Original Research

Life Cycle Assessment for Solid Waste Disposal Options in Malaysia

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Abstract

The largest percentage of MSW in Malaysia is contributed by the state of Selangor, with a 3,923 tons generated daily. Therefore, the aim of this study is to consider the current condition of the open dumps and sanitary landfills in Selangor from an environmental point of view. Moreover, the local authorities of Malaysia prefer to use landfills that have no liners, biogas capture, and many others as a method of getting rid of collected waste. In Malaysia, this is the first time life cycle assessment (LCA) is being used. In this study, LCA is used to weigh up different treatment scenarios and SimaPro7 (2006) software with CML 2 base line 2000 v2.04 methodology applied to model the three scenarios. Research has shown that all scenarios have a high amount of different potential impacts. Further analysis illustrated that S3 (100% sanitary landfill) is more preferable than the others because of its low contribution on eutrophication, global warming and photochemical oxidation impacts. Results also confirmed that landfilling, which is the current waste disposal method for the country, is not a preferable method environmentally. Further studies should involve other decision-making tools and a wide range of scenarios that consider the economic and social effects of solid waste management methods to introduce environmentally and economically preferable methods to the Malaysian authorities.

Keywords: environmental management, municipal solid waste, impact assessment, LCA Malaysia

Introduction

Waste management is one of the most important sectors of environmental protection and should be regarded as a priority. Sorting out waste management through the introduction of a complex system of management has an important significance in fulfilling the sustainable development principle [1]. Studies on modeling of solid waste management systems started in the 1970s and have been amplified with the development of computer models in the 1980s. While 1980s models were generally based on an economic perspective [2], models that included recycling and other waste management methods were developed for planning municipal solid waste management systems in the 1990s [3]. Models developed in recent years have taken an integrated solid waste management approach, and included both economic and environmental analyses. These models have included linear programming with Excel-Visual Basic [4], Decision Support Systems [5], fuzzy logic [6], and Multi-Criteria Decision-Making techniques [7]. Environmental LCA is a system analysis tool that was developed rapidly during the 1990s and has reached a certain

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Table 1. The composition of municipal solid waste of Selangor.

Items	Paper	Plastics	Kitchen Waste	Glass	Metal	Textiles	Ceramics	Miscellaneous	Total
Weight	14.3	16.9	48.8	2.4	2.1	0.9	0.8	13.8	100

level of harmonization and standardization. LCA studies the environmental aspects and potential impacts throughout a 'product' life (i.e. cradle-to-grave) from raw material acquisition through production, use, and disposal. This is done by compiling an inventory of relevant inputs and outputs of a system (the inventory analysis), evaluating the potential impacts of those inputs and outputs (the impact assessment), and interpreting the results (the interpretation) in relation to the objectives of the study (defined in the goal and scope definition at the beginning of a study). LCA is currently being used in several countries to evaluate treatment options for specific waste fractions [8-12]. So, the LCA methodology was used to analyze and to evaluate different alternatives for Malaysia. The SimaPro7 (2006) software was applied to model waste disposal scenarios.

Waste Management in Selangor

The largest percentage of MSW in Malaysia is contributed by Selangor, with a generation of 3,923 tons daily. With most states experiencing rapid development, a similar trend is expected to take place in other states. Selangor had a population of approximately 5 million in 2009. Municipal waste is in general disposed by landfilling or incineration and only a small proportion of the MSW stream (about 2%) is recycled or treated by biological composting [13]. Also, in Selangor all MSW collected by the waste collectors from defined areas are disposed of in an open dump landfill. The management of the landfill includes the monitoring and leveling of waste. The landfill is an open-dump that lacks any lining system and leachate collection pond. The waste management system in Selangor state is basically under the responsibility of three main authorities that cover areas of Kuala Lumpur, Rawang, Sepang and Banting, Huluselangor, and the township of Kajang. One of the authorities is the consortium appointed by the Ministry of Housing and Local Government to provide waste management services in the central region of Peninsular Malaysia. The consortium currently is handling approximately 7,100 tons of waste every day [14]. The composition of Selangor MSW completed in 2009 by the National University of Malaysia is illustrated in Table 1 [15].

Table 1 shows that the waste is mainly composed of kitchen waste (48.8), paper (14.3%), and plastics (16.9%). Another authority is located approximately 20 km to the south-east of Kuala Lumpur. The area includes the cities of Sungai Langat, Sungai Bangi, Sungai Semenyih, and Sungai Chua. Kajang has a population of 189,400 people, with major activities including commerce, education, and agriculture.

