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Sustainable Electronic Waste (E-Waste) Management Using Enabling Strategies and Techniques: A Literature Review

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Abstract

New changes in technologies and tremendous growth in population have created many environmental related problems worldwide. One of the significant issues is the production of variety of toxic substances from different electronic devices and appliances. These substances have serious threats to the environment and human health. This is a literature review paper which discusses an overview of electronic waste and their potential environmental and human health impacts. In different countries, various tools of strategies have been adopted in order to manage the e-waste through life cycle assessment, material flow analysis, multi-criteria analysis, extended producer responsibility, reverse logistics and their features. Comparisons of features with advantages and disadvantages are also presented in this paper.

Keywords: E-waste, Reverse Logistics, Strategies, Sustainability, Literature Review

Introduction

The term electronic waste (e-waste) has been used for all consumable components and sub-assemblies of small and large household appliances. There are various items included in e-waste such as lighting, communication devices, automatic dispensers, microwave, and refrigerator. Rapid economic and social growth plus technological advancements have changed the lifestyle and the way people dealing with environment. In view of this rapid growth, different concerns have been raised in the e-waste management sectors such as environmental management, recycling, collection, reverse logistics and treatment. Information and communication technologies including social and electronic media have developed the awareness and purchased power by using an attractive promotion initiatives and advertisement. Companies, agencies and industries have offered

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different types of incentives on electronic products. Due to competitive market scenario, telecommunication companies launched new products better than previous ones. These situations have led to increasing numbers of e-waste items. These issues have gained a great attention worldwide especially in developed countries. According to a report (Schwarzer, De Bono, Giuliani, Kluser, & Peduzzi, 2005), around 20 to 50 million tons of waste have been produced in developed nations. In another United Nation report (Cooper, 2015), it is predicted that in 2020, the e-waste would increase dramatically and 18 times higher than now. There are various precious metals contained in electronic devices such as Cadmium (Cd), Mercury (Hg), Hexavalent chromium (Cr6+) and Arsenic (As) (Memon & Pitroda, 2016).

Recycling is one of the processes to control e-wastes that are valuable and with high-grade values. Through recycling processes, rare and non-ferrous metals can be used further for other purpose. However, the recycling process needs proper management because during the recycling process, these trace elements pose adverse human and environmental impacts. Some examples of serious trace elements in human life are Pb. The toxic nature of e-waste is one of the significant effect to human health and environment. Another important issue is e-waste disposal can transfer toxin through food cycle into human body (Kiddee, Naidu, & Wong, 2013). Disposal of e-waste is also harmful due to toxic materials and has a direct impact on human health especially working in e-waste locations, recycling industries, and scrap stores. The beryllium chemical is another dangerous substance due to its carcinogen properties which located in power supplies of devices. Exposer of these dangerous chemicals have negative or chronic effects. Figure 1 shows the e-waste separation cycle and output items. Selected literatures were reviewed and extracted in order to study the suitable techniques and strategies for e-waste management. After selecting the relevant journal papers, selected literatures were categorised and discussed based on their features and current usage.

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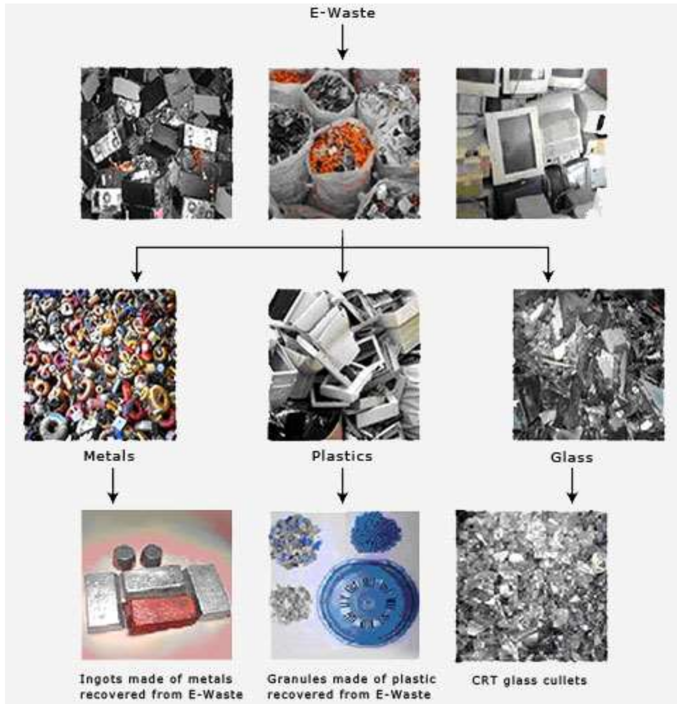

