International Journal of Engineering & Technology, 7 (4) (2018) 3268-3275

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 10.14419/ijet.v7i4.15169
Research paper

Strategies to manage electronic waste approaches: an overview in east Asia

Waleed Al-Rahmi [1], Norma Alias [1], Akhtar Ali1, Noraffandy Yahaya [2], Muneer Saleh [3],Qusay Al-Maatouk [4]

[1] Ibnu Sina Institute for Scientific &Industrial Research (ISI-SIR), Faculty of Science, University Technology Malaysia, 81310, UTM Skudai, Johor, Malaysia
[2] Faculty of Education, University Technology Malaysia, 81310, UTM Skudai, Johor, Malaysia
[3] Faculty of Chemical & Energy Engineering, University Technology Malaysia, 81310, UTM Skudai, Johor, Malaysia
[4] Faculty of Engineering, Computing and Technology, Asia Pacific University of Technology & Innovation (APU), Technology Park Malaysia, Bukit Jalil-57000 Kuala Lumpur, Malaysia
**Corresponding author E-mail: waleed.alrahmi@yahoo.com*

Abstract

The issue of e-waste is becoming an increasingly threatening problem as it contains many toxic materials that can severely harm both human beings and the environment. This problem is expected to worsen if not serious efforts are taken to manage this e-waste. The current research introduced the best strategies and techniques with managerial efforts taken in this regard to deal with the e-waste in East Asia countries. Countries have been using a variety of techniques to deal with this problem namely: Life Cycle Assessment (LCA), Multi Criteria Analysis (MCA), Material Flow Analysis (MFA), and Extended Producer Responsibility (EPR). Therefore, these strategies are prosed to work to-gether to insure the best results in dealing with this problem. Moreover, this research involves a systematic and organized review of 308 research articles regarding electronic waste from 2000 to 2017. An analysis of studies dedicated to manage e-waste in East Asia countries was carried out on the basis of certain dimensions, namely, year of publication, journal, country, and subject area. Based on the obtained findings, the most of studies are from environmental science, chemistry, engineering, medicine and an energy area in the rate of (33.8%), (12.3%), (8.8%), (8.4%) and (5.8%) respectively. Furthermore, the findings have shown an increasing trend over recent years from 2010-2017.

Keywords: *Electronic Waste; Strategies to Manage Electronic Waste; Systematic Literature Review.*

1. Introduction

E-waste in East Asia normally coming from several sources namely industrial, household and business entities. Currently only e-waste generated from industries implemented a proper management of e-waste. Department of Environment Malaysia (DOE) recorded the generation of e-waste from the industrial sector between year 2009 and 2010 with amount 134,035.70 metric ton and 163,339.80 metric tons (Idris, 2012). E-Waste in Malaysia is handled by the licensed recovery facilities. However, there are issues faced by the recovery facilities in achieving the goal of converting e-waste into a source material (Suja et al., 2014). Social and human health problems have been recognized in some developing countries and it is worth noting that Malaysia, China, and some other Asian countries have recently amended their laws to address the management and disposal of e-waste imports (Widmer et al., 2005; Suja et al., 2014). Moreover, some manufacturers of electronic goods have attempted to safely dispose of e-waste with advanced technologies in both developed and developing countries (US Government Accountability Office, 2008; Widmer et al., 2005). Problems associated with e-waste have been challenged by authorities in a number of countries and steps were taken to alleviate them with the introduction of management tools and laws at the national and universal levels. Life cycle assessment (LCA), material flow analysis (MFA) and multi criteria analysis (MCA) are tools to manage e-waste problems and extended producer responsibility (EPR) is the regulation for e-waste management at the national scale. This study provides an overview of the risk that e-wastes poses to human and environmental health from recycling and landfill disposals together with tools for the management of such wastes. Human toxicity of hazardous substances in e waste is based on previous studies from e-waste recycling in Malaysia. Several tools including LCA, MFA, MCA and EPR approach for e-waste management could ultimately ameliorate most e-waste problems. Any one tool may be imperfect but in concert they can complement each other to solve this issue. Moreover, a national scheme such as EPR is a good policy tool to solve the growing e-waste problem. Interaction of four tools can drive to success for e-waste management that is to develop eco-designed devices, to properly collect e-waste, recover and recycle material by safe methods, dispose of e-waste by suitable techniques, forbid the transfer of used electronic devices to developing countries, to raise awareness of the impact of e-waste pollution of both users and manufacturers. The current study maintains that one of the most important objective to be taken into consideration while establishing an e-waste management is to create a society that understands the importance of ecological recycling and adhere to specific regulation in this regard. Various techniques and strategies are used nowadays around the world to manage e-waste. Some of these strategies are material flow analysis (MFA), life cycle assessment (LCA), extended producer responsibility (EPR) and multi criteria analysis (MCA). The origin of the e-waste issue can be traced back to the developed countries and now this problem exists in the developing countries. One of the main reasons that the issue of e-waste exists in some countries due to the fact that a huge a mounts of e-waste and being shipped to the developing counties (Sthiannopkao and Wong, 2013).

2. Strategies to manage e-wastes

It is known that the rapid increase of e-waste in huge amounts is the financial development as well as the growth in technology

Table 1: Tools for E-Waste Management Approaches Being Used or Proposed

Tools	Application	Aspects	Country	References
LCA	Recycling e-waste	Environment and economic	Malaysia	Kalana (2010)
LCA	Recycling of end-of-life of personal computers	Environment and economic	Korea	Choi et al. (2006)
LCA	Recycling potential	Environment and economic	Korea	Kim et al. (2004)
LCA	Compare different disposal methods (recycle and non-recycle): case study of fluorescent lamps	Environment	Thailand	Apisitpuvakul et al. (2008)
LCA	Recycling systems: case study of notebook computers	Environment	Taiwan	Lu et al. (2006)
LCA	Recycling of end-of-life	Environment and economic	Japan	Nakamura and Kondo (2006)
MFA	The flow of used personal computers	Recycling system	Japan	Yoshida et al. (2009)
MFA	The flow of e-waste	Generation	China	Liu et al. (2006a)
MFA	The flow of e-waste and e-waste trade	Law and environmental pollution	Asia	Shinkuma and Nguyen Thi Minh (2009)
LCA&MFA	The environmental pollutions	Recycling system	Hong Kong	Wang et al. (2009)
LCA&MFA	The environmental pollutions	Environment	Singapore	Lin et al. (2017)
MCA	The environmental of e-waste	Waste hierarchy	Indonesia	Rochman et al.(2016)
MCA	The environmental of e-waste	Material flow analysis	Philippines	Yedla (2016)
MCA	The solid waste dumping	Waste management	Cambodia	Kwan et al. (2013)

These factors are widening the range of technology expansion. Buying such products makes it natural for the e-waste to appear (Kang and Schoenung, 2005). Nowadays, the e-waste managements all over the world have this assessment to alleviate the dangers of this waste. Much research is done on e-waste all over the world trying to find the most suitable ways of alleviating the dangers of this e-waste. See Table 1.

