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A Life Cycle Assessment Study for Integrated Management of Electronic Waste

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Abstract

An amount of 21,378,553 tonnes of electronic waste or e-waste is expected to be accumulated in Malaysia in the near 2020. To manage this increasing volume of solid wastes, the waste management technologies have to be further integrated. Knowledge of electronic waste compositions, contamination compounds in wastes, laws, guidelines and the management methods is essential to form a cost-effective and an environmental friendly management system. The aim of this study is to propose a technique for managing the electronic wastes through an integrated and holistic manner. The study proposed the use of a life cycle assessment to predict the burden and impacts of the integrated electronic waste management system towards the surroundings. The result of this study was obtained from a field study, data collection, life cycle assessment model, as well as by computer calculation development and impact analysis study. The findings of the study proposed that the implementation of an integrated electronic waste management must combine sustainable techniques for waste collection, waste sorting, materials recycling, thermal treatment and landfill methods to achieve the maximum system effectiveness. However, the pollution control facilities are important to be part of the sustainable technique to ensure that the system will produce the best management method for electronic waste. The advantages of implementing an integrated electronic waste management are that this system is able to contribute to the economic growth of a country and reduce the impacts of pollutants to the environment.

Keywords: Waste collection, Central sorting, Recycling process, Thermal treatment, Landfill

1 Introduction

Electronic products are one of the most important needs in today's society. Technological advances have made electronic products to be constantly changing. Fundamentally, technological and lifestyle advances are factors that influence the replacement of old electronic products with new ones. This scenario contributes to increase in electronic waste accumulation. Electronic wastes contain high toxic compounds that are able to pollute the environment [1]. The toxic constituents are heavy metals (cadmium, lead, chromium, mercury, plumbum, arsenic, and selenium), precious metals like silver, gold, copper and platinum [2] and organic chemical compounds, i.e., flame retardant, including plastic resins polyvinyl chloride [3].

Electronic waste management has become a global issue and the difference in technology and expert factors has led to difference in waste management methods. However, studies on management methods and technological applications by other countries can be set as guidelines to select the suitable techniques for local adaptation [4]. From the accepted techniques in managing electronic waste from various countries, it can be derived that electronic products with environmental-friendly designs are preferable in reducing the environmental impacts which exist during the waste management process of the products [5]. The characteristics of environmental-friendly products include products that are reusable, have durable life span, can be recycled, energy savers, can be disposed in an environmental friendly manner.

To encourage the usage of environmental friendly products, the government gives a tax exemption to buyers upon a purchased product. Manufacturers have to tag their products as environmental friendly products [5]. When the products turn into electronic wastes, electronic products producers are responsible for the electronic waste management, whereby they have to recollect the products from users (extended producer response) [6]. The products have to be reused and recycled to reduce the volume of wastes at disposal sites. To dispose the wastes, the incineration method is able to convert wastes into energy and the ground burial technology can be applied. However, the

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environmental effects have to be considered when disposing the wastes.

In Malaysia, the Ministry of Housing and Local Government is responsible for assisting the preparation of jurisdictions and guidelines related to solid waste management as procedures for the state government and local authorities. The Department of Environment has a role in controlling environmental pollution which originates from such activities. In Malaysia, the Department of Environment is an organisation has responsibilities towards environmental issues. The department is accountable for the observations of jurisdictions to safeguard the country's environment from being polluted. Therefore, all industrial premises have to comply with the acts and guidelines set for managing industrial wastes. Electronic waste includes categories listed in the First Scheduled of Environmental Quality (scheduled waste) Regulations 2005[7]. Based on the stated regulation, the control of hazardous waste is based on the cradle-to-grave concept, whereby waste generated, storage, transportation, treatment and disposal are regulated. The key provision under the regulations is the control of waste generated by the notification system, licensing of hazardous waste recovery facilities, treatment and disposal of hazardous waste at prescribed premises and implementation of manifest system for tracking and controlling the movement of wastes [8].

An effective solid waste management system has to be environmental-friendly and economic-friendly. Environmental-friendly management characteristic means that it can minimise the management system impacts on the energy usage, including land, sea and air pollutions [9]. Economic-friendly management characteristic means that it can be operationalised at an accepted cost by the society [9]. To achieve an environmental-friendly management pattern, integrated solid waste management has to be implemented. The system has to be integrated towards its waste compounds, waste sources, collection methods and treatment methods.

