



# E-Waste Management in Asia Pacific Region: Review of Issues, Challenges and Solutions

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## ABSTRACT

Proper management of used electrical and electronic equipment (EEE), known as e-waste, is causing a significant challenge for many countries around the world. United Nations estimate that the world generated 53 million metric tonnes (Mt) of e-waste in 2019, mostly from the Asian region. Poor handling of e-waste can cause severe environmental and human health issues due to the toxic compounds in e-waste. E-waste also contains valuable metals worth recovering. Environmentally sound management (ESM) of e-waste is either absent or limited in developing countries due to the informal recycling sector's dominance. Many countries are in the process of developing regulations based on extended producer responsibility (EPR) concepts. This paper aims to review the current status, issues, and challenges faced by Asia Pacific countries and suggest a way forward for the ESM of e-waste.

## INTRODUCTION

The waste from used electrical and electronic equipment (EEE), commonly known as electronic waste or e-waste, is growing at an alarming rate in many countries. The rapid advancement of high technology equipment has helped to drive the economy in many countries. However, the knowledge of detrimental impacts on the environment and human health due to poor management of e-waste has only come up in recent years. The availability and affordability of many EEE with newer features have motivated the consumers to retire EEE well before their end-of-life (EOL), requiring a significant amount of e-waste to be handled and processed safely. The average life span of many essential EEE, such as computers and mobile phones, has fallen dramatically, causing the early obsolescence of these items. The United Nations (UN) has estimated that the world generated around 53 million tonnes (Mt) of e-waste in 2019 with a projection to reach 74 Mt by the year 2030 (Forti et al. 2020). The UN has also predicted that e-waste generation will be doubled from current levels to 111 Mt by the year 2050, effectively increasing by 2 Mt every year (Parajuly et al. 2019).

The transboundary movement of e-waste from industrialised countries to emerging and developing economies has caused significant challenges in countries in the Asia Pacific region due to a lack of infrastructure and financial resources

to deal with the issue. To compound the problems, the domestic consumption of EEE has also risen significantly in the region, further adding to the e-waste quantities. Due to the limited availability of formal e-waste recycling sector in countries in the Asia Pacific region, e-waste is predominantly handled by the informal e-waste recycling sector that utilises rudimentary recycling methods to extract the valuable metals while disposing the toxic compounds into the open environment. Such practices have caused severe environmental and health impacts. The industrialised countries have successfully developed regulations to deal with the issue based mainly on the extended producer responsibility (EPR) concepts where the manufacturers are required to finance the e-waste recycling operations. The Asia Pacific countries have been the target by many industrialised countries to dispose of their e-waste stream due to weak regulatory frameworks in those countries and cheap labour for recycling e-waste. To mitigate the adverse impacts on the environment and human health due to the transboundary movement of e-waste and the significant increase in domestic EEE consumption, the Asia Pacific countries are now developing stringent regulations mainly based on EPR concepts.

This paper aims to review the current status, issues, and challenges faced by Asia Pacific countries and suggest a way forward for environmentally sound management (ESM) of e-waste.

Table 1: Classification of e-waste.

Category	Items
Temperature equipment	Refrigerators, air conditioners, freezers
Monitors and Screens	Televisions, laptops, notebooks, monitors, tablets
Lamps	Light bulbs, fluorescent bulbs,
Large items	Washing machines, dryers, dishwashing machines, PV panels, photocopiers, electric stoves
Small items	Microwaves, vacuum cleaners, electric kettles, video cameras, calculators, toys, electrical tools, small medical devices, toasters, shavers, hairdryers, scales, many small EEE used in the kitchen
Small high tech items	Mobile phones, personal computers, printers, telephones, routers

Source: Forti et al. (2020)

## GLOBAL GENERATION OF E-WASTE

The United Nations (UN) defines EEE a wide range of products with electronic circuits or electrical components that requires power supply from electric power supply or batteries. EEE comprises several household and business items and equipment used in services such as health, transport, and security systems. With the invention of the Internet of Things (IoT), EEE is widely used in developing smart cities. Table 1 summarises some of the EEE used in our society once discarded become part of the e-waste stream.

The generation of reliable data to determine the e-waste generation has been a challenge as many countries have not developed proper inventories. Most of the estimates are based on either sales data or predictions based on the estimated life span of EEE. The problem is compounded by many consumers deciding to store their used EEE hence not reaching the collection and recycling channels. The most reliable and recent statistics related to global e-waste generation can be found in 'The Global E-waste Monitor 2020' published by the United Nations University (Forti et al. 2020). Tables 2 and 3 summarise the regional and selected country data on e-waste generation in the year 2019.

According to Table 2, the Asia Pacific region (Asia and Oceania combined) generated nearly half the global e-waste quantities in 2019. Among the Asian nations, China (10.1Mt), India (3.2Mt), Japan (2.5 Mt), and Indonesia (1.6 Mt) are the highest e-waste generators in the region (Forti et al. 2020).

