Criteria Analysis
MCDA	-	Multi-Criteria Decision Making Attributes
MCDM	-	Multi-Criteria Decision Making
MCE	-	Multi-Criteria Evaluation
MCO	-	Multi Criteria Optimization
MHLG	-	Ministry of Housing and Local Government
MOO	-	Multi Objective Optimization
MOH	-	Ministry of Health
MOP	-	Multi Objective Programming
MRF	-	Material Recovery Facilities
MSW	-	Municipal Solid Waste
MSWM	-	Municipal Solid Waste Management
MAVT	-	Multi Attribute Utility Theory
MUAT	-	Multi-Attribute Value Theory
ODP	-	Ozone Depletion Potential
OSHE	-	Occupational Safety, Health and Environment
PIPA	-	Policy impact potential analysis
POCP	-	Photochemical Ozone Formation Potential
PROMETHEE	-	Reference Ranking Organization Method for Enrichment Evaluations
RDF	-	Refuse Derived Fuel
RI	-	Random Index
SCA	-	Spatial Cluster Analysis
SW	-	Solid Waste
TOPSIS	-	Technique for Order Preferences by Similarity to Ideal Solutions
USEPA	-	United States Environmental Protection Agency
UTM	-	Universiti Teknologi Malaysia
VOC	-	Volatile Organic Compounds
WAMM	-	Weighted Arithmetic Mean Method
WEEE	-	Waste Electrical and Electronic Equipment

WMDM	-	Waste Management Decision Making
WLC	-	Weighted Linear Combination
WtE	-	Waste to Energy

LIST OF SYMBOLS

C_2H_4	-	Ethylene
C_6H_6	-	Benzene
$(C_6H_6)CH_3$	-	Toluene
$(C_6H_6)(CH_3)_2$	-	Xylenes
$Ca(OH)_2$, CaO	-	Lime
CFC	-	Chlorofluorocarbon
CH_4	-	Methane
$CHCl_3$	-	Chloroform
Cl_2	-	Chlorine
Cl_3	-	Chloride
CO_2	-	Carbon dioxide
CO	-	Carbon Monooxide
HCFC	-	Hydro chlorofluorocarbon
HCl	-	Hydrogen Chloride
HF	-	Hydrogen Fluoride
H_2S	-	Hydrogen Sulphide
H_2SO_4	-	Sulphuric Acid
N	-	Total Nitrogen
HNO_3	-	Nitric Acid
NH_3	-	Ammonia
NH_4	-	Ammonium
NO_X	-	Nitrogen Oxide
N_2O	-	Nitrous Oxide
NO_3^-	-	Nitrate ion
NO_2	-	Nitrite ion

O_2	-	Oxygen
O_3	-	Ozone
P	-	Total Phosphorus
PCDD/F	-	Dioxins/furans
PM	-	Particulate Matter
SO_X	-	Sulphur Oxide
UV	-	Ultra Violet Light
VOC	-	Volatile Organic Compounds
Hg	-	Mrecury
Cd	-	Cadmium
As	-	Arsemic
Co	-	Cobalt
Cr	-	Cromium
Cu	-	Copper
Mn	-	Manganese
Ni	-	Nickel
Pb	-	Lead
Λ	-	lamda

