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LIFE CYCLE ASSESSMENT: A COMPARISON STUDY ON THE VARIOUS ELECTRONIC WASTE MANAGEMENT OPTION

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ABSTRACT

Electronic waste is a global issue either to developed or developing countries. The difference between each country is only in their ways to encounter the electronic waste problem through management and legislation. The end of electric and electronic equipment lives will pose a significant amount of problems to the environment and human health if the waste generated is not properly treated. The study aims to evaluate the best management practice (BMPs) for electronic waste management through the simulation study using life cycle assessment tool to measure the environmental impact of various electronic waste management options. Three types of management scenarios are considered in this study. For scenario 1, landfill technology consists of management options according to the order starting with collecting and transporting wastes and finally, disposing the wastes at the landfill. Scenario 2 represents recycling technology that consists of management options according to the order, starting with collecting, transporting, and recycling wastes, and waste central sorting, and finally, disposing the waste at the landfill. Scenario 3 represents integrated technology that consists of management options according to the order, starting with collecting, transporting, and recycling wastes, waste central sorting, and thermal treatment (convert waste to energy), and finally, disposing the waste at the landfill. The result of the study showed that based on the balance between saving the world's source of energy and raw materials and impact to the environment, the electronic waste management options that will give minimum impact to the environment and able to save the world's source of energy and raw materials are integrated technology, followed by recycling technology, and lastly landfill technology. The finding of the study will assist the local authorities in the formulation of the most efficient and effective options for managing electronic waste in a sustainable manner.

Key words: Integrated Technology, Recycling Technology, Landfill Technology.

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1. INTRODUCTION

In today's modern life, the generation of a new type of waste is the waste from electrical and electronic equipment or e-waste. It is growing exponentially due to the increasing diffusion of electrical and electronic devices into every aspect of modern lifestyle [1, 2]. By referring to the data by the United Nation Environmental Protection (UNEP, 2014) and United Nation (UNU-IAS, 2015) [3], the world's production of electronic waste is estimated about 40 million tons per year. Electronic waste is alleged to be the fastest growing waste stream in the world [4-6] with the growth rate at 3% to 5% per year [7], a rate three times faster than the urban solid waste [8]. Malaysia is also facing problems with the rapid growth of domestic electronic waste volume. In 2008, the total electronic waste generated in Malaysia was approximately 405,590 million tons [9]. This amount is projected to increase in 2020 by 761,507 million tons per year [10]. The lifespan of electric and electronic appliances used by Malaysian citizens were around 0 to 15 years [11]. This prediction was proven by a previous study in 2013 which stated that 73% of Malaysians threw their electric and electronic appliances within 10 years either it was broken, malfunctions, or demanding for newer technology [12]. These two studies proved that in the nearest future, Malaysia will generate a lot of electronic waste.

The rising amount of electronic waste generated per year in Malaysia will bring negative impact to the environment if the issue is not properly treated. The substance in the electronic waste can lead to possible hazards to human health. Basically, heavy metals that exist in the electronic glass and metals are potentially hazardous to human health as well as to the environment. In addition, brominated flame retardants and poly brominated biphenyls that exist in the electronic plastic also can post potential risks to the health and environment. The toxic rudiments in electronic waste may be released to the environment in three ways. Firstly, electronic waste is commonly disposed along with municipal solid waste and in non-hazardous landfill or being incinerated due to its inappropriate disposal [13]. Dumped material containing heavy metals and brominated and chlorinated flame retardants can affect soils. In these occurrences, the toxic elements in electronic waste may enter the soil and contaminate the groundwater, or enter the atmosphere as toxic fumes if burning is used as a way of disposal [4]. In the United State of America, it was assessed that 70% of mercury and cadmium pollution, and 40% of lead pollution in landfills were affected by leakage of electronic waste [14]. Secondly, toxic substances are freed into the environment through improper dismantling and precious material recovery processes, where open burning is used to recover precious material, which releases toxic substances into the air, soil, and water [15]. Finally, hazardous substances are possible to enter the environment through probable leakage in the process of movement of electronic waste from one country to another [16].