This integrated approach will reduce disposal site burdens and open an opportunity for a new technology to manage solid wastes [10]. The eco-effective solution will generate an optimal balance between the environment and economic cost impacts from the initial production to disposal [11]. To implement the above mentioned proposal, the authorities have to acquire a comprehensive central data of the accumulated solid waste quality and quantity in Malaysia [11]. The central data has to encompass solid waste composition analyses, such as the vicinity analysis, final analysis and analysis to identify waste calorie values that act as fuel energy. This data is helpful in designing modified solid waste plants [12].

The proper waste management is not possible without having the proper awareness and knowledge in waste management [13]. For developing an integrated electronic waste management approach, the integrated system has to combine waste collection, waste sorting, materials recycling, thermal treatment, ground burial disposal and pollution control methods. The combination of management selection plays an important role in ensuring the maximum effectiveness of the integrated waste management system. Basically, the aim of developing an integrated electronic waste management is to offer maximum benefits to the environment, optimise the economy as well as to be accepted by the society; hence, an integrated approach in managing electronic wastes from the point of accumulation to the point of disposal.

The lifecycle assessment technique can be used to predict burden and impacts towards the surroundings from beginning until the end of management system. If electronic wastes are disposed or recycled without proper supervision, its impacts on the environment and human health are predictable. For that reason, this paper is to introduce the integrated concept for managing electronic waste. To achieve a sustainable management concept, conducting a life cycle assessment of the integrated system for electronic waste management is essential to predict the environment and economic impact of the system. Life-cycle assessment is the best technique that can be used to analyse the selection of a solid waste management technology that practises the integrated approach. The technique can produce data for predicting the environmental effects that exist due to activities generated by the integrated solid waste management

2 Methodology

The methodology is divided into five, i.e. field study, data collection, life cycle assessment (LCA) model development, computer calculation development and impact analysis study. The field study will list waste component facilities in the study area, such as waste collection, central sorting, recycling plant, thermal treatment plant and landfill disposal site. Data collection is where the input and output of waste facilities component system is obtained. It is normally done by listing the life cycle inventory for each waste component facility. The LCA model is design by considering the applied waste management concept, including selection of a suitable technology as a sub-system for a chosen system. The computer calculation model is built by using excel spreadsheet as the database. The impact analysis will be carried out based on the result obtained from the database. Then result will be interpreted and evaluated.

In this study, the input of the system was 700 tonnes/day of electronic waste. Other inputs such as raw materials, energy (petrol and diesel usage) for transportation activities and electrical energy for processing activities are stated in Table 1 and Table 2. The outputs of the system are recovery materials, such as secondary raw materials and energy and emission due to processing and transportation activities, as stated in Table 3, Table 4 and Table 5.

3 Result

Table 1 and Table 2 summarise the input data, such as fuel usage for transportation activities as well as water and energy usage for processing activities in the integrated technology option. Table 3, Table 4 and Table 5 summarise the output data, such as emission from the processing activities and transportation activities, as well as secondary raw materials and energy recovery from the integrated technology option. Referring to Table 1, prediction of the fuel usage for transportation activities are 1184.7 litres per day for diesel usage and 31.5 litres per day for petrol usage.

In this option, the route of waste transportation activities was from source of produced electronic wastes, such as residential, commercial and industrial premises direct to the central sorting plant. Then, the electronic wastes will be sent to the recycling plant and thermal treatment plant. Residuals from central sorting facilities, recycling plant and thermal treatment plant as well as from effluent treatment plant will be sent to the landfill site for ultimate disposal. In Table 2, the prediction of total electricity usage for processing activities at central sorting, recycling plant, thermal treatment plant as well as effluent treatment plants is 318.15 MW per day, while the total water usage at stated plants is 9,652.9 tonnes per day. The diesel usage for processing activities at landfill site is 414.06 litres per day, of which 284 litres of diesel usage per day is at secured landfill and 130.06 litres of diesel usage per day is at sanitary landfill.