2.1. Life cycle assessment (LCA)

LCA is considered an effective methodology to be used by firms as a means of monitoring the e-waste in all of its stages (Hong et al., 2015). This tools is also helpful when deciding to produce eco-design products such as printers (Pollock and Coulon, 1996), desktop personal computers (Kim et al., 2001), heating and air conditioner devices (Prek, 2004), washing machines (Park et al., 2006), and toys (Munoz et al., 2009). This true because it helps to assess and predict the environmental effects of these things. Belboom et al. (2011) & Duan et al. (2009) highlights that LCA is characterized of being systematic as it classify some products such as carcinogens, climate change, ozone layer, ecotoxicity, acidification, eutrophication and land use. This classification aims at improving the environmental performance of products

This methodology has been used in Asia in the field of e-waste estimation and management. An example for that is a study conducted in Korea. The LCA was used to assess recycling possibilities based on both environmental and economic considerations. Elements such as glass, circuit boards, iron, copper, aluminum and plastic, respectively received the highest values in terms of the environmental score. Economically, copper, aluminum, iron, plastic, glass and circuit boards in order received the best results represented by the highest values.

The practical recycling value of an EoL personal computer was put under research and was evaluated for its environment impact. The two main ways of disposing were landfills and recycling. The outcome of the study proved that latter way of disposal was the better option. Recycling was not the preferred option as well in the study by (Lu et al., 2006) that was conducted in Taiwan. The option of reuse was found to be the best available option after testing the notebook computer disposal. That assessment was based on environmental and economic conservations. The disposal by recycling was not preferred as it produced hazardous materials that have a great danger on environment. Nakamura and Kondo (2006) conducted a similar study in japan. The assessment revolved on the cost. They found the option of landfill saved the cost more than recycling. However, recycling was more environmental friendly than landfills as the latter produced toxic carbon emissions. LCA was used in India to assess the management of computers' e-waste (Ahluwalia and Nema, 2007). The assessment was based on economic aspects, perceived risk and environmental impacts. The main finding was that the life cycle of a computer desktop was 25% shorter than the optimized cost and value of computer waste influence on both environment or any perceived risk of the public. Apisitpuvakul et al. (2008) found that as the rate of recycling is increase, the impacts on environment are lessened. That was the result of examining the environmental impact of fluorescent lamp disposal in several proportions of recycling LCA was also used in South America to assess the environmental impact and the management of e-waste. Both the computer supply scenarios from local or overseas refurbishment and new low-cost computers donated to Colombian schools were put under research examining their sustainability. Environmentally, the local second hand computers were the less preferred option and they were not a good option in terms of maintenance. However, they were the best options according to technical standards. Law enforcement and regulation and the promotion of e-waste recovery activities were some methods applied by the Malaysian government to guarantee the safe, effective and economic management of e-waste. In Malaysia, the Department of Environment (DOE) is the authorized party to dispose the uncommercial e-waste. As for the segregation, dismantling, and treatment of e-waste, 18 full recovery facilities and 128 partial recovery facilities are used for these tasks and are equipped with the necessary technology (Suja et al., 2014).

2.2. Material flow analysis (MFA)

MFA is a method used for studying the course of materials when moved to other locations for reuse. This method takes into considerations the space and time. It works by connecting certain pieces of information like foundations, paths, intermediary and last endpoints of the gadget. MFA is a good instrument for health environment and waste administration (Kiddee et al., 2013). This is true when there is a free access to the information and there is a rapid economic development. Within this methodology, the identification of materials or e-waste follows a number of steps and certain indicators are used to assess and evaluate the quality of this technique. In this connection, Mangold et al. (2015) mentions that this technique classifies materials based on their types, locations, inputs and outputs before and after recycling procedure. Prior to actual application of Basel Convention, developing countries such as China, India and South Africa used to import large amounts of e-waste from developed countries for reusing and recycling. Brunner and Rechberger (2004) mentioned that Material Flow Analysis is a tool that insures environmental and waste management. (Table 1) illustrates that this tool can be utilized to develop an effective e- waste management. This tool assessed and evaluates such flow of e-waste based on criteria related to environmental, economic and social values. An Example from Asia would by the study by (Shinkuma et al., 2009) that used MFA to examine and assess the transfer of e-waste.

2.3. Multi-criteria analysis (MCA)

MCA is a technique of managing and resolving the related problems. It provides an allowance for judging and resolving complicated problems (Kiddee et al., 2013). MCA technique has been used a wide range of applications. Some of these applications are environmental problems with a special attention to energy consumption (Horie, 2004) Environmental impacts (Belboom et al., 2011) Washing machines Eco-design (Park et al., 2006) IT and telecommunications equipment Printers Product development (Pollock and Coulon, 1996). CD-ROM drives Environmental impacts (focus on carbon Electronic components (semiconductor devices, passive components, transducers, CRTs, connecting components, printed circuit boards, liquid crystal display devices) Electronic components (semiconductor devices) emissions) (Satake and Oishi, 1998) Environmental impacts (focus on energy consumption and emission) including those of e-waste management, to provide optional e-waste management strategies (refer to Table 1). Hula et al. (2003) utilized this methodology in the case of coffee makers. The aim of the study was to identify the trade-offs between the environmental benefits and economic profit of the EoL processing. For that, the researcher followed a methodology of six phases: defining the EoL scenarios, defining product models, developing an EoL evaluation model, formulating a multi objective problem, working out solutions for the Pareto set, and constructing a EoL strategy graphs for the Pareto set of optimal EoL strategies that alleviate environmental impacts and economic cost. In another study, MCA was utilized to identify appropriate locations for plants recycling e-waste in Spain (Queiruga et al., 2008). The study was quantitative as it touched upon the economics of warehouse locations. Another study conducted in Cyprus was to assess other alternative systems of e-waste management (Rousis et al., 2008). In that study, 12 alternative systems were ordered based on their quality and effectivity. The study concluded by mentioning that the best possible option was the partial disassembly of these materials and transferring them to local prevailing to be deposed at landfill sites.

