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Managing Australia's electronic waste (e-waste) problem through product stewardship and extended producer responsibility (EPR)

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Abstract Electronic and electrical waste or e-waste is the fastest-growing global waste stream with a current generation of around 53 million metric tonnes (Mt) and projected to reach 74 Mt by 2030. Not properly managed, e-waste can cause severe environmental and health impacts. The Australian government has implemented a product stewardship program using the extended producer responsibility (EPR) concept to manage televisions and computers through the National Television and Computer Recycling Scheme to reach an 80% recycling rate by 2027. The paper provides an overview of how the Australian government and industry deal with the e-waste problem.

Keywords e-waste; extended producer responsibility; product stewardship; recycling; Australia

Introduction

The rapid advances in information and technology sector have driven the economy of many countries around the world for a long time. However, knowledge of adverse effects on the environment and health due to poor management of many electrical and electronic equipment (EEE) used in this sector has only emerged in recent years. The availability of newer designs at low prices has prompted customers to discard many of this EEE well before their end-of-life (EOL), resulting in large quantities of waste, commonly known as electronic waste or e-waste. The average life span of many EEE has fallen dramatically in the recent past due to the products being manufactured with increased memory and processing power, and attractive features. In 2019, the global generation of e-waste exceeded 53 million metric tonnes (Mt) with a projection to reach 74 Mt by 2030 (Forti et al. 2020). E-waste is comprised of several toxic compounds that are difficult to manage without any advanced recycling options. Many countries, particularly emerging and developing economies, lack the infrastructure and financial resources to develop sustainable e-waste management systems. In these countries, e-waste is predominantly managed by the informal waste recycling sector who, most of the time, adopt rudimentary recycling methods to extract valuable metals from e-waste. The resulting discard of toxic compounds has resulted in severe environmental and health impacts in many of these countries. To improve the management of e-waste, the policymakers around the world have developed or in the process of developing suitable regulatory and policy frameworks utilising the concepts of product stewardship. The product stewardship tools enable the policymakers to make the manufacturer or the importer physically and financially responsible for managing their products at the EOL. Such a process known as the extended producer responsibility (EPR) shifts the burden of financing of proper EOL recycling from the government sector to the manufacturing industry.

This paper aims to provide an overview of the current e-waste management scenarios in Australia with a special focus on regulations and policies developed to implement product stewardship and EPR schemes. The paper will discuss the current government initiatives and EOL recycling operations conducted by the industry to manage e-waste in Australia safely.

Generation of e-waste in Australia

Global e-waste generation

E-waste comprises a range of products with circuits that are powered by electrical power or battery supply. Table 1 describes some examples of EEE.

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)

The global generation of e-waste has been steadily increasing in the past few years by passing the increased rate of municipal solid waste streams. According to the latest study from the United Nations University (Forti et al. 2020), the Asian region generated the highest amount of e-waste (24.9 Mt), followed by the Americas (13.1 Mt), Europe (12 Mt), Africa (2.9 Mt), and Oceania (0.7 Mt). The study also estimated that within the Asian region, China generated the largest amount of e-waste (10.1 Mt), followed by India (3.2 Mt), Japan (2.5 Mt), and Indonesia (1.6 Mt). Table 2 summaries the e-waste generated in selected countries around the world during 2019.

Table 2 E-waste in selected countries

Country	E-waste (tonnes/year)	E-waste (kg/person)
Algeria	309,000	7.1
Argentina	465,000	10.3
Australia	554,000	21.7
Belgium	234,000	20.4
Brazil	2,143,000	10.2
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
Nigeria	461,000	2.3
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
United Kingdom	1,598,000	23.9
United States of America	6,918,000	21.0

Source: Forti et al. (2020)

E-waste generation in Australia

Australia is the 6th largest country in the world by land area occupying an entire continent in the world map. Together with New Zealand, Polynesia, Micronesia, and Melanesia, Australia, form the Oceania region in the world. Australia, with a population of around 25 million, has one of the most urbanised populations globally, with over 80% of the people living within 100km of the coast. The Australian Federation consists of six States and two Territories; Queensland (QLD), New South Wales (NSW), Victoria (VIC), South Australia (SA), Tasmania (TAS), Western Australia (WA), Australian Capital Territory (AC), and Northern Territory (NT). The Australian population is heavily concentrated in the capital cities of the States. Given the large geographical area of the Australian continent, the distance between the capital cities is vast, making transport and logistics a significant challenge in any waste management system (Australian Bureau of Statistics, 2020).