Table 1: Fuel Energy usage for transportation activities in the integrated electronic waste management system

Sub-system	Transportation Petrol	Diesel
Waste collection	31.5litres/day	1,030.56litres/day
Central sorting	0	107.92litres/day
Recycling process	0	25.52liters/day
Thermal treatment	0	20.7litres/day
Non-hazardous landfill	0	0
Hazardous Landfill	0	0
TOTAL	31.5 litres/day	1,184.7Litres/day

Table 2: Water and Energy usage for processing activates in the integrated electronic waste management system

Sub-system	Processing Water	Electricity	Diesel
Waste Collection	0	0	0
Central Sorting	7 tonnes/day	21MW/day	0
Recycling process	8820 tonnes/day	286.7MW/day	0
Thermal Treatment	825.9 tonnes/day	10.1 MW/day	0
Non-hazardous landfill	0	0	130.06litres/day
Hazardous Landfill	0	0	284litres/day
ETP 1		35.31 MW/day	0
ETP 2		0.11 MW/day	0
ETP 3		0.24 MW/day	0
TOTAL	9,652.9 tonnes/day	318.15 MW/day	414.06 litres/day

Briefly, from Table 3 the generated calculation found that 349.59 kg of the emission were produced by transportation activities from the accumulation areas to the central sorting, in which 327.15 kg from the emission was air emission and 22.44 kg was water emission. From Table 3, the generated calculation found that the emission produced by waste transportation activities from the central sorting facilities to recycling plant, RDF power plant and disposal site as well as electricity usage at stated plants, including effluent treatment plants, were 333.82 kg, in which 330.0 kg was air emission and 3.82 kg was water emission.

Table 3: Emission from the transportation in the integrated electronic waste management system

Sub-system	Transportation Water	Air
Waste collection	22.44kg	327.15kg
Central sorting	2.31kg	50.13kg
Recycling process	1.0kg	236.9kg
Thermal treatment	0.45kg	14.5kg
Non-hazardous landfill	0	0
Hazardous Landfill	0	0
ETP 1	0.06 kg	28.2 kg
ETP 2	0	0.1 kg
ETP 3	0	0.2 kg
TOTAL	26.26 kg pollutant	657.18kg pollutant

Referring to Table 4 and Table 5, the generated calculation found that emission produced from the processing activities at the central sorting was water emission from washing activities, i.e. 7.0 tonnes of washing water per day. The residual produced from central sorting facilities was 70.0 tonnes per day. From the calculation, the recovery materials, such as plastics, ferrous metal and non-ferrous metal, woods, glass as well as bulky waste that were produced by the central sorting facilities were 490 tonnes per day, while the source of energy in the form of RDF pellets was 140 tonnes per day. The emission produced from processing activities at the recycling plant was water emission from washing activities, i.e. 8,820 tonnes of washing water per day. From the calculation, the residual produced from recycling plant was 17.8 tonnes per day, while the secondary raw materials produced at the recycling plant were 472.2 tonnes per day. The generated calculation found that the emission produced from the processing activities at the thermal treatment plant consists of air emission of 1,155.5 g/Nm^3 per day, and residuals of 15.8 tonnes per day. The produced recovery material, i.e. electrical energy is 123.96 MW per day from the RDF power plant. The generated calculation found that the emissions produced from the landfill activities at the non-hazardous landfill sites are 40.2 kg of air emission and 2.75 kg of water emission. From the calculation, the processing activities at the non-hazardous landfill sites will produce 104,474 m^3 of landfill gas per day and 27.1 tonnes of leachate per day. The prediction of the emissions produced from landfill activities at the hazardous landfill site were 88 kg of air emission and 6 kg of water emission. From the calculation, the processing activities at the non-hazardous landfill site will produce 228,119 m^3 of landfill gas per day and 59.14 tonnes of leachate per day.