Table 2: E-waste generation in regions.

Region	Annual e-waste generation (Mt)	% of world e-waste generation	E-waste (kg/person)
Asia	24.9	46.5	5.6
Americas	13.1	24.4	13.3
Europe	12	22.4	16.2
Africa	2.9	5.4	2.5
Oceania	0.7	1.3	16.1

Source: Forti et al. (2020)

Table 3: E-waste generation in selected countries.

Country	E-waste (tonnes/year)	E-waste (kg/person)
Argentina	465,000	10.3
Australia	554,000	21.7
Austria	168,000	18.8
Bangladesh	199,000	1.2
Belgium	234,000	20.4
Brazil	2,143,000	10.2
Cambodia	19,000	1.1
Canada	757,000	20.2
China	10,129,000	7.2
Columbia	318,000	6.3
Hong Kong	153,000	20.2
France	1,362,000	21.0
Germany	1,607,000	19.4
India	3,230,000	2.4
Indonesia	1,618,000	6.1
Italy	1,063,000	17.5
Japan	2,569,000	20.4
Malaysia	364,000	11.1
Nigeria	461,000	2.3
Pakistan	433,000	2.1
Philippines	425,000	3.9
Republic of Korea	818,000	15.8
Russian Federation	1,631,000	11.3
Saudi Arabia	595,000	17.6
Singapore	113,000	19.9
Sri Lanka	138,000	6.3
Thailand	621,000	9.2
United Kingdom	1,598,000	23.9
United States of America	6,918,000	21.0
Vietnam	257,000	2.7

Source: Forti et al. (2020)

## PROBLEMS AND OPPORTUNITIES ASSOCIATED WITH E-WASTE

### Description of Problems

The problems associated with poor e-waste management are readily described in the scientific literature. In general, EEE contains a significant number of materials, a mixture of highly toxic compounds and valuable substances. The production of semiconductors and printed circuit boards are associated with several heavy metals such as antimony, silver, chromium, zinc, lead, tin, and copper. Although the regulations in certain countries have prohibited the use of toxic metals such as lead, mercury, cadmium, hexavalent chromium, current e-waste streams contain these metals due to previously used EEEs. In addition to the heavy metals, EEE also contains chemical compounds such as polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs), which are also known as brominated flame retardants (BFRs).

Due to the complex nature of compounds, proper recycling and resource recovery of e-waste require advanced technologies and skilled operations, which can be costly in industrialised countries due to stringent environmental regulations. For this reason, there is a tendency for industrialised countries to move their e-waste to emerging and developing nations where weak regulatory structures and cheap labour are common. Unfortunately, many recycling and resource recovery facilities in these countries operate in an environmentally unsound manner using rudimentary technologies. It is common to observe e-waste being disposed of in open-land and waterways. The informal sector that dominates e-waste recycling in emerging and developing economies extracts the valuable metals and eliminates toxic residues into an open environment causing significant impacts on human health. The open burning of e-waste to recover precious metals has caused significant environmental pollution and the generation of persistent organic pollutants (POPs).

### Description of Opportunities

E-waste is widely considered as a problem due to the adverse environmental and health impacts that occur due to rudimentary methods adopted during the recycling process. However, if adequately recycled using safe and advanced formal technologies, e-waste also presents an opportunity to extract valuable and precious metals. The extraction of metals contained in e-waste, known as above-ground mining, requires only a fraction of energy compared to mining them from natural ores.

E-waste contains up to 69 elements in the periodic table. These include precious metals such as gold, silver, copper,

platinum, palladium, and critical raw materials such as cobalt, indium, and germanium bismuth, and antimony which are considered to be diminishing from natural ores. The UN estimates that the value of selected raw materials in e-waste amounts to USD 57 billion during 2019. Iron (24 billion USD), copper (11 billion USD), gold (9 billion USD), Aluminium (6 billion USD) are considered to be the highest value materials contained in e-waste (Forti et al. 2020).

### INTERNATIONAL POLICIES, REGULATIONS, AND INITIATIVES RELATED TO E-WASTE

To overcome the adverse impacts on the environment and human health, many countries in the world have developed or in the process of developing regulations and policies related to e-waste management. Initially pioneered by the European Union (EU), the concept of EPR has become the central theme of many of these regulations. EPR is regarded as a policy approach where the producer's responsibility is extended beyond the sales stage. Such responsibility shifts the physical and financial responsibility of managing e-waste from governments or local authorities to the producers. EPR also incentivises producers to take environmental considerations during design and manufacturing phases (design for the environment) to reduce environmental impacts during the whole life cycle of a product from raw material extraction to the final disposal. The product take-back scheme is one of the most common EPR applications where producers are required to organise facilities for consumers to deposit their used EEE (free of charge) at designated outlets and finance the cost of safe recycling. Such schemes are generally administered by government-appointed producer responsibility organisations (PROs) who act on behalf of the Government to achieve the set recycling targets. This section of the paper will describe the regulations developed by major e-waste generating countries.