2.4. Extended producer responsibility (EPR)

Crediting the obligation to producers in retrieval of items is a strategy methodology that falls under the view of contaminator-compensations standards (Kiddee et al., 2013). According to the EPR environment policy approach, it is the responsibility of the manufacturers to collect back their products after being used. This policy includes the polluter-pays principles (OECD, 2001; Widmer et al., 2005). Table 2 illustrates the EPR approaches to e-waste management in the national level. Advanced nations such as European Union (EU), Switzerland, Japan and some states or provinces of the United States and Canada are the leaders of these EPR programs concerned with e-waste. The Organization supported an environment friendly program for Economic Cooperation and Development (OECD). Within that program, a manual of guidelines was published and directed to governments (OECD, 2001). A Japanese take back system needed to be paid for by end users who then took their e-waste to retail or second hand shops. Then, the e-waste materials are recycled and dismantled. The recycling rate is 50–60% based on the weight of the e-waste material. Both local government and manufacturers who are concerned to protect the environment form such e-waste are the ones how support these recycling operations (Nnorom and Osibanjo, 2008; Tojo, 2001). Manufactures also contribute to the EPR as they invent new environment friendly designs (DfE). Examples for that would be the production of lead-free solders and bromine-free printed circuit boards. These manufacturers also design products that can be disassembled and reused (Lease, 2002; Nnorom and Osibanjo, 2008; Tojo, 2001). A progressive EPR is an approach of EPR that was developed in Canada. This approach highlights the management of products and pollution prevention. Nowadays, Canada does not have a national EPR system concerning the management of e-waste. According to the results obtained from a national municipal survey for the disposal of e-waste back in 2003, some municipalities were of the view that the manufacturers themselves should be responsible for the collection, recovery, recycling and disposal of e-waste. Some provinces decided to take actions and manage the e-waste problems on spot. The first initiative was taken by Alberta in 2004. The initiative was to establish a management program for the e-waste that mainly aimed at collecting computers and televisions. Later, another province called Ontario initiated a more comprehensive program collecting e-waste from 200 sorts of items. Other provinces followed the EPR policy as an effective policy of e-waste management (McKerlie et al., 2006). Some Canadian provinces namely Alberta, British Columbia, Nova Scotia, Ontario, Prince Edward Island and Saskatchewan announced that they will take back the e-waste from seven e-waste products. These products were computers (laptop and/or desktop), monitors, printers, peripherals (e.g., keyboard, mouse), televisions, DVD players and CD players by the end of 2010 (Lepawsky, 2012). See Table 2.

Table 2: E-Waste Management Approaches to EPR

Country	Policy	Target	References
Malaysia	• Take back (electronic waste).	Recycling e-waste	Agamuthu and Victor. (2011)
Thailand	• Developing legal framework.	Collection and recycling	Manomaivibool and Vassanadumrong-dee (2011)
Japan	• Take back (four large household appliances: TV sets, refrigerators, air conditioners and washing machines). • Product redesigns (lead free solders and bromine free printed circuit boards).	Recycling rate 50–60% by weight	Nnorom and Osibanjo (2008)
Hong Kong	• Take back (electronic waste).	Recycling system	Wang et Al. (2009)
Singapore	• Take back (electronic waste).	Environment	Lin et al. (2017)
Indonesia	• Take back (electronic	E-waste	Rochman et al.(2016)

	• waste).		
Philippines	• Take back (electronic waste).	Material flow analysis	Yedla (2016)
Cambodia	• Take back (electronic waste).	Waste management	Kwan et al. (2013)
Taiwan	• Take back (electronic waste).	Recycling system	Lu et al. (2006)
China	• Take back (electronic waste).	Generation	Liu et al. (2006a)

3. Results and analysis

E-waste short for electronic waste is the name given to all electronic and electrical appliances which are at the end of its life. E-waste in short is a term that refers to any electric and electronic apparatus that of no more use to their owners. E-waste is a broad and growing range of electronic devices ranges from large household equipment (refrigerators, air conditions, cell phones, personal stereos) and consumer electronics to computers that have been discarded by the users (Puckett et al., 2002). As highlighted by Association of Plastics Manufacturers in Europe (APME) e-waste is a multifarious combination composed of ferrous, nonferrous, plastic and ceramic materials (APME, 2004). The findings of the review are provided in this section. First, the answers to the above research questions are answers. What are the research issues that have been addressed in e-waste literature on the Asia? (Table 1) illustrates various tools utilized for helping research in the area of e-waste management. These tools are LCA, MFA, MCA and EPR. Research includes the idea of recycling especially for the precious materials. This search resulted in 308 related articles published between 2000 and 2017. Thus, in this research all articles were selected. The articles were analyzed by the year of publication, journal, country and author. This particular analysis provides guidelines for pursuing rigorous research on electronic waste in East Asia. The details are presented below.

3.1. Distribution by the year of publication

The distribution of the articles from 2000 to 2017 is shown in Table 3. From the data, it is clear that there is an upward trend in the number of e-waste studies during this time period. From this trend, it appears that the attention given to e-waste has risen over time and remains an important area of research. For example, it was found that more than half 241 studies (78.2%) of the studies were published in the last seven years i.e., from 2010 to 2017. See Tables 3 & 4.

Table 3: Distribution by the Year of Publication

Year	Article Count	Year	Article Count	Year	Article Count	Year	Article Count	Year	Article Count
2017	22	2013	33	2009	15	2005	5	2001	1
2016	37	2012	32	2008	17	2004	3	2000	4
2015	31	2011	31	2007	10	2003	2		
2014	35	2010	20	2006	8	2002	2		

3.2. Distribution by journal

Table 4 shows the outcome results based on distribution of articles by the journal where authors published. The majority papers was published on waste management journal (54 papers), waste management and research journal (27 papers), and environmental science and technology journal (22 papers). Moreover, the average papers was published on the following journals: journal of hazardous materials (21 papers), chemosphere (16 papers), resources conservation and recycling (15 papers), journal of cleaner production (12 papers), environmental pollution (10 papers), science of the total environment (10 papers), environmental science and pollution research (9 papers), journal of material cycles and waste management (8 papers), journal of the air and waste management association (7 papers), bioresource technology (7 papers), journal of environmental science and health part a toxic hazardous substances and environmental engineering (7 papers), environment international (5 papers), and journal of environmental management (4 papers). As well as other papers was published on 62 various journals see Table 4. This result and analysis depends on scope of journals.

Table 4: Distribution by Journal

Journal	Article Count	Journal	Article Count
Waste Management	54	Environmental Health Perspectives	1
Waste Management And Research	27	Expert Systems With Applications	1
Environmental Science And Technology	22	Frontiers Of Environmental Science And Engineering	1
Journal Of Hazardous Materials	21	Future Generation Computer Systems	1
Chemosphere	16	Geosystem Engineering	1
Resources Conservation And Recycling	15	Infor	1
Journal Of Cleaner Production	12	International Journal Of Advanced Manufacturing Technology	1
Environmental Pollution	10	International Journal Of Applied Environmental Sciences	1
Science Of The Total Environment	10	International Journal Of Distributed Sensor Networks	1
Environmental Science And Pollution Research	9	International Journal Of Engineering Intelligent Systems For Electrical Engineering And Communications	1
Journal Of Material Cycles And Waste Management	8	International Journal Of Environment And Waste Management	1
Journal Of The Air And Waste Management Association	8	International Journal Of Environmental Research And Public Health	1
Bioresource Technology	7	International Journal Of Environmental Science And Technology	1
Journal Of Environmental Science And Health Part A Toxic Hazardous Substances And Environmental Engineering	7	International Journal Of Environmental Technology And Management	1
Environment International	5	International Journal Of Fuzzy Systems	1
Journal Of Environmental Management	4	International Journal Of Innovative Computing Information And Control	1
Bulletin Of Environmental Contamination And Toxicology	3	International Journal Of Life Cycle Assessment	1
Environmental Toxicology And Chemistry	3	Iranian Journal Of Environmental Health Science And Engineering	1

Environmental Engineering Science	2	Journal Of Electronic Packaging Transactions Of The ASME	1
Environmental Management	2	Journal Of Environmental Biology	1
Environmental Monitoring And Assessment	2	Journal Of Environmental Monitoring	1
Environmental Research	2	Journal Of Environmental Sciences	1
Environmental Sciences Processes And Impacts	2	Journal Of Intelligent Manufacturing	1
Environmental Technology United Kingdom	2	Journal Of Medical Systems	1
Journal Of Industrial Ecology	2	Journal Of Residuals Science And Technology	1
Water Environment Research	2	Journal Of Solid Waste Technology And Management	1
Water Science And Technology	2	Journal Of Transport Geography	1
Advanced Science Letters	1	Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics	1
Aerosol And Air Quality Research	1	Marine Pollution Bulletin	1
Asian Journal Of Microbiology Biotechnology And Environmental Sciences	1	Nature Environment And Pollution Technology	1
Clean Technologies And Environmental Policy	1	Research Journal Of Chemistry And Environment	1
Corporate Social Responsibility And Environmental Management	1	Review Of European Community And International Environmental Law	1
Ecological Engineering	1	Robotics And Computer Integrated Manufacturing	1
Ecotoxicology	1	Sustainability Switzerland	1
Ecotoxicology And Environmental Safety	1	Water Air And Soil Pollution	1
Energy	1	Water Research	1
Environment Protection Engineering	1	Wit Transactions On Ecology And The Environment	1
Environmental Earth Sciences	1	Zhongguo Renkou Ziyuan Yu Huan Jing China Population Resources And Environment	1

3.3. Distribution by country

The distribution of articles by the country where authors collected data is shown in Table 5. At the country level, 7 countries were represented, and the most frequently studied countries were China (132), Japan (39), Taiwan (38), South Korea (22), Hong Kong (19), Malaysia (18), and Thailand (13), Singapore (9), Indonesia (8), Philippines (6), Cambodia (4). Cumulatively, research works conducted in China, Japan and Taiwan accounted for 209 articles or 67.9% of the total number of articles, while the rest of the countries accounted for 99 articles or 32.1% of the total number of articles. At the level of geographical regions, most studies dealt with East Asia countries, see Table 5.

Table 5: Distribution by Country

Country	Article Count	Country	Article Count	Country	Article Count	Country	Article Count
China	132	South Korea	22	Thailand	13	Philippines	6
Japan	39	Hong Kong	19	Singapore	9	Cambodia	4
Taiwan	38	Malaysia	18	Indonesia	8		

3.4. Distribution by subject area

Table 6 shows the distribution by the subject area. The researchers noted that most of the studies were from the environmental science area 104 studies (33.8%) and the chemistry sciences area (38 studies or 12.3%). There were 27 (8.8%) studies in the engineering area, 26 (8.4%) studies in the medicine area and 18 (5.8%) studies in the energy area. The number of studies in the economics, econometrics and finance area was 15 (4.9%), and that of pharmacology, toxicology and pharmaceutics area was also 15 (4.9%). Moreover, computer science accounted for 14 studies (4.5%), and chemical engineering area accounted for 12 studies (3.9%). There were 9 businesses, management and accounting studies (2.9%), and social sciences comprised of 7 studies (2.3%). Agricultural and biological sciences comprised of 6 studies (1.9%), and earth and planetary sciences area comprised of 5 studies (1.6%), mathematics area was also 5 studies (1.6%). Further, the biochemistry, genetics and molecular biology area accounted for 4 studies (1.3%). Finally, health professions area; immunology and microbiology area, and materials science area accounted for each area study (0.3%). The authors understand that most of the studies are from environmental science, chemistry, engineering, medicine and an energy area because these areas of study are more closely related to e- was. See table 6.

Table 6: Distribution by Subject Area

No	Subject Area	Documents	Percentage
1	Environmental Science	104	33.8
2	Chemistry	38	12.3
3	Engineering	27	8.8
4	Medicine	26	8.4
5	Energy	18	5.8
6	Economics, Econometrics and Finance	15	4.9
7	Pharmacology, Toxicology and Pharmaceutics	15	4.9
8	Computer Science	14	4.5
9	Chemical Engineering	12	3.9
10	Business, Management and Accounting	9	2.9
11	Social Sciences	7	2.3
12	Agricultural and Biological Sciences	6	1.9
13	Earth and Planetary Sciences	5	1.6
14	Mathematics	5	1.6
15	Biochemistry, Genetics and Molecular Biology	4	1.3
16	Health Professions	1	0.3
17	Immunology and Microbiology	1	0.3
18	Materials Science	1	0.3
	Total	308	100.0

4. Discussion

As reported in some studies, developing countries are producing e-waste twice more than developed countries within next 6–8 years. Countries around the world are expected to dispose 400–700 million and 200–300 million obsolete computers by 2030, respectively (Sthiannopkao and Wong, 2013). The computer model has been predicted that the developing countries will trash more computers than developed countries by 2016 (Devi et al., 2004). Moreover developed countries are also exporting their e-waste to developing countries for dumping leading to serious concerns. Illegally, much of the e-waste is being sent to Africa or Asia even having an authorization to export the unnecessary goods to poor countries for reuse or refurbish. Some of these “used goods” are actually non-functional goods. A considerable amount of e-waste exports are directing outside Europe countries, including West African countries because of its treatment in the unceremonious regions, causing significant environmental pollution and health risks for a local population. The failure to recover rare-earth minerals is also creating problems to make future generations of electronic equipment (Duan et al., 2015).

E-waste generation was categorized by the Malaysian DOE into two categories namely Industrial and Non Industrial sectors (Households, Business and Institutions). In 2009, E- waste generated from the industrial sector was reported to be 134,036 tones. This amount increased to 163,340 tons in 2010 and dropped to 152,722 tons in 2011. As for the non-industrial sector, the amounts of E-waste generation by households were 652,909 tons in 2006, 695,461 tons in 2007 and 688,068 tons in 2008 (Malaysia DOE, 2012). The results indicate that most of the e-waste in Malaysia is those resulting from households, commercial outlets and institutions. Back in 2008, it was predicted by the Malaysian DOE that E-waste generation in Malaysia would be 1.1million tons per year by 2020. In that same year, a research supported by Ministry of Environment of Japan found out that the amount of E-waste was already 1.1 million tons (Agamuthu and Victor, 2011).

The institutions of tertiary education were parts of the e-waste problems worldwide. This is true since universities continuously use the information and communication technology (ICT) with the various collections of the related tools and devices. That leads to the disposal of a huge numbers of laptop computers, printers and photocopy machines. Killick (2007) reports the average lifespan of ICT electronics as 3-4 years for desktop PC, 5 years for monitors, 2 years for laptop and 3-5 years for printers and copiers. With the awareness of e-waste, these institutions are replacing these devices more environmentally harmful Cathode Ray Tube (CRT) with more environment friendly ones such as flat screens. This has s positive impact in terms of E-waste generation.

Environmental impacts of e-waste during treatment processes it was not until 20 years ago, people started to be aware of the e-waste and their dangers represented by the toxic substances. Before that, there were no regulations concerning the handling of these waste materials. Both the rapid innovation of electronic products and the absence of appropriate regulations of how to deal with this waste contributed in the present deep impact these toxic products have on environment. This was the case in both developed and developing counties. One of the problems causing the pollution of the environment is the lack of management skills in handling the e-waste. This stems from the fact that there is a shortage of treatment facilities and the absence of clear regulation in this regard especially in developing countries. In Malaysia, the heavy metal pollution of e-waste was originated from informal activities and spread out to the environment (Suja et al., 2014). Thus, there is a need to be aware of this and take the certain actions to solve this problem. A long-term risk assessment of the leachability and migration of these toxic meatal should be conducted in order to better understand the potential dangers of this type of waste and its influence on humans. As mentioned by Robinson (2009) & Wong et al. (2007), the disposal of this waste into the landfills or recycling them proved to be dangerous to the environment. While there are many tools available for the management of e-waste problems, we focussed on LCA, MFA, MCA and EPR given its popularity in some countries. Each tool has distinctive features when applied to e-waste management and these are summarized in Table 7.

Table 7: The Distinctive Features of LCA, MFA, MCA and EPR for E-Waste Management

Tools	Benefits	Country	References
LCA	• Estimates the effects of materials consumption. Assesses eco-design and product development. • Allocates the impacts of the examined product or process of environmental interest. • Evaluate the environmental and economic aspects related to the end of life dis-posal of electronic devices. • Takes better decisions regarding e waste disposal.	Japan	Nakamura and Kondo (2006)
		Korea	Choi et al. (2006)
		Thailand	Apisitpuvakul et al. (2008)
		Taiwan	Lu et al. (2006)
MFA	• Investigates the flow of e-waste. • Estimates e-waste generation. • Used for environmental decision-making.	Asia	Shinkuma and Nguyen Thi Minh(2009)
		Japan	Yoshida et al. (2009)
		China	Liu et al. (2006a)
		Hong Kong	Wang et al. (2009)
MCA	• Used for environmental decision-making.	Philippines	Yedla (2016)
		Singapore	
		Cambodia	Kwan et al. (2013)
EPR	• Solve e-waste problems in national scale. • Enforce producers based on polluter-pays principle.	Indonesia	Rochman et al.(2016)
		Japan	Nnorom and Osibanjo (2008)
		Malaysia	Suja et al. (2014)
		Thailand	Manomaivibool and Vassanadumrongdee (2011)

In general, all the tools summarised in Table 7 are useful for e-waste management. Each environment management tool has a specific information category when applied to e-waste management some of which overlap. The findings indicated that LCA, MFA and MCA overlap with regards to environmental decision making while each tool has a distinctive feature that separates them with EPR which is being used at national scale especially in terms of national policy (see Figuer 1) on polluter pays principal.

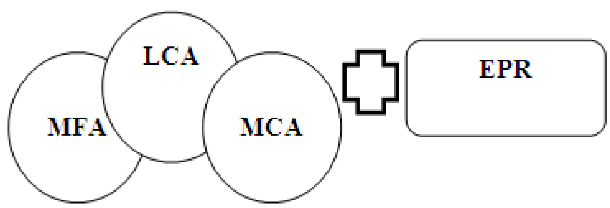

Fig. 1: Optimum E-Waste Management Requires A Combination of LCA and MFA and MCA And EPR Kiddee Et Al., 2013.

E-waste refers to the end-of-life electronics that are accumulating all over the world due to the rapid developments of the 21st century including that of the electronic innovation (Perez-Belis et al., 2015). Balde et al. (2015) report the estimations that about 42 million tons (Mt) are disposed every year. Therefore, a combination of LCA, MFA or MCA with EPR may be the optimal model to promote for the management of e-wastes irrespective of the nature of e-waste problem. Indeed, EPR may be most appropriate for all countries in order to minimise generation of e-waste given that the responsibility for e-waste generated post Basel Convention is passed back to the producers.

5. Conclusion

Some proposed ideas to deal with this problem are developing eco-design devices, collecting e-waste with caution, recovering and recycling materials, disposing e-waste using proper techniques, forbidding the shipping of second hand electronic devices to the developing countries, and raising awareness of the impact of e-waste. The issue e-waste is a known problem at local and global levels. The origin of this problem can be traced to developed countries but now it seems to be expanding to other countries and regions. The main reason behind the emergence and the expansion of this problem is the consumer technology. The rapid growth in technology makes many products obsolete which lead to this huge problem of e-waste. One of the most serious problems is that these products might contain toxic materials threatening the life of humans which requires a better management in this regard. Through the study of e-waste recycling plants, studies concluded that these chemical toxic materials such as the persistent organic pollutants (POPs) are considered a danger on environment. This pollution can affect the ecosystem leading to negative impacts on humans. Thus, Landfills of e-waste should be avoided, especially for washing machines, TVs, and refrigerators. As observed in studies especially on laboratory simulation and landfill leachates, it appears that there is a considerable among of toxic pollution released by toxic waste in different levels. Currently, much research is being conducted on e-waste studying the different aspects such as the rate of e-waste, the nature of its pollution and its impact on humans. Other studies also study e-waste management as to lessen its impact on the surrounding environment. The current study is an effort to decrease the danger and solve e-waste problems. For that, it utilized different tools such as LCA, MFA, MCA and EPR. Over and above all of these, no matter how well the policies are introduced and implemented benefits will only arise provided end users are prepared to accept introduced policies and adhere to them.

References

[1] Afroz, R., Masud, M. M., Akhtar, R., & Duasa, J. B. (2013). Survey and analysis of public knowledge, awareness and willingness to pay in Kuala Lumpur, Malaysia – a case study on household WEEE management. Journal of Cleaner Production, 52, 185–193. https://doi.org/10.1016/j.jclepro.2013.02.004.

[2] Agamuthu, P., & Victor, D. (2011). Policy trends of extended producer responsibility in Malaysia. Waste Management & Research, 29(9), 945–953. https://doi.org/10.1177/0734242X11413332.

[3] Ahluwalia, P.K., & Nema, A.K., (2007). A life cycle based multi-objective optimization model for the management of computer waste. Resources, Conservation and Recycling, 51, 792–826. https://doi.org/10.1016/j.resconrec.2007.01.001.

[4] Alias, A. F., Ishak, M. B., Zulkifli, S. N. A. M., & Jalil, R. A. (2014). E-waste management: An emerging global crisis and the Malaysian scenario. International Journal of Environmental Sciences, 4(4), 444-457.

[5] Apisitpuvakul, W., Piumsomboon, P., Watts, D.J., & Koetsinchai, W., (2008). LCA of spent fluorescent lamps in Thailand at various rates of recycling. Journal of Cleaner Production, 16, 1046–1061. https://doi.org/10.1016/j.jclepro.2007.06.015.

[6] Arora, R. (2008). Best Practices for e-waste management in developing nations. Europe Aid Co-operation Office, 1-24.

[7] Babington, J. C., Siwar, C., Fariz, A. M., & Ara, R. B. (2010). Bridging the Gaps: An E-waste management and recycling assessment of material recycling facilities in Selangor and Penang. International Journal of Environmental Sciences, 1(3), 383.

[8] Balde, C.P., Wang, F., Kuehr, R., & Huisman, J., (2015). The Global E-waste Monitor 2014. Quantities Flows and Resources. United Nations University, IAS e SCYCLE, Bonn,

[9] Belboom, S., Renzoni, R., Deleu, X., Digneffe, J.-M., & Leonard, A., (2011). Electrical waste management effects on environment using life cycle assessment methodology: the fridge case study. In: SETAC EUROPE 17th LCA Case Study Symposium Sustainable Lifestyles, Budapest, Hungary, p. 2.

[10] Brunner, P., & Rechberger, H., (2004). Practical handbook of material flow analysis. The International Journal of Life Cycle Assessment, 9, 337–338. https://doi.org/10.1007/BF02979426.

[11] Bushehri, F. I. (2010). UNEP's role in promoting environmentally sound management of e-waste. In fifth ITU Symposium on ''ICTs, the Environment and Climate Change''Cairo, Egypt.

[12] Choi, B.C., Shin, H.S., Lee, S.Y., & Hur, T., (2006). Life cycle assessment of a personal computer and its effective recycling rate. The International Journal of Life Cycle Assessment, 11, 122–128. https://doi.org/10.1065/lca2004.12.196.

[13] Department of Environment (2009). The e-waste inventory project Malaysia. Department of Environment, Malaysia World Bank. World Bank 2014.pdf. World Bank. 2014.

[14] Devi, B. S., Shobha, S. V., & Kamble, R. K. (2004). E-waste: the hidden harm of technological revolution.196-205.

[15] DOE (2010). Guideline for the Electrical and Electronic Equipment in Malaysia. Jab Alam Sekitar. 2010. www.doe.gov.my.

[16] Duan, H., Eugster, M., Hischier, R., Streicher-Porte, M., & Li, J., (2009). Life cycle assessment study of a Chinese desktop personal computer. Science of the Total Environment, 407, 1755–1764. https://doi.org/10.1016/j.scitotenv.2008.10.063.

[17] Duan, H., Wang, J., & Huang, Q. (2015). Encouraging the environmentally sound management of C&D waste in China: An integrative review and research agenda. Renewable and Sustainable Energy Reviews, 43, 611-620. https://doi.org/10.1016/j.rser.2014.11.069.

[18] Fatihah S, Rahman RA, Yusof A, & Masdar MS (2014). E-Waste Management Scenarios in Malaysia. Journal Waste Management, 1-7.

[19] Garfi, M., Tondelli, S., & Bonoli, A., (2009). Multi-criteria decision analysis for waste management in Saharawi refugee camps. Waste Management, 29, 2729–2739 https://doi.org/10.1016/j.wasman.2009.05.019.

[20] Hasan, M. A., Abbasi, T. A., Mahapatra, R. P., Ahmed, S., & Abbasi, M. S. (2010). E-waste management and hazardous effect on environment. In Proceedings of the fourth National Conference. INDIACom.

[21] Hicks, C., Dietmar, R., & Eugster, M., (2005). The recycling and disposal of electrical and electronic waste in China-legislative and market responses. Environmental Impact Assessment Review, 25, 459–471. https://doi.org/10.1016/j.eiar.2005.04.007.

[22] Hong, J., Shi, W., Wang, Y., Chen, W., & Li, X. (2015). Life cycle assessment of electronic waste treatment. Waste Management, 38, 357-365. https://doi.org/10.1016/j.wasman.2014.12.022.

[23] Horie, Y.A., (2004). Life cycle Optimization of Household Refrigerator–Freezer Replacement. Natural Resources and Environment. University of Michigan, Michigan, USA, p. 81.

[24] Hula, A., Jalali, K., Hamza, K., Skerlos, S.J., & Saitou, K., (2003). Multi-criteria decisionmaking for optimization of product disassembly under multiple situations. Environmental Science & Technology, 37, 5303–5313. https://doi.org/10.1021/es0345423.

[25] Idris K.M, (2012). E-Waste Management Network Department of Environment. 2012.

[26] Kalana, J. A. (2010). Electrical and electronic waste management practice by households in Shah Alam, Selangor, Malaysia. International Journal of Environmental Sciences, 1(2), 132.

[27] Kang, H. Y., & Schoenung, J. M. (2005). Electronic waste recycling a review of US infrastructure and technology options. Conservation and Recycling, 45(4), 368-400. https://doi.org/10.1016/j.resconrec.2005.06.001.

[28] Kiddee, P., Naidu, R., & Wong, M. H. (2013). Electronic waste management approaches: An overview. Waste Management, 33(5), 1237-1250. https://doi.org/10.1016/j.wasman.2013.01.006.

[29] Kim, J., Hwang, Y., Matthews, H.S., & Park, K., (2004). Methodology for recycling potential evaluation criterion of waste home appliances considering environmental and economic factor. IEEE, 68–73.

[30] Kim, S., Hwang, T., & Overcash, M., (2001). Life cycle assessment study of color computer monitor. The International Journal of Life Cycle Assessment 6, 35–43. https://doi.org/10.1007/BF02977594.

[31] Kwan, C. S., Takada, H., Mizukawa, K., Torii, M., Koike, T., Yamashita, R, & Santiago, E. C. (2013). PBDEs in leachates from municipal solid waste dumping sites in tropical Asian countries: phase distribution and debromination. Environmental Science and Pollution Research, 20(6), 4188-4204. https://doi.org/10.1007/s11356-012-1365-3.

[32] Lease, K., (2002). Asian Countries Jump on the EPR Bandwagon. Institute for Local Self-Reliance, Washington, DC.

[33] Lepawsky, J., (2012). Legal geographies of e-waste legislation in Canada and the US: Jurisdiction, responsibility and the taboo of production. Geoforum 43, 1194-1206. https://doi.org/10.1016/j.geoforum.2012.03.006.
[34] Lin, W. Y., Heng, K. S., Nguyen, M. Q., Ho, J. R. I., Noh, O. A. B. M., Zhou, X. D., ... & Wang, J. Y. (2017). Evaluation of the leaching behavior of incineration bottom ash using seawater: A comparison with standard leaching tests. Waste Management, 62, 139-146. https://doi.org/10.1016/j.wasman.2016.12.003.
[35] Lu, L.T., Wernick, I.K., Hsiao, T.Y., Yu, Y.H., Yang, Y.-M., & Ma, H.W., (2006). Balancing the life cycle impacts of notebook computers: Taiwan's experience. Resources, Conservation and Recycling, 48, 13–25. https://doi.org/10.1016/j.resconrec.2005.12.010.
[36] Mangold, J., Cristobal, K., Mars, C., & Dornfeld, D. (2015). Assessment framework and material flow analysis of material recovery facilities within the US to track consumer electronics by product category. Procedia CIRP, 29, 556-561. https://doi.org/10.1016/j.procir.2015.02.202.
[37] McKerlie, K., Knight, N., & Thorpe, B., (2006). Advancing extended producer responsibility in Canada. Journal of Cleaner Production, 14, 616–628. https://doi.org/10.1016/j.jclepro.2005.08.001.
[38] Md. Bakri I, Shaik Md., Noor Alam S. M. H. & Abdul Rahman A. A., (2004), Legal regime of waste/industrial waste management in Malaysia as compared to U.K. and U.S.A. Unpad Journal of International Law, 3(2), 145-157.
[39] Munoz, 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, 64–72. https://doi.org/10.1007/s11367-008-0044-6.
[40] Nakamura, S., & Kondo, Y., (2006). A waste input-output life cycle cost analysis of the recycling of end-of-life electrical home appliances. Ecological Economics, 57, 494–506. https://doi.org/10.1016/j.ecolecon.2005.05.002.
[41] Nnorom, I.C., & Osibanjo, O., (2008). Overview of electronic waste (e-waste) management practices and legislations, and their poor applications in the developing countries. Resources, Conservation and Recycling, 52, 843–858. https://doi.org/10.1016/j.resconrec.2008.01.004.
[42] Norazli O, Roslina M, Ezlin ABN, & Noor MYM (2015).Technology A, Teknologi U. Developing an Integrated Electronic Waste Management Approach in Malaysia.1(1):5-13.
[43] OECD, (2001). Extended Producer Responsibility: A Guidance Manual for Governments. OECD, Paris, France. https://doi.org/10.1787/eco_surveys-fra-2001-en.
[44] Park, P.J., Tahara, K., Jeong, I.T., & Lee, K.M., (2006). Comparison of four methods for integrating environmental and economic aspects in the end-of-life stage of a washing machine. Resources, Conservation and Recycling, 48, 71–85. https://doi.org/10.1016/j.resconrec.2006.01.001.
[45] Pérez-Belis, V., Bovea, M. D., & Ibáñez-Forés, V. (2015). An in-depth literature review of the waste electrical and electronic equipment context: Trends and evolution. Waste Management & Research, 33(1), 3-29. https://doi.org/10.1177/0734242X14557382.
[46] Perunding Good Earth (PGE) (2009). The e-waste inventory project in Malaysia," Department of Environment, Malaysia & EX- Corporation, Japan, 2009.
[47] Pollock, D., & Coulon, R., (1996). Life cycle assessment of an inkjet print cartridge. In: Proceedings of the 1996 IEEE International Symposium on Electronics and the Environment, pp. 154–160. https://doi.org/10.1109/ISEE.1996.501870.
[48] Priya M., (2010), Sisa elektronik, standard dan pengguna. Laman Berita Pengguna. Available at http//www.konsumerkini.net.my/v1/index.php/berita-terkini/alam-sekit ar/177-sisa-elektronik-standard-dan-pengguna.
[49] Puckett J, Byster L, &Westervelt S (2002). Exporting harm: the high-tech trashing of Asia, the basel action network (BAN) and silicon valley toxics coalition (SVTC). SVTC report; 2002 <http://www.ban.org/E-waste/technotrashfinalcomp.pdf>.
[50] Queiruga, D., Walther, G., González-Benito, J., & Spengler, T., (2008). Evaluation of sites for the location of WEEE recycling plants in Spain. Waste Management, 28, 181–190. https://doi.org/10.1016/j.wasman.2006.11.001.
[51] Ramachandran S. & Renganayar C. D., (2011), returning old and used for disposal, New Sunday Times, April 11, 2011, p 10.
[52] Robinson, B.H., (2009). E-waste: an assessment of global production and environmental impacts. Science of the Total Environment, 408, 183–191. https://doi.org/10.1016/j.scitotenv.2009.09.044.
[53] Rochman, F. F., Ashton, W. S., & Wiharjo, M. G. (2017). E-waste, money and power: Mapping electronic waste flows in Yogyakarta, Indonesia. Environmental Development. https://doi.org/10.1016/j.envdev.2017.02.002.
[54] Rousis, K., Moustakas, K., Malamis, S., Papadopoulos, A., & Loizidou, M., (2008). Multicriteria analysis for the determination of the best WEEE management scenario in Cyprus. Waste Management, 28, 1941–1954. https://doi.org/10.1016/j.wasman.2007.12.001.
[55] Satake, K., & Oishi, S., (1998). LCA for electronic products. A case study for CD-ROM drives. In: Proceedings of IEEE International Symposium on Electronics and the Environment, pp. 176–179. https://doi.org/10.1109/ISEE.1998.675053.
[56] Shinkuma, T., & Nguyen Thi Minh, H., (2009). The flow of e-waste material in the Asian region and a reconsideration of international trade policies on e-waste. Environmental Impact Assessment Review, 29, 25–31. https://doi.org/10.1016/j.eiar.2008.04.004.
[57] Sthiannopkao, S., & Wong, M. H. (2013). Handling e-waste in developed and developing countries: Initiatives, practices, and consequences. Science of the Total Environment, 463, 1147-1153. https://doi.org/10.1016/j.scitotenv.2012.06.088.
[58] Streicher-Porte, M., Marthaler, C., Böni, H., Schluep, M., Camacho, Á. & Hilty, L.M., (2009). One laptop per child, local refurbishment or overseas donations? Sustainability assessment of computer supply scenarios for schools in Colombia. Journal of Environmental Management, 90, 3498–3511. https://doi.org/10.1016/j.jenvman.2009.06.002.
[59] Suja, F., Abdul Rahman, R., Yusof, A., & Masdar, M. S. (2014). E-Waste management scenarios in Malaysia. Journal of Waste Management, 2014. https://doi.org/10.1155/2014/609169.
[60] Tojo, N., (2001). Extended Producer Responsibility Legislation for Electrical and Electronic Equipment- Approaches in Asia and Europe.
[61] Wang, F., Leung, A. O. W., Wu, S. C., Yang, M. S., & Wong, M. H. (2009). Chemical and ecotoxicological analyses of sediments and elutriates of contaminated rivers due to e-waste recycling activities using a diverse battery of bioassays. Environmental Pollution, 157(7), 2082-2090. https://doi.org/10.1016/j.envpol.2009.02.015.
[62] Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., & Böni, H. (2005). Global perspectives on e-waste. Environmental impact assessment review, 25(5), 436-458. https://doi.org/10.1016/j.eiar.2005.04.001.
[63] Wong, C.S.C., Duzgoren-Aydin, N.S., Aydin, A., Wong, M.H., (2007a). Evidence of excessive releases of metals from primitive e-waste processing in Guiyu, China. Environmental Pollution, 148, 62–72. https://doi.org/10.1016/j.envpol.2006.11.006.
[64] Yedla, S. (2016). Development of a methodology for electronic waste estimation: A material flow analysis-based SYE-Waste Model. Waste Management & Research, 34(1), 81-86. https://doi.org/10.1177/0734242X15610421.