Department of Environment Malaysia becomes a party to the Basel convention on transboundary movement of hazardous waste and their disposal. Specifically, the Basel convention stated that import and export of hazardous wastes into and from Malaysia are prohibited except with prior written approval from the Director General of Environmental Quality [17]. Normally, Malaysia will only allow the exportation of hazardous wastes for recovery outside the country, if only the local recovery facilities do not have capability to carry out such activity. In Malaysia, Public Cleansing Management Act (Act 627) [18] was enacted to allow for centralization and coordination of solid waste by the federal government. Basically, Act 627 empowers the minister to publish matters which promote reduction, reuse and recycling of solid waste including possible mandatory source separation of recyclable materials. In general, there are about 146 electronic waste recovery facilities in Malaysia with the total capacity to handle more than 24,000 metric tonnes of electronic waste per month. For physical or manual segregation of electronic wastes, there are about 128 partial recovery facilities while about 18 full recovery facilities can process the electronic waste to recover precious metal [19]. Currently, all of the electronic waste recovery facilities in Malaysia are built and operated by private companies. Generally, the electronic waste recovery facilities are paying industries or electronic waste generators when they obtain the supply of electronic waste [20].

Scheduled waste is defined as waste falling within the categories listed in the first schedule of Environmental Quality [21]. Specifically, e-waste has been categorised under schedule waste by Environmental Quality regulation 2005; i.e., SW103 for waste of batteries containing cadmium and nickel or mercury or lithium, SW109 for waste containing mercury and its compound, and SW110 for waste from electrical and electronic assemblies containing components such as accumulators, mercury-switches, glass from cathode ray tubes, and other types of activated glass or polychlorinated biphenyl capacitors or contaminated with cadmium, mercury, lead, nickel, chromium, copper, lithium, silver, manganese or polychlorinated biphenyls [21]. Scheduled wastes give potential risks to human health and the environment. Environmental Quality Act 1974 (Act 127) prescribes the regulations for the control of hazardous waste based on cradle to grave concept where generation, storage, transportation, treatment, and disposal are regulated. The key provision under this regulation is to control the waste generation by notification system, licensing of hazardous waste recovery facilities, treatment and disposal of hazardous wastes at prescribed premises, and implementation of the manifest system for tracking and controlling the movement of wastes [20].

In general, some of the environmental management and performance improvement tools are cleaner production (CP), life cycle assessment (LCA), environmental accounting (EAC), environmental performance evaluation, environment auditing, environmental management system, design for the environment, material, energy and toxic- analysis and material input per service unit. In brief, LCA is divided into two parts; i.e., the product life-cycle and the waste life-cycle. The life-cycle of a product starts from the point of manufacturing the product from the earth raw materials until the production of the usable product. Conversely, the life-cycle of a waste begins when a product has lost its values to the consumers and is converted into garbage until it is returned to earth using the landfill technique. At present, the LCA technique has been applied by many countries in assessing their solid waste management system whether using an integrated or an individual way. The technique has given an opportunity on the selection of various suitable waste management techniques to be compared and then considered in achieving certain solid waste management strategies. For that reason, this paper intends to compare and evaluate the performance of the electronic waste management option based on simulation study using Life cycle assessment tool. Conducting life cycle assessment of the electronic waste management option is essential to achieve sustainable management concept in order to predict the impact of the waste management option on the environment.

2. METHODOLOGY

The selection of various waste management options for this study was done by diversifying the waste management scenarios as follows.

a)Scenario 1 (landfill technology): It consists of management options according to the order starting with collecting and transporting wastes and finally, the landfill.

b)Scenario 2 (recycling technology): It consists of management options according to the order starting with collecting and transporting wastes, central sorting, recycling (MRF), and finally, the landfill.

c)Scenario 3 (integrated technology): It consists of management options according to the order starting with collecting and transporting wastes, central sorting, recycling (MRF), thermal treatment (waste to energy), and finally, the landfill.

