# LIFE CYCLE ASSESSMENT OF AN INTEGRATED SOLID WASTE MANAGEMENT SYSTEM IN JOHOR BAHRU

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*I dedicated this entire work to my beloved family and friends who were always be my side…*

*For all their selfless love, support, inspiration and encouragement*

*Thanks…*

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# ABSTRACT

The disposal of municipal solid wastes in landfill resulted in significant emissions of greenhouse gases (GHGs), predominantly methane ($CH_4$) and causes green house effect leading to global warming. The aim of this study is to assess the environmental impacts of municipal solid waste management in Johor Bahru, Malaysia. It is also aimed at reducing the GHGs emission from the related waste-disposal activities based on several scenarios by utilizing the concept of integrated solid waste management (ISWM). This approach has been applied to optimize the management of the wastes with the main targets of GHGs emissions reduction and its impacts to the environment. In this proposed scenarios, wastes were being fractioned for different waste management options which include source separation, recycling, composting, incineration and landfilling. Subsequently, comparison of the existing and alternatives wastes management scenarios was performed based on their respective impacts to the environment via cradle-to-grave approach known as life cycle assessment (LCA). Scenario 1 is an integrated system which involves recycling, composting, incineration and landfill. Meanwhile, only three treatments involved in scenario 2 (composting, incineration, landfill) and scenario 3 (recycling, incineration, landfill). Scenario 4 is the current situation which involve recycle and landfill. Even though scenario 4 shows an emission of 2.04 kg $CO_2$-eq of $CH_4$ and 31.63 kg $CO_2$-eq of carbon dioxide but by taking integrated system into account, scenario 1 gave less impact compared to others (scenario 2; 1404.99 kg $CO_2$-eq and scenario 3; 1837.64 kg $CO_2$-eq) with emission of 10.59 kg $CO_2$-eq and 1292.7 kg $CO_2$-eq for $CH_4$ and $CO_2$ respectively. ISWM system, with a combination all treatments of recycling, composting, incineration and landfill (scenario 4) has shown best result in general and less emissions compared to the others. A combined facility or integrated solid waste management would be ideal for Johor Bahru.

# ABSTRAK

Pelupusan sisa pepejal di tapak pelupusan telah menyebabkan kesan rumah hijau hasil pelepasan gas rumah hijau (GHG) yang kebanyakannya adalah gas metana ($CH_4$) dan seterusnya membawa kepada pemanasan global. Tujuan kajian ini adalah untuk menilai kesan terhadap alam sekitar hasil daripada pengurusan sisa pepejal perbandaran di Johor Bahru, Malaysia. Ia juga bertujuan mengurangkan pelepasan GHG daripada aktiviti pelupusan sisa yang berkaitan berdasarkan beberapa cadangan senario dengan menggunakan konsep pengurusan sisa pepejal bersepadu (ISWM) demi mengoptimumkan pengurusan sisa pepejal. Berdasarkan cadangan senario, pembahagian sisa telah dilakukan untuk pengurusan yang berbeza seperti pengasingan di sumber, kitar semula, kompos, pembakaran dan pembuangan di tapak pelupusan. Setelah itu, perbandingan dilakukan terhadap pengurusan sedia ada dan senario alternatif berdasarkan kesan masing-masing kepada alam sekitar melalui kajian penilaian kitar hayat iaitu daripada awal sehingga akhir proses. Senario 1 adalah satu sistem bersepadu yang melibatkan kitar semula, kompos, pembakaran dan tapak pelupusan. Hanya tiga rawatan terlibat dalam senario 2 (kompos, pembakaran, pelupusan) dan senario 3 (kitar semula, pembakaran, pelupusan). Senario 4 adalah keadaan semasa yang melibatkan kitar semula dan tapak pelupusan. Walaupun senario 4 menunjukkan pembebasan $CH_4$ sebanyak 2.04 kg $CO_2$-persamaan dan karbon dioksida ($CO_2$) 31.63 kg $CO_2$-persamaan tetapi dengan mengambil kira sistem bersepadu, senario 1 memberi kesan yang kurang berbanding yang lain (senario 2; 1404.99 kg $CO_2$-persamaan dan senario 3; 1837.64 kg $CO_2$-persamaan) dengan pelepasan 10.59 kg $CO_2$-persamaan dan 1292.7 kg $CO_2$-persamaan untuk $CH_4$ dan $CO_2$. Senario 1, sistem ISWM menunjukkan hasil yang terbaik secara umum dan kurang pembebasan GHG berbanding yang lain. Pengurusan sisa pepejal secara bersepadu adalah sesuai untuk Johor Bahru.