Table 4. Emission from the processing activities in the integrated electronic waste management system

Sub-system	Processing		
	Water	Air	Residual waste
Waste Collection	0	0	0
Central Sorting	7.0tonnes/day	0	70.0tonnes/day
Recycling process	8,820tonnes/day	0	17.8tonnes/day
Thermal Treatment	0	1,155.5g/Nm^3.day	15.8tonnes/day
Non-hazardous landfill	2.75 kg and 27.1tonnes/day	40.2 kg and 104474 m^3/day	0
Hazardous Landfill	6.0 kg and 59.14 tonnes/day	88 kg and 228,119 m^3/day	0
ETP 1	0	0	0
ETP 2	0	0	0.05tonnes/day
ETP 3	0	0	0.12tonnes/day
TOTAL	8.75 kg pollutant and 9,082.2tonnes/day leachate and washing wastewater	128 kg pollutant, 1,155.5 g/Nm^3.day air pollutants and 163,617 m^3/day landfill gas	103.77 tonnes/day electronic waste to be landfill

For effluent treatment plants, the generated calculation found that the sludge waste produced from the effluent treatment plants, i.e. effluent treatment Plant 1 (ETP1), effluent treatment Plant 2 (ETP2) and effluent treatment Plant 3 (ETP3) were 0.17 tonnes per day.

Table 5. Recovery material in the integrated electronic waste management system

Sub-system	Recovery material	
	Secondary raw material	Energy
Waste collection	0	0
Central sorting	490tonnes/day	140tonnes/day RDF pellet
Recycling process	472.2tonnes/day	0
Thermal treatment	0	123.96MW/day
Non-hazardous landfill	0	0
Hazardous Landfill	0	0
TOTAL	472.2tonnes/day secondary raw materials	140tonnes/day Refuse derived fuel (RDF) that produce 123.96MW/day electricity

3 Discussion

The environmental effect analysis found that the integrated management of electronic waste was able to solve issues related to the reduction of world's raw materials and energy resources, as shown in Table 5. This was because the system was based on the concept of converting wastes into secondary raw materials and energy resources. Basically, economic increase and environmental sustainability are achievable based on the reduction of energy usage (electricity, gas, diesel or petrol), re-use of wastes as secondary raw materials, reproduction of energy from wastes, reduction of the waste total volume at disposal sites and reduction of pollutants in the environment. Therefore, it can be summarised that, the integrated system for managing electronic waste has given a minimum impact towards the reduction of world's energy source and raw materials. In addition, the existing pollution control systems, such as pollutant eliminators in gasses, effluent treatment plant and secured landfills, are able to reduce the pollutants in the environment. In general, global warming primarily caused by increases in greenhouse gases such as carbon dioxide (CO_2), nitrous oxide (NO), Sulphur dioxide (SO_2) hydrogen and other gases [14].

Basically, the pollution control that resulted from the waste management activities can be divided into three, namely air pollution control, water pollution control and residual disposal control. The air pollution control system acts as a pollutant eliminator of gasses before they are released into the air. The wastewater treatment plant acts as a water pollution control system for wastewater which resulted from managing waste activities, such as leachate and washing wastewater. As for the control of residual disposals at disposal sites, it is done by disposing the residuals at sanitary disposal sites for non-hazardous residuals, while the hazardous residuals will have to be initially modified before being disposed at secured landfill sites [10].

5 Conclusions

The best management system has to be successful in overcoming issues related to the electronic waste management and in overcoming the problems of pollution and the lack of the world's natural resources, such as the resources for natural fuel and raw materials. The integrated electronic waste management technique is suggested as one of the best management practice (BMPs) to handle electronic wastes in a sustainable manner. In order for HRM function to stay relevant for the years to come, current evolutionary changes will need to make way for a more transformative or disruptive revolution. This study indicates that HRM function in BankCo is moving in the right direction, although more requirements are still to be met. To be transformative, a true HRM transformation needs to be integrated and aligned with a business-focused approach to reinventing the way HRM delivers its services and practices to its key stakeholders. Therefore, the role of HRM function in helping organizations to become more sustainable can be demonstrated in different ways, and there is a need for a deep understanding about sustainable workplace environment practices. This requires new pattern of thought and behaviour, where HRM looks at how the function can respond, drive, and re-imagine employees' experience using data and proper employee management system in improving workplace management effectiveness that can lead to business impact (21). HRM function has an inherent accountability to consider the broader implications of HRM decisions, not only on employees, but also on their families, the larger communities, economies, and societies in general. Potential areas for future academic research include a further exploration on the effectiveness and contribution of HRM functions in the digital banking transformation journey of banking institutions.

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Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

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Authors' contribution

The researchers hereby acknowledge that they had a complete contribution to data collection, data analyses, and manuscript writing in this paper.

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