The management scenarios were analysed using the Life Cycle Assessment tool in order to identify the various scenarios that produce a very minimal environmental impact. The scenario was then selected as BMPs to be adapted at a particular location of the study. In the study, the inputs of the system were 700 tonnes/day electronic wastes. Other inputs were such as raw materials, energy such as petrol and diesel usage for transportation activities and electrical energy for the processing activities as stated in Tables 1 and 2. The outputs of the system were recovered materials such as secondary raw materials and energy as well as an emission generated from the processing and transportation activities.

3. RESULTS AND DISCUSSION

Figure 1 illustrates the model development for various electronic waste management options based on life cycle assessment structure. Tables 1 and 2 summarise the input data such as fuel usage for transportation activities as well as water and energy usages for processing activities of each electronic waste management option. Comparison of the evaluation result on the various electronic waste management options is tabulated in Table 3 while Table 4 shows the comparison of emission result on the various electronic waste management options.

Referring to Table 3, the environmental effect analysis on the case study found that the integrated technology was able to solve issues related to the reduction of the world energy resources and raw materials compared to landfill technology and recycling technology. This is because the system is based on the concept of converting wastes into raw materials and energy resources such as secondary raw materials and electrical energy. Hence, it can be summarised that the integrated technology has given a minimum impact towards the reduction of the world sources of energy and raw materials. From the analysis, integrated technology produced 472.2 tonnes/day secondary raw materials and 123.96 MW/day electricity compared to recycling technology that only produced 472.2 tonnes/day secondary raw materials. For landfill technology, there was no secondary raw material as well as electricity generated. Hence, it can be said that the integrated technology has given a minimum impact towards the reduction of the world source of energy and raw materials.

Referring to Table 4, the analysis of the effect of pollution on problems such as global warming, eutrophication phenomenon, and acidification potentials by the various management option activities found that in general, the most potential resulting effect of pollution is the problem of global warming. This is due to the usage of energy through the waste processing and transporting activities. However, landfill technology was found as the main potential contributor for the global warming; i.e., 1279.19 kg pollutants followed by the integrated technology; i.e., 820.39 kg pollutants and recycling technology; i.e., 733.17 kg pollutants. The impact analysis also revealed that SOx and NOx content in the air emissions will significantly contribute to the eutrophication phenomenon and acidification potentials. Therefore, it can be clarified that the most waste management options that can give impact to the environment are global warming effect, eutrophication phenomenon, and acidification potentials are landfill technology, followed by integrated technology and recycling technology. However, for air and water emissions generated from processing activities, the existing of air treatment unit and effluent treatments plant will significantly control the air and water pollution problems for all of the waste management facilities. Waste water treatment plant facilities act as a water pollution control system for waste water resulting from managing waste activities such as leachate and washing wastewater. As for the control of residual disposals at disposal sites, it can be done by disposing the residuals at sanitary disposal sites for non-hazardous residuals while the hazardous residuals will have to be initially modified before disposing them at secure landfill sites [22].