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| | | |
|---|---|---|
| BEs | - | Business entities |
| C | - | Carbon |
| $CH_4$ | - | Methane |
| $CO_2$ | - | Carbon Dioxide |
| EDIP | - | Environmental Design of Industrial Products |
| GHG | - | Greenhouse Gas |
| GWP | - | Global Warming Potential |
| HCS | - | Hauled Container System |
| ISO | - | International Organization for Standardization |
| ISWM | - | Integrated Solid Waste Management |
| JICA | - | Japan International Cooperation Agency |
| JPSPN | - | Department of Solid Waste Management (Jabatan Pengurusan Sisa Pepejal) |
| kg $CO_2$ equiv | - | kilogram Carbon Dioxide Equivalent |
| KPI | - | Key Performance Index |
| LA | - | Local Authority |
| LCA | - | Life Cycle Assessment |
| LCI | - | Life Cycle Inventory |
| LCIA | - | Life Cycle Impact Assessment |
| MBJB | - | Majlis Bandaran Johor Bahru |
| MHLG | - | Ministry of Housing and Local Government |
| MINT | - | Malaysian Nuclear Agency |
| MPJBT | - | Majlis Perbandaran Johor Bahru Tengah |
| MRF | - | Material Recovery Facility |
| MSW | - | Municipal Solid Waste |
| MSWM | - | Municipal Solid Waste Management |
| N | - | Nitrogen |

| | | |
|---|---|---|
| NIMB | - | Not-In-My-Backyard |
| $N_2O$ | - | Nitrous Oxide |
| PPSPPA | - | Perbadanan Pengurusan Sisa Pepejal dan Pembersihan Awam (Waste Management and Public Cleansing Corporation) |
| RCRA | - | Resource Conservation and Recovery Act |
| SCS | - | Stationary Container System |
| SWM | - | Solid Waste Management |
| SWM Sdn. Bhd | - | Southern Waste Management Sdn. Bhd. |
| tpd | - | ton per day |
| TS | - | Transfer station |
| USEPA | - | United State Environmental Protection Agency |
| WTE | - | Waste to Energy |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| r | - | Rate |
| t | - | Time |
| y | - | Vapor composition |
| x | - | Liquid composition |
| i | - | Component |
| N | - | Initial population at time = 0 |
| $N_o$ | - | Population at time t |
| T | - | Temperature |
| P | - | Pressure |
| $\gamma$ | - | Activity coefficient |
| $\alpha$ | - | Relative volatility |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background

Nowadays, wastes have become a major problem to the environment. If not properly managed and taken care of, it can lead towards environmental and health problem. Solid waste will be the focus of this research. Solid wastes are defined as wastes arising from human and animal activities that are normally solid and unwanted. The classification of solid waste uses a variety of schemes such as physical (solid, liquid, gaseous), original use (packing waste), material (glass, paper, plastics), physical properties (combustible, compostable), origin (domestic, commercial, industrial, agricultural) and safety parameters (hazardous, radioactive). There are four main categories of solid wastes which are municipal solid waste (MSW), agricultural wastes, industrial waste and hazardous wastes.

A community mostly generates both municipal and industrial waste materials. Previous study found that the main components of Malaysian waste are food, paper and plastic which comprise 80% of overall weight (Kathirvale *et al*., 2003). The disposal of these wastes recently has become an issue of immense proportions. These problems had been considered in the news as with political and social concerns overshadowing technical and economic issues.

According to Agamuthu (1997), waste generation within Malaysia was found to depend very much on the sources of municipal solid waste. The rate of generation

varied greatly depending on the premises (house, shop, etc.), affluence of population (low income or high income), occupations or business.

Municipal solid wastes are mainly the household wastes including commercial waste and institutional waste. This type of waste is highly heterogeneous and its composition depends on factors like living standards, type of housing, seasons and country including cultural habits of individuals. MSW also includes solid residue from municipal functions and services. Meanwhile, industrial waste comprises wastes from industrial processes and some of these could also include hazardous waste. The problem of this waste disposal began when human first started to congregate in relatively small areas. Everyone is responsible and must take action, especially in disposal management of the waste.