Figure 1
E-Waste Cycle

In this paper, the author elaborates the existing strategies on the e-waste management. In addition, this paper also discusses the prevailing issues in e-waste control. The paper also presents proposed solutions to control and manage e-waste.

Existing Strategies of E-waste Management

Extensive research was conducted on e-waste management to mitigate the challenges. There are many tools introduced and applied to e-waste management worldwide. One of the programs developed with the main purpose to control the e-waste impact to the environment was initially started by the European Union (EU) in 2002 which named as 'Directive 2002/96/EC'. The objectives of the directive are to provide guidelines and enforcement on control, recycling and separation of materials for e-waste (Directive, 2012). This section discuss the strategies of e-waste management implemented in different parts of the world.

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Life Cycle Assessment (LCA)

This technique is used to develop and design electronic devices based on environmental requirements. The main objective of the Life Cycle Assessment (LCA) technique is to minimize e-waste related issues. This strategy has been adopted since the 1990s for creating environmental friendly and eco-design devices and a better alternative and powerful tool to reduce the environmental threats due to e-waste. There are different types of devices that were designed based on this technique such as desktop, printers, washing machines and air conditioners. The toys industries have also adopted this tool to design environmental-friendly toys (Muñoz, Gazulla, Bala, Puig, & Fullana, 2009). LCA is a systematic tool to describe various environmental impact categories such as the ozone layer, eco-toxicity, eutrophication, and carcinogens. These environment impacts improve the performance of the device (Belboom, Renzoni, Deleu, Digneffe, & Leonard, 2011). This technique has gained popularity in e-waste management especially in Europe where they used LCA to evaluate the end-of-life treatment of e-waste. In Switzerland (Hischier & Baudin, 2010), an LCA based recycling system namely Swiss take-back was proposed to test on the environmental impacts. In this study, the results indicated the positive advantages as compared to incineration process. In another study (Wäger, Hischier, & Eugster, 2011), the author showed that the environmental impacts were lower than the previous results. This is due to recycling plastic waste instead of incineration. In the United Kingdom, a study conducted (Mayers, France, & Cowell, 2005), on an alternative disposal method and discussed that landfill without material recovery was not preferred as compared to recovery and recycling alternatives.

Various research was conducted on the utilisation of LCA and discussed that recycling is the most preferred strategy for managing e-waste as compared to landfill. The electronic waste material is considered difficult to recycle with traditional methods. This is because of the toxic nature of e-waste materials. New technologies have minimise the difficulty by adopting new recycling solutions for better separation and recycling parts and spare parts of old electronic items. The advance recycling systems and technologies separate the optical sensors, plastic, and metal.