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CHAPTER 1

INTRODUCTION

1.1 Background

Municipal solid waste management (MSW) has always been a major burden of most nations because improvements in technology and services delivery have resulted in growth in populations and simultaneous generation of waste. More alarmingly, the twenty first century witnesses about 30-50% population increase especially in the developing countries. Mostly, city growth rates exceed 4% per annum (Zerbock, 2003) in these countries. Unfortunately, more than 90% of collected wastes end up into the landfill without pretreatment in developing countries (Abd Kadir *et al.*, 2013). Unfortunately, the 20 to 40 percents of municipal revenues spent to manage waste are not enough to handle the rising trend of the waste generated. While this is the case in these countries, less than 30% of city population get adequate and regular refuse removal (Senkoro, 2003); thus characterizing the waste by unfavorable economic, institutional, legislative, technical and operational constraints (Imam *et al.*, 2008). Indiscriminate littering of scraps of papers, plastic bags, paper and plastic containers, packaging materials, plastic bottles, piles of rotten garbage in the drains and streets, broken chairs and metals became very common in most areas in these countries (Abba et al., 2013). Furthermore, inadequacy in provision of basic services such as proper sanitation facilities, transport infrastructure, waste collection and sanitary water supply has complicated the problem (Rathi, 2007). These challenges have been posing threat to the environment and human health locally and globally (Abba et al., 2013). As a result, solid waste will continue to be one of the contending challenges; and hence contribute a lot to climate change and global warming. More research on the subject matter will always be a hot topic presently and in the near future since direct adverse effects of improperly managed waste on human health and the entire ecosystem have been repeatedly reported (Abba *et al.*, 2010; Agamuthu and Fauziah, 2008).

In Malaysia for example, growing economy due to several factors such as: conducive climate that favours strong agricultural base (food and export crops); manufacturing and service based industries; diverse tourism industry with sustainable future potentials; and viable, committed and successful development policies have led to the population growth which subsequently resulted in more consumption of goods and services that translated into more waste generation (Othman *et al.*, 2013; Samsudin and Mat Don, 2013). In 2003 for instance, waste generation rate in the country was 0.5-0.8 kg/p/d on average and up to 1.7 kg/p/d in the major cities (Manaf *et al.*, 2009). According to them, this much is due to rapid economic development and population growth, inadequate infrastructure and expertise on one hand and habit and mindset on the other. The population has been increasing at a rate of 2.4% per annum or about 600,000 per annum since 1994. As this trend is likely to continue, by the year 2020, the quantity of MSW to be generated will rise to 31,000 tonnes per day. Consequently, management of MSW will continue to be one of Malaysia's most critical environmental challenges. In addition, there are many cases of illegal dumping of all categories of wastes in isolated areas which are not detected by the government. This could be as much as 30% of the total waste generated in the country (Lee, 2007). The few that were detected cause authorities huge sums of expenditure to collect and dispose adequately. The campaigns and regulations for the implementation of the 3Rs were not complied by the populace as well (Agamuthu and Fauziah, 2011).

However, the country has taken some bold steps to manage municipal solid waste by privatizing the sector since 2007 (Abba *et al.*, 2013a). Previously, the regulation of solid waste was mostly undertaken by the federal government (Lee, 2007). In 1974, the quality act was enacted to protect the environment. Specifications under the act states that; the environmental impact assessment of the existing solid waste management be conducted (Lee, 2007; Manaf *et al.*, 2008). This was agreed under the amended version of the act "Environmental Quality (Clean Air) Act of 1978". By 1987, Environmental Impact Assessment act was passed to cater for wider environmental quality with extension in 1989 to take care of scheduled waste. The country signed the international protocols related to the protection of the environment. These among others included implementation of the resolutions of the United Nations Conference on Environment and Development Agenda 21 in 1992. Earth Summit in the same year and World Summit on Sustainable Development in 2002 were some of the activities participants from the country attended (Abba et al., 2013). Repeated regulations on 3Rs were re-emphasized every year though not enforced.

In the area where this research is conducted (three municipalities of Johor Bahru), there are huge infrastructural, economic and technological development currently going on to transform the city to an international standing by the year 2025. These activities call for an efficient and systematic way of handling the solid waste that is bound to be generated. However, solid waste handling and management is a complex problem. The selections of treatment facilities require the evaluation and integration of a lot of issues from municipalities, larger governments and other interest groups (Khadivi and Fatemi Ghomi, 2012). The task involves all stakeholders' participation in devising sustainable measures during generation, handling, transporting, treating and disposal of the waste. Stakeholders are thus faced with complexity in embarking on the suitable and acceptable decision on waste disposal option. The need to understand, compile and harmonize stakeholder's views and ideas had been a very difficult task and sometimes, taking decision on issues relating to the public results in series of conflicts and misunderstandings. Research indicates that these unnecessary controversies can be avoided. In the current case, the views of the public on impacts of solid waste bound to be generated in Johor Bahru Malaysia were identified and evaluated.