The composition of MSW reflects the affluence of the society, their way of life, their economic status and their social behavior. The characteristics of MSW changes with time as the society evolve to the needs of development (Agamuthu, 1997).

Numerous basic principles and methods of solid waste management were introduced at the beginning of twentieth century (Parsons *et al*., 2005). The general methods for the final disposal of solid wastes are dumping on land and in surface waters, feeding to swine, mixing into soil, reduction and incineration. Most large cities, however, still dump solid waste on land or in water. But as today, the dumping of waste into any body of water is no longer allowed, so most municipal solid waste is currently disposed of in a landfill.

Understanding solid waste management may relate concurrently to the control of generation, storage, collection, transfer and transport, processing and finally disposing of solid waste with the best doctrines of public health, economics, engineering, conservation, aesthetics and environmental considerations. Hence, this study will focus on integrated solid waste management instead of landfill disposal only.

Integrated Solid Waste Management (ISWM) can be defined as a combination of waste management programs which are including thoroughly waste prevention, recycling, composting and disposal. An effective ISWM system should be considered the best way to prevent, recycle, and manage solid waste which then gave good effect in protecting human health and the environment (USEPA, 2002). In ISWM systems, the most suitable waste management activities can be done is after evaluating the local needs. These needs will guide further for necessary action. The most important ISWM activities are waste prevention, recycling, composting, combustion and disposal in landfills that are designed, constructed and manage appropriately. Each of these activities requires precise planning, financing, collection and transport.

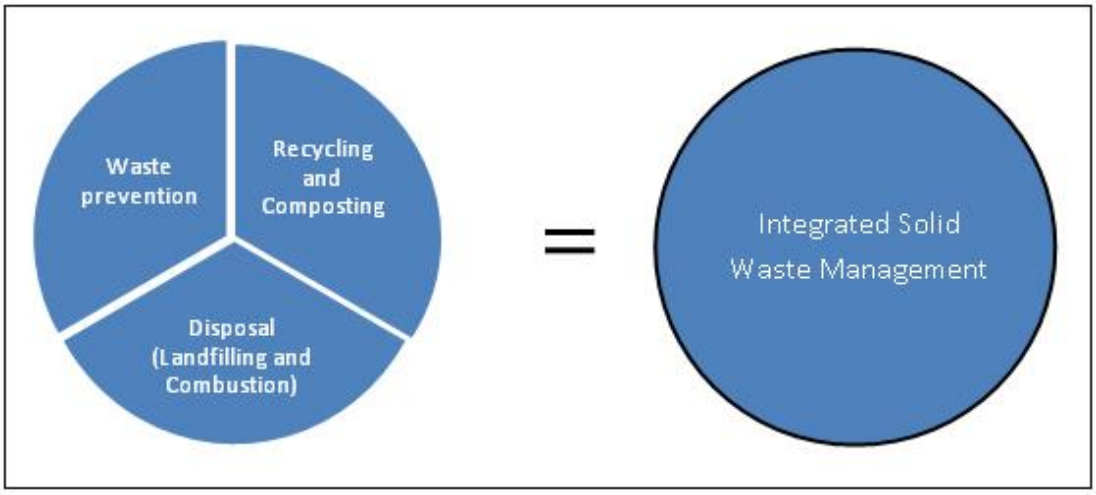


**Figure 1.1** Integrated Solid Waste Management (USEPA, 2002)

Normally, a material or product will go through a long cycle before it becomes solid waste. Mostly it involves removing and processing raw materials, manufacturing the product, transporting the materials and products to markets and using energy to operate the product. From these activities, greenhouse gas (GHG) emission potentially generated through one or more of the subsequent process (USEPA, 2002):

- Energy consumption: From fossil fuels used in transporting and marketing of materials and products to market all generates GHG emissions.

- Methane emissions: A greenhouse gas, methane will generates when organic waste decomposes in landfills.

- Carbon storage: By planting trees and other crops, carbon emission will be sequestered in plant as carbon and thus minimize climate change impacts that caused by $CO_2$, greenhouse gas.