Australia's Information and Communication Technology (ICT) sector, which includes industries and businesses such as computer hardware and software services, telecommunication, and internet providers is one of the largest ICT in the world. Within the ICT sector, the Australian computer industry occupies a large segment, which includes global companies such as Hewlett Packard, Acer, Dell, Toshiba, IBM, and Apple. There is no large computer manufacturing industry in Australia. Most of the computers are imported while there is also the existence of 'non-brand' computers where computers are assembled from imported generic parts.

Several studies and estimates are describing the generation and prediction of e-waste generation in Australia. According to Forti et al. (2020), Australia generated 554,000 tonnes of e-waste during 2019, with a per capita generation of 21.3 kg. The per capita generation of e-waste in Australia is also one of the highest in the world. Australian Bureau of Statistics (2019) estimates that during 2016-17, Australians generated 465,818 tonnes of e-waste, with 79.2% generated by the households. The Bureau also estimates that 54.4% of the e-waste was landfilled while the rest (45.6%) was collected for recycling.

The reliable estimate of e-waste generation in Australia is difficult to obtain. Many households tend to store the used EEE, thereby contributing what is known as the historical e-waste stream. To accommodate these challenges, several researchers have conducted modelling studies using export data and life span of EEE to estimate the e-waste generation correctly. Golev et al. (2016), using the e-waste modelling process recommended by United Nations University, found that e-waste generation in Australia rose by 43% from 410,000 tonnes in 2010 to 587,000 tonnes in 2014. The study estimated an increase in per capita generation from 18.6 kg to 25 kg during this period. Golev et al. (2017) attempted to quantify the metal values. They found that the potential metal recovery value from e-waste generated in Australia to be US$370 million, with the majority contributing from printed circuit boards. Further studies by Golev et al. (2019) on metal recovery rates found that the number of printed circuit boards recovered from Australian e-waste to be 10,000 tonnes per year, with an estimated value of US$78 million.

Islam and Huda (2019) conducted a modelling study to find that Australians generated 115,000 tonnes of e-waste during 2010, increasing to 485,000 tonnes during 2000. The study attempted to model the e-waste growth from 2000-2047 and found an annual growth rate of 3%. Islam and Huda (2020) noted that Australia currently regulates televisions, computers, IT peripheral products, and mobile phones only. Hence they argue that most of the estimates of e-waste generation are based upon these products alone. However, a large proportion of e-waste from other EEE also contributes to the e-waste stream. The study estimated Australia would generate 342,000 tonnes of e-waste from unregulated EEE during 2020 and growing to 461,000 tonnes by 2030 with an annual increase rate of 3.7%.

3.0 Problems associated with e-waste

The human health and environmental impacts of e-waste recycling are becoming well known among the researchers and the general public. The manufacture of EEE involves the complicated assembly of different materials, most of them highly toxic to the environment if not correctly managed. The manufacture of semiconductors, disk drives, and printed circuit boards utilises a number of chemicals. Although some of these toxic materials are banned in certain countries, e-waste generated from previously used EEE contains toxic metals such as lead, cadmium, chromium, copper, etc. The EEE also contains brominated flame retardants (BFRs) such as polybrominated biphenyls (PBBs)and polybrominated diphenyl ethers (PBDEs) which are known for negative environmental and health impacts. E-waste also contains valuable, non-toxic metals that are becoming scarce and hence the importance of recovering them for reuse. Given the complexity of toxic and valuable materials, it is vital that the recycling of e-waste is conducted using proper technologies to recover precious metals and safely dispose of the toxic compounds. Unfortunately, in many developing and emerging economies where informal e-waste recycling sector dominates, recycling occurs using rudimentary methods resulting in severe environmental and health impacts. Tables 3summarises selected studies conducted on the effects of e-waste recycling on human health and the environment.