Data were collected through contacts, literature and questionnaire survey. Stakeholder views and opinions on current and future environmental impacts resulting from the solid waste disposed of in the area as stated earlier constitute the pilot of the research. Four solid waste disposal options, namely: landfilling, recycling, composting and incineration were assessed. Analytical hierarchy process (AHP), a concept from multi-criteria decision making tools is used to assess and rank stakeholder's judgments on how impacts from these activities interfere with the physical environment, social wellbeing and economy of the area of study. Life cycle assessment (LCA) is subsequently conducted on these disposal options further. This is meant to reexamine the choices of the stakeholders to enable more informed bases for embarking on an adequate and sustainable way of managing the rising generation of waste and corresponding impacts. The uses of both concepts independently were reported in literature to a considerable extent. Multi objective optimization (MOO) was reported in the works of Čuček *et al.* (2012). This was utilized to support economic, environmental social and technical decisions. In 2012, there were 136 articles in science direct as well as 51 of such in Scopus reported to assess impacts/environmental footprints to support decisions on environment (Cucek et al., 2012). Similarly, about 1341 and 1538 articles have been published in Science Direct and Scopus respectively using LCA to support decisions.

While this is ongoing, there are few instances where LCA and AHP were integrated to assess environmental impacts (Contreras *et al.*, 2008). In Malaysia, both concepts are still fresh and based on our investigation; there are no instances where these concepts (AHP and LCA) are put together to assess impacts of municipal solid waste disposal. It is therefore worthwhile to conduct this assessment so that bases in stakeholder views on solid waste disposal might be established and supported adequately. Authorities can be advised on the most sustainable way of waste disposal. In this wise, models will be presented as to serve as guide in identifying, evaluating and pointing out waste disposal impacts for future planning and management with a view of exploiting opportunities in waste to benefit practices in Johor Bahru. This is one of the major contributions of the thesis. As will be seen latter in the thesis, an environmental assessment of the solid waste disposal system has been carried out to further determine at which stages of the system the major pollution burdens occur more. In the LCA, those impacts from landfilling, mechanical biological treatment (composting) plan and incineration scenarios were evaluated and reported.

1.2 Problem Statement

The problem of environmental pollution caused by disposal of solid waste has been an issue of concern in many townships in Malaysia. This is linked to several factors, such as inability of the local authorities to pick up all the wastes, lack of proper and accurate data, lack of adequate financial resources, lack of skills, improper disposal facilities, and improper organizational structure of the authority responsible to manage the waste (Lee, 2007). It is also reported that, there are many cases of illegal dumping of all categories of wastes in isolated areas which are not detected by the government. This could be as much as 30% of the total waste generated in the country. The few that were detected cause authorities huge sums of expenditure to collect and dispose adequately (Lee, 2007). There is also the problem of annual increase in Malaysian population of 2.4% or 600,000 people per annum and the estimated quantity of 31,000 tons/day of solid waste to be generated by the year 2020 (Manaf et al., 2009), thereby posing an outstanding environmental concern. According to Manaf *et al.* (2008) and Johari *et al.* (2012), 76% and 80% of the generated waste in Malaysia is collected. The amount abandoned in the environment causes pollutants of various health and environmental concerns. It is also reported that 98 or 99 percent of the collected waste is deposited in landfills (Abd Kadir *et al.*, 2013; Oh *et al.*, 2010). If this trend continues, a serious environmental concern will be created. It will take a lot of effort and resource commitment to manage or abate. The size of land at the disposal of the country is another constrain if a lot of waste continues to flow to the landfills. For these and other reasons, new effective waste management policy and technique needs to be exploited. The implementation of waste disposal facilities and the reduction of impacts created need a holistic evaluation because abating pollutants created involves evaluation of implications of processes of those activities in a holistic perspective. So, researchers and waste management authorities are confronted with challenges of interdisciplinary dimension in identifying which impacts are of most critical environmental and health concerns, and how and where to put more efforts and emphasis to control for waste management. Waste composition is highly heterogeneous and can contain a lot of pollutants (Damgaard and Christensen, 2010) which single technique of treatment is not enough, therefore, multicriteria and life cycle assessment models are required for outlining impacts and environmental implications incurred in treating and disposing the waste.

In most cases of MSW management in Malaysia, the public (those people or stakeholders affected by the implementation of solid waste management system) are not adequately involved during the decision making process. These reasons and others led to protests and opposition from the masses when facilities such as incinerators and even landfills are proposed to be installed. It is reported that strong opposition and protests faced by authorities during the installation of these waste management facilities are due to perceived emission of pollutants and high cost of installation and maintenance and most importantly; lack of information on disposal facilities, e.g., incinerators since there is no any fully functional MSW incinerator in the country (Manaf et al., 2008). A typical case is the strong opposition for the installation of a thermal treatment plant in Kuala Lumpur which was intended to commence operation in 2008 and cater for incinerating 1500 tonnes of MSW per day (Forti *et al.*, 2004b). To avert this unnecessary confrontation, sustainable municipal solid waste management (MSWM) models can be developed to seek and transform stakeholder views and opinions into decision-making that involves public participation in the decision-making process. Currently, the public are only apprised and sometimes rarely take part in discussions. This leaves them with little contribution on decision making in most waste management systems. Therefore, integration of concepts such as multi-criteria decision making technique and a life cycle approach to assess and inform the stakeholder the processes of solid waste management from generation, transportation, treatment and disposal (cradle to grave) is thus vital. LCA is needed to present more insight to evaluate, identify and diagnose hot spot problems areas and possible improvements on reducing and controlling the current solid waste management practice. Waste data regarding composition, characteristics, properties, need to be updated and made available every year. LCA can be used to develop data inventory from time to time. This also gives room for proper analysis and environmental impact assessment (EIA).

An increase in waste flow is ultimately expected as a result of development and population growth. These activities call for an efficient and systematic way of handling the solid waste that is bound to be generated. Hence, the need for other modes of waste treatments (such as thermal treatment, composting and to some extent waste recovery) should be necessary.

1.3 Objectives of the Research

The main aim of the research is to investigate and compare sustainable solid waste disposal scenarios for the city of Johor Bahru involving environmental, social and economic impacts percieved by stakeholder in choosing disposal alternatives (landfilling, recyling composting and incineration) using AHP on one hand and comparing the environmental implications of the disposal options using LCA.

1.3.1 Specific Objectives

This aim can be chieved through the following specific objectives:

1. To identify MSW disposal impacts through public/stakeholder opinions and views based on consultations in the city of Johor Bahru.
2. To use AHP structure views/opinions of the public on their importance or criticality in proposing different solid waste disposal alternatives considering environmental, economical and social implications thereof.
3. To assess the potential environmental impacts of the disposal alternatives using LCA approach.
4. To determine sustainable MSW disposal alternatives based on findings from both AHP and LCA (based on scenario assessed on environmental hot spots of impacts on each disposal alternative).

1.4 Scope

This research consists two parts. The first part comprises of evaluating the impacts of solid waste disposal in terms of environment, social and economic aspects in three municipalities of Johor Bahru (Municipals of Johor Bahru Tengah, Johor Bahru municipal council and Pasir Gudang municipality). Initially, disposal of solid waste was conceived to be improved by proposing some additional disposal options (recycling, composting and incineration) in addition to the current solid waste practice (landfilling). To obtain data for the studies, questionnaire were structured and administered to stakeholders. Part of the data comes from visits and contacts with the three municipalities; Johor DOE; Iskandar Malaysia city Planners and Universiti Teknologi Malaysia environmentalists. Meetings, workshops, symposia conferences and deliberations were held during the periods of data collections 2010 to 2012 (2 years). Another part of the data (impacts) obtained from literature was used to support and validate some of the factors identified by the respondents (stakeholders). Thus these impacts consisted of noise, visibility, fauna and flora, stream ecology, air quality, land use, habitat depletion and vibration for environmental aspects. Social aspects include public health and safety, traffic congestion, odour effects, population growth, housing type, employment, skills, cooperation and public awareness), while economic aspects constitute: capital cost, operation and maintenance cost, recruitment and training cost, labour cost, income, bad debt, landfill capacity, regulation influence and incentives/disincentives). These impacts were structured in questionnaire formats and administered to respondents who included the residents, staff of the solid waste management in the municipalities, environmentalists (researchers in UTM, Johor DOE staff). Explanations were advanced on the impacts in selection of the alternatives.