Methodology

Applying LCA on solid waste management options in order to evaluate different methods of waste management for Malaysia is a new subject. Currently in Malaysia, a number of industries are doing LCA in order to have sustainable products; nevertheless, there are no institutes and solid waste management companies that have emphasized LCAs to consider the environmental impacts of their disposal options. The comparison was done by Simapro 7.2, the software used to compare the environmental impacts of open dumps and sanitary landfills in Malaysia. This evaluation was conducted according to TSE EN ISO 14040 (1996). According to TSE ISO 14040, an LCA comprises four major stages: goal and scope definition, life cycle inventory, life cycle impact analysis, and interpretation of the results.

Goal and Scope Definition

The aim of this study is to select a suitable waste disposal option for Malaysia by evaluating alternatives from an environmental point of view. The results of the study would be helpful for the Metropolitan Municipality of Malaysia. The functional unit of this study was the average total tonnage of MSW generated per year for a 20-year design life of landfill based on 2,257 tons per day generated in the Federal Territory of Kuala Lumpur. In this study, in order to conduct the analysis on different solid waste management methods in Malaysia, three alternative scenarios to the current waste management system in Selangor were defined, and these scenarios were evaluated by means of LCA. The first one was based on the present condition of waste management technology, which is 97% open dump and 3% sanitary landfill. The second one was 50% of household waste disposed in open dumps and 50% in sanitary landfills. The third scenario was 100% household waste disposed in sanitary landfills.

System Boundary

The system of the study began with the collection of MSW from residential areas and included waste treatment alternatives (open-dump and sanitary landfill) of waste. Life cycle assessment of transportation was not considered. Fig. 1 shows the system boundary of the study.

Life Cycle Inventory

The total life cycle inventory model for landfill consists of the inventory of energy consumption, air emissions, and water emissions during the phase of landfill construction, operation, closure, and post-closure care. However, in this study only landfill operation, leachate gas emissions and leachate generation are modeled. Additionally, the data for life cycle inventory was gathered from actual applications in Malaysia, literature, and the SimaPro7 database. Regarding energy consumption, fuel (diesel) and electricity consumption during landfill operation was modeled to estimate the energy consumed in terms of Kwh of electricity and the amount of fuel (diesel) for managing one ton of solid waste in a landfill. Electricity consumption during landfill operation is the electricity consumed for lighting the administration building and garbage site, and operation of weighbridge and the leachate treatment plant. Diesel consumption is the amount consumed by landfill machinery to place, spread and compact the waste, as well as the transport and spread, of daily, intermediate, and final cover.

The estimation of the quantity of landfill gas generated from the landfill was modeled using the triangle gas production model [16] that divides waste into two categories, i.e. rapidly biodegradable waste (RBW) and slowly biodegradable waste (SBW). The RBW gas generation rate was assumed to peak at the end of year one after waste was landfilled and totally decomposed after five years, while for SBW it was assumed to peak at year five and totally decompose after 15 years of being landfilled. The composition of the landfill gas was in the range of 45% to 60% for CH_4 and 40% to 60% for CO_2 [16] and for the purpose of the generation estimation of CH_4 and CO_2 from landfills in Malaysia, the percentage of CH_4 emission was 55% and 45% for CO_2 emission. The estimation of the amount of trace gases such as NH_4, total HC, and total NMVOC was estimated using USEPA 4.2, model [17].

Landfill leachate is characterized by high contents of organic and inorganic compounds, the content of a wide range of toxic substances, and high variability [18]. The leachate quantity generated from landfills was estimated using the water balance method [16]. The BOD concentration in the leachate was modeled by assuming that BOD concentration started at high concentration and diminished over time as the waste aged. The COD concentrations were calculated using BOD/COD ratio of landfill leachate. Other pollutants in landfill leachate were assumed to be constant throughout the landfill design life. The leachate quality used for estimating water emissions was based on the raw

Table 2. Life cycle inventory of open dump and sanitary landfill (air emissions).

Parameter	Unit/ Ton of waste	Open Dump	Sanitary Landfill
CH_4	kg	5.63E+06	6.90E+05
CO_2 (fossil)	kg	3.89E+06	1.38E+07
N_2O	kg	8.48E+01	1.84E+02
HCI	kg	3.27E+01	4.39E+02
HF	kg	3.45E+OO	4.60E+01
NH_4	kg	7.20E-Ol	1.05E+01
NO_x	kg	6.10E+04	1.52E+05
SO_x	kg	5.84E+03	2.07E+04
Total HC	kg	7.83E+02	3.36E+02
Total NMVOC	kg	5.12E+03	2.20E+03
Total Metals	kg	3.20E+OO	9.20E+01

leachate from Air Hitam with regard to energy consumption between open dumps and sanitary landfill, it is obvious that sanitary landfill consumed more energy than open dumps.