#### E-Waste Regulations in the European Union

The EU has developed the following Directives to manage used EEE in the region:

- Waste Electrical and Electronic Equipment (WEEE) Directive
- Restriction of Hazardous Substances (RoHS) Directive

The WEEE Directive aims to minimise the adverse effects of used EEE by enhancing the reuse and recycling rates and reducing the waste from reaching landfills. To achieve the objectives, the WEEE Directive requires producers to take full financial and physical responsibility of their products by financing the collection, treatment, and recovery of e-waste without any cost to the consumers. The original

Directive 2002/96/EC was passed in European Parliament in February 2003 and came into force in August 2005 (European Commission 2003b). The Directive required the producers to set up collection outlets for consumers to return their used EEE free of charge and achieve a rate of 4kg of e-waste per person/year from December 2006. The Directive was revised in 2008 with the new Directive 2012/19/EU entering into force in August 2012 and valid from February 2014 (European Commission 2012). The new Directive moved away from the fixed weight requirement to a collection target of 45% of the average weight of EEE sold in the market from 2016, increasing to 65% from 2019. The WEEE Directive has been instrumental in reducing a significant amount of e-waste moving from the EU to developing countries. Further, many other countries in the world have taken the lead from the Directive to establish their regulations.

The RoHS Directive aims to restrict the use of certain hazardous substances during the manufacture of EEE. The RoHS 1, which came into effect in July 2006, required EEE manufacturers to avoid six hazardous substances: lead, mercury, hexavalent chromium, cadmium, PBDEs, and PBBs (European Commission 2003a). The RoHS 1 was recast in 2011 to accommodate the challenges of growing volumes of e-waste in the EU. The revised Directive 2011/65/EU on the restriction of the use of certain hazardous substances in EEE referred to as RoHS 2, came into force in January 2013 (European Commission 2011). The revised Directive did not add more substances but recommended to remove hexabromocyclododecane (HBCDD), bis (2- ethylhexyl phthalate (DEHP), butyl benzyl phthalate (BBP), and dibutyl phthalate (DBP) from EEE. The Directive is recast regularly to accommodate new scientific knowledge about the toxicity of materials used in EEE manufacture. As with the WEEE Directive, many countries around the world have taken the lead from EU Directive to develop their own RoHS regulations.

### E-Waste Regulations in Japan

Japan is the 3<sup>rd</sup> highest generator of e-waste in the world, producing 2.5 Mt in 2019 and 10% of e-waste generated in the Asian region. Japan has a long history of waste reuse and recycling due to the shortage of natural resources. The first Japanese law on recycling (Law for Promotion of Utilisation of Recyclable Resources) or LPUR came into force in 1991 to promote recycling and design for resource recovery. This law was amended in 2000 to accommodate waste prevention, eco-design, and design for recycling (Law for Promotion of Effective Utilisation of Resources). Japan's regulations related to e-waste are:

- Law for Recycling of Specific Kinds of Home Appliances, commonly known as the 'Home Appliance Recycling Law.'

- Law for Recycling of Small Electronic Appliances, commonly known as 'Small WEEE Law.'

The 'Home Appliance Recycling Law' came in to effect April 2001, covering air conditioners, refrigerators/freezers, televisions, and washing machines/clothes dryers. Consumers cover the cost of recycling. The consumers pay a collection fee when they drop off their used product to finance the collection, transport, and recycling costs. The retailers are responsible for collecting used home appliances, and the manufacturers are responsible for the recycling of them. The consumers are required to return their above-used appliances to retailers or municipalities and pay the required fees.

The 'Small WEEE Law' came into force in 2013 to cover all household appliances such as personal computers, cameras, video game consoles, and mobile phones that are not covered by the 'Home Appliances Recycling Law.' Funded by the Government, the law requires consumers to deliver the used small appliances to the retailer of the designated collector. Manufacturers are required to reduce the recycling costs by improving design and using recyclable materials in their production.

### E-Waste Regulations in China

China is the largest producer of EEE in the world. In 2019, China produced 10.1 Mt of e-waste to become the top e-waste generator in the Asian region. During this period, China produced 40% of the total e-waste generated in the Asian region (Forti et al. 2020). Given the significant quantities of e-waste to deal with, China has developed quite several environmental laws and regulations. The key regulations related to e-waste are:

- Law on the Promotion of Cleaner Production (2002) promotes the concepts of waste prevention during the design and production of EEE and their treatment at the end of life
- Law on the Promotion of Circular Economy (2008) specifies concepts of 3R (Reduce, Reuse, Recycle) during the production, consumption, and other stages of the life span of EEE
- Law on the Prevention of Environmental Pollution from Solid Waste (2004) requires e-waste treatment plants to safely obtain permits from local environmental protection agencies to handle hazardous components of e-waste.