Material Flow Analysis (MFA)

Another strategy of e-waste management is Material Flow Analysis (MFA) in which the large volume of e-waste exported for recycling and reusing. The most popular countries adopted this technique are India, China, and South Africa. This technique is used to route the e-waste material into recycling sites and links the sources towards the destination. MFA is a decision-based tool applied to e-waste management systems. In this strategy, the second-hand devices from Japan is reused in Asia. In Japan (Yoshida, Tasaki, & Terazono, 2009), the ratio of domestic disposal and recycling decreased to 37% in year 2004, whereas the domestic reuse and export ratios increased to 37% and 26%, respectively. Steubing, Böni, Schluep, Silva, and Ludwig (2010) also investigated e-waste management using MFA. By using this technique, business tends to experience higher growth and increases economic cycle. There are various applications using MFA such as the flow of e-waste, e-waste trade value chain, the pathway of recycling and e-waste trade. This tool is found to be a useful practice for economic evaluation of e-waste management. However, this tool is more useful when limited data is available.

Multi Criteria Analysis (MCA)

MCA is a technique used for decision making and solving complex problems. This tool is also useful for multi-criteria problems including analysis of quantitative and qualitative aspects. It is also used to overcome environmental impact related to e-waste management. Different methods are used to analyse the economic benefits by using defined products models, development and evaluation, formulation and construction of strategy chart in order to minimize the economic cost. This tool has been used (Queiruga, Walther, Gonzalez-Benito, & Spengler, 2008), to select the feasible method for e-waste management in Spain. This study

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adopted quantitative criteria for warehouse locations. There are several management systems compared based on efficiency and performance systems. The best option was to disassemble partially and forward the recycling materials to the local market and waste disposal remains for landfill. However, this technique was not widely used for e-waste management. It has been adopted for solid waste management and hazardous waste management (Hatami-Marbini, Tavana, Moradi, & Kangi, 2013). There are various applications used for e-waste management such as optimization of product disassembly, decision making for e-waste management and decision for location of e-waste processing and recycling plants.

Extended Producer Responsibility (EPR)

EPR is another approach used in industries for taking back products after use. This tool is based on polluter-pays principles. It has been adopted by advanced nations such as Switzerland, Japan, and the European Union (EU) and has gained popularity since then. Switzerland has adopted this tool to regulate their e-waste management policy. On the other hand, Japan has also adopted this strategy as a policy since 1990s. Japan also regulates their e-waste management policy through two (2) laws including home appliances recycling and electric household appliances recycling law such as refrigerator, TV and washing machine. Another law is related to the promotion of effective utilization of resources related to personal batteries and computers. Japan offered payback options by end users for e-waste to retail or second-hand devices. Figure 2 shows the take-back system implemented in Japan. The funds and incentives are provided by the government and industries in the form of product design which is environmentally friendly.

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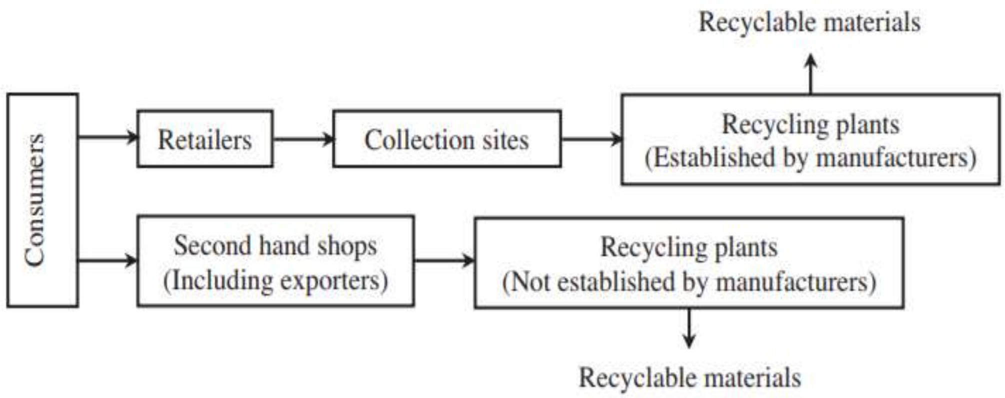

Figure 2: Take-back System in Japan (Chung & Murakami-Suzuki, 2008)

In Canada, Extended Producer Responsibility (EPR) approach is slightly different from EU approach. Canada is focusing on product stewardship and pollution prevention. In 2004, Alberta in the western province of Canada has adopted the first e-waste management program which was more flexible and feasible. In six provinces of Canada, seven (7) e-waste items have been included in the e-waste management programs which are printers, monitor, DVD, keyboard, peripherals and laptop (Lepawsky, 2012).