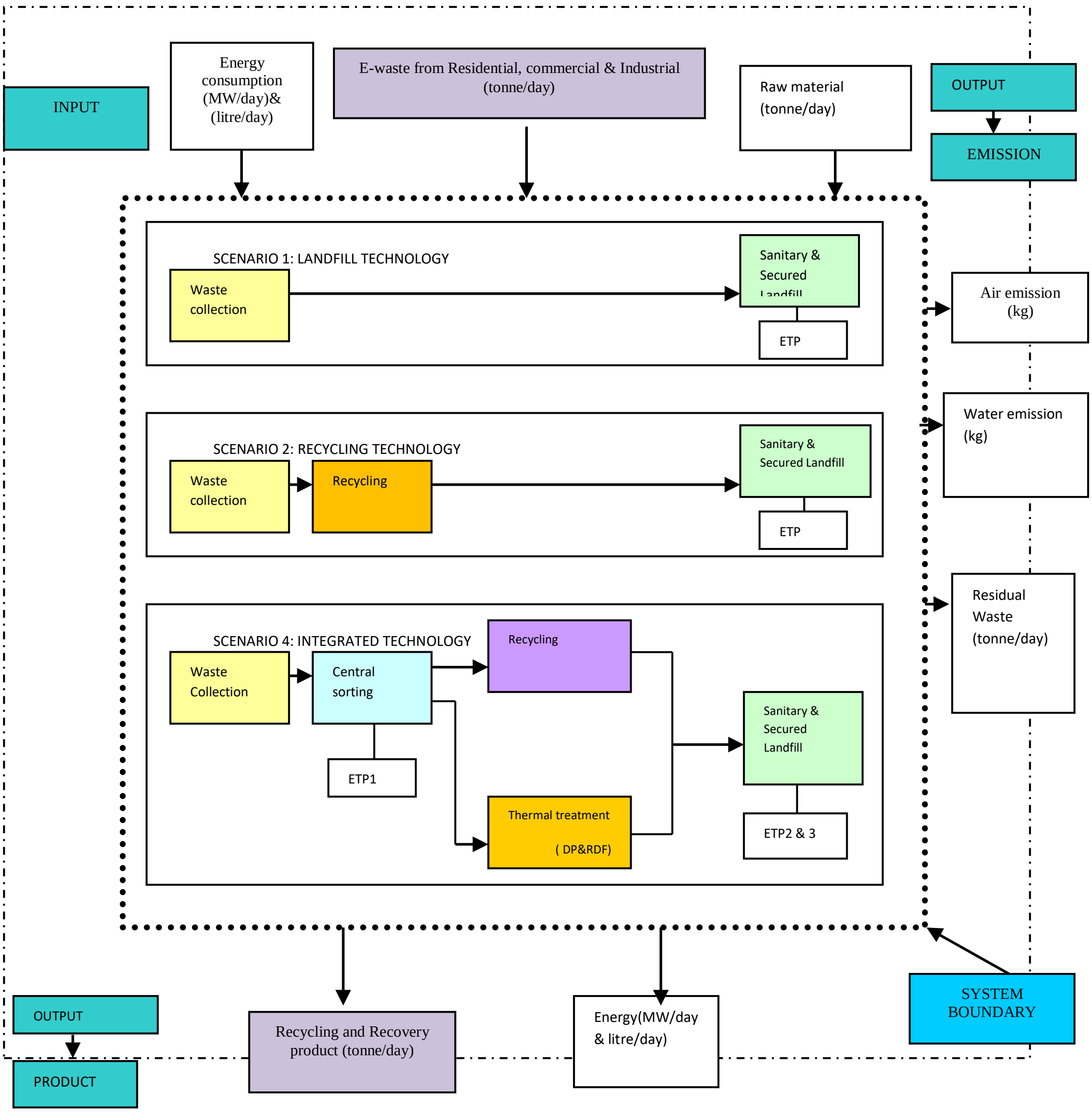

Figure 1 Model development for various management options based on Life Cycle Assessment Structure

Table 1 Fuel usage for transportation activities in the various electronic waste management options

Waste Management Option	Transportation	
	Water	Air
Scenario 1: Landfill Technology	0	1,069.44 liters/day
Scenario 2: Recycling Technology	31.5 liters/day	1,272.4 liters/day
Scenario 3: Integrated Technology	31.5 liters/day	1,184.71 liters/day

Table 2 Water and Energy usage for processing activities in the various electronic waste management options

Sub-system	Processing		
	Water	Electricity	Diesel
Scenario 1: Landfill Technology	0.25 tonnes/day	2.33 MW/day	2,800 liters/day
Scenario 2: Recycling Technology	8820 tonnes/day	322.69 MW/day	911.05 liter/day
Scenario 3: Integrated Technology	9,652.9 tonnes/day	318.15 MW/day	414.06 liters/day