China has also developed several Administrative Measures to deal with the e-waste problem. The 'Administrative measures on the prevention and control of environmental pollution by WEEE' (2007) deals with the prevention and control of environmental impacts resulting from the disas-



sembly, recycling, and disposal of e-waste. The 'Administrative measures on the qualification of WEEE treatment' (2010) requires the licencing procedure and qualification of e-waste treatment facilities, including supervision activities. The 'Administrative measures on the distribution of used electrical and electronic products' (2013) deals with the procedures related to the purchase or sale of used EEE.

China also passed the following two laws to strengthen e-waste management further:

- Ordinance on Management of Prevention and Control of Pollution from Electronic and Information Products (2006) - referred to as China's RoHS Directive.
- Administrative Regulation for the Collection and Treatment of Waste Electronic and Electrical Equipment (2009) – referred to as China's WEEE Directive, came into force in 2011 with emphasise on EPR, centralised disassembly of e-waste, and qualification of recycling plants.

### **E-Waste Regulations in India**

India is the 2nd highest generator of e-waste in the Asian region producing 3.2 Mt of e-waste during 2019 (Forti et al. 2020). The informal sector dominates India's e-waste recycling industry. India's Central Pollution Control Board (CPCB) published the 'Guidelines for Environmentally Sound Management of E-waste in India' in 2005. The guidelines provided directions for the identification of various sources of e-waste with recommended procedures for handling e-waste. India's Ministry of Environment and Forest (MoEF) enacted the 'E-waste (Management and Handling) Rule of 2011, ' which came into force in May 2012. The Rule requires manufacturers to take responsibility for collecting and financing the e-waste management system through the EPR concept. In 2016, the Government of India developed the new 'E-waste (Management) Rules, 2016' (the EWM Rules, 2016), which superseded the 2011 rule and came into effect from October 2016. The revised Rule improved the EPR concept. In 2018, the Ministry of Environment, Forest and Climate Change (MoEF&CC) amended the 2016 Rules introducing e-waste collection targets to be met according to a graduating scale from 10% in 2018 to 70% in 2023. The amended Rule 'E-waste (Management) Amendment Rules, 2018' has the provision of registering a PRO for managing the EPR system.

### **SPECIFIC CHALLENGES, ISSUES, AND OPPORTUNITIES RELATED TO E-WASTE MANAGEMENT IN ASIAN COUNTRIES**

#### **Issues and Challenges for Environmentally Sound Management (ESM) of E-Waste**

The issues and challenges of ESM of e-waste in the Asia Pacific region have compounded due to the transboundary movement of e-waste from industrialised countries to the region. A large amount of used EEE is currently being exported to Asian countries, particularly India, China, Indonesia, Cambodia, Vietnam, Sri Lanka, Pakistan, Philippines, and Bangladesh, for reuse. With the recent China ban on the waste import, most e-waste is now ending up in neighbouring countries like Thailand and Vietnam. However, most of these used EEEs are in the final stages of their life span and end up as e-waste in Asian countries quickly. There are also reports that e-waste is illegally transported to Asian countries in containers that contain used EEE. According to the Basel Convention, used EEE can be exported for reuse, whereas toxic compounds contained in e-waste are not allowed.

The e-waste recycling sector in Asian countries is dominated by the informal sector, which works in smaller groups employing mainly women and children with minimum safeguards to their health and safety of handling e-waste. The informal sector workers have limited knowledge about the health impacts of poor handling of toxic components in e-waste. Using basic recycling processes, the informal sector concentrates on extracting valuable metals components in e-waste while disposing of the poisonous residues to open the environment and waterways. Examples of environmental and health impacts of poor e-waste management in Asian countries are discussed in the next section.

The existence of the informal e-waste recycling sector also present challenges to the formal e-waste recycling sector whose operations have minimum environmental and health impacts. The formal e-waste recycling operations require investment in advanced technologies to ensure efficient recovery of valuable metals while any toxic residues are treated and managed correctly. Unfortunately, in Asian countries, used EEE is collected by the informal sector by providing financial incentives to the customers, thereby denying the necessary inputs for the formal sector to operate.

As observed in a later section of the paper, many Asian countries have a weak regulatory framework to deal with the e-waste issue. Many Asian countries have developed regulations to deal with hazardous waste streams but lack specific regulations on e-waste. Also, many Asian countries have no official inventory of e-waste generation. Besides, financing the infrastructure required for proper collection, storage, transportation, and processing of e-waste, educating the public on the toxicity of e-waste components, and implementing mandatory or useful product take schemes through EPR are additional challenges facing Asian countries to manage e-waste properly.