Reverse Logistics

Reverse logistics is another effective area for products flows from point of consumption to its point of production or origin. Different types of processes have been applied to reverse logistics such as planning, controlling and implementing. Reverse logistics is well known and one of the broad domain and has advanced features for recycling and reproducing components and electronic items. Reverse logistics also used in e-waste management for recycling the products. In supply chain management, reverse logistics has gained a prominent role due to its professional and significant key competence (Dowlatshahi, 2000; Fleischmann, Krikke, Dekker, & Flapper, 2000; Govindan, Soleimani, & Kannan, 2015). According to White (1994), reverse logistics are used to handle the products, materials, transportation, distribution, storing, moving and controlling the materials. Due to advance processes, company sustains in the market by their

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conversion processes. Companies can manage their waste processes with conversion methods and enhance their economic growth and development. Reverse logistics is used for the management of hazardous materials, logistics recycling, and waste disposal. It is also related to all logistics activities carried out in source of reduction, disposal, reuse and recycle of materials. Recently, the global attention and commitment to environmentally friendly operations encompass the reverse logistics. Reverse logistics is more than handling the returns and recovering/reusing discarded parts. It is also used to extend the design and other elements of the product's life cycle (De Brito & Dekker, 2004). If reverse logistics processes are well established, the e-waste management also will improve.

Various policies have been adopted for e-waste management such as take-back electronic appliances, product re-design, advance recycling fee and disposal ban in a landfill. After discussing the existing and adopted strategies to control the e-waste in different countries, the author summarized several features of these techniques and strategies in Table 1.

Table 1: Comparisons of E-waste Management Strategies and Techniques

S/No	Strategies	Features	Applications
1	Life Cycle Assessment (LCA)	Material consumption estimation, Eco-design and development, Environmental aspects evaluation, Economic evaluation, Decision making, Life disposal of electronic devices	Recycling of computers, mobile phones, notebook computers, Decision maker, Treatment scenario, Recycling systems
2	Material Flow Analysis (MFA)	E-waste generation investigation, E-waste estimation, Decision making	E-waste flow, Trade value chain, Flow of used computers, E-waste quantities
3	Multi Criteria Analysis (MCA)	Decision making, Provide environmental evaluation	Decision making, E-waste management decision systems, Location evaluation
4	Extended Producer Responsibility (EPR)	E-waste problems solutions, Polluter-pays principle based enforce producers	Flow systems, Decision making
5	Reverse Logistics	Control flow of e-waste, Enhance flow process, Improve economic values	Flow system, Decision making, Flow control

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Analysis

The paper discusses and compares features on LCA, MCA, MFA, EPR and reverse logistics techniques and strategies used for e-waste management. Each technique has its own features as summarised in Table 1. LCA has numerous advantages to support e-waste management by evaluating the impact of eco-design products, product development, allocation and examined the product process. Based on the literature review conducted, LCA is the most popular tool and used widely in many countries including India, Nigeria and China. On the other hand, MCA is very useful for decision making and entirely focused on policy to take-back the products. EPR is also available in many developed countries but its policy varies and difficult for the end user to implement. LCA, MFA and LCA are overlapping to each other. Table 2 shows the discussed tools implementation statistics country wise.