Table 3 Selected studies on health and environmental impacts of informal e-waste recycling

Contaminants and study area	Reference
Assessing the health risks of PBDEs and metals among the workers at an informal e-waste recycling site in Nigeria	Ohajinwa et al. (2019)
Cancer risk levels from airborne cadmium, copper, nickel, and lead among e-waste dismantling workers in Thailand	Puangprasert and Prueksasit (2019)
Heavy metal exposure to children living in the vicinity of informal e-waste recycling activities in Indonesia	Soetrisno and Saborit (2020)
Exposure of e-waste dismantlers to PBDEs and flame retardants in Bangladesh	Wang et al. (2020)

Cytogenetic and DNA damage of adult men involved in informal e-waste recycling in China	Wang et al. (2018)
Assessment of liver metabolic burden and liver function of patients from an e-waste polluted area in China	Chen et al. (2019)
Risk associated with consumption of vegetables grown in regions with contaminated with heavy metals from informal e-waste recycling in China	Han et al. (2017)
Concentration of heavy metals in pregnant women and neonates living near informal e-waste recycling site in China	Kim et al. (2019)
Impact on hearing loss and developmental auditory system of children exposed to lead and cadmium from informal e-waste recycling in China	Liu et al. (2018)
Exposure assessment of heavy metals from e-waste recycling in households in a Vietnamese village	Oguri et al. (2018)

The studies on environmental and health impacts of poor e-waste recycling sites demonstrate the urgent need to address the transboundary movement of e-waste. It is well known that large amounts of used EEE are exported to developing countries to reuse, recycle, and recover precious metals. The nations like India, China, Philippines, Hong Kong, Indonesia, Sri Lanka, Pakistan, Bangladesh, Malaysia, Vietnam, and Nigeria are favoured nations by developed countries towards the export of e-waste for recycling due to their low labour costs and weak environmental regulations. However, the environment and health of these nations have suffered heavily due to the pollution caused by the informal recycling of e-waste. Hence, the developed nations must address this global issue by managing their e-waste within the country as much as possible and only exporting e-waste to countries with proper formal e-waste recycling facilities. The next section of the paper provides some description of the Australian government, and the industry is attempting to achieve this goal.

Drainage of e-wastes into streams and rivers

If the e-wastes enter the rivers and streams, it may enter the food chain, and though them to human being as food. Several toxic heavy metals thus go into human body.

Since e-waste does not reach rivers and streams in Australia, this is not an issue. However, in many developing economies this is totally true. Examples of research papers related to this can be found in other Sections.

4.0 Government and industry initiatives for managing e-waste

Many countries around the world have now developed regulations and policies to manage their e-waste streams. The European Union leads the world in this regard through the development of 'Waste Electrical and Electronic Equipment (WEEE) Directive' and 'Restriction of Hazardous Substances (RoHS) Directive.' The WEEE Directive is based on making the manufacturer responsible for financing e-waste recycling by implementing EPR concepts. The Australian Federal and State governments have worked together with the industry to develop similar regulations to deal with e-waste. Currently, there are four key policy/regulatory elements that govern the e-waste management in Australia:

- National Waste Policy 2019
- Product Stewardship Act 2011
- Product Stewardship (Televisions and Computers) Regulations 2011
- National Television and Computer Recycling Scheme 2011 (NTCRS)

4.1 National Waste Policy 2019

The Australian National Waste Policy presents a national framework for waste and resource recovery by outlining the roles and responsibilities of businesses, governments, communities, and individuals for collection action. The first policy was published in 2009 and updated in 2018 to accommodate the latest developments in the sector (e.g., circular economy). The policy is based on the following principles:

- Waste avoidance
- Enhance resource recovery
- Increase the use of recycled material and build demand and market for recycled products
- Better manage material flows to benefit human health, environment, and economy
- Support innovation and guide investment for resource recovery

(https://www.environment.gov.au/protection/waste-resource-recovery/publications/national-waste-policy-2018)

The National Action Plan, based on the above policy, has the following targets:

- Ban the export of waste plastic, paper, glass, and tyres, commencing in the second half of 2020
- Reduce the total waste generated in Australia by 10% per person by 2030
- Achieve 80% average recovery rate from all waste streams by 2030
- Significantly increase the use of recycled content by governments and industry.
- Phase out problematic and unnecessary plastics by 2025
- Halve the amount of organic waste sent to landfill by 2030

(https://www.environment.gov.au/protection/waste-resource-recovery/publications/national-waste-policy-action-plan)

4.2 Product Stewardship Act 2011

Product stewardship involves manufacturers, importers, governments, and consumers taking shared responsibility for managing the environmental impact of a product throughout its life cycle. It acknowledges that those involved in producing, selling, using, and disposing of products share the responsibility for managing those products to ensure minimal impacts on the environment and human health. Such responsibility can be implemented in several ways with varying government and industry level involvement.