## Environmental and Health Impacts of E-Waste Management in Asian Countries

The recent past has seen an increasing number of research publications related to human health and environmental impacts due to poor e-waste processing in developing countries. These studies, mainly conducted in countries like China, India, and Ghana, where the informal e-waste sector is thriving, have studied the adverse impacts on soils and sediments, impacts on human health, and impacts on general biota.

Huo et al. (2020) conducted a study to investigate the relationship between chronic exposure of Pb and oral anti-inflammatory potential of preschool children living near an informal e-waste recycling site in China. They found a strong correlation between excessive Pb exposure and lower oral anti-inflammatory ability of oral sialic acids. Liu et al. (2018) evaluated the association of e-waste exposure in children with paediatric hearing ability. The study concluded that early childhood exposure to Pb maybe is a risk factor for hearing loss in children living near e-waste sites. The adverse impacts of poor e-waste recycling are not only limited to direct human health. They extend to indirect health impacts as a result of consuming food grown inland contaminated with e-waste recycling. Wu et al. (2019) found a serious health risk associated with paddy cultivation near informal e-waste recycling sites. Tables 4: Summaries some studies undertaken to measure the impact of e-waste recycling in soils, sediments, and human health.

## CURRENT PRACTICES IN ASIA PACIFIC REGION ON E-WASTE MANAGEMENT

### Australia

The Australian Government introduced the National Tele-

vision and Computer Recycling Scheme (NTCRS) in 2011 under the Product Stewardship Act 2011 to provide households and small businesses free access to an industry-funded e-waste recycling scheme to dispose of their used televisions, computers, and printers. The 'Product Stewardship Act 2011' provides the regulatory framework for NTCRS under the 'Product Stewardship (Televisions and Computers) Regulations 2011'. Under NTCRS, companies who import or manufacture computer and television products over a certain threshold are required to pay a fee based on the proportion of recycling by becoming a member of the co-regulatory arrangement (PRO). The television and computer industries are needed to fund the collection and recycling of the proportion of televisions and computers disposed of in Australia each year to achieve an 80% recycling rate in 2026-27. Currently, the Australian Government approved the following PROs:

- Australian & New Zealand Recycling Platform Ltd (TechCollect)
- Electronics Product Stewardship Australasia
- E-Cycle Solutions Pty Ltd
- MRI PSO Pty Ltd (Drop Zone)

The approved PROs are required to provide annual reports to ensure the annual government targets are met. PROs are also needed to engage recycling services providers certified to AS5377: The Australian Standard for collection, storage, transport, and treatment of end-of-life electrical and electronic equipment (<https://www.environment.gov.au/protection/waste-resource-recovery/television-and-computer-recycling-scheme>)

The co-regulatory arrangement appointed by the Government is responsible for the day-to-day operations of the scheme by organising the collection and recycling of e-waste on behalf of their members. The households and small businesses can dispose of their used televisions and

Table 4: Impacts on soils, sediments and human health near e-waste recycling sites in Asia.

Study details	Reference
Effects of PBDEs and heavy metals generated from e-waste recycling on microbial species in soil	Wu et al. 2019
Investigation of heavy metal contamination in soils from an abandoned e-waste recycling site in Moradabad, India	Singh et al. 2018a
Genotoxicity of e-waste and heavy metal exposure from e-waste recycling site in Manila, Philippines	Alam et al. 2019
Assessment of decrease in serum cortisol levels and an increase in sensory integration difficulties among preschool children living near e-waste recycling site	Cai et al. 2019
Blood Pb and Cd levels in hospitalised patients living close to an e-waste recycling site in Guiyu, China	Chen et al. 2019
High exposure to PAHs generated from informal e-waste recycling sites in China on pregnant women.	Huo et al. 2019
Cancer risk of e-waste dismantling workers in Thailand due to airborne exposure of Cd, Cu, Ni, and Pb from e-waste operations	Puangprasert 2019
Health risk assessment of households in a Vietnamese village due to exposure of heavy metals from e-waste processing	Oguri et al. 2018
Health risks associated with heavy metals generated in e-waste recycling sites in Punjab, India	Singh et al. 2018b
Contamination of PBDEs in sediments and plant issues adjacent to an e-waste recycling site in China	Zhou et al. 2019

computers at designated collection points. Under the Product Stewardship (Televisions and Computers) Regulations 2011, the PROs are required to provide independently verified annual reports to the department outlining the achievements in the given period. The department has the authority to cancel the co-regulatory arrangement if the PRO is found to be unsatisfactory. Currently, Ecycle Solutions (Ecycle), Australian and New Zealand Recycling Platform (ANZRP), Electronics Product Stewardship Australasia (EPSA), and MRI PSO (MRI) manage the day-to-day operation of the scheme.