For residual waste, its total volume for disposal at the secure and sanitary landfills will directly influence the lifespan of the landfills. As stated in Table 4, the study analysis showed that landfill technology contributes to the highest volume of the residual for disposal; i.e., 701.17 tonnes/day followed by recycling technology 228.1 tonnes/day and integrated technology 103.77 tonnes/day. Based on the balance between saving the world source of energy and raw materials and impact to the environment, therefore, it can be stated that the most waste management option that will give minimum impact to the environment are integrated technology, followed by recycling and landfill technologies.

Malaysia has ways more to come to have a sustainable electronic waste management system. A lot of steps need to be taken and a lot of problems, which relate to policy, technology, and awareness need to be solved. There were several issues raised by the recovery facilities such as lacking e-waste supply and electronic waste processing technology. The issue of lacking electronic waste supply may happen due to improper electronic waste management that comes from a household or due to lower awareness and readiness of the Malaysian citizens. Currently, Green Technology Foresight 2030 is a joint initiative between the Ministry of Green Technology, Energy and Water (KETTHA) and MIGHT in the process to build future scenarios of green technology in Malaysia. One of the targets of green technology is to ensure sustainable development in sectors including waste management [23]. Specifically, prioritized green technology application focuses on the recovery of waste, for example, waste energy recovery. However, on the whole, long term strategies for waste sectors vision needs to concentrate on the integrated waste collection, recovery, treatment, and disposal as well as the creation of the national waste grid [23].

Table 3 Evaluation results for various electronic waste management option

	Secondary material		**Emission**				
			Process			**Transportation/fuel**	
Electronic Waste Management option	Secondary Material	Energy/ Source of energy	Water	Air	Residual waste	Water	Air
Scenario 1: Landfill Technology	0	0	59.19 kg pollutants and 583.1 tonnes/day leachate	866.9 kg pollutants and 2,249,100 m^3/day landfill gas	701.17 tonnes/day E-waste to be landfill	22.61 kg pollutants	330.49 kg pollutants
Scenario 2: Recycling Technology	472.2 tonnes/day secondary raw material	0	19.26 kg and 8871.5 tonne/day leachate	28.1 kg pollutants and 731,801m^3/day Landfill gas	228.1 tonnes/day E-waste to be landfill	28.06kg pollutants	657.75 kg pollutants
Scenario 3: Integrated Technology	472.2 tonnes/day secondary raw material	140 tonnes/day RDF pellet that produces 123.96 MW/day electricity	8.75 kg pollutant and 9,082.2 tonnes/day leachate and washing waste water.	128.2 kg pollutant, 1,155.5 g/Nm^3.day air pollutant and 163,617 m^3/day Landfill gas	103.77 tonnes/day E-waste to be landfill	26.26 kg pollutants	657.18 kg pollutants

Table 4 Comparison of Emission result on the various electronic waste management option.

Electronic Waste Management Option	**Residual Waste**	**Water Emission**	**Air Emission**		
			Fuel	**Landfill gas**	**Thermal**
Scenario 1: Landfill Technology	701.17 tonnes/day	583.1 tonnes/day	1279.19 kg	2249100 $m^{3/}$day	0
Scenario 2: Recycling Technology	228.1 tonnes/day	8871.5 tonnes/day	733.17 kg	731801 m^3/day	0
Scenario 3: Integrated Technology	103.77 tonnes/day	9082.2 tonnes/day	820.39 kg	163617 m^3/day	1155.5 g/Nm^3.day

4. CONCLUSIONS

BMPs for electronic waste management system need to solve the problem of environmental degradation and reduction of the world source of energy and raw materials. Integrated electronic waste management system that consists of waste collection, sorting, recycling, and recovery, as well as disposal with the support of pollution control facilities for each waste management facilities should be brought forward and implemented drastically in the current Malaysian waste management plan.

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