Water vapor, methane, carbon dioxide, ozone and nitrous oxide are types of greenhouse gases that occur naturally in the air, while others could arise from human actions. By burning wood and wood products, fossil fuels (oil, natural gas and coal) and solid waste will cause carbon dioxide to be emitted to the atmosphere. Meanwhile, decomposition of organic waste at landfills and by livestock will generate methane emissions. Also during the production and transport of coal, natural gas, and oil will give the same effects. Besides, through the combustion of fossil fuels and solid waste will cause emission of nitrous oxide. It happened as well as during agricultural and industrial activities (USEPA, 2002).

## 1.2 Problem Statement

Natural resources are being depleted fast to meets demands since the human population is constantly growing. The more food we consumed, the more waste is generated. Before the waste is dumped in the landfill, first, it must be sent to the municipal waste collection centre by the state agency. However, the condition of the waste determines whether the waste will be sent off to landfill site, dumping area or waste treatment available in the country.

However the municipal solid waste will emit greenhouse gases which can contribute to global climate change. The climate change issue is not something new. For the past 100 years or so, the earth's temperature has increased (USEPA, 2002) and no doubt that will prolong and become warmer. This happens because of the heat from the trapped GHG in the atmosphere which caused the destruction of the ozone layer, which lead to the increase earth's temperature. In consequences, the warmer climate change may cause severe heat waves, change in weather of seasons in some places which later gave a serious impact on human health and environmental.

At present, management of the vast quantities of solid waste generated by urban communities is a very complex process. Serious public health and environmental problems might occur if these wastes are not handled and disposed properly. As to minimize this problem, a thorough knowledge of the problem and its individual elements is necessary.

The fiscal impact of any municipal waste program must be carefully considered. Planning for municipal solid waste management requires an analysis of budgetary constraints and the potential impact of alternatives. Financing options, including states and federal funding, as well as technical alternatives should be assessed.

The generation of waste will increase from time to time and year to year. At the same time, waste recovery for recycling and composting will also increased. Thus, varieties of programs and technologies are available, and there is a considerable market for more technologies. For example, the volume of total waste may be reduced by approximately 90% in waste to energy facilities, but the remaining 10 percent, as well as the materials that cannot be incinerated must still be disposed somehow (Kanti, 2000). Only two realistic options are available for the long term handling of solid waste and residual matter which are disposal on or in the earth's mantle and disposal in the ocean. But, most of the federal law in developed countries prohibits the latter. Therefore, a landfill is needed for disposal of the residue left by waste-to-energy and other material recovery.

Waste generation will proportionally increase with the expansion of population and development of economic as stated earlier. Human health and environmental will be at risk if the solid waste is not managed properly. Variety of problems can occur from the uncontrolled dumping and poor waste management such as water contamination and blocked canals or gullies which lead to increase in flooding and cause more bad impacts including attracting insects and rodents. In addition it may result in safety hazards from fires or explosions. The increase of GHG emissions, which contribute to climate change, can be prevented via proper planning and execution of comprehensive integrated waste management which involve collection, transportation and disposal activities as well as recycling and reduction of waste. In short, the ISWM program can help reduce GHG emissions and slow the effects of climate change.

In order to achieve the removal and disposal of unwanted material also known as wastes, technical, environmental, administrative, economic and political problem must be solved. This practice of solid waste management encompassed the planning, design, financing, construction and operation of facilities for the collection, transportation, and processing, recycling and final disposal of residual solid waste materials. All this is based on sound principles of public health, engineering, economics, aesthetics, conservation and environmental considerations, along with social and ethical issues (Tchobanoglous, 1993).

In Malaysia, Department of Solid Waste Management (JPSPN) under the Ministry of Housing and Local Government (MHLG) is the authority which is responsible for managing municipal solid waste. Basically, this department is the one responsible for policy and planning of SWM in the country while Corporation (PPSPPA) will be the one responsible on the enforcement and the concessionaire will do the work like waste collection etc. Based on the act issued by this department, the local authorities have to ensure that the municipal waste within their respective jurisdiction is collected and disposed hygienically by themselves or by private companies that have been contracted to do so.

However, starting September 2011, the concessionaire had taken over to collect wastes with fulfilling of the certain Key Performance Indicators (KPIs) which are useful in measuring the performance of waste management programmes and activities. The KPIs will provide an indication of their applicability and effectiveness. The two categories of the indicators are known as operational indicators which consist of recycling rate, waste minimisation costs per population served and level of public awareness on waste minimisation and the other is environmental indicators that consist of rate use landfill space and frequency and magnitude of illegal dumping (MHLG, 2006). It is recognized that local authorities (LAs) may begin with a minimum number of KPIs and revise or add more when LA capacity improves.