Table 2:
E-Waste Management Techniques Implemented by Country

S/No	E-Waste Management Technique	Country
1	LCA	Japan, Korea, India, Switzerland, Columbia, Germany, Taiwan, United Kingdom, Thailand
2	MFA	Chile, Columbia, China, India, Nigeria, Japan, Switzerland
3	MCA	Spain, Cyprus, USA
4	EPR	Canada, Thailand, Germany, Netherlands, United Kingdom

Figure 2:
Number of Countries Implemented E-Waste Management Techniques

Discussion

In this section, the author summarised the discussion on e-waste management, its challenges, and existing techniques and strategies. There are

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some common issues which are identified from selected literature including environmental aspects, positive and negative features of existing strategies, economic and trade aspects. Typically, the 'waste' word is used for useless items or valueless items but the actual reality is the opposite. Electronic waste is useful, valuable and also a recyclable resources. There are many questions raised when we discuss issues related to e-waste. The first main issue related to e-waste is environmental pollution due to lack of awareness, inappropriate handling and mismanagement of e-waste items. Next concern would be the environmental pollution which leads to health issues such as skin diseases, stomach and organs related problems. These health issues caused are due to low standard and low-cost methods of e-waste management processing especially on metal recovery from electronic devices (Herat & Agamuthu, 2012). Most employees working at landfill sites are also prone to be affected by these toxins. There is another low-cost strategy for e-waste disposal which is open burning of devices, cables, and batteries. However, this method is more harmful to the environment and human health due to direct inhalation from the smoke exhaustion. Some other issues are related to the economic trade of e-waste such as inappropriate technologies, less lifetime of used devices, hard to control and recollection of e-waste (Cruz-Sotelo et al., 2017). E-waste also contains Brominated Flame Retardants (BFRs) which are very dangerous for the environment and human health. Issues related to e-waste are becoming more significant and need further attention from policy makers and industries. In some countries, e-waste issues become more pertinent and require urgent policies in order to manage and control the adverse effect to the environment and human health.

Proposed Recommendations

This section discusses the proposed recommendations for e-waste management after taking consideration of techniques and strategies discovered from the selected literature:

- New policies to control e-waste and recycle the process;

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- Clear guidelines and policy on e-waste management;
- New technologies and innovation for recycling and disposal of e-waste;
- New policy and regulations on pollution control by central and local government bodies;
- Timeline for adoption of rules and regulations for e-waste management;
- Channel of information for public sharing and awareness;
- Monitoring system to control e-waste generation;
- Incentives for e-waste processing and recycling plants/industries;
- Tax incentives for exporters to trade e-waste worldwide;
- International market access for local recycling industries.

Based on the proposed recommendations, the author summarised the importance of government and industries involvement in the e-waste management initiatives such as disposal and recycling. There are several techniques and strategies that have been adopted worldwide in order to deal with the issues of e-waste. Most importantly, research work must be undertaken to explore newer ways to deal with e-waste to make it more eco-friendly and these initiatives should be continuoud and sustainable in the future.

Conclusion

E-waste is one of the areas that need serious attention at local and global level. Electronic devices contain dangerous substances and could lead to a severe impact to the environment and human health. Improper and low-cost strategies of disposal and recycling process could cause the exposure of toxic materials. There are different types of strategies adopted by many countries around the world to manage the e-waste processes. This paper deliberates on the existing techniques, strategies and its important features for e-waste management and control. The paper also discusses the existing issues in this area and proposes recommendations (but not limited) for better e-waste management practices. Lastly, the paper concluded that there is a requirement to plan and develop new policy framework and advanced strategies for e-waste management and practices.

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http://proceedings.itltrisakti.ac.id/index.php/atlr

References

Belboom, S., Renzoni, R., Deleu, X., Digneffe, J., & Leonard, A. (2011). *Electrical waste management effects on environment using life cycle assessment methodology: the fridge case study.* Paper presented at the SETAC EUROPE 17th LCA Case Study Symposium Sustainable Lifestyles, Budapest, Hungary.

Chung, S.-W., & Murakami-Suzuki, R. (2008). A comparative study of e-waste recycling systems in Japan, South Korea and Taiwan from the EPR perspective: implications for developing countries. *Kojima. Chiba, 21*.

Cooper, H. C. (2015). Local and Global Perspectives on E-Waste: Integrating the Humanities, Social Science, and Engineering to Examine the Life Cycle of Electronics.

Cruz-Sotelo, S. E., Ojeda-Benítez, S., Jáuregui Sesma, J., Velázquez-Victorica, K. I., Santillán-Soto, N., García-Cueto, O. R., . . . Alcántara, C. (2017). E-Waste Supply Chain in Mexico: Challenges and Opportunities for Sustainable Management. *Sustainability, 9*(4), 503.

De Brito, M. P., & Dekker, R. (2004). *A framework for reverse logistics*: Springer.

Directive, E. (2012). Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment, WEEE. *Official Journal of the European Union L, 197*, 38-71.

Dowlatshahi, S. (2000). Developing a theory of reverse logistics. *Interfaces, 30*(3), 143-155.

Fleischmann, M., Krikke, H. R., Dekker, R., & Flapper, S. D. P. (2000). A characterisation of logistics networks for product recovery. *Omega, 28*(6), 653-666.

Govindan, K., Soleimani, H., & Kannan, D. (2015). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European Journal of Operational Research, 240*(3), 603-626.

Hatami-Marbini, A., Tavana, M., Moradi, M., & Kangi, F. (2013). A fuzzy group Electre method for safety and health assessment in hazardous waste recycling facilities. *Safety science, 51*(1), 414-426.

Herat, S., & Agamuthu, P. (2012). E-waste: a problem or an opportunity? Review of issues, challenges and solutions in Asian countries. *Waste Management & Research, 30*(11), 1113-1129.

Hischier, R., & Baudin, I. (2010). LCA study of a plasma television device. *The International Journal of Life Cycle Assessment, 15*(5), 428-438.

Kiddee, P., Naidu, R., & Wong, M. H. (2013). Electronic waste management approaches: An overview. *Waste management, 33*(5), 1237-1250.

Lepawsky, J. (2012). Legal geographies of e-waste legislation in Canada and the US: Jurisdiction, responsibility and the taboo of production. *Geoforum, 43*(6), 1194-1206.

Mayers, C. K., France, C. M., & Cowell, S. J. (2005). Extended producer responsibility for waste electronics: An example of printer recycling in the United Kingdom. *Journal of Industrial Ecology, 9*(3), 169-189.

Memon, A., & Pitroda, J. (2016). The Recovery of Precious and Base Metals from E-Waste: A Review. *International Journal of Constructive Research in Civil Engineering, 2*(5), 1-7.

Muñoz, I., Gazulla, C., Bala, A., Puig, R., & Fullana, P. (2009). LCA and ecodesign in the toy industry: case study of a teddy bear incorporating electric and electronic components. *The International Journal of Life Cycle Assessment, 14*(1), 64-72.

Queiruga, D., Walther, G., Gonzalez-Benito, J., & Spengler, T. (2008). Evaluation of sites for the location of WEEE recycling plants in Spain. *Waste management, 28*(1), 181-190.

Schwarzer, S., De Bono, A., Giuliani, G., Kluser, S., & Peduzzi, P. (2005). E-waste, the hidden side of IT equipment's manufacturing and use.

Steubing, B., Böni, H., Schluep, M., Silva, U., & Ludwig, C. (2010). Assessing computer waste generation in Chile using material flow analysis. *Waste management, 30*(3), 473-482.

Wäger, P., Hischier, R., & Eugster, M. (2011). Environmental impacts of the Swiss collection and recovery systems for Waste Electrical and Electronic Equipment (WEEE): A follow-up. *Science of the Total Environment, 409*(10), 1746-1756.

White, J. (1994). Reverse logistics moves forward. *Modern Materials Handling, 49*(1), 29.

Yoshida, A., Tasaki, T., & Terazono, A. (2009). Material flow analysis of used personal computers in Japan. *Waste management, 29*(5), 1602-1614.