The 'Product Stewardship Act 2011'provides a framework to effectively manage the environmental, health, and safety impacts of products, particularly those impacts associated with the disposal of used products. The Act allows products to be regulated or implement Australian government accredited product stewardship programs. The Act provides for products and materials to be covered as the need arises by publishing a list of products being considered for coverage by the legislation. The Minister for the Environment has listed batteries, child car seats, electrical and electronic products, plastic oil containers, plastic microbeads and products containing them, and photovoltaic systems as priority product classes to be considered for product stewardship approach in 2020-21.

The framework allows the following options for implementation:

- Voluntary product stewardship
- Co-regulatory product stewardship
- Mandatory product stewardship

Under the voluntary product stewardship option, the industries can take voluntary action to reduce the environmental, health and safety impacts of their products by forming product stewardship arrangements. The voluntary product stewardship schemes are industry-led and funded schemes without the need for government regulations although the government accreditation of the scheme can be sought. Australia's MobileMuster program (https://www.mobilemuster.com.au/) is an excellent example of a voluntary product stewardship program. The program has over 3500 outlets around Australia that includes post offices, schools, mobile retailer outlets, and local councils. The aim of theMobileMuster program is to keep mobile phone products away from the landfill and recycle them safely. The Australian government accredited the program in 2014 and administered by the Australian Mobile Telecommunication Association (AMTA) on behalf of the industry. The members that include a number of major mobile phone manufacturers and network carriers voluntarily fund the scheme to promote and recycle mobile phones, batteries, charges, etc. The program has many public drop off points around the country in addition to a free post back option.

The co-regulatory product stewardship schemes entail a combination of industrial action and government regulations, where the government sets the minimum targets to be achieved and operational requirements. The National Television and Computer Recycling Scheme (NTCRS) described in section 4.3 below is a well-established co-regulatory product stewardship scheme under the Product Stewardship Act 2011.

The mandatory product stewardship schemes require a legal obligation on parties to take action concerning a product. Such obligations could include labelling products, requiring deposit and refund to be applied to a product, or banning certain substances from use in products.

4.3 National Television and Computer Recycling Scheme 2011 (NTCRS)

The National Television and Computer Recycling Scheme (NTCRS) is one of the most effective EPR schemes implemented in Australia under the Product Stewardship Act 2011. The NTCRS came into effect in 2011 under the Product Stewardship (Televisions and Computers) Regulations 2011 to allow Australian households and small businesses access to an industry-funded collection and recycling scheme for televisions and computers. The television and computer industries are obliged to fund the collection and recycling of the proportion of televisions and computers disposed of in Australia each year with the aim of achieving an 80% recycling rate in 2026-27 (https://www.environment.gov.au/protection/waste-resource-recovery/television-and-computer-recycling-scheme).

The NTCRS is operated on behalf computer and television industry by government-approved co-regulatory arrangements (Producer Responsibility Organisations or PROs) that determine how to deliver the outcomes efficiently. 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 legally required to provide independently audited annual reports to the government to publish. The government has the power to remove any of the PROs should they fail to satisfy the obligations. The PROs are also required to only contract with recycling services providers that are certified to AS5377: the Australian Standard for collection, storage, transport, and treatment of end-of-life electrical and electronic equipment.

5.0 Current end-of-life management of e-waste in Australia

End-of-life (EOL) management of e-waste, including but not limited to used computers, printers, mobile phones, and other electronic devices can be achieved by using one of the methods below:

- Home or office storage

- Reuse by giving used electronic equipment to family and friends, selling via an online platform such as Gumtree or Marketplace (Facebook), donating to charitable organisations.
- Disposal to commercially used e-waste recyclers
- Disposal through e-waste take-back schemes (MobileMuster, NCTRS)
- Disposal through local council e-waste drop-off schemes.