The energy consumed by the sanitary landfill was 7.31E+04 GJ per year, 3.01E+04 GJ more than open dump. The high consumption of energy by sanitary landfill was due to facilities used by the landfill, such as the leachate treatment plant, site lighting, and the administration building that are not available at open dumps. When considering air emissions between open dumps and sanitary landfills, the highest CH_4 emission was emitted by an open dump, at 5.63E+06 kg per year. However, sanitary landfill emitted more CO_2 (fossil) and N_2O than open dumps, at 1.38E+07 kg and 1.84E+02 kg per year, respectively. For other air emissions such as HCl, HF, NH_4, NO_x, SO_x, and total metals, sanitary landfills emitted more than open dumps, except for total HC and total NMVOC. The high emissions of HCl, HF, NH_4, NO_x, and SO_x were due to the process of electricity generation and the production and use of diesel fuel. As for emissions of total HC and total NMVOC, these were due to the decomposition process of organic matter in the landfill [19].

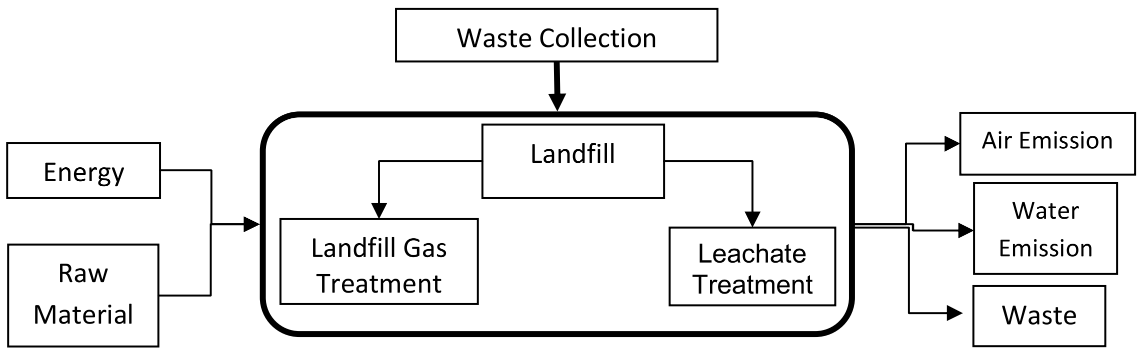

Fig. 1. Landfilling system boundary.

Table 3. Life cycle inventory of open dump and sanitary landfill (water emissions).

Parameter	Unit/ Ton of waste	Open Dump	Sanitary Landfill
BOD	kg	4.42E+06	8.84E+04
COD	kg	1.19E+07	2.38E+05
N	kg	4.64E+06	4.64E+04
NH_3	kg	3.9SE+06	4.96E+04
P	kg	2.61E+04	2.61 E+02
PO_4	kg	9.34E+OO	1.34E+02
Total Metals	kg	6.43E+03	3.46E+03

This disposal method had the highest output of water emissions for all parameters studied except PO_4 as compared to sanitary landfill. BOD and COD emitted per year by the open dump were 4.42E+06 kg and 1.19E+07 kg, respectively, while the sanitary landfill emitted 8.84E+04 kg of BOD and 2.38E+05 kg of COD. However, the sanitary landfill emitted higher PO_4 with 1.34E+02 kg per year as compared to 9.34E+00 kg by the open dump. The high emission of PO_4 was due to the high consumption of electrical energy and diesel fuel.

Malaysia's Electricity Mix Generation

Malaysia has approximately 16 (GW) of electric generation capacity, of which 87% is thermal and 13% is hydroelectric. In 2003 Malaysia generated around 79 billion Kwh of electricity. Throughout 2010 the Malaysian government expected that an investment of $9.7 billion would be required in the electric utility sector. Much of that amount was for coal-fired plants, as the Malaysian government had adopted a policy of attempting to reduce the country's heavy reliance on natural gas for electric power generation [20]. The electricity generation mix (1995-2005) of Malaysia is illustrated in Table 4 based on Hamdan Mokhtar`s study [20] on Malaysian energy.

Results and Discussion

In this study, 5 impact categories included in the CML 2 baseline 2000 method (an update from the CML 1992 method) were investigated to carry out life cycle impact assessment. These are global warming, human toxicity, acidification, eutrophication, and photochemical oxidation. After comparing the three different scenarios (S1: 97% open dump and 3% sanitary landfill, S2 is 50% of household waste disposed in open dump and 50% in sanitary landfill, and S3 is 100% household waste disposed in sanitary landfill.) with CML 2 baseline 2000 V2.04 by considering the 5 potential impacts (acidification, eurtrophication, global warming, human toxicity, and photochemical oxidation), the results showed that scenario 3 (100% household waste disposed in sanitary landfill) has the highest contribution in terms of acidification. This is mainly caused by the high emissions of HCL, HF, NH_4, NO_x, and SO_x, which are due to the process of electricity generation and the production and use of diesel fuel. S2 (50% open dump and 50% sanitary landfill) also has a high contribution of acidification. In contrast, S1 has the lowest impact of acidification. In considering eutrophication, analyses showed that S1 has an immense contribution on the potential of eutrophication. This impact category is caused by the high amount of nitrogen (N) and phosphorus (P) involved in eutrophication. Meanwhile the amount of PO_4 in an open dump is higher than a sanitary landfill. Consequently, S3 is the best scenario for the environment in this impact category.

Table 4. Primary commercial energy supply source (%).

2005	2000	1995	Source
54.3	5.2	5.0	Crude Oil & Petroleum Products
35.5	53.1	5.4	Natural Gas
4.4	37.1	50.8	Hydro
5.9	3.4	39.9	Coal & Coke
9.8	12.2	13.5	Total generation (GWh)

Regarding global warming (GWP100), S1 had the highest potential of global warming while S3 had the lowest contribution of that potential impact. Results showed that in considering the potential of global warming, the ranking is placed as S1>S2>S3. This is mainly because of the high volume of CH_4 discharged into the environment. Another potential impact on the environment was human toxicity: the impact assessment method showed that S3 had the highest contribution of human toxicity compared to S2 and S1. The photochemical oxidation impact potential in S1 is much higher than S2 (53%) and S3 had the lowest (2%) contribution of that potential impact. This is basically for the emissions of total HC and total NMVOC emissions due

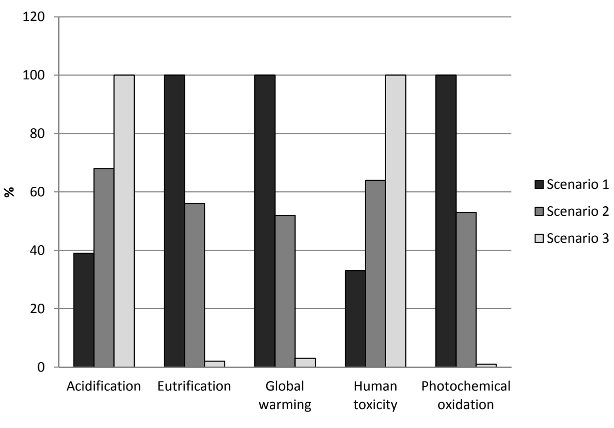

Fig. 2. Comparing scenario 1 (97% open dump + 3% sanitary landfill'), scenario 2 (50% opendump - 50%sanitary land fill), and scenario 3 (100% sanitary land fill).

to the decomposition process of organic matter in the landfill. Finally, analysis showed that S3 (100% sanitary landfill) is more preferable than the other methods because of its low contribution in terms of eutrophication, global warming. and photochemical oxidation impacts. Landfilling as a current waste disposal method for the country is not a preferable method environmentally.

Furthermore, different studies that are done in different countries verified the results of this study. For example, Mendes et al. [21] examined the management of the biodegradable MSW fraction in Sao Paulo, Brazil, and it was revealed through the study that Landfilling was the scenario with the highest environmental impact, except in the case of acidification potential. Additionally, Miliūtė and Staniškis [22] applied LCA on the MSW management systems in Lithuania. The results showed that landfilling gives the worst environmental results compared to the other waste management options. In addition, Manfredi and Christensen [23] conducted a study on environmental assessment of solid waste landfilling technologies by means of LCA-modeling, the environmental performance of six landfilling technologies, including open dump and conventional landfill with flares and conventional landfill with energy recovery were compared. The findings of the environmental assessments showed that the open dump has the highest impact potentials, in the categories of global warming, ozone depletion, photochemical ozone formation, and human toxicity via soil. The reason is because open dumps do not implement any technical measure to control gas and leachate emissions. The generated gas from open dumps is therefore assumed to be emitted to the atmosphere, while the produced leachate is assumed to reach the groundwater table.

In this study, waste management alternatives were investigated from only an environmental point of view. However, in the future this should be completed by different solid waste management methods to introduce the most environmentally friendly and economic method to the authorities in Malaysia. Additionally, it could be supported with other decision-making tools that consider the economic and social effects of solid waste management. By adopting the use of LCA as part of the waste management decision-making process, countries can avoid the possibility of making serious long-term environmental mistakes by rigid adherence to the hierarchy. Instead, a life cycle data-based decision-making process will ensure that future investment in waste management will result in overall environmental improvements.

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