### **Bangladesh**

As with many developing countries, there are several estimates related to e-waste generation in Bangladesh. According to Masud et al. 2019, Bangladesh generates around 2.81 Mt of e-waste annually, with most of it ending up in an open environment. The shipbreaking is a major industry in Bangladesh. According to Islam (2016), e-waste generated ship breaking yards alone is around 2.5 Mt annually. More recent studies on e-waste conducted by Mahmud et al. (2020) found e-waste generation to be approximately 400,000 metric tonnes annually, which more in agreement with Forti et al. (2020) estimate of 199,000 metric tonnes annually. As observed above, data on e-waste generation varies significantly, justifying the need for a formal national inventory of e-waste generation. This is vital as Bangladesh aims to achieve a fully digital country status by 2021. Hence, it will develop many IT-related projects, which will ultimately generate a significant amount of e-waste.

Bangladesh currently has no specific regulations or guidelines directly related to managing e-waste. The Bangladesh Environment Conservation Act of 1995, the Environmental Court Act of 2000, and The Environmental Conservation Rules of 1997 provide a necessary framework for developing the e-waste regulation. Recently, the Bangladesh Department of Environment (DoE) has announced the draft e-waste management rules referred to as 'Hazardous Waste (E-Waste) Management Rules, 2019'. The Rule restricts the use of as many as 15 substances or group of substances in certain EEE. The products under Rule include household appliances, monitoring, and control equipment, medical equipment, automatic machines, and IT & telecommunication equipment. The manufacturers are required to register with the DoE and present a detailed plan as to how they intend to treat the EOL EEE. Also, they must provide a list of hazardous substances contained in the product.

### **Cambodia**

Cambodia currently has no specific regulations related

to e-waste management, although some regulations exist on activities related to impacts on human health and the environment. The existing laws lack the strength to enforce e-waste activities. The informal e-waste recycling sector is highly active in the country resulting in significant environmental and health impacts. There is no formal inventory of e-waste generation in Cambodia. The Ministry of Environment, Cambodia, in collaboration with the Ministry of Environment, Korea has recently developed the 'Guideline on Environmental Sound Management of Waste Electrical and Electronic Equipment (Xavier et al. 2020).

### **Malaysia**

The data related to e-waste generation in Malaysia vary significantly. According to Azad et al. (2017), e-waste generation in Malaysia in 2006 was estimated to be 652,909 tonnes, increasing to 706,000 tonnes by 2010 and finally reaching 1.2 Mt in 2020. More recent estimates by Yong et al. (2019) have stated that Malaysia will generate 1.1 Mt of e-waste with an annual increase of 14%. Forti et al. 2020 have estimated the e-waste generation to be 364,000 tonnes in 2019.

E-waste management in Malaysia is governed by the Department of Environment (DOE) within the Ministry of Natural Resources and the Environment. Currently, there are no specific rules or regulations directly related to e-waste management. The Environmental Quality (Scheduled Waste) Regulations 2005 and the Environmental Quality (Prescribed Premises) (Treatment, Disposal Facilities for Scheduled Waste) Regulations, 1989 (control on the collection, treatment, recycling, and disposal of scheduled waste including e-waste). The 'Guidelines for Classification of Used Electrical and Electronic Equipment in Malaysia' was issued by DOE in January 2008 (Azad et al. 2017)

### **Pakistan**

Pakistan lacks reliable data on e-waste generation and research studies related to environmental and health impacts due to improper e-waste management. A survey conducted by Iqbal et al. (2015) has estimated e-waste generation to be 315,000 tonnes in 2015. A more recent study by Shaikh et al. (2020) estimates Pakistan's e-waste generation during 2018-2019 to be 1.79 Mt. The informal e-waste recycling sector is very active in Pakistan with open burning of e-waste becoming an everyday activity.

Currently, there are no laws or regulations to deal with the e-waste problem. The Pakistan Environmental Protection Act (1997), the National Waste Policy (2005), and Import Policy Order (2016) have provisions to prohibit e-waste imports to Pakistan. However, several used EEE is still being imported as second-hand EEE.

## Philippines

The high growth of domestic consumption of EEE has created a significant e-waste issue in the Philippines. In the absence of formal recycling facilities, most of the e-waste is handled by the informal sector, which consists of more than 2300 registered and unregistered junkshops with the Metropolitan Manila Development Authority. There are several waste pickers, women, and children engaged in e-waste recycling (Alam et al. 2019). There is no formal inventory of e-waste generation in the Philippines. The Department of Environment and Natural Resources has published the 'Guidelines on the Environmentally Sound Management (ESM) of Waste Electrical and Electronic Equipment (WEEE) 'under the Republic Act (RA) 6969.

## Vietnam

Vietnam lacks an official inventory of e-waste generated in the country. However, few studies have managed to estimate the e-waste generation using sales information and modelling. Hai et al. (2017) report on estimates by 2020, Vietnam will generate 10.6 million Units of e-waste which will include 4.85 million TV's, 2.27 million refrigerators, 2.6 million washing machines as 873 thousand air conditioners, Another estimate reports that by 2020 Vietnam will generate 12.1 million Units of e-waste by 2020 which will include 6.5 million TVs, 3.4 million refrigerators, 1.9 million washing machines, 284 thousand air conditioners.