Reuse involves the transfer of ownership of the used electronic equipment for continued use by someone else. An example of a non-profit organisation that encourages and delivers the reuse of computers in Australia is Computer Bank. The organisation refurbishes donated computers and provides to disadvantaged groups, including pensioners, disabled people, and children, etc. Recycling and recovering used electronic equipment involve disassembling computers into constituent parts to recover raw and valuable materials such as metals, plastics, and glass.

According to the MRI Product Stewardship Arrangement 2017-18 Annual Report, the material recovery rate was 95%. MRI has established a Drop Zone Collection Network, which provides free accessible collection network for households and small businesses, including a combination of 284 permanent and event-based collection sites across metropolitan, regional and remote areas within Australia. The scheme involves working closely with local councils and Officeworks through initiatives such as Bring I.T. Back and RecycleTV. During the period 2017-18, MRI's recyclers have processed a total of approximately 8,500 tonnes of televisions, computers, and computer-related products and ensured no stockpile outside of a recycling facility (MRI PSO, 2018). More details about MRI operations can be found in (https://mri.com.au/)

Electronic Product Stewardship Australasia (EPSA) is owned by Sims Recycling Solutions (SRS) and is an approved co-regulatory arrangement of the Product Stewardship (Televisions and Computers) Regulations 2011. EPSA’s Annual Report 2017-18 has shown that the initial recovery rate or waste diverted from landfill after initial processing is of 98.94%. The final recovery rate (after removing all downstream losses and waste to energy) is 93.19%. Many large electronic companies registered as a member of EPSA, for example, The Good Guys, Fujitsu, Sony Australia, Samsung Electronics, etc., to divert e-waste from landfills while maximising the material recovery from the collected commodities (Electronics Products Stewardship Australasia, 2018).

ANZRP, or TechCollect, provides a free recycling service to all Australians and small businesses under the NCTRS co-regulatory arrangement requirements. According to their 2017-18 Annual Report, TechCollect has a comprised of 148 permanent locations and eight one-off e-waste collection events across the country. This includes the major office equipment and stationary retailer, Officeworks. The majority of the permanent collection services operate in conjunction with local government authorities (LGAs) and waste management organisations. In 2017/18, ANZRP has recovered 23,522 tonnes from the recycling of end-of-life products (ANZRP, 2018). Complete details about the TechCollect program and its operations can be found in (https://techcollect.com.au/).

In addition, there are other e-waste management schemes that encourage recycling and reduce the amount of e-waste going to landfill, such as MobileMuster (mobile phone recycling), Cartridges 4 Planet Ark (printer cartridge recycling) and Australian Battery Recycling Initiative.

South Australia and the Australian Capital Territory have legislation in place for nearly a decade to ban and keep e-waste out of landfills. Victoria has followed and introduced a ban on electronic waste, including mobile phones, from landfills from 1 July 2019. MobileMuster is the product stewardship program for the mobile phone industry in Australia and is accredited by the federal government (MobileMuster 2018). The program accepts all brands and types of mobile phones and accessories, providing a collection network with 3,500 drop-off points across the country and a free post-back option.

6.0 Conclusions

E-waste is the fastest growing waste stream globally, growing at an alarming rate due to early obsolescence of EEE as a result of rapid advances in technology and affordable availability of newer designs and features, encouraging the customers to discard their EEE well before their end-of-life. The European Union pioneered the implementation of EPR as a tool for making the producer responsible for managing the e-waste problem. The Australian government has followed a similar path by successfully co-regulating the management of used televisions and computers. Through this scheme, the Australian government has managed to curb the export of e-waste to countries where proper processing facilities do not exist. One of the main limitations of the NCTRS is that the Australian public is mostly unaware of the Scheme and, therefore, does not actively participate in the

Scheme. It is recommended that a federally led education and awareness campaign on the Scheme and local council initiatives for their residents should be encouraged to increase the participation rate of consumers within this scheme. The e-waste recycling rate of Australia is considered low compared to other European countries, largely due to the lack of infrastructure and insufficient incentives to invest in reprocessing facilities. The challenge ahead for the Australian government would be how to deal with the used EEE, which are not currently regulated. There is an urgent need to add new EEE product categories to the legislation. End of life management of e-waste in Australia has significantly improved over the last few years. However, mandatory landfill ban on e-waste and more awareness-raising initiatives for the public can contribute to higher waste diversion and participation rate to reduce the amount of e-waste going to landfill.

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