The enforcement is done and implement phase by phase. On the first year should be focus on the transition of the takeover from LAs to federal/by concessionaires. On the second year will be implement first to MPJB while to the municipal will be on the third year. On the fourth year as next phase, it will go to the district.

Currently, municipal solid waste in Peninsular Malaysia is being managed by three companies that have been given the concessions by the authority. These three companies namely Alam Flora Sdn. Bhd., Southern Waste Management (SWM) Sdn. Bhd., and Idaman Bersih Sdn. Bhd. are responsible for central regions, southern regions and northern regions respectively. Meanwhile, in west east Malaysia which are Sabah and Sarawak, the municipal solid waste has been managed by their local authorities. Mainly, the data needed for this research will be collected through this corporation which will be about composition of components in MSW generated by various sources, MSW generation rate per capita, characteristics and current solid waste management in Malaysia. The data will be assessed by Life Cycle Assessment (LCA) to obtain the impact of solid waste management activities in Malaysia towards the environment. Consequently, the finding of the analysis can be used to determine the best solid waste management scenario that post minimum impact to the environment. As for this research, data collection was done based in Johor Bahru which is under the responsibility of SWM Sdn. Bhd. for waste collection.

## 1.3 Research Objective

The main objectives of this research include:

i. To perform inventory of inputs/ outputs of MSW management in Johor.

ii. To develop different model of MSW management scenario through ISWM approach.

iii. To assess the environmental impacts of MSW scenarios using LCA.

iv. To select the best scenario that optimized GHG emissions reduction.

## 1.4 Research Scope

The scopes of this research include:

i. Collecting data of population and solid waste generated per capita in Johor Bahru.

ii. To analyze and projecting current data for the future solid waste management of year 2015, 2020 and 2025.

iii. To identify the environmental impact caused by the improper handling of waste management in Johor Bahru.

iv. To describe the link between solid waste management and climate change by GHG emissions through an inventory of inputs/outputs of MSW management.

v. To optimize the GHG emission reduction in an integrated solid waste management by implementing life cycle approach using GaBi software as a tool.

## 1.5 Research Contribution

Today, the dumping of waste into any body of water is no longer allowed. Early incinerators were a source of noticeable air pollution, and the sanitary landfill was developed as a relatively inexpensive alternative to incineration, especially for communities with sufficient land areas. Thus, this research aims to develop an integrated solid waste management plan with the specific goals of protecting human health, water supplies, decrease landfill area, increase 3R (Reduce, Reuse, Recycling) activities as well as reducing the future GHG emissions based on the collected current data. Several of factors will be consisted in the process such as the impact on public health, economics, conservation and environmental along with social and ethical issues as stated earlier.

## 1.6 Thesis Layout

Before starting the thesis, here is the layout of setting out each chapter, section and sub-sections. This part will help to introduce the reader systematically to the necessary background and make the ideas and conclusions acceptable.

First chapter is the introduction which introduce to the topic, telling the reader precisely on what's going on with the research and why is it worth doing. It is like a project proposal explaining the purpose of study by including research background, problem statement, specifying the objective of the study within a certain scope and possible contribution in the end.

Literature review as for chapter two identifies the research that already has been completed and provides an analysis of all current information relevant to the topic. In this chapter consist of several sections such as introduction of municipal solid waste, the current practice of solid waste management, plan on the integrated solid waste management and issue on greenhouse gas emission. In addition, literatures on life cycle assessment, the software and case study of different countries also discussed in this part.

In chapter three explain to readers the method used to gather info and data to answer research questions. In research design section, overall view of the method used was showed in the beginning to describe all about the method. There also method on data collection and data evaluation that showed how the method was executed.

Next chapter of results and discussions is said as the body of the thesis, consist of final results of the research, analysis and sub-conclusion. The projection of waste generation, scenario analysis and optimization of the GHG emission were include as part of it. It was made as logical, cumulative and simple as possible.

Last but not least in chapter five, conclusions were made to tell the reader what have discovered in each phase of the research process. It also gives an overview of the research process clearly regarding the research problem, sub-problems or hypothesis.

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