In August 2013, the Prime Minister of Vietnam signed the Decision No. 50/2013/QD-TTg, which requires the enterprises manufacturing or importing electrical and electronic products to be responsible for the collection, transport, and processing of e-waste. This decision has now been replaced by the Prime Minister's Decision No. 16/2015/QD-TTg that came into effect from 1 July 2016. Currently, the Vietnamese Government is revising the e-waste regulations to improve the efficiency of EPR implementation.

## CONCLUSIONS

E-waste generation in the world is currently much higher than most other waste streams. Although Asia Pacific countries have developed several initiatives to achieve ESM of e-waste, success and effectiveness are challenged by many issues. Identifying the key stakeholders and promoting cooperation among them is the key to tackling these issues. Asia Pacific countries are experiencing significant challenges due to a lack of policies, infrastructure, and financial resources. Although e-waste is a problem due to its hazardous components, it is also a solution to the depletion of scarce materials that the manufacture of EEE depends on. If undertaken correctly, re-

cycling of e-waste can provide an excellent business opportunity by harvesting these resources. The e-waste recycling step consists of three stages: collection, sorting and dismantling, and end-processing. In Asia Pacific countries, these steps are all undertaken by the informal waste recycling sector that lacks skilled operations. The formal e-waste recycling sector is very limited in these countries. The informal sector could conduct the first two stages of the e-waste recycling without much environmental and health impacts. However, the last step, if undertaken by the informal sector, could result in severe environmental pollution.

The transfer of formal technology to Asia Pacific countries should be undertaken considering the social, environmental, and economic boundaries. Direct technology transfer without any consideration given to inter-linked non-technical aspects of waste management could lead to unsustainable systems. In particular, the transfer of technology to Asia Pacific countries needs to consider the informal sector's dominance and success. Innovative models that allow the informal sector to be involved in the process by adopting safe recycling practices while hazardous operations are transferred to formal recycling recyclers are the key to a successful e-waste management program. Such business models would require consideration given to improved collection and pre-processing of e-waste by the informal sector through training and technology transfer to ultimately benefit the operations of state-of-art e-waste processing facilities towards the end of recycling chain.

Many Asia Pacific countries favour EPR for developing regulations to deal with the e-waste. Most industrialised countries have had much success in implementing EPR successfully. The proper implementation of EPR requires several pre-conditions to be met, including the correct indemnification of the producer/importer and managing the producers' funds. Due to the informal sector operations, implementation of EPR in Asia Pacific countries has become very challenging. Hence, Asia Pacific countries should avoid directly adopting EPR procedures adopted in industrialised countries and develop their EPR schemes based upon their capacity to implement them.

As a way forward, Asia Pacific countries need to develop well defined national e-waste management strategy based upon circular economic concepts. Such an approach should not only look at solving the existing environmental and health impacts of e-waste but also reduce e-waste through design for environment practices. The strategy should also create enabling conditions for the private sector to develop business and economic opportunities to recover the materials from e-waste. The strategy should take into account the financial, institutional, political, and social aspects of the



country, focusing on how to synergise the informal e-waste recycling sector with the formal sector.

## REFERENCES

- Azad, A.K., Islam, MohdAminul and Hossin, M.M. 2017. Generation of electronic-waste and its impact on environment and public health in Malaysia. *Annals of Tropical Medicine and Public Health*, 10(5): 1123-1127.
- Alam, Z.F., Riego, A.J.V., Samson, J.H.R.P. and Valdez, S.A.V. 2019. The assessment of the genotoxicity of e-waste leachates from e-waste dumpsites in Metro Manila, Philippines. *International Journal of Environmental Science and Technology*, 16(2): 737-754.
- Cai, H., Xu, X., Zhang, Y., Cong, X., Lu, X. and Huo, X. 2019. Elevated lead levels from e-waste exposure are linked to sensory integration difficulties in preschool children. *Neuro Toxicology*, 71: 150-158
- Chen, Y., Xu, X., Zeng, Z., Lin, A., Qin, Q. and Huo, X. 2019. Blood lead and cadmium levels associated with hematological and hepatic functions in patients from an e-waste-polluted area. *Chemosphere*, 220: 531-538.
- European Commission 2017. Directive (EU) 2017/2102 of the European Parliament and of the Council of 15 November 2017 amending Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment. *Official Journal of the European Union*, 305: 8-10.
- European Commission 2011. Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. *Official Journal of the European Union*, 174: 88-110.
- European Commission 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*, 197: 38-71.
- European Commission 2005. Commission decision of 18 August 2005 amending Directive 2002/95/EC of the European Parliament and of the Council for the purpose of establishing the maximum concentration values for certain hazardous substances in electrical and electronic equipment. *Official Journal of the European Union*, 48: 65.
- European Union 2003a. Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. *Official Journal of the European Union*, 46: 9-23.
- European Commission 2003b. Directive 2002/96/EC of the European Parliament and the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE). *Official Journal of the European Union*, 46: 24-39.
- Forti, V., Balde, C.P., Kuehr, R. and Bel, G. 2020. The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential. United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam
- Hai, H.T., Hung, H.V. and Quang, N.D. 2017. An overview of electronic waste recycling in Vietnam. *Journal of Material Cycles and Waste Management*, 19(1): 536-544.
- Huo, X., Wu, Y., Xu, L., Zeng, X., Qin, Q. and Xu, X. 2019. Maternal urinary metabolites of PAHs and its association with adverse birth outcomes in an intensive e-waste recycling area. *Environmental Pollution*, 245: 453-461.
- Iqbal, M., Breivik, K., Syed, J.H., Malik, R.N., Li, J., Zhang, G. and Jones, K.C. 2015. Emerging issue of e-waste in Pakistan: A review of status, research needs and data gaps. *Environmental Pollution*, 207: 308-318.
- Islam, M. N. 2016. E-waste management of Bangladesh. *International Journal of Innovative Human Ecology and Nature Studies*, 4(2): 1-12.
- Liu, Y., Huo, X., Xu, L., Wei, X., Wu, W., Wu, X. and Xu, X. 2018. Hearing loss in children with e-waste lead and cadmium exposure. *Science of the Total Environment*, 624: 621-627.
- Mahmud, I., Sultana, S., Rahman, A., Ramayah, T. and Cheng Ling, T. 2020. E-waste recycling intention paradigm of small and medium electronics store managers in Bangladesh: An S-O-R perspective. *Waste Management and Research*, DOI: 10.1177/0734242X20914753.
- Masud, M.H., Akram, W., Ahmed, A., Ananno, A.A., Mourshed, M., Hasan, M. and Joardder, M.U.H. 2019. Towards the effective e-waste management in Bangladesh: a review. *Environmental Science and Pollution Research*, 26(2): 1250-1276.
- Oguri, T., Suzuki, G., Matsukami, H., Uchida, N., Tue, N.M., Tuyen, L.H., Viet, P.H., Takahashi, S., Tanabe, S. and Takigami, H. 2018. Exposure assessment of heavy metals in an e-waste processing area in northern Vietnam. *Science of the Total Environment*, 621: 1115-1123.
- Parajuly, K., Kuehr, R., Awasthi, A. K., Fitzpatrick, C., Lepawsky, J., Smith E., Widmer, R. and Zeng, X. 2019. Future E-waste Scenarios, StEP (Bonn), UNU VIE-SCYCLE (Bonn) & UNEP IETC (Osaka).
- Puangprasert, S. and Prueksasit, T. 2019. Health risk assessment of airborne Cd, Cu, Ni and Pb for electronic waste dismantling workers in Buriram Province, Thailand. *Journal of Environmental Management*, 252: 109601
- Shaikh, S., Thomas, K. and Zuhair, S. 2020. An exploratory study of e-waste creation and disposal: Upstream considerations. *Resources, Conservation and Recycling*, 155: 104662.
- Singh, A., Dwivedi, S.P. and Tripathi, A. 2018a. Study of the toxicity of metal contamination in soil samples collected from abandoned e-waste burning sites in Moradabad, India. *Nature Environment and Pollution Technology*, 17 (3): 973-979.
- Singh, M., Thind, P.S. and John, S. 2018b. Health risk assessment of the workers exposed to the heavy metals in e-waste recycling sites of Chandigarh and Ludhiana, Punjab, India. *Chemosphere*, 203: 426-433.
- Wu, Z., Gao, G. and Wang, Y. 2019. Effects of soil properties, heavy metals, and PBDEs on microbial community of e-waste contaminated soil. *Ecotoxicology and Environmental Safety*, 180: 705-714.
- Xavier, L.H., Giese, E.C., Ribeiro-Duthie, A.C. and Lins, F.A.F. 2019. Sustainability and the circular economy: A theoretical approach focused on e-waste urban mining. *Resources Policy*, 101467.
- Yong, Y.S., Lim, Y.A. and Ilankoon, I.M.S.K. 2019. An analysis of electronic waste management strategies and recycling operations in Malaysia: Challenges and future prospects. *Journal of Cleaner Production*, 224: 151-166.
- Zhou, H., Tam, N.F.Y., Cheung, S.G., Wei, P., Li, S. and Wu, Q. 2019. Contamination of polybrominated diphenyl ethers (PBDEs) in watershed sediments and plants adjacent to e-waste sites. *Journal of Hazardous Materials*, 379: 120788.