Evaluation of questionnaire responses were based on AHP, a concept developed by Thomas L. Saaty in 1980 using the principle of multi-criteria decision making attributes (MCDA).

SuperDecision, AHP software is used to compute the responses in a pair-wise comparison to derive the priority judgments of the stakeholders (experts) and the final ranking of the alternative solid waste disposal plans.

The second part comprises life cycle assessment (LCA) of the disposal options evaluated by the AHP. In the current model, a range of specific and selected environmental aspects were assessed; investigating system performances under different points of view, such as material and energy requirements, environmental impacts and ecological footprints. Such approach is applied because the LCA of a product or service should be the assessment of the product with regard to its impacts on the environment and on human health, and should aim to be an overall ecological assessment.

The specific goal of the LCA is to compare the impacts from municipal solid waste disposal plans (Landfilling, Mechanical biological treatment (-consisting recyclable materials and Composting, and Incineration) for the city of Johor Bahru identified by stakeholders from the evaluation using AHP. The functional unit in the comparison is one tonne of treated/disposed solid waste within a time frame of 100 years. The cradle of the assessment is the point at which the waste is collected; the grave of the assessment is final emissions from collection, landfilling, thermal treatment and disposal that will impose some environmental impacts within the period of 100 years.

In summary, the LCA assessment will involve landfilling, compsting and finally incineration of the waste. Energy, material and products within the scope of the assessment are presented in various sections of the methodology and discussion of the result sections.

These inputs- outputs constitute the system boundary of the LCA. One tonne of waste was used as the bases for comparison of the scenarios assessed. Emissions from construction of facility (landfilling), manufacture of plants incinerators and MBT plants are not included.

As pointed out earlier, those impact categories evaluated consist of those causing Global warming potential, Acidification potential, Eutrophication potential, Ozone depletion potential and Photochemical oxidation potential. The impacts are based on CML 2010 methods (midpoint). Gabi software is used for modeling processes, life cycle inventory and life cycle inventory assessment since its data base is automatically designed with different impact categories computation methodologies including the CML methods.

1.5 Significance of the Study

The significance of this thesis is to present some possible ways of evaluating the waste disposal plans that could be sustainable, and then use the result to suggest different strategies that can be adopted for the treatments using two concepts (AHP and LCA) that are supportive of each other. The thesis also intends to highlight critical factors that may significantly influence the choice of a sustainable waste disposal scheme as in setting up an integrated waste management (IWM) system, data on the waste amounts and composition as well as infrastructure, economy and culture of the system. Without the knowledge of these factors any attempt to making a sustainable system is bound to fail. The results are intended to be used as basis for decisions on strategies and policies for waste management and investments for new waste treatment facilities by decision makers in local, regional, national and industrial sectors.

Municipal solid waste management (MSWM) has emerged as one of the most important areas of planning and management. Environmentally sound management of waste (a vital tool for sustainable development) is a very tasking venture. Many approaches were adopted in the past to manage waste. Landfill was initially used for disposal. This alone cannot be sustainable especially when cities urbanize and land use become highly competitive (Tchobanoglous etal., 1993). Incineration reduces the volume significantly but the high cost of incineration facility and the effects of the release of persistent organic pollutants (POPs) to the environment with so much concern on health and aesthetic effects makes it not a single solid waste treatment option in most developing countries especially. Composting needs a lot of fund and time with some unfavourable odour as well as space. Separate collection and recycling are emphasized and enforced in some countries (Japan, Korea and Singapore). This practice alone cannot do away with all the waste (Indeed, even when separate collection and recycling applied to its full potential, there will still be considerable quantities of residual urban waste (Di Lonardo *et al.*, 2012). The task of sustainable, integrated solid waste management is difficult, as it necessitates properly taking into account diverse factors as noted earlier, such as environment, social, economic, technical and other concerns that relates to environmental conservation. An integration of waste treatment strategies; with attention during collection and treatment via disposal methods for all the contents in waste stream in an environmentally friendly, economically affordable and socially acceptable way is a vital step to reduce MSW problem (Abeliotis, 2011). As a result, Managers and planners are paying increasing attention to formulate and follow a sustainable approach by integrating strategies that will produce the best practical option. With these considerations, this study proposes to use an analytical hierarchy process (AHP), a MCDM tool, to evaluate the different alternatives for waste disposal in the townships in Malaysia. The impacts derived from the options proposed evaluated in AHP are further evaluated using LCA. This is because LCA gives a holistic (cradle to grave) assessment of the impacts (Othman *et al.*, 2013)

1.6 Organization of the Thesis

The organization of this dissertation is presented as follows:

In chapter 1, the research background, problems statement/motivation, research direction, objective and structure of organization of the study were put up.

In Chapter 2, a comprehensive literature review on solid waste management was conducted. Waste generation and characteristics in Malaysia were presented. Bases for controlling the problem of municipal solid waste using multi-criteria decision-making, AHP applications, LCA applications and interpretation were presented. Attempts to integrate the two concepts (AHP and LCA) for solid waste disposal sustainability were presented. Limitations and discrepancies in the usage of both concepts were included.

Chapter 3 presents analytic hierarchy process (AHP), a multi-criteria decision-making methodology. Data obtained from primary source (such as questionnaire survey personal visits, interaction) and literatures were used in modelling and ranking impacts and disposal alternatives with the AHP. AHP, based on (1) structuring the decision problem; (2) creating pair-wise comparison matrix; (3) determining normalized weights; and (4) synthesizing the priorities of the assessment were detailed and explained in the chapter. Life cycle assessment, a chemical Engineering principle methodology used in the research was described. The use of LCA and procedure was described based on ISO 14040 and 14044 standards. Thus based on its four stages; goal and scope definition, life cycle inventory (LCI), life cycle inventory assessment (LCIA) and interpretation of the results within the set goals of the assessment were covered in the methods.

Chapter 4 presents Results and Discussion of the AHP section. The chapter consists of modeling and generating results obtained from survey with AHP questionnaire. Based on the results, impacts implications were evaluated and discussed. The use of those impacts to prioritize and propose sustainable solid waste disposal alternatives were reported.

Chapter 5 involves the use of LCA on solid waste disposal plans proposed by the assessment in AHP chapter. Here, conventional LCA according to ISOs 14040 and 14044 were employed to investigate the environmental aspects and burdens in implementing each MSW disposal plan. Results in materials consumption, energy used and emissions to air, water and soil as well as products formed were reported. Environmental implications of these aspects were discussed using environmental impacts categories based on CML 2010 methodology. Conclusion part of this chapter presents why each of the MSW disposal plan was to be considered or not considered based on their environmental burden or benefits.

Chapter 6 presents the findings from the merger of both AHP and LCA to presents better and well informed perceived and practical environmental burdens or benefits each of the evaluated MSW disposal plans offers.

Chapter 7: The chapter presents conclusions and recommendations based on the findings of the thesis. Briefly, data related to solid waste composition and characterization was presented. Municipal solid waste management methods with AHP and LCA were reviewed. Proposed integrated approach in sustainable municipal solid waste management disposal for Malaysia using AHP and LCA was put up. Significant factors influencing solid waste disposal in Johor Bahru using AHP technique were determined. Findings in form of improvement in waste management practices consisting of public participation and compliances to environmental regulatory codes were highlighted. Benefits of sustainable waste management ranging from reduced government expenditures as well as sustainable environment were shown.

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