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FACULTY OF ENGINEERING AND PHYSICAL SCIENCES

School of Engineering

Evaluating the urban mining potential of distinct anthropogenic spaces for the management of waste electrical and electronic equipment (WEEE)

by

Olanrewaju Sheriff Shittu

Thesis for the degree of PhD Engineering and the Environment

June 2021

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ABSTRACT

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Circular Economy (CE) has been championed as a concept that aims to address the current unsustainable linearity in resource consumption by circulating resources in the so-called ‘material loop’ for as long as possible. This concept is relevant to the production, consumption and end-of-life management of electrical and electronic equipment (EEE) which has seen a rapid increase in usage in recent years. End-of-life (EoL) management of EEE has often been discussed in the context of material recovery and recycling via means such as Urban Mining. This option is desirable as it is contributory towards attainment of circularity. However, this EoL option should ideally cater for EEE with no residual reuse value, a quality that depreciates over the period of a product’s usage life. For this reason, there is a need for the consideration of product reuse when and where possible ahead of product recycling. This study investigates the potential for this outcome by investigating EEE reuse within the context of urban mining. The study begins with a review of the current end-of-life management practices in different regions across the world together with associated and relevant regulatory and legislative provisions. The review presents the current situation in EEE management as well as contemporary issues on current and future management scenarios. The study then explores the potential for product reuse. This was carried out by an empirical investigation on Distinct Urban Mine (DUM) potential for EEE reuse as well as a demonstration of the recovery of EEE with residual reuse value from a DUM. The key contributions of the study include: i) comprehensive review of existing EoL management of EEE; ii) identification and discussion of contemporary issues in EoL management of EEE; iii) empirical data on EEE stocks with reuse value in hibernation in an exemplar distinct urban mine at different levels (meso- and macro levels); iv) estimation of economic potential of EEE with reuse value in hibernation and finally v) demonstration of a conceptual reuse-centred recovery protocol with the aim of EEE recovery and redistribution at local and regional levels. The findings presented in this study have implications for stakeholders at different stages of a product’s lifecycle (from manufacturers to product users). It presents the case for product reuse as a viable option and desirable outcome to support the shift from a linear to a circular economy.

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Academic Thesis: Declaration of Authorship

I, Olanrewaju Sheriff Shittu, declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

I confirm that:

1. This work was done wholly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. Part of this work has been published as:
    - Shittu, O.S., Williams, I.D. and Shaw, P.J. (2021). Global E-waste management: Can WEEE make a difference? A review of e-waste trends, legislation, contemporary issues and future challenges. *Waste Management* 120, 549 – 563.
    - Shittu, O.S., Williams, I.D., Shaw, P.J., Monteiro, N. and Creffield, R. (2021). Demonstrating EEE recovery for reuse in a distinct urban mine: a case study. *Detritus* 15, 78 – 93.
    - Shittu O.S., Williams I.D. and Shaw P.J. (2021). The 'WEEE' challenge: is reuse the "new recycling"? *Resources, Conservation and Recycling* 174, 105817.

Signed: ....

Date: ....

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Acronyms and Abbreviations

CRM:	critical raw material
DfD:	design for disassembly
DUM:	distinct urban mine
EA:	Environment Agency
EEE:	electrical and electronic equipment
EoU:	end of use
EPR:	extended producer responsibility
EU:	European Union
EV:	electric vehicle
GDP (PPP):	gross domestic product (purchasing power parity)
GPS:	Global Positioning System
ICT:	information and communication technology
IoT:	Internet of Things
KT:	kilo-tonnes
MS:	Member State (European Union)
MT:	million tonnes
NGO:	non-governmental organisation
OECD:	Organisation for Economic Co-operation and Development
OEM:	Original Equipment Manufacturers
PBDE:	polybrominated diphenyl ether
PCS:	producer compliance scheme
PM:	precious metals

Acronyms and Abbreviations

POM:	put on market
POPs:	persistent organic pollutants
REM:	rare earth metals
RoHS:	Restriction of Hazardous Substances Directive
SDG:	Sustainable Development Goals
SWM:	solid waste management
UEEE:	used electrical and electronic equipment
UN:	United Nations
WEEE:	waste electrical and electronic equipment

Chapter 1 Introduction

1.1 Research context

Waste Electrical and Electronic Equipment (WEEE), also known as electronic waste (e waste) is the fastest growing single waste stream in the world with annual growth rate of 3 – 5% (Forti *et al*., 2020). Four key global issues make WEEE a priority waste stream, specifically: global quantities of WEEE (including outer-world materials such as space debris); resource impacts; potential health and environmental impacts; and ethical concerns (Ongondo & Williams, 2011, WEF, 2019). Annual generation estimates vary markedly because of diverse methodologies employed to quantify the volumes generated (Widmer *et al.*, 2005; Ongondo *et al*., 2011; Baldé *et al.*, 2015; Forti *et al*., 2020). The trajectory in the volumes generated remains upward and has raised concerns about WEEE management (Baxter *et al.*, 2016), particularly WEEE that is subjected to poor end-of-life management and a significant quantity being exported to developing and frontier countries (Ongondo *et al*., 2011; Salhofer *et al.*, 2016). Priority areas of concern and priority include impact on health and environment (Ongondo *et al*., 2011) and resource depletion. One of the solutions proposed is urban mining, which encompasses the cyclical material usage and flows within the human environment (Anthroposphere) (Ongondo *et al.*, 2015; Pierron *et al.*, 2017), involving a structured management system of resources which includes waste with the overarching aim of promoting resource conservation and environmental protection. This is in line with the Circular Economy (CE)[1], a concept which is gaining traction as a replacement for the traditional linearity of resource consumption. Its increase as a subject of debate in the context of resource conservation amongst scholars and practitioners is highlighted in studies including Kirchherr *et al* (2017); Kalmykova *et al* (2018) and Reike *et al* (2018).

1.1.1 WEEE Definition

Electrical and electronic equipment (EEE) is defined as a gadget or equipment that requires electrical currents or electromagnetic fields to perform the function for which it was designed and manufactured (Environmental Protecton Agency, 2017). A more detailed definition is given by the European Union (Directive 2012/19/EU) which defines it as

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[1] The circular economy is the concept of keeping resources in a closed-loop, which involves their prolonged use, maximisation of resources while in use and recovery of materials from products at their end of use.

> **"equipment which is dependent on electrical currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1000 Volts for alternating current (AC) and 1500 Volts for direct current" (European Union, 2012).**

The European Union Directive (WEEE Directive 2012/19/EU) describes electronic waste as waste electrical and electronic equipment inclusive of peripherals which are part of the product at the time of disposal. EEE is often designed to function for a period, after it ceases to function (end-of-life) or performs sub-optimally (functional obsolescence). When this occurs, the user or owner of the device may choose to discard it; when an item is discarded it becomes waste electrical and electronic equipment (WEEE), also known as electronic waste (e-waste). WEEE includes peripherals and accessories that are included as part of the equipment at the time of disposal (WEF, 2019). WEEE is also a term used to describe EEE and its sub-components that have been, or intended to be, discarded by its owner with no intention of reuse (European Union, 2012).

1.2 Study rationale and aims

There has been an increase in research on WEEE in recent years. The narrative of the growing research interest, as illustrated in Figure 1.1, has ranged from studies on rudimentary WEEE end-of-life management techniques and their potential adverse impacts on human health and the environment, particularly in developing countries (Osibanjo & Nnorom, 2007; Nnorom & Osibanjo, 2008a; Ongondo *et al*, 2011; Li *et al.*, 2013; Igharo *et al.*, 2014) to research on WEEE as a secondary source of raw materials such as ferrous metals, precious metals (PM) and rare earth metals (REM) (Chancerel & Rotter, 2009; Oguchi *et al*., 2011; Mueller *et al.*, 2015; Ongondo *et al*., 2015; Mueller *et al.*, 2017; Pierron *et al.*, 2017; Ramanayaka *et al*., 2019), as well as the potential prospecting of mineral-rich WEEE and the recovery of reusable EEE via urban mining (Mueller *et al.*, 2015; Ongondo *et al*., 2015; Mueller *et al.*, 2017; Pierron *et al.*, 2017; ProSUM, 2018; Wilkinson & Williams, 2020). Many of the studies have focused on WEEE recovery/diversion from landfill for material recovery and recycling. However, recovery of EEE for reuse is currently under-researched; it is a route in WEEE management which aims to extend product usage life (Ilankoon *et al*., 2018; Anandh *et al*., 2021). Adopting reuse promotes circularity of materials and products and is considered the preferable outcome with regards to environmental and socio-economic impacts (Kissling *et al*., 2012; Clarke *et al*., 2019). Urban mining, which is often discussed in the context of material recovery for recycling, is a means of recovery with reuse value.

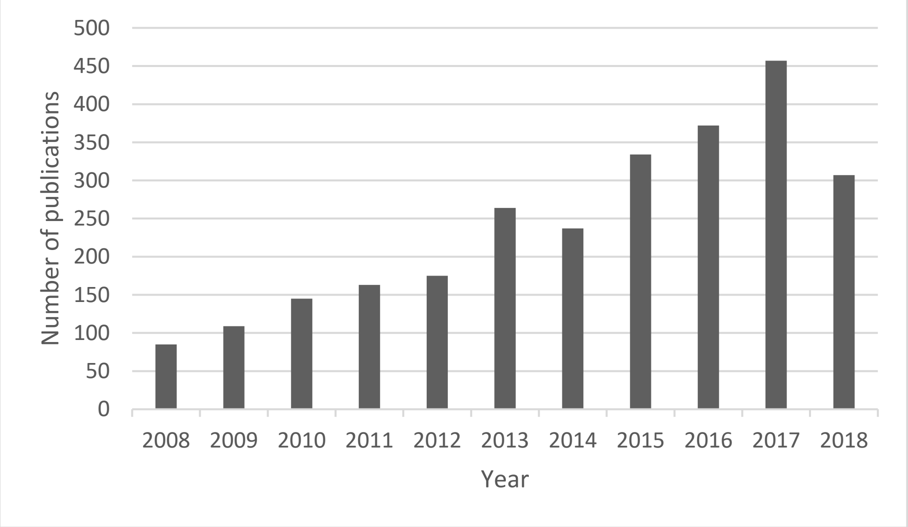

Figure 1.1. Research publications on WEEE (2008 – 2018) illustrating the increase in research interest over the years.

Adapted from Zhang *et al*. (2019)

Urban mining encompasses the cyclical material/product usage and flows within the human environment (Anthroposphere) (Cossu & Williams, 2015; Ongondo *et al*., 2015; Pierron *et al.*, 2017). This concept is central theme of this research work; it involves a structural management system of resources with the overarching aim of promoting resource conservation and environmental protection. Urban mining is often discussed in the context of material extraction from products for reintroduction to the circular economy. However, urban mining can also be viewed as recovery of products with reuse value from dormancy/destined for disposal in order to get more usage cycles from them. This aspect of urban mining is currently under-researched, and this study aims to explore this aspect which involves prolonging a product's useful life in solving the WEEE challenge by evaluating reuse potential of EEE within the context of urban mining and distinct urban mines (DUM). The overall aims of research are shown in Table 1.1. Each research aim represents a separate phase of the research with each phase addressed by a set of objectives.

Table 1.1. Aims and objectives of research

Aims	Objectives
1. Review of on current WEEE management practices and identification of contemporary issues	• Synthesise trends and scenarios of WEEE generation • Analyse collection, recycling and disposal data from selected countries and regions

Aims	Objectives
	- Identify current and emerging issues in WEEE management, including novel concepts such as distinct urban mines
2. **Empirical investigation of a DUM**	- Design and execute survey on ownership and stockpiling patterns of electrical and electronic equipment (EEE) within a DUM - Quantify ownership levels of EEE within a DUM - Evaluate and appraise reuse potential of DUM
3. **Assessment of a DUM as a recovery hub for electrical and electronic equipment (EEE)**	- Develop a reuse-based recovery system for a university DUM - Evaluate urban mining potential of selected DUM via recovery of EoU EEE - Assess functionality and reuse potential of end-of-use/end-of-life EEE

1.3 Research design and thesis structure

The research adopted a sequential mixed-methods approach involving different phases. This approach is widely used in science-related research (Mertens & Hesse-Biber, 2012) and involves a combination of quantitative and qualitative data collection. Data collection can occur sequentially or concurrently, with each phase informing the direction of the other (Johnson & Onwuegbuzie, 2004). This method involves identification of variables of interest from a body of knowledge (qualitative analysis) (Hesse-Biber & Johnson, 2015). These variables can then be studied quantitively. This study combined qualitative and quantitative methods; the qualitative analysis involved a review of WEEE management practices and the identification of contemporary issues. This was done by desk study and the issues identified were scored using an Urgency/Importance scoring system. The outcome of this phase of the study helped to inform the subsequent phases of the research. This approach allows for robust encapsulation of relevant features of a study and exploring relevant gaps within the field of interest (Denzin, 1989).

This study follows a tiered convention by presenting the research work at different phases (illustrated in Figure 1.2) using data from documentary sources and empirical studies. It begins with a review of global WEEE management practices. In the review, WEEE management is highlighted with an analysis of contemporary issues. This is followed by a study based on urban mining at a regional level, a contemporary issue identified in the review. This phase of the work involved a survey of a cluster of DUMs for the potential recovery of reusable EEE. Final project phase involved a case study on the recovery of EEE within a DUM. Details of these phases are provided in subsequent chapters.

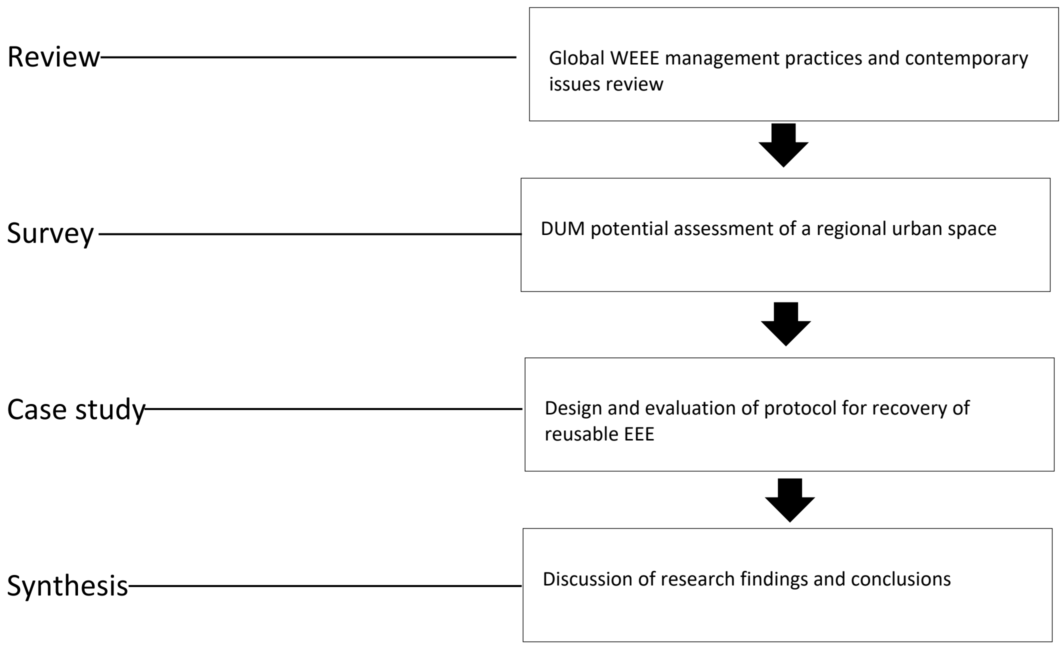

Figure 1.2. Research/Thesis road map

The outcome of these research phases is presented in chapters in this thesis. The thesis structure is as follows:

- **Chapter 1** (current chapter) presents an introduction and the primary context of research as well as introduce themes and concepts including urban mining and circular economy which are core areas of the research. The chapter concludes by outlining the aims, objectives and scope of research.
- **Chapter 2** The chapter is an overview of the scale of the WEEE management challenge. It presents a review of global WEEE management practices as well as a discussion on contemporary issues about WEEE management. The chapter concludes with a summary of findings as well as linkage to proceeding chapters.
- **Chapter 3** begins by providing a background on Distinct Urban Mines. The chapter presents the design, execution and outcome of a DUM survey on ownership and stockpiling of EEE.
- **Chapter 4** presents the outcome a case study on the implementation of a reuse-based EEE recovery system for the recovery of functional reusable EEE in a university DUM

- **Chapter 5** General discussion and synthesis of research results and applicability of reuse-based recovery model to enhance EEE recovery as well as conclusions and recommendations.

Chapter 2 Waste Electrical and Electronic Equipment management: a global review

2.1 Chapter overview

This chapter aims to build on the existing knowledge by reviewing WEEE management practices in selected countries from different regions across the world. The chapter begins with an overview of global WEEE generation and scenarios. This is followed by a country by country review of WEEE management with an inclusion, where available, data on generation, collection and treatment of WEEE in country reviewed. A discussion of trends and contemporary issues in WEEE management follows this and the chapter concludes with a summary of key findings. The chapter presents the first phase of the research (*see* Figure 2.1). A modified version of this chapter has been published in *Waste Management* journal titled *Global E-waste management: can WEEE make a difference? A review of e-waste trends, legislation, contemporary issues and future challenges.*

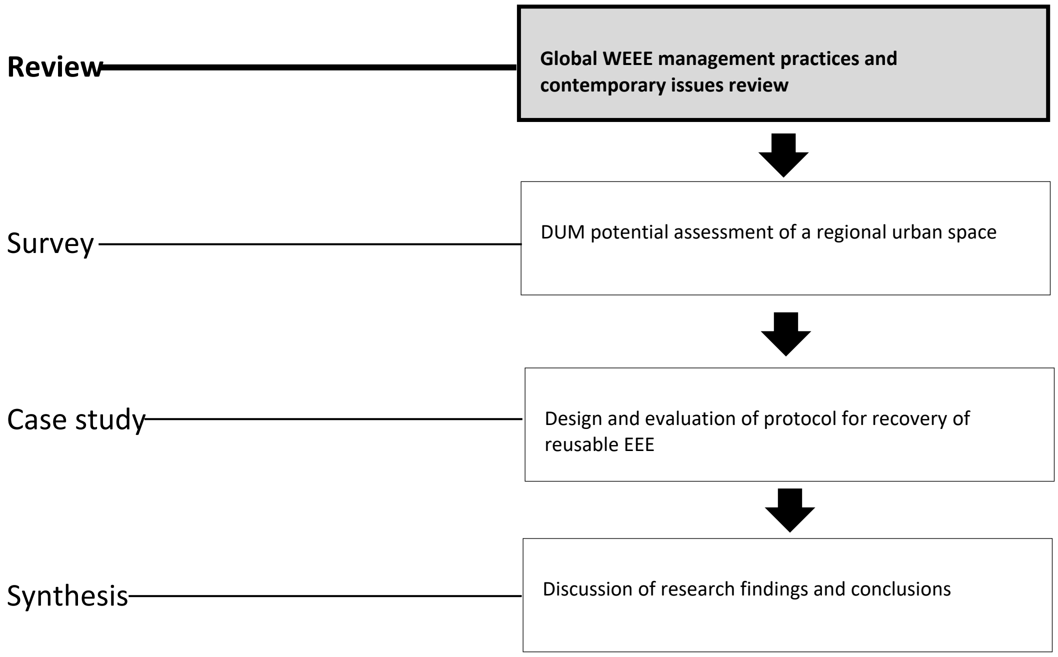

Figure 2.1. Thesis road map showing WEEE review chapter

For this review, WEEE management practices across the world were examined with the goal of identifying trends and scenarios. The review was entirely desk-based and involved a literature search using the search tool Google Scholar. Words including 'WEEE management', 'E-waste management', 'collection and recycling' coupled with regions/continents (Africa, Americas, Asia, Europe and Oceania) were used as the primary keywords for the review. Information sources were not limited to academic literature; other publications such as books, government-commissioned reports, newspaper articles and online databases were also included. The initial review was carried out in 2018 using a time filter to select publications from 2008 – 2018 with search update carried in 2020.

2.2 Introduction

The use of EEE has become integral to present-day living and lifestyles and they exist in a myriad of forms, with varied functionality and levels of complexity (Beigl *et al.*, 2017). EEE, and by extension WEEE, are categorised based on factors including size and weight, functionality and material composition. (W)EEE can be broadly classified into 6 categories (Baldé *et al.*, 2015), as seen in Table 2.1. A broader classification, as the described by the European Union Directive on WEEE (2012/19/EU, Annex I) (European Union, 2012) is shown in Table 2.2 while Table 2.3 shows total weight generated per category in 2019.

Table 2.1. WEEE Directive Classification of WEEE (Annex III)

Category	**Examples**
Heat exchange equipment	Freezers; air-conditioners
Screen/Monitors	Television sets; laptops
Lamps	Straight fluorescent lamps, LED lamps
Large equipment	Washing machines, Photovoltaic(PV) panels, tumble dryers
Small equipment	Vacuum cleaners, microwaves
ICT /Telecommunications equipment	Mobile phones; GPS equipment

Adapted from Baldé *et al.* (2015), European Union (2012)
GPS: global positioning satellite**; ICT**: information and communication technology; **LED**: light emitting diode; **PV**: photovoltaic panel

Table 2.2. WEEE Directive Classification of WEEE (Annex I)

Category	**Examples**
Large household appliances	Refrigerators, microwaves
Small household appliances	Vacuum cleaners, toasters
ICT/Telecommunication equipment	Tablet/laptop computers, mobile phones

Category	**Examples**
Consumer equipment and Photovoltaic Panels	Television sets, DVD players, PV panels
Lighting equipment	Fluorescent lamps, LED lamps
Electrical and electronic tools	Sewing machines, electric drills
Toys, leisure and sport equipment	Game consoles
Medical devices (excluding implanted and infected products)	Dialysis equipment, nuclear medicine equipment
Monitoring and control instruments	Thermostats, smoke detectors
Automatic dispensers	Automated Teller Machines (ATMs), automatic drink dispensers

Source: European Union (2012)

DVD: digital versatile disk; **ICT**: information and communication technology; **LED**: light emitting diode; **PV**: photovoltaic

Table 2.3. Global WEEE generation estimates for each product category

WEEE category	**Total weight generated (2019) (MT)**
Small equipment	17.4
Large equipment	13.1
Temperature exchange equipment	10.8
Screens/monitors	6.7
Small ICT devices	4.7
Lamps	0.9

Adapted from Forti *et al.* (2020)

WEEE is non-homogenous and forms a complex mixture of materials and components, often containing hundreds of different substances, many of which are potentially toxic (Williams, 2016). The composition of WEEE varies markedly, depending on the design and functionality of the device. Typically, WEEE comprises a mixture of different substances and, while constituent material fractions have varied over the years and between devices, certain substances are common. The main uses of all metals in EEE are summarised in Williams (2016), alongside estimates of geogenic and anthropogenic stocks. Ongondo et al., (2011) noted that whilst the metal content of typical WEEE constitutes most of materials used in the manufacture of WEEE, components that are potentially more hazardous have reduced steadily. Generally, materials present in WEEE can be grouped into five categories (Tanskanen, 2013; Baldé *et al.*, 2015; Beigl *et al.*, 2017):

- Ferrous metals
- Non-ferrous metals
- Glass
- Plastics
- Other materials

Ferrous metals tend to constitute the largest proportion of a typical WEEE in size and weight (Ongondo *et al.*, 2011; Tanskanen, 2013; Baldé *et al.*, 2015; Beigl *et al.*, 2017). WEEE is non-homogenous and forms a complex mixture of materials and components, often containing hundreds of different substances, many of which are potentially toxic (Williams, 2016). The composition of WEEE varies markedly; it is hugely dependent on the design and functionality of the device. Typically, WEEE is a mixture of different substances and while constituent material fractions have varied over the years, and from device to device, a typical W/EEE contains certain basic substances. The main uses of all metals in EEE are summarised in Williams (2016), alongside estimates of geogenic and anthropogenic stocks. Ongondo *et al*., (2011) noted that whilst metal content of a typical WEEE constitutes the majority of materials used in the manufacture of WEEE, components that are potentially more hazardous have reduced steadily. Generally, materials present in WEEE can be grouped into five categories (Tanskanen, 2013; Baldé *et al.*, 2015; Beigl *et al.*, 2017):

- Ferrous metals
- Non-ferrous metals
- Glass
- Plastics
- Other materials

Studies have shown that ferrous metals constitute the largest proportion of a typical WEEE in size and weight (Ongondo *et al*, 2011; Tanskanen, 2013; Baldé *et al.*, 2015; Beigl *et al.*, 2017). A summary of the composition of WEEE can be found in Williams (2016).

2.3 Global WEEE management

WEEE is the fastest growing solid waste stream in the world. Global WEEE generation in 2019 was approximately 54 million tonnes (MT) (Forti *et al*., 2020), a rise from 45 MT reported in 2016

(Balde *et al*., 2017), with a global average of 7.3 kg/person/year. This generation rate is expected to increase significantly annually over the next few years, as illustrated in Figure 2.2, with total volume generated expected to rise to 75 MT by 2030 (Forti *et al*., 2020).

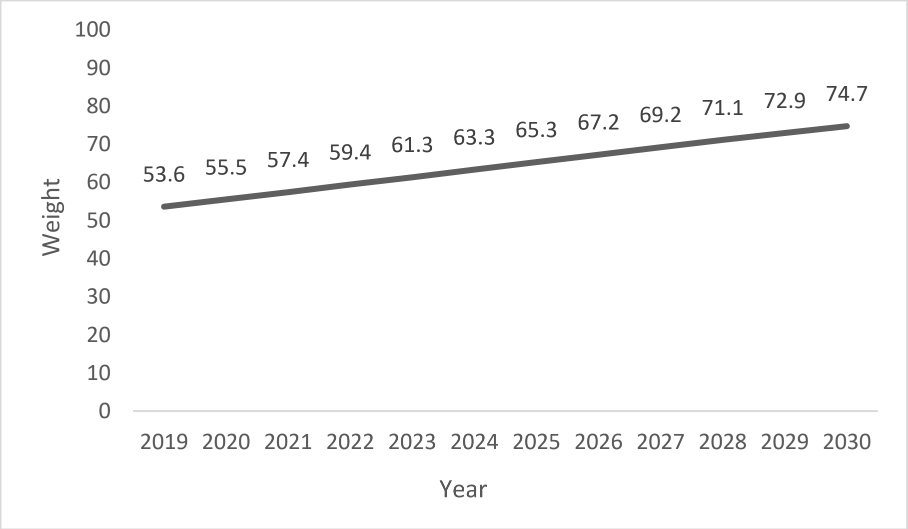

Figure 2.2**.** WEEE generation between 2019 and 2030.
Adapted from Forti *et al*. (2020)
Note: figures from 2020 onwards are projections; weight unit is in million tonnes (MT)

It is proving immensely challenging to develop strategies to manage WEEE effectively on a global scale (Williams, 2016). Different methods and scenarios of WEEE management occur around the world, with variation in scenarios from region to region. The flows and movement of W/EEE can be intertwined and complex often with unaccounted flows, as shown in the case study by Peagram *et al.* (2014).

2.3.1 WEEE management: Europe

WEEE management scenarios in Europe can be assessed from two different perspectives; European Union (EU) countries and non-EU countries. WEEE generation data from 2019 indicates that 12 million tonnes (MT) of WEEE was generated in Europe (EU + non-EU countries) (Forti *et al.*, 2020). WEEE management in the EU is largely governed by two legislatives instruments: EU Waste Electrical and Electronic Equipment (WEEE) Directive and the Restriction on Hazardous Substances (RoHS) Directive.

2.3.1.1 European Union WEEE Directive

The Waste Electrical and Electronic Equipment Directive (WEEE Directive) is a legislative instrument established by the European Union (EU) to enable environmentally sound management of WEEE. In force since 2003, it sets targets for the collection and recycling of WEEE for all Member States (MS) (Eurostat, 2017). The primary aim of the WEEE Directive is the minimisation of the generation of WEEE by promoting and enhancing environmental performance through reuse, recycling and material recovery (Ongondo *et al*., 2011; Yla-Mella *et al*., 2015; Eurostat, 2017). As an EU Directive, each Member State is required to devise various schemes and strategies to achieve collection and recycling targets set by the Directive. The Directive classifies EEE broadly into 10 categories (Annex 1), as shown in Table 2.2 and effective from 2018, all EEE will be classified into 6 categories (European Union, 2014) as seen in Table 2.1.

The WEEE Directive (Directive 2002/96/EC) was established based on the principle of extended producer responsibility (EPR)[2], mandating producers (manufacturers, importers) of EEE to collect end-of-use and end-of-life EEE from consumers and treating the collected volumes in an environmentally sound manner (European Union, 2003b; Widmer *et al.*, 2005). When enacted, the Directive set a minimum collection target of 4 kg per person every year (4 Kg/capita/year). Implementation of the WEEE Directive resulted in significant hurdles in Member States, particularly with legal and technical frameworks for collection and treatment (Ylä-Mella *et al.*, 2014). To address some of the problems, the WEEE Directive, in 2012, was revised. The recast (Directive 2012/19/EU) was aimed at providing more clarity on scope and set new collection targets, based on WEEE generation in each Member State (European Union, 2012; Yla-Mella *et al*., 2015). The Recast WEEE Directive (Directive 2012/19/EU) officially replaced Directive 2002/96/EC in 2014, and from 2016, each Member State is required to collect, annually, a minimum of 45% of the average weight of EEE put on market (POM; i.e. EEE sales) in the preceding three years (Yla-Mella *et al*., 2015). From 2019, the minimum required collection rate will be 65% of average EEE put on market in the three preceding years, or 85% of annually-generated WEEE within each Member State (European Union, 2012).

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[2] According to the Organisation for Economic Co-operation and Development (OECD), Extended Producer Responsibility (EPR) is a policy approach under which producers are given a significant responsibility – financial and/or physical – for the treatment or disposal of post-consumer products.

2.3.1.2 RoHS Directive

Directive 2002/95/EC (Restriction on Hazardous Substances Directive) came into force in 2004 with the primary aim of restricting the use of toxic substances lead, mercury, poly-brominated diphenyl ether (PBDE) and other persistent organic pollutants (POPs) in the manufacture of EEE (European Union, 2003a). The Directive has been recast (Directive 2011/65/EU) to expand the restriction of toxic substances to more types of EEE, details of which are summarised in European Union (2017).

2.3.1.3 Country Examples

2.3.1.3.1 United Kingdom

The Environment Agency (EA) is responsible for the oversight of WEEE management in England (Ongondo *et al*, 2011; Environment Agency, 2017), and until 2013, Wales (Natural Resources Wales, 2017); in Scotland, the Scottish Environmental Protection Agency is responsible (SEPA, 2017). The WEEE Directive was transposed in the United Kingdom (UK) as the WEEE Regulation, which was fully implemented in January 2007 (Ongondo *et al*., 2011; WRAP, 2017).

The implementation of the WEEE Directive in the UK involves the following structures and players:

- Producer Compliance Scheme (PCS)
- Approved Authorised Treatment Facilities (AATF)
- Distributor Takeback Scheme (DTS)
- Approved Exporters

The Producer Compliance Scheme (PCS) is set up with the responsibility of funding environmentally- sound treatment and recycling of WEEE. It is a legal requirement, as a producer of EEE, to enlist with an approved PCS (Ongondo *et al*, 2011; Environment Agency, 2017; WRAP, 2017). The approved authorised treatment facilities (AATF) and approved exporters (AE) are responsible for documented handling and treatment of WEEE.

Generation of WEEE in the UK has steadily been on the rise with generating in 2019 estimated to be 1.59 MT in 2019. In 2011, an estimated 1.3 MT of new EEEs were acquired by consumers (WRAP, 2012) and an identical amount reportedly disposed of. In 2014, the figure for WEEE put on market (POM) increased to 1.5 MT (Baldé *et al.*, 2015); with collected WEEE reported to be 522,000 tonnes (Eurostat, 2017), approximately 35% of average WEEE generated. According to data from Eurostat (2017), large household appliances (category 1) constitute the highest percentage of EEEs put on market (47%) and WEEE collected in the UK (55%).

2.3.1.3.2 Germany

WEEE generation in Germany, with regards to absolute quantity, was approximately 1.6 Mt in 2011, 1.7MT in 2014 (Baldé *et al.*, 2015) and 1.6 MT in 2019 (Forti *et al*., 2020). As in the United Kingdom (UK), large household appliances constitute the majority of EEE put on the market (43%) and WEEE collected officially (40%) (Eurostat, 2017).

The WEEE Directive was transposed into Germany via the legal Act Governing the Sale, Return, and Environmentally Sound Disposal of Electrical and Electronic Equipment (ElektroG) (Walther *et al.*, 2009). Producers are required to register with the Elektro-Altgeraete Register (National Register for Waste Electrical Equipment) (Rotter *et al*, 2011). The structures in place for WEEE management in Germany involve the following players:

- Clearing House (Elektro-Altgeraete Register)
- Public Waste Management Authorities (PWMAs)
- EEE Producers

The Public Waste Management Authorities (PWMAs) are responsible for facilitating collection of discarded EEE, although retailers and producers also carry out collection (Walther *et al.*, 2009).

2.3.1.3.3 Switzerland

The Swiss have, arguably, led the way globally in terms of recycling and urban mining for many decades. The high standard of Swiss waste management is the product of strict environmental regulations, persistent enforcement and the willingness of the population to pay for progressive and environmentally-sound waste management facilities and systems (Williams, 2017). Switzerland was the first country in the world to inaugurate a formal WEEE management system (Duygan & Meylan, 2015). Activities involving WEEE collection and recycling in Switzerland predates the WEEE Directive in Europe. It began with the initiation of the Swiss Association for Information, Communication and Organisation Technology (SWICO) (Ongondo *et al*., 2011). At inception, it oversaw the collection of information technology (IT) equipment and office electronics. Coverage of collection extended over the next few years to include consumer electronics and small I.C.T devices (Ongondo *et al*, 2011; Duygan & Meylan, 2015). The S.EN.S, also known as the Swiss Foundation for Waste Management, is the first WEEE management EPR scheme in Switzerland, which collects WEEE on behalf of manufacturers and retailers. Initially with a limited scope of just refrigerators and freezers collection, it expanded to collect a wider range of household EEE (Ongondo *et al*., 2011). Over 90% of collected household generated WEEE in Switzerland is collected and managed by these schemes (Savi et al., 2013). Both schemes are funded by a charge payed by consumers when EEE are purchased called Advanced Recycling Fee (ARF) (Borthakur & Govind, 2017).

Switzerland collected 15kg/capita/year of WEEE in 2011 (Duygan & Meylan, 2015), which was significantly higher than the initial collection target of 4 kg/capita/year set by the WEEE Directive for Member States at the time. It generates 0.18 MT annually as of 2016 and 0.2MT in 2019, with per capita generation of 22.2 kg/person/year (Baldé *et al.*, 2017; Forti *et al*., 2020). Its success rate in WEEE collection and management is largely attributed to huge support of the schemes by consumers, who routinely discard their WEEE at designated points, including retail outlets and recyclers (Hischier *et al*., 2005; Borthakur & Govind, 2017).

2.3.1.3.4 Finland

Finland is amongst the top WEEE generators per capita in Europe. It generated 21.1 kg/capita/year of WEEE in 2016 (Baldé *et al.*, 2017) with a total of 110 KT in 2019 (Forti et al., 2020). Finland had a producer responsibility scheme prior to the existence of the WEEE Directive for the management of waste tyres, waste paper and packaging (Ylä-Mella *et al.*, 2014). The WEEE Directive was harmonised with existing legislation (Finnish Waste Act [1072/1993]) to establish a framework for WEEE management. The amended legislation (Finnish Waste Act 452/2004) requires producers to facilitate the management (including reuse and recovery) of EEE they put on the market, including bearing the costs incurred (Ylä-Mella *et al.*, 2014).

2.3.1.3.5 Other European Countries

The Balkan sub-region in Europe has, in the past, been a destination of WEEE from developed countries (Baldé *et al.*, 2015). This, in addition to internally generated WEEE, has led to challenges in WEEE management in the region. A number of countries in the region have WEEE legislation including Albania, Bosnia, Slovenia and Bulgaria, the latter two being EU Member States. Albania generates 20 KT of WEEE annually with 0.6 kg generated per capita/year (Baldé *et al.*, 2017), making it one of the lowest generators of WEEE in Europe. On the higher end of per capita generation is Slovenia, which generates 16.1 kg/capita/year and a total of 33 KT annually. Bulgaria and Bosnia & Herzegovina generate 79 KT and 25 KT of WEEE respectively (Baldé *et al.*, 2017). WEEE collection and recycling in relatively low in this region compared with western Europe, although Bulgaria reportedly collects over 60% of WEEE generated annually (Baldé *et al.*, 2015).

2.3.2 WEEE management: Africa

An estimated 2.9 MT of WEEE was generated in Africa in 2019 (Forti *et al*., 2020), with the highest quantities originating from western Africa (Baldé *et al.*, 2017; Forti *et al*., 2020). Also, a number of countries are the destination of significant quantities of WEEE exported by developed countries (Ongondo *et al*, 2011; Baldé *et al.*, 2015; Snyman *et al.*, 2015). The shipments, mostly imported as used electrical and electronic equipment (UEEE) are often not subjected to robust functionality tests before being exported (Ongondo *et al*., 2011; Odeyingbo *et al*., 2016). The trend, coupled with inadequate infrastructure for WEEE management and inadequacy or lack of WEEE legislation, has contributed to the WEEE management challenge in Africa.

While WEEE-specific legislation is lacking or not adequately enforced in many African countries, there are international agreements such as the Basel Convention and Bamako Conventions (*see* sections 2.3.2.1 & 2.3.2.2) to regulate and control trans-boundary movement of hazardous waste (including WEEE) (Li *et al.*, 2013; Snyman *et al.*, 2015).

2.3.2.1 Basel Convention

The Basel Convention is an International Environmental Agreement (IEA), currently with 53 countries as signatories, which took effect in 1992 to control trans-boundary movement of hazardous waste. It specifically targets the restriction of movement of toxic waste from developed countries to developing/less developing countries (LDCs) (Andrews, 2009; Li *et al.*, 2013). The Basel Convention has no direct influence on WEEE management or movement. However, with WEEE known to contain trace amounts of hazardous substances, its trans-boundary movement falls within the convention’s purview. The Basel Convention originated as a result of high profile transboundary movement of toxic waste, most notably the incident involving an Italian shipment of toxic waste to Nigeria in 1988 (Amanze, 2013). The Convention allows for movement of hazardous waste provided there is bilateral or multilateral agreement for its safe treatment within the countries importing the waste (Lepawsky & McNabb, 2010).

The assessment of the effectiveness of IEAs such as the Basel Convention is challenging partly due to lack of data on activities before the enactment of such agreements; this makes comparative analysis difficult. However, it has been argued that the Basel Convention has failed to deliver on its mandate of limiting toxic waste trading (Andrews, 2009; Daum *et al*., 2017); the Convention permits trading of waste between member countries (as stipulated in Article 4 of the

Convention[3]). There is also no provision in the Convention to ensure the availability of appropriate treatment protocol in the importing country. It was the failure of the Basel Convention in curbing dumping of toxic waste in Africa that led to the enactment of the Bamako Convention (UNEP, 2018).

2.3.2.2 Bamako Convention

The Bamako Convention is an African treaty adopted in 1991 and came into force in 1998. As with the Basel Convention, it restricts the importation into, and movement of hazardous waste within Africa. The Bamako Convention aims to be complementary to the Basel Convention in the prevention of transboundary toxic waste to African countries (UNEP, 2018). The Convention also seeks - together with stemming transboundary waste movements – to protect African communities from the environmental and human health hazards posed by indiscriminate dumping of waste and uncontrolled incineration whilst creating a framework for the environmentally sound management of toxic waste (UNEP, 2018).

The effectiveness of the Bamako Convention in curbing transboundary movement of toxic waste has been the subject of considerable debate (UN Environment, 2018). It has been argued that the lack of an enforcement arm of the Convention stifles its potency in delivering on its mandate (Daum *et al*., 2017). This has been exemplified with the occurrence of high profile dumping incidents such as the Probo Koala incident[4] in Ivory Coast, and the net inward flow of e-waste to countries such as Ghana and Nigeria despite being signatories to the Convention. As with the Basel Convention, the Bamako Convention in its current form only plays an advisory role and does not enforce member countries to comply with its mandate (UN Environment, 2018).

2.3.2.3 Country Examples

2.3.2.3.1 Nigeria

The ICT sector in Nigeria has been growing in recent years. A notable indicator of this is the number of active telephony (mobile, fixed wireless) subscriptions. Figures published by the Nigerian Communications Commission (NCC), which is the government department with regulatory oversight of the telecommunication sector, show active subscriptions in 2020 was approximately 200 million (NCC, 2021). This is based on a population of approximately 190 million

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[3] Article 4 of the Basel Convention which gives provisions on waste trading between ratified members

[4] Probo Koala incident involved the dumping of 500 tonnes of toxic waste by an international company in and around Abidjan, Ivory Coast in 2006

people. However, it is common practice in Nigeria for an individual to have two or more active subscriptions partly due to issues bothering on network coverage from the major telecommunications companies. The increasing tele-density is contributing to WEEE generation within the country.

UNEP (2019) estimates the amount of WEEE generated annually to be close to 300 KT. WEEE generation rates vary across Nigeria; urban areas generating more than rural areas (Ogungbuyi *et al.*, 2012). Large household items (Category 1)[5] constituted the majority of EEE (54%) imported into Nigeria between the year 2000 and 2010 (Ogungbuyi *et al.*, 2012). While companies dealing with assembling EEEs are present in Nigeria, majority of WEEE consumed are imported (Ogungbuyi *et al.*, 2012). Nigeria has a budding EEE production sector. However, majority of EEE consumed are imported (Ogungbuyi *et al*., 2012). The estimated quantity of imported categories 1 – 4 EEE, based on the WEEE Directive classification, was 1.2 MT in 2010 (Schluep *et al.*, 2012).

Nigeria moved to stem the influx of WEEE through its borders when, in 2011, it put in place a ban on the importation of used electronics. WEEE/end-of-use EEE is often mixed with used electrical and electronic equipment (UEEE) (Ogungbuyi *et al.*, 2012; Li *et al.*, 2013). The NESREA regulation (National Environmental [Electrical/Electronic Sector] Regulations 2010 S.1.No 23) requires importers of UEEE to register with the National Environmental Standards and Regulations Enforcement Agency (NESREA) before commencing with importation (NESREA, 2016). However, the effect has been minimal as importation of WEEE persists. Initial results from a study carried out by the United Nations University in conjunction with Basel Convention Co-ordinating Centre (BCCC-Africa) and the United States Environmental Protection Agency (USEPA) between 2015 and 2017 indicated that up to 60 KT of WEEE was shipped into Nigeria (Odeyingbo el al, 2016; Gbonegun, 2017).

Whilst there have been recent efforts to formalise WEEE management in Nigeria, informal collection and recycling of WEEE still thrives and these activities are common in and around markets dealing in used electrical and electronic equipment (Schluep *et al.*, 2012). These activities are predominately carried out manually using basic tools such as hammers and screwdrivers to manually disassemble the WEEE. Metal scraps obtained are sold to metal dealers or second-hand dealers. Open burning of WEEE is common and residue obtained are disposed of in open dumps (Ogungbuyi *et al.*, 2012; Schluep *et al.*, 2012). Steps to formalise WEEE management led to the

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[5] According to the WEEE Directive Classification (Annex I)

creation, in 2018, of a producer responsibility platform called Extended Producer Responsibility Organisation of Nigeria (EPRON).

2.3.2.3.2 Kenya

In common with other African countries, WEEE generation in Kenya is on the rise alongside an increase in many African countries with increase in consumption of EEE. A 200% increase in the importation of ICT equipment was recorded in 2007, with subsequent increase in WEEE generation. Ongondo (2013) reported that the annual generation of WEEE in Kenya was 7.4 KT with recent estimates reported to be 38 KT (Baldé *et al.*, 2017) and 50 KT in 2019 (Forti *et al*, 2020). Per capita generation is 0.8 kg/person/year, which is lower than the African average generation of 1.9 kg/person/year (Baldé *et al.*, 2017). Refrigerators and TVs constitute the largest percentage by weight of WEEE generated at 19% and 38% respectively (Ongondo, 2013). The overall amount of WEEE generated is expected to increase as the use of EEE, particularly mobile phones and other ICT devices becomes more widespread. Penetration of mobile telephony is 77%, with 30 million mobile subscriptions (CCK, 2013).

Kenya is a signatory to both Basel and Bamako Conventions that restrict the transboundary movement of WEEE (Ongondo *et al*, 2011). The Kenyan E-waste Act is the most recent WEEE related legislation but is yet to be formally approved and it stipulates the end-of-life management of WEEE as the responsibility of manufacturers (Baldé *et al.*, 2017). Prior to this, Kenya had developed national legislation guidelines (the WEEE Guidelines) and it is the first country in east Africa to draft WEEE-related guidelines (African Business, 2010). The legal guidelines are based on extended producer responsibility (EPR) principle and requires the registration of importers of EEE (NEMA, 2013). However, the guidelines have had little effect on the increasingly common illegal importation of WEEE (Ongondo, 2013) and this situation remains prevalent.

WEEE legislation in Kenya has provided a legal framework for the establishment of WEEE treatment facilities and recycling centres. Most of these are informal and lack cutting-edge technology and infrastructure (Ongondo, 2013), ICT equipment manufacturer Hewlett-Packard initiated a WEEE recycling project in 2013; through this project the company has helped in providing required training of the locals on the operation of WEEE collection and recycling (Gale, 2015). The WEEE Centre, a partnership involving local and international organisations is also involved in the reuse and recycling of WEEE and it operates on a closed-loop model (Ongondo, 2013). The WEEE Centre has established collection network and channels with government and the private sector (Souza *et al.*, 2015).

2.3.2.3.3 Ghana

Ghana's annual generation of WEEE is an estimated 50 KT (2019) with a per capita generation of 1.4 kg/person/year (Forti *et al.*, 2020). This is comparable to the African average of 1.9 kg/person/year. Ghana largely imports EEE that are consumed within the country, with assembling of electronics done minimally; approximately 215 KT of EEE is reported to be imported annually as at 2009 (Schluep *et al.*, 2012). Of these, 70% were used electronics (UEEE) and composed mainly category 1 – 4 EEE.

Ghana, together with Nigeria, has been a major hub for the importation of WEEE in recent years (Schluep *et al.*, 2012; Doyon-Martin, 2015; Campen & Enders, 2016). This, together with the increasing volume of internally generated WEEE, has led to a flurry of informal collection and recycling activities. Schluep *et al.* (2012) reported that 95% of WEEE collection was undertaken informally by a thriving informal sector and recycling heavily involves manual disassembly. The informal e-waste sector is estimated to generate over $100 million annually, supporting the livelihoods of over 200,000 people (Daum *et al*., 2017). Uncontrolled burning of plastics and open dumping of WEEE are common, resulting in severe environmental pollution and human health hazards (Daum *et al*., 2017).

WEEE legislation was passed in Ghana in 2016. Known as the Hazardous and Electronic Waste Control Management Bill, 2016, it aims to bring some control to the WEEE management sector (Campen & Enders, 2016). It aims to regulate and restrict the influx of WEEE from abroad, as stipulated by the Basel Convention, and manage WEEE generated internally (Campen & Enders, 2016; Baldé *et al.*, 2017).

2.3.2.3.4 South Africa

WEEE generation has increased steadily in recent years in South Africa. It generated more than 410 KT in 2019 (Forti *et al.*, 2020); per capita generation is 5.7 kg/person/year (Balde et al., 2017), well above the continental average. Contributing sectors to the WEEE streams are businesses, households and governments; categories most common in the WEEE streams are ICT and consumer electronics, and large and small household goods (Salhofer *et al*., 2017). The increase in usage of mobile phones and ICT equipment has contributed most to the growing annual WEEE generation.

The Basel Convention is ratified by South Africa, though it is notably not a signatory to the Bamako Convention, which places complete ban on hazardous substances including WEEE. This is to ensure possible hazardous waste trading and recycling in the country (Snyman *et al.*, 2015). There is currently no national WEEE-specific legislation, although there is the National Waste Management Strategy, under which WEEE is classified as hazardous waste (Snyman *et al.*, 2015; Salhofer *et al*, 2017). A WEEE management plan developed by the electronics industry has been forwarded to the Department of Environmental Affairs, which is planning to introduce an EPR tax to be collected from producers of WEEE and used to fund producer compliance schemes (PCS) (Campen & Enders, 2016).

Recycling of WEEE in South Africa currently occurs both formally and informally. Informal collection typically involves waste pickers who collect WEEE from a wide range of places including landfills and shopping malls. These are then sold to low-level WEEE recyclers (Salhofer *et al*., 2017). Formal collection occurs in one of three ways; collection of WEEE by well-established waste management companies which have significant clientele and networks; collection by smaller recyclers who collect directly from consumers to refurbish and recycles; and designated drop-off points where consumers can take their WEEE directly (Salhofer *et al*., 2017). Once collected, the WEEE is dismantled into component parts and material fractions such as metals are then sold to companies for further processing. Some of the WEEE collected are refurbished and put back on the market for sale, earning the firms involved some revenue (Salhofer *et al*., 2017).

2.3.2.3.5 Other African countries

In North Africa and the Maghreb sub-region, Algeria generates 252 KT of WEEE with per capita generation of 6.2 kg/person/year (Baldé *et al.*, 2017), making it one of the biggest contributors of WEEE in Africa (Campen & Enders, 2016; Baldé *et al.*, 2017). The country currently has no WEEE-specific legislation and no recorded official collection of WEEE. Libya has a very high rate of annual WEEE generation per capita at 11kg (Baldé *et al.*, 2017). This rose from a reported 8.3 kg/person/year in 2014 (Baldé *et al.*, 2015). There is little information on collection and recycling, as there it is not done officially. Mauritania is on the lower end of the generation trend as it produces 1.3 kg/person/year, which is lower than the continental average. Total amount generated in 2016 was approximately 5.1 KT (Baldé *et al.*, 2017). Morocco is not known to have WEEE legislation. It produced 127Kt of WEEE in 2016, 3.7 kg/person/year. Tunisia has mooted plans to introduce a tax system believed to be for funding compliance schemes (Campen & Enders, 2016). Total WEEE generation is 63 KT (Baldé *et al.*, 2017).

In east and south Africa, Tanzania generated 38 KT of WEEE in 2016 (Baldé *et al.*, 2017). There is no legislation on WEEE management and there is significant informal sector focused on collection and recycling. A partnership between Finland and Tanzania is in place for knowledge and skills transfer involving the assembling of 3D printers using material fractions from recycled WEEE (Gale, 2015). Rwanda drafted a policy on WEEE management in 2012 (Campen & Enders, 2016). The proposed WEEE management scheme is to be based on the EPR principle and the framework development is still ongoing. Madagascar generated 14 KT of WEEE in 2016 (Baldé *et al.*, 2017). It put in place a decree in 2015 to develop a national electronic waste management plan based on EPR principle on historic and future WEEE streams (Campen & Enders, 2016). Seychelles generated the highest amount of WEEE/person in Africa in 2016 (11.5 kg/person/year) (Baldé *et al.*, 2017). This could be partly attributed to its high GDP and per capita income. WEEE is reported to be generally commingled with general waste. Mauritius also on the high end with regards to WEEE generation estimates (8.5 kg/person/year). It currently has no WEEE-related legislation.

2.3.3 WEEE management: Asia

A high number of Asian countries have experienced economic prosperity in the last few decades, and this in turn has resulted in a steep rise in the amounts of WEEE generated (Ongondo et al., 2011; Baldé *et al.*, 2017; Forti *et al*., 2020). In 2014, WEEE generation was an estimated 16 MT (Baldé *et al.*, 2015), with China alone contributing approximately 6 MT (38%). The figure for Asia increased to 24.9 MT in 2019 (Forti *et al.*, 2020), constituting almost 50% of WEEE generated globally. This makes Asia the largest WEEE generator globally.

2.3.3.1 Country Examples

2.3.3.1.1 China

The drivers for WEEE flows, reuse and recycling in China are particularly distinctive (Williams, 2016). China experienced an average gross domestic product (GDP) increase of 10% between 1978 and 2011 (Steuer *et al*., 2017), making it the second largest economy in the world. The rapid growth has resulted in significant environmental challenges, particularly with regard to solid waste management. China is ranked first in the world for WEEE generation; estimated WEEE generation for 2014 was 6.0 MT (Baldé *et al.*, 2015). This increased to 10.1 MT in 2019 (Forti *et al.*, 2020). Major contributors to the WEEE stream are mobile phones, computers, printers, refrigerators and TVs.

As a global leader in the electronics sector, which involves manufacturing, refurbishing and recycling, China plays a key role in the WEEE industry. China exports more EEE than any other country in the world (Ongondo *et al*, 2011; Baldé *et al.*, 2017). Its strong EEE sector, together with being the most populous country on earth makes China a major input to translates to global WEEE generation. China is historically a large importer of WEEE, receiving huge quantities from Europe, the US and Japan (Wang *et al*., 2013; Lin *et al*., 2020). It plays a major role in the recycling of WEEE as well as other mixed waste (waste plastics, paper) imported from Europe and the United States. This, however, is set to change as the Chinese government has moved to enforce the ban on waste imports. The ban will cover 24 different waste materials including plastics and WEEE (Hancock, 2018). This development is likely to have significant consequences, especially for countries reliant on exporting their waste to China, and the Chinese companies that thrive on the waste feedstock from abroad.

WEEE-related legislation in China has been developed over the last decade, providing the legal framework for official collection and treatment of WEEE. The national legislation encompasses the collection and treatment of small and large electrical equipment such as TVs, refrigerators, washing machines; screen/monitors and ICT equipment (Wang *et al.*, 2013) – 18% percent of total generated WEEE was reportedly collected in 2016, amounting to 1.3 MT (Baldé *et al.*, 2017). Despite the legal framework for official treatment of WEEE, there is widespread informal sector collection and treatment of WEEE (Wang *et al.*, 2013; Baldé *et al.*, 2017; Steuer *et al*, 2017). There is a system of formal WEEE collection in China which comprises licensed collection stations and recyclers. These entities are in direct competition for WEEE with informal collectors who are more prevalent and easily accessible. Informal collection is mainly carried out by door-to-door pick-ups, mostly by street peddlers. The WEEE collected via these channels is rarely destined for official treatment systems (Cao *et al*., 2018), but goes to repair shops or dismantling houses, depending on the condition of the items. The activities of the informal sector are known to have largescale adverse environmental and health impacts (Ongondo *et al*, 2011; Li *et al.*, 2013; Wang *et al.*, 2013; Baldé *et al.*, 2017). There is also a poorly-defined guidance on WEEE management, especially with regard to implementation of collection of WEEE, and the distinction of roles and responsibilities of consumers and recyclers (Cao *et al*., 2018). However, it is believed the management of WEEE has widely improved since the introduction of WEEE-related legislation in 2012 (Lin *et al*., 2020) especially with regards to illegal WEEE imports. There have also been proposals made to integrate the informal collecting systems into regulated channels to form a unified collection system (Cao *et al*., 2018).

2.3.3.1.2 Japan

Japan has a highly sophisticated and developed electronics industry. It is at the forefront of electronics manufacture, particularly consumer electronics. This, together with a very high GDP, translates to high demand and consumption of EEE and thus, high WEEE generation. In 2016, Japan generated 2.1 MT of WEEE, with a per capita generation of approximately 17 kg/person/year; mostly comprising air conditioners, TVs, laptop computers, washing machines and mobile phones (Baldé *et al.*, 2017).

Japan was amongst the first countries in Asia to develop and implement a WEEE management system based on EPR (Baldé *et al.*, 2015; Sugimura & Murakami, 2016; Forti *et al*., 2020). In 2001, a law on WEEE recycling was introduced called Home Appliance Recycling Law (HARL) that specifically targets consumer electronics (Zhang & Kimura, 2006; Ongondo *et al*., 2011). Consumer electronics such as washing machines, air conditioners and TVs constitute the highest percentage by volume and weight (Ongondo *et al*, 2011). The HARL law underwent amendment to include new and emerging consumer products such as LCD (Liquid Crystal Display) and Plasma TVs. The HARL law requires producers of EEE to take back products that have reach end of life (EoL) and treat, with materials recovered reused or recycled (Aizawa *et al*, 2008; Ongondo *et al*, 2011).

The Law for the Promotion of Recycling of Small Waste Electrical and Electronic Equipment was implemented in 2013 to further promote the recovery of more secondary resources from WEEE generated (Sugimura & Murakami, 2016). It specifically targets increased materials recovery from the recycling of small WEEE by providing the legal framework for collection and treatment. Export of WEEE from Japan still occurs and it has been argued that the WEEE exported, mostly to other Asian countries including China, detrimentally affects the effectiveness of domestic WEEE recycling systems by limiting feedstock (Sugimura & Murakami, 2016). Recycling of TVs, refrigerators, air conditioners and washing machines are 87%, 87%, 89% and 87% respectively (Menikpura *et al*., 2014).

W/EEE collection in Japan is partly achieved by retail shops receiving discarded UEEE and WEEE from consumers. These are then transported to storage areas. Consumers also have the option of taking their W/EEE directly to authorised collection points (Borthakur & Govind, 2017). The cost of recycling is borne by the consumers, and this has resulted in some consumers selling their W/EEE to exporters instead to avoid this cost (Shinkuma & Huong, 2009).

2.3.3.1.3 India

India is a significant contributor to WEEE generation in Asia. This is as a result of huge quantities generated internally (1.5 MT in 2015) (Turaga & Bhaskar, 2017) rising to 3.2 MT in 2019 (Forti *et al*., 2020). Illegal imports of WEEE mingled with UEEE also contributes significantly to the WEEE stream in India and is reported to occur persistently (Turaga & Bhaskar, 2017). Imports largely consist of consumer electronics and demand has been growing steadily over the years (Manomaivibool, 2009; Borthakur & Govind, 2017).

India's per capita generation is 1.5 kg/person/year, which is lower than the continental average generation of 4.2 kg/person/year. This is partly due to relatively low penetration of EEE in the country compared with other Asian countries like China and Japan (Manomaivibool, 2009; Ongondo *et al*., 2011).

India introduced a WEEE-related legislation called E-waste Management and Handling Rules which came into force in 2012 (Turaga & Bhaskar, 2017). In common with other WEEE legislation, it is based on an EPR framework. The regulation requires producers to attain set collection targets in an effort to boost collection and recycling rate in a country that still has a hugely dominant informal WEEE sector (Turaga & Bhaskar, 2017); 95% of recycling is carried out in the informal sector (Awasthi *et al*., 2016). Under the regulation, producers (including recyclers and dismantlers) are required to register with state-controlled environmental regulators. The regulators-known as State Pollution Control Boards (SPCBs) are responsible for the issuance of permits for WEEE collection and treatment (Turaga & Bhaskar, 2017). The regulation has been amended to promote higher recycling rates. The amendment, similar to the changes made to the EU WEEE Directive, sets collection targets as a percentage of EEE put on market (Turaga & Bhaskar, 2017). The regulation has resulted in an increase in the number of registered WEEE treatment facilities (Turaga & Bhaskar, 2017).

2.3.3.1.4 South Korea

South Korea generated approximately 800 KT of WEEE in 2019, with per capita generation of 13.1 kg/person/year (Forti *et al.*, 2020). A combination of rapid economic growth and a very strong EEE manufacturing sector has contributed to growing domestic electronics market. Production and sales of consumer electronics is high in South Korea as indicated by the number of electronics as far back as 2006. Jang (2010) reported that 35 million mobile phones, 22 million TVs and 13 million personal computers were in active use in 2006. In 2011, 52 million mobile phones, 24 million TVs, 17 million refrigerators and 12.8 million computers were in use (Kim *et al*, 2013).

WEEE generated in South Korea is managed using an EPR based system under the Waste Management Act (Act on the Promotion of Conservation of Resources) (Hyunmyung & Yong-Chul, 2006; Kim *et al*., 2013), which was introduced in 2003. There are collection networks within municipalities involving either kerbside drop-off points or door-to-door collection (Kim *et al*., 2013). Collected WEEE is then transported by authorised transporters to designated recycling facilities (Turaga & Bhaskar, 2017). Under the Korean WEEE Act, six hazardous substances are regulated (lead, cadmium, mercury, poly-brominated diphenyl ethers, hexavalent chromium & poly-brominated biphenyls). Coverage of EEE under the Act is limited to 10 types of EEE including refrigerators, washing machines, mobile phones and TVs (Kim *et al*., 2013).

2.3.3.1.5 Hong Kong

Hong Kong generated approximately a total of 150 KT and 19 kg/capita/year of WEEE in 2019 (Forti *et al.*, 2017), amongst the biggest generators in Asia. The high generation rate can be attributed to economic growth and increasing demand for consumer electronics, as seen in other emerging economies in Asia.

In Hong Kong, illegal dumping of WEEE occurs, together with scavenging and informal recycling of items such as washing machines, TVs and refrigerators (Bland, 2018). However, over 80% of its generated WEEE is exported to countries abroad, particularly in Africa where they are improperly disposed of (Bland, 2018).

Hong Kong recently established its first recycling plant for processing WEEE. The facility, which is government-supported and in partnership with a German waste management company, handles large and small WEEE under strict and controlled conditions (Bland, 2018). This has been followed up with plans to impose a levy on imported EEE, with the income generated from this used to fund the recycling facility (Bland, 2018). However, there remains a number of illegal WEEE recycling sites still in operation and their impact on the environment is poorly understood due to a paucity of data (Lin *et al*., 2020).

2.3.3.1.6 Vietnam

Vietnam generates 141KT of WEEE annually (1.5 kg/person/year) (Baldé *et al.*, 2017). WEEE is generally stockpiled in Vietnam due to perceived value attached to it. This behaviour, according to Nguyen *et al.* (2009), is partly as a result of years of war and devastation.

Vietnam's WEEE-related policy, the Prime Ministerial Decision on E-waste, came into effect in 2016, with huge dominance of informal recycling and transboundary importation persisting (Baldé *et al.*, 2017; Borthakur & Govind, 2017). EEE producers are presently responsible for only discarded EEE that originate from the production line, not consumer generated WEEE (Borthakur & Govind, 2017).

2.3.3.1.7 Other Asian Countries

Singapore has a high generation rate of 17.9 kg/person/year of WEEE annually, generating 100 KT in total (Baldé *et al.*, 2017). Importation of WEEE is prohibited (de Oliveira *et al*., 2012), though is presently no policy on WEEE management.

Bangladesh records high level of crude and uncontrolled informal recycling activities, with resultant pollution of farmlands and surface water. There are cases of recycling related deaths, especially amongst children exposed to toxic chemicals emitted (Baldé *et al.*, 2017). The generation rate is reported as 0.9 kg/person/year with total annual generation of 142 KT (Baldé *et al.*, 2017).

The United Arab Emirates has a high EEE turnover rate, ranking high amongst countries with lowest life expectancy of EEE (Baldé *et al.*, 2017). Annual generation rate is 134 KT, with per capita generation of 13 kg/person/year (Baldé *et al.*, 2017). There is currently no formal WEEE legislation in UAE, however a partnership with Switzerland is to deliver a recycling plant in Dubai which, when finished, will handle 39 KT of WEEE annually (Gulf Today, 2017).

2.3.4 WEEE management: North America

North America has two of the most affluent countries globally in Canada and the United States of America, with GDP (PPP) of $45,000 and $57,000 respectively (OECD, 2018b). This is evident in the consumption and turnover of EEE in both countries.

2.3.4.1 Canada

Canada generated approximately 725 KT of WEEE in 2014, with per capita generation of 20.4 kg/person/year (Kumar & Holuszko, 2016). The figures are comparable to those reported by Baldé *et al.* (2017); 724Kt and 20 kg/person/year respectively. Major contributors to the e-waste stream are screen/monitors, temperature exchange equipment and small & large equipment (Kumar & Holuszko, 2016). Generation rates vary widely between provinces, with provinces such as British Columbia and Ontario generating the most (Kumar & Holuszko, 2016). Collection rate of total WEEE generated in 2014 was 20% (Kumar & Holuszko, 2016). Most WEEE generated end up in landfills or are exported to developing countries. Approximately 140 KT of WEEE end up in landfill annually (Kumar & Holuszko, 2016). Disposal practices of WEEE in Canada are thought to be responsible for the relatively low recycling rate; WEEE is often disposed of with general waste.

Kumar & Holuszko (2016) reported that 45% of Canadians had WEEE in possession with intention to dispose in 2011.

Canada has no federal WEEE legislation. However, the Ministry of Environment is responsible for WEEE management. The management of WEEE in Canada is predominately handled by the private sector under a Stewardship Programme called Electronic Product Stewardship Canada (EPSC) (Kumar & Holuszko, 2016; Baldé *et al.*, 2017). Eight provinces have product stewardship programs in Canada; Alberta, British Columbia, Manitoba, Newfoundland & Labrador Nova Scotia, Ontario, Quebec and Saskatchewan (Kumar & Holuszko, 2016; Borthakur & Govind, 2017). The programs have resulted in proliferation of WEEE management organisations in the provinces. These organisations require operating licences, which are issued subject to an audit carried out by the Recycler Qualification Office (RQO). The RQO runs the national Recycler Qualification Programme which ensures that WEEE is recycled in an environmentally safe manner (Recycler Qualification Office, 2015). The recyclers majorly collect and recycle laptops, personal computers, together with other associated peripherals and small household appliances.

2.3.4.2 United States of America

The USA is the biggest producer of WEEE in North America, generating 6.9 MT of WEEE in 2019 (20 kg/person/year) (Forti *et al.*, 2020). Estimates from the United States Environmental Protection Agency (US-EPA) give a total of 438 million new electronic products sold in 2009, with the figure rising annually (US-EPA, 2017c). An average American household possessed 28 EEE including mobile phones, laptops, and TVs with WEEE constituting 1% of municipal solid waste in 2014 (US-EPA, 2017a). Stockpiling of obsolete WEEE is common practice in the USA, as many people prefer to store their old and non-functional electronics (Lepawsky, 2012; Borthakur & Govind, 2017). Items such as TVs and computers are commonly put in storage as opposed to being recycled or disposed of. (Wagner, 2009; Lepawsky, 2012).

WEEE management in the USA is varies between states as there is no federal legislation on WEEE. California, in 2003, adopted an EPR management system which laid financial responsibility by the consumers of EEE for EoL management (Li, 2011). The state of Maine followed up with an EPR-based e-waste law in 2004, which is based on involvement of all stakeholders (producer, consumer & municipality) in shared responsibility of WEEE management (Ongondo *et al*., 2011; Borthakur & Govind, 2017). Currently, 15 out of 50 states have no form of regulation or legislation in place for WEEE management (Baldé *et al.*, 2017).

Different schemes and initiatives exist in the USA for WEEE management. One of such is the National Strategy for Electronics Stewardship (NSES). The program enables the promotion of environmentally safe EoL management of WEEE, reduction of WEEE exports to developing countries as well as encouraging concepts such as eco-design in electronics manufacturing (US-EPA, 2017c). Its framework has been adopted widely for the development of action plans for WEEE management across different states in the USA (Baldé *et al.*, 2017). Another initiative is the US-EPA managed Sustainable Materials Management (SMM) program. This involves the partnership between the US-EPA and original equipment manufacturers (OEMs) for the collection of WEEE from consumers. It also advocates for the purchase of certified 'green' electronics, particularly by federal agencies and to recycle generated WEEE at certified recycling facilities, including in states without WEEE takeback regulations (Baldé *et al.*, 2017).

There are two certification programs for the recycling of WEEE in the USA; the Responsible Recycling Standard for Electronic Recyclers (R2) Standard, which is run by the Sustainable Electronics Recycling International (SERI), and the E-Stewards certification programme, by Basel Action Network (BAN). The programs provide accreditation to electronic recycling facilities, subject to auditing and meeting set criteria. Over 550 recyclers in the US across different states are accredited by one or both schemes (US-EPA, 2017b).

2.3.5 WEEE management: Latin America

Latin America is experiencing increased penetration of ICT with sales of computers and mobile phone on a rapid rise. As a whole, it generates 4.5 MT of WEEE annually and this figure is expected to rise steadily (Forti *et al.*, 2020). This can be attributed to rapid urbanisation, with a rate of 75% compared to the global average of 50% (de Oliveira *et al*., 2012). A number of legal and regulatory frameworks on WEEE exist in Latin America, which have led to WEEE management practices in some of the countries.

2.3.5.1 Country Examples

2.3.5.1.1 Argentina

Argentina has experienced a marked increase in the consumption of EEE, particularly ICT and home appliances (Ongondo *et al*., 2011; Torres *et al.*, 2016). The high consumption of consumer electronics has led to steady increase in WEEE generation. Argentina generated approximately 2.5kg/person/year of WEEE in 2009 (Protomastro, 2009). The amount generated is reported to be closer to 8.5kg/person/year in 2016 with total generation of 460 KT in 2019 (Forti *et al.*, 2020), making Argentina one of the top WEEE producing countries in Latin America.

Argentina is a signatory to the Basel Convention, but it currently has no national WEEE legislation. Laws on hazardous waste treatment exist and currently cover the handling and treatment of WEEE (Torres *et al.*, 2016). The national government is currently collaboration with the National Institute of Industrial Technology on a programme that will establish WEEE recycling facilities and provide necessary training for relevant stakeholders (Torres *et al.*, 2016). The primary objective of the programme is to increase collection and recycling rates, currently only 3% (Torres *et al.*, 2016), and divert WEEE away from landfill.

2.3.5.1.2 Brazil

Brazil, like Argentina, is experiencing rapid ICT and consumer electronics penetration resulting in growing generation rate of obsolete EEE. More widespread usage of mobile phones, laptops, TVs, washing machines and temperature exchange equipment has contributed to approximately 2.1 MT of WEEE generated annually, at a rate of 7.4 kg/person/year (Forti *et al.*, 2020).

Brazil has regulations and policies aimed at the management of WEEE. The National Solid Waste Policy (Waste Law) mandates every single stakeholder within the lifecycle of EEE to be responsible for its EoL management (Torres *et al.*, 2016); the policy aims to promote reverse logistics of WEEE. There are recycling companies operating in Brazil, specialising in dismantling and recovery of materials such as aluminium, plastics and wires. Despite the significant increase in WEEE generation rate in Brazil, few authorised WEEE management systems are present, with large quantities of WEEE commingled with household waste and landfilled (de Souza *et al.*, 2016).

2.3.5.1.3 Chile

Chile is amongst the top generator of WEEE amongst countries in Latin America. Per capita generation annually is 8.7kg/person; a higher generation rate than Brazil and Argentina in 2016 (Baldé *et al.*, 2017). Like most Latin American countries, consumer electronics account for a significant proportion of WEEE generated in Chile.

Chile introduced a WEEE-specific law in 2016 which provides a legal framework for WEEE management via extended producer responsibility (Silva & Baigorrotegui, 2020). The law is unique as, unlike other legislation in Latin American countries, it incorporates informal recyclers such as waste pickers into the WEEE management system (Silva & Baigorrotegui, 2020).

2.3.5.1.4 Other Latin American Countries

Bolivia generates 40 KT of WEEE annually with per capita generation of 3.3 kg/person/year; WEEE generated mostly discarded consumer electronics (Forti *et al.*, 2020). There is no WEEE legislation currently in Bolivia, but government has a partnership with United Nations Industrial Development Programme (UNIDO) on tackling persistent organic pollutants (POPs) emitted from uncontrolled WEEE recycling.

In Paraguay, a significant amount of the 44 KT of WEEE it generates annually ends up in open dumps, as there is currently no WEEE legislation. Peru, with its rapid ICT penetration in recent years, generates 182 KT of WEEE mainly from ICT devices (Torres *et al.*, 2016). WEEE-related legislation called National Regulation for the Management of Waste Electrical and Electronic Equipment specifies the roles of producers, retailers. Official collection occurs with planned capacity enhancements.

Mexico is a major contributor of WEEE in Latin America, generating an estimated 950 KT in 2014 (Kuehr *et al.*, 2015). This was predicted to exceed 1MT by 2018 and by 2019 it was 1.2 MT (Forti *et al*., 2020). According to waste legislation in Mexico, WEEE is classified as special handling waste and there is a framework in place that sets out the responsibilities of various players (from manufacturers to consumers) (Cruz-Sotelo *et al.*, 2016). Columbia generates an estimated 250 KT of WEEE annually (Kuehr *et al*., 2015; World Resources Forum, 2017). The first WEEE-related guidelines were set in 2013 which provided a framework for WEEE compliance schemes (Kuehr *et al*., 2015). This was followed up with a national policy on WEEE management in 2017 with key objectives including responsible consumption and proper end of life management of WEEE (World Resources Forum, 2017).

Nicaragua’s generation of WEEE is estimated to be 2 kg/person/year (Central America Data, 2020) with total generation estimated at 11 KT in 2014 (Kuehr *et al*., 2015). There are no known official treatment channels for WEEE management (Central America Data, 2020).

Uruguay currently has no WEEE-specific legislation to deal with the 32 KT of WEEE it generates annually (Kuehr *et al*., 2015). Collected WEEE is dealt with mostly by manual disassembly and recovery of metals.

2.3.6 WEEE management: Oceania

2.3.6.1 Country Examples

2.3.6.1.1 Australia

With 23.6 kg/capita/year of WEEE generated in 2016 (Baldé *et al.*, 2017), Australia ranks amongst the top WEEE generating countries (per capita) in the world. It generates 574 KT of the approximated 700 KT of WEEE generated in Oceania. A total of 60% of the entire population in Oceania lives in Australia, which has a population of 23.5 million (OECD, 2018a). This factor, together with Australia being a top EEE consumer has led to high EEE turnover (Morris and Metternicht, 2016). In 2014, an average person acquired 35kg of EEEs, mostly consumer electronics, mobile phones, and disposed of 25 kg of WEEE (Golev *et al.*, 2016).

Australia has a number of regulations that cover WEEE management; the National Waste Policy (2009); Product Stewardship Act (2011); Product Stewardship (for TVs and computers) regulations and the National Television and Computer Recycling Scheme (NTCRS) (Morris and Metternicht, 2016). These regulations have led to the introduction of schemes for EoL management of WEEE. The Product Stewardship (TVs and computers) regulation that came into force in 2011 provides legal framework for the establishment of the NTCRS for recycling services. These privately funded schemes, supported by the national government, provide services for the collection and recycling of computers and TVs (Morris & Metternicht, 2016; Baldé *et al.*, 2017). While the scheme lacks coverage for other WEEE categories, it aims to attain 80% collection rate of computers and TVs; there are currently 1,800 services available, collecting over 130 KT of computers and TVs, with a 35% recycling rate (Australian Government, 2018).

The Australia Mobile Telecommunications Association (AMTA) coordinates discarded mobile phones collection and recycling. It carries out collection and recycling through its accredited programme, Mobile Muster, which are then recycled. (Australian Mobile Telecommunications Association, 2018).

2.3.6.1.2 New Zealand

New Zealand generates approximately 95 KT of WEEE, with per capita generation estimated to be 20.1kg/person/year (Baldé *et al.*, 2017; Forti *et al.*, 2020). There is paucity of information on amount of WEEE collected and recycled, with high likelihood of comingling of WEEE with general waste.

There is currently no WEEE legislation in New Zealand. However, the government has explored the possibility of creating a product stewardship scheme by undertaking stakeholder consultations and WEEE data collection and analysis (Baldé *et al.*, 2017).

2.3.6.1.3 Other Oceanic Countries

WEEE management in the Pacific Island countries and territories (PICTs) is mostly informal. The Pacific Regional Waste Pollution Management Strategy was recently adopted to facilitate waste management in the sub-region (Baldé *et al.*, 2017). Current and future WEEE management, alongside other waste streams, are included in the strategy. Another project backed by the European Union known as PacWaste which is based in Samoa is ongoing to collect relevant data on WEEE management, including generation data and current management practices in the Pacific Island Countries (Baldé *et al.*, 2017).

2.4 Discussion

2.4.1 Global scenarios and trends of WEEE

The rapid growth in global WEEE generation is attributable to advances and evolution of EEE and the ever-increasing integration of these into day-to-day activities. While the developed countries (particularly in Europe and America) have been predominately the biggest generators of WEEE, developing and emerging countries in Asia and Africa are catching up in this regard; a summary of generation figures in countries reviewed is presented in Figure 2.3. In addition to terrestrial forms of WEEE, we note that there are likely >500,000 pieces of anthropogenic space debris, many of which may be defined as WEEE. Whilst there is currently no mechanism for bringing space debris back to Earth for potential recovery, strategies for removing space debris are currently evolving (White & Lewis, 2014).

Four typical management scenarios have been identified and classified:

Scenario 1 involves formally-documented and collected WEEE, in accordance to statutory requirements provided by existing WEEE/WEEE-related legislation. The collection of WEEE in this scenario is usually carried out via municipal collection points, EEE producers and retailers or through dedicated pick-up arrangements. Items of WEEE collected are transported to specialised treatment facilities, where they are treated via processes (including manual disassembly, shredding and materials recycling) under controlled conditions to ensure environmentally sound manner (ESM) of treatment.

Scenario 2 is characterised by the direct disposal of WEEE together with commingled household waste. Consumers dispose of WEEE together with non-segregated household waste. The commingled waste may then be destined for landfill or incineration, depending on prevalent disposal methods.

Scenario 3 involves unofficial collection of WEEE. Waste brokers and dealers may be involved in these activities. Outcomes include recycling of collected WEEE at specialist facilities, refurbishment or exportation to developing countries. Unlike scenario 1, collected WEEE in this scenario is not officially documented, making generation and collected amounts difficult to track; this may be due to the absence of legal requirements or framework for WEEE management. Consequently, treatment of WEEE collected may not be environmentally sound or may be destined for illegal export.

Scenario 4 is more prevalent in developing countries[6] and involves informal collection of WEEE from consumers by waste brokers and scrappers. These activities are not regulated as there is absence, or no enforcement of, legislation relating to WEEE management. Consequently, treatment methods are often basic and crude; typically, collectors are after the metals constituents within the WEEE and would often resort to open burning and acid leaching for metal extraction. This scenario, which also involves reuse, repair and cannibalising WEEE for parts, also occurs within Europe. The sequence for informal recycling of WEEE and a summary of the actors/steps involved can be found in Williams (2016).

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[6] Based on World Trade Organisation classification https://www.wto.org/english/tratop_e/devel_e/d1who_e.htm

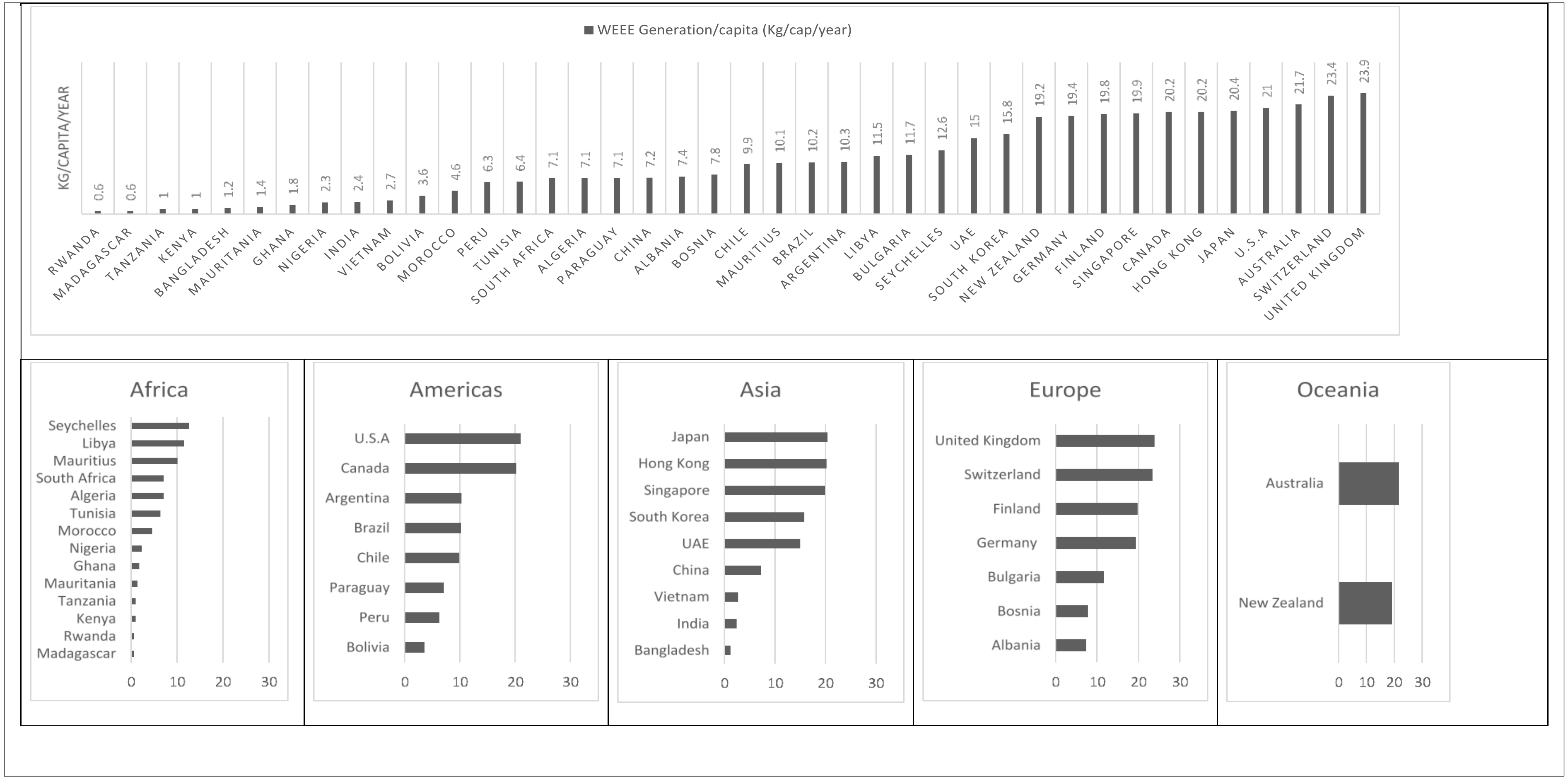

Figure 2.3. Summary of global WEEE generation (kg/person/year). Data from Forti *et al*. (2020)

Integrated WEEE management still presents a significant challenge and, perhaps, one of the most notable challenges in WEEE management is data reporting on generation and disposal of WEEE. The use of different methodologies for classification and reporting of WEEE means that generation, recycling and disposal data available from certain countries may be underestimated or misreported. This is especially true for countries with significant informal recycling sectors. There is a standardised framework developed by the United Nations University which considers parameters such as total EEE put on the market, WEEE generated and collection rate (Baldé *et al.*, 2015; Baldé *et al.*, 2017; Forti *et al.*, 2020). The framework is based on classification of WEEE into six main categories (Annex III of the EU WEEE Directive; *see* Table 2.1). Table 2.4 summarises some changes in global WEEE management since 2011.

Table 2.4. Summary of WEEE management changes based on review of literature (2011 – 2019)

Changes	**2011**	**2019**
WEEE Legislation coverage	<44%	66%
Total WEEE generated	35.8 MT	54 MT
% of WEEE official collected	-	<20%
EU WEEE Directive collection targets	4 kg/capita/year	45% of EEE y in 3 preceding years[7]

WEEE management in Europe has evolved significantly since the transposition of The European Union WEEE Directive into the national laws of Member States. While countries like Finland already had measures in place pre-dating the WEEE Directive, its introduction has helped other Member States to put in place structures and mechanisms for WEEE management. The Recast WEEE Directive (2012/19/EU) aims to further enhance recycling rates by setting targets based on EEE put on market. Whilst imperfect, the defined framework has resulted in Europe being the top collector and recycler of WEEE globally, with 42% recycling rate (as shown in Figure 2.4) (Forti *et al.*, 2020). Of the total 12.3 MT generated in Europe in 2016, approximately 5.1 MT was reportedly collected (Forti *et al.*, 2020). Although collection rate in countries such as Finland and

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[7] Collection rate to increase to 65% average EEE POM in three preceding years or 85% of annually generated WEEE from 2019

Sweden collect above the European average (55% and 69% respectively), areas like the Balkan region and eastern Europe currently achieve lower collection rates.

Figure 2.4. WEEE collection rate by region (Figures in million tonnes)
Adapted from Forti *et al.* (2020).

Africa has seen a surge in levels of ICT penetration and sales of consumer electronics in recent years. With widespread usage of electronics and electrical devices, due in part with increasing affordability and economic growth, many African countries, particularly in the Maghreb, western and southern sub-regions of Africa, use more EEE. There is also an influx of used electronics/WEEE from developed countries in Europe, America and Asia; this compounds the challenges of WEEE management on the continent, especially in West Africa where countries such as Nigeria and Ghana have booming informal WEEE trading and recycling. With WEEE management strategies and legislation still sparse on the continent, informal dismantling and recycling is rife, often resulting in adverse environmental and health outcomes (Nnorom & Osibanjo, 2008b; Ongondo *et al*., 2011; Ogungbuyi *et al.*, 2012; Schluep *et al.*, 2012; Li *et al.*, 2013; Odeyingbo *et al*., 2016; Williams, 2016). A host of African countries has ratified the Basel Convention, and countries such as Nigeria and Ghana have legislated against WEEE importation. A recent study in Nigeria to evaluate WEEE imports shows that the 2 main container ports in Lagos (Apapa and Tin-Can ports) still receive huge shipments of WEEE, mostly from China and the European Union (Odeyingbo *et al*., 2016). Asia is home to over a third of the total global human population, with China and India accounting for over half of the total. The activity of China in the WEEE sector dominates, due to its population and economic power. As a major EEE manufacturer, and indeed, generator of WEEE, China influences the movement of electronics within the Asian region and across the world. China has legislation to regulate WEEE management, but activities of the informal recycling sector still overshadows official management schemes; only 18% of WEEE generated (7.2 MT) in 2016 was officially collected and recycled (Baldé *et al.*, 2017). India, with a population of over 1 billion, also contributes in terms of total WEEE generated in South East Asia region, though its per capita generation of 1.5 kg is amongst the lowest (Baldé *et al.*, 2017). As in China, informal sector collection and recycling is highly established, involving over 1 million people (Baldé *et al.*, 2017). Countries such as Japan and South Korea have developed their collection and recycling networks in recent years. WEEE generation is significantly high in the Middle East, especially in the Gulf nation states such as United Arab Emirates and Kuwait where turnover rates of EEE are amongst the highest in the world (Baldé *et al.*, 2017).

In the Americas, there is distinct disparity between generation in the north and south. In North America, Canada and United States per capita generation is approximately 20 kg/person/year and 19 kg/person/year respectively. Both countries have WEEE-related legislation, which varies from state to state in the USA. Generation rates vary wildly; a state like New York would generate more WEEE than Wyoming due to huge difference in their respective populations. This also has an effect on decisions on the type and scale of infrastructure needed for WEEE management. However, WEEE collection in the USA is selective with only items such as video & audio equipment, screens & monitors, mobile phones mostly covered in collection schemes. Canada collects are wider range of products, but recycling rate is reported to be 20% (Kumar & Holuszko, 2016). In South America, WEEE related legislation is not widespread, although countries like Argentina and Brazil have recently drafted related legislation for WEEE management. The WEEE generation rate is on the rise, as seen in countries such as Chile and Peru. Official collection and recycling is currently not well developed in the sub-region but with further development of WEEE legislation in the coming years, this is expected to increase steadily.

In Oceania, Australia and New Zealand are the largest producers of WEEE. While Australia has a product stewardship programme that has spawned schemes for takeback and recycling of WEEE, New Zealand is yet to develop a legal framework to support WEEE management.

2.4.2 Transboundary movement of WEEE

Transboundary movement of WEEE occurs on a global scale. Movements include new and used electrical and electronic products. UEEE are exported predominately from developing countries in Europe, Asia and America to less developed countries, where demand for cheaper used electronics has been high in recent years. However, due to difficulty in distinguishing between UEEE and WEEE, thousands of tonnes of the latter end up being shipped to developing and less developed countries, especially in Africa and Asia. These shipments end up becoming burdensome to the importing country, many of which lack adequate infrastructure to environmentally safe WEEE management.

Transboundary movement is banned under the Basel Convention and signatory countries are expected to restrict the movement of hazardous waste, including WEEE, in or out of their boundaries. This has done little to stem the movements in some signatory countries as WEEE still gets imported disguised as UEEE. While product reuse including UEEE is desirable (Hursthouse *et al*., 2017; Diop & Shaw, 2018; Williams & Powell, 2019; Wilkinson & Williams, 2020), difficulty in distinguishing WEEE from UEEE, as well as loose enforcement at importing countries, has resulted in continued movement of WEEE. In Nigeria, for instance, despite the ban on the importation, shipments of WEEE make their way into the country disguised as used electronics, with 19% of such electronics failing basic functionality tests (Odeyingbo *et al*., 2016). A significant amount of electronics originates from the EU and China. Another study by Hopson and Pucket (2016) involving the use of Global Positioning System (GPS) trackers recorded transboundary movement, mainly from the EU and United States to developing countries in Asia.

2.4.3 Contemporary Issues

2.4.3.1 WEEE and the Sustainable Development Goals (SDGs)

In 2015, the United Nations (UN), in collaboration with Member States, pledged to an ambitious plan for sustainable development. The plan involves achieving 17 major goals (SDGs) by the year 2030 (United Nations, 2017); goals include ending poverty and promoting sustainable prosperity. Waste management, among other activities, is crucial in the realisation of all 17 SDGs (WasteAid, 2016; Rodic-Wiersma & Wilson, 2017). Increased prosperity will lead to higher standards of living, and by extension, contribute to increase in the generation of WEEE. The environmentally safe management of WEEE contributes in some way to the attainment of the 17 goals, it contributes majorly to the following SDGs:

- Goal 3: Good health and well-being
- Goal 6: Clean water and sanitation
- Goal 12: Responsible consumption and production
- Goal 13: Climate action

It is well known that crude treatment such as uncontrolled burning and recycling of WEEE poses a health risk to not only those directly involved, but the larger area. Contamination of air, water and soil by effluents emanating from such activities undermines achieving SDG goals 3 and 6. In addition, closed-loop management of WEEE potentially helps with achieving goal 12 in ensuring recovery of secondary resources and minimisation of waste. The effective recovery and reuse or recycling of WEEE can contribute significantly towards a net climate benefit (goal 13) (Clark *et al*., 2019).

2.4.3.2 Urban mining for material recovery

EEE are of different categories and forms. The constituents vary largely between different categories; while an electric kettle consists of mainly plastics and ferrous metals, a smartphone is a more complex mix of ferrous, non-ferrous metals and rare earth elements. As many as 60 elements can be found in some EEEs; materials such as plastics, precious metals (PMs) and rare earth metals (REE) are commonly used to manufacture of these products. Some examples are shown in Table 2.5. Technically, recovery of most of these constituents is possible due to recent advances in metallurgical and recovery technology (Wang *et al*., 2017; Hsu *et al*. 2019), though the economic viability is a crucial factor. In addition to mining for electronics in urban spaces on earth, there are plans to extend this to outer space with the recovery of potentially valuable materials from space debris from earth's orbit (Devlin, 2019).

Table 2.5. Select material contents of WEEE and quantities

Material	**Top primary producers**	**Quantities present in WEEE (2019) (in KT; approximated)**
Iron (Fe)	China, Australia, Brazil	20,500
Copper (Cu)	Chile, Peru, China	1,800
Cobalt (Co)	Democratic Republic of Congo China, Zambia	13
Silver (Ag)	Mexico, Peru, China	1.2
Gold (Au)	China, Australia, United States	0.2

Adapted from Royal Society of Chemistry(2017); Forti *et al*. (2020)

An estimated value of 57 billion Euros worth of secondary raw materials are present in total WEEE generated in 2019 (Forti *et al.*, 2020). With such value locked in WEEE, recovery of secondary materials is important to conserve depleting primary raw materials. This will involve a closed loop (circular economy) model of operation as the linear model leads to higher waste generation.

Whilst WEEE can be seen an urban mine of valuable resources, it also contains potentially hazardous substances that, if not adequately handled, can pose health and environmental risks. Such substances such as mercury and other heavy metals are the prevalent sources of pollution at sites of uncontrolled and crude recycling of WEEE.

2.4.3.3 REM availability

Rare earth metals (REMs) are a sub-category of metals which, together with rare light metals, rare refractory metals, rare scattered metals and rare radiation metals, belong to a larger group of metals called Rare Metals (RM). Despite the name, REMs are a relatively abundant group of metals naturally occurring in the Earth's crust. However, the difficulty and danger of extraction of these metals has meant that they are produced in limited quantities in few places in the world, predominately in China. Despite their 'rarity', their applications have become widespread in the areas of aviation, robotics and EEE manufacture. They are considered strategic resources for national economic and technological growth (Wang *et al*., 2017).

The use of REM such as terbium and yttrium is crucial in the technology behind smart devices such as LED TVs, and currently, China extracts and produces the largest amounts of REM (Schüler *et al.*, 2011). This could lead to potential accessibility and supply issues with these metals in the future, especially as China has been known to place export quotas on them (Wilburn, 2012).

2.4.3.4 Device stockpiling/hoarding

Holding on to devices after end of use (stockpiling/hoarding) is rapidly increasing, particularly with small electronic devices (Ongondo & Williams, 2011; Ongondo *et al*., 2015; Pierron *et al*., 2017) and this largely contributes the 'home landfill' phenomenon known as hibernation. Small items are hoarded more often as they are more convenient to keep, requiring little storage spaces (Pierron *et al.*, 2017; Wilkinson & Williams., 2020). Their perceived value, together with users wanting to have a 'back-up' device, despite not in use also accounts for stockpiling and hoarding. This subject is explored further in Chapter 3.

2.4.3.5 EEE obsolescence

Device obsolescence contributes immensely to WEEE generation challenges. Turn-over of a device by its owner can occur for a number of reasons: a device performing sub-optimally as a result of prolonged use (technical obsolescence); introduction of newer and trendy models which offer better fashion and economic value (fashion obsolescence) (Wilkinson & Williams, 2020). Miniaturisation and increased versatility of devices have also contributed in the redundancy of older devices; this is common particularly with small, handheld smart devices such as smart phones and tablets computers, which are increasingly replacing larger devices due to their ability to access, produce and share digital media contents. Device obsolescence also occurs on a large scale after one-off events such as digital TV switchover; and the gradual emergence of digital radio broadcast (DAB). It is expected that device obsolescence will accelerate even further with emergence of new technologies, resulting in an increase in WEEE generation. New and emerging technology in areas such as electronic textiles (e-Textiles) and smart agriculture will in turn lead to the emergence of new WEEE streams as these new devices reach their end-of-life. Device obsolescence is linked to hibernation highlighted in section 2.4.3.4 and will be discussed further in Chapter 3.

2.4.3.6 Internet of Things (IoT) and data protection

The Internet of Things is the term used to describe the interfacing and interconnectivity through a network (the Internet) between multiple EEE. This allows for the interaction and exchanging of data between connected devices. Modern variants of devices such as sandwich toasters, refrigerators, portable speakers, as well as items such as coffee mugs, are becoming internet-enabled making them capable of accessing and storing personal information. It is estimated that the total number of IoT devices will exceed 30 billion by end of 2020 (Nordrum, 2016).

End of use (EoU) and end of life (EoL) management of such IoT EEE can potentially result in personal data theft and security threats, as highlighted by Doyon-Martin (2015) which brings to fore concerns about data theft and other forms of cyber-crime. With more EEE becoming smart and IoT-enabled, there is growing concern about unauthorised access to, and usage of, personal information; indeed, data theft and unauthorised access to personal information is on the rise (Kuchler, 2018; Murray, 2018).

2.4.3.7 Free-riding

So-called “Free-riding” occurs when EEE retailers do not register with a take-back scheme for EoL/EoU collection and management of (W)EEE. The issue is particularly exacerbated by online trading of EEE by retailers and seller. Registration of EEE producers and retailers with compliance and WEEE take-back schemes is required in certain countries. However, online traders are known to circumvent this; the issue being made more pronounced with the upward trend in online purchases.

2.4.4 Evaluation of Contemporary issues: Urgency-Importance Matrix

Contemporary issues on WEEE management discussed previously were evaluated using the Urgency-Importance Matrix (*see* Table 2.6). This matrix is used to aid decision-making by ranking actions or events in order of priority (Likert, 1932; Parducci, 1983; Krosnick & Fabrigar, 1997; Menold & Tausch, 2016; Ghoushchi & Khazaeihli), 2019). The scores and rankings presented were based on author's evaluation of the issues discussed. The scores are based on assigning ranks to the issues based on their importance and urgency. Seven issues were identified and evaluated. Of these, 4 were ranked highest (with score of 12). Device stockpiling and hoarding was identified as an urgent (urgency rating: 3) and important (importance rating: 4) as well as urban mining for material recovery. Focus on these two issues is believed to be crucial in WEEE management which explains their high ratings.

Table 2.6. Contemporary issues in WEEE management including urgency/importance rating

Contemporary issue	**Remarks**	**Urgency rating**	**Importance rating**	**Urgency/Importance rating**
WEEE and SDG	WEEE recovery + EoU EEE reuse contributes to realisation of SDGs, particularly 3, 6 & 12	3	4	12
Urban mining for material recovery	materials recovery from discarded EEE/WEEE is in line with circular economy and a shift away from linear production and consumption	3	4	12
REM availability	REMs such as indium and access to them are increasingly important with their use in devices such as LED flat panel displays (FPDs)	2	2	4
Device stockpiling/hoarding	perceived value of discarded devices together with little or no EoL/EoU management infrastructure contributes to stockpiling/hoarding	3	4	12
Device obsolescence	technical obsolescence likely to increase as technological improvements are made, especially with consumer audio/visual EEE	2	3	6
IoT and data protection	with more appliances becoming smart and internet-enabled, concerns over personal data stored within them will increase particularly after EoL/EoU	2	4	8
Free-riding of EEE	increase in online trading of EEE has resulted in 'free-riding' in countries/regions where EEE producers are required to belong to a producer compliance scheme (PCS)	3	4	12

Definitions for Urgency rating: 1: Requires action in 5+ years; 2: Requires action in 5 years; 3: Requires action in 2-4 years; 4: Requires action immediately.
Definitions for importance rating: 1: Not important; 2: Least important; 3: Important; 4: Most important

2.5 Chapter conclusions

From this review the following conclusions can be drawn: (1) Globally, there are few countries or regions in which existing WEEE is properly collected and treated; (2) New and emerging technologies will continue to accelerate obsolescence and create new WEEE streams; (3) An increase in global WEEE legislation coverage, especially in Asia and Africa, is anticipated. In the EU, the EU WEEE Directive (Recast) will enhance collection and recycling rates; (4) Harmonisation of key terms and definitions in WEEE management and standardisation of WEEE data reporting is required for better management; (5) The activities of the informal WEEE sector need to be better regulated and recorded such that their value is known and risks to human health and the environment are reduced; (6) Manufacturers need to adopt circular economy principles from design to end-of-life of WEEE; (7) Stockpiling and hoarding need to be de-incentivised to allow for recovery of reusable and recyclable items; (8) A rapid move towards circular economic approaches to WEEE management and the urban mining of secondary raw materials from discarded EEE is necessary; (9) Recovery of reusable EEE which will turn require setting clear reuse standard for products to be reintroduced into the circular economy; (10) Synergy of activities amongst all players, from manufacturers to consumers, to properly tackle the WEEE management challenge is essential. Collaboration between all players as well as policy frameworks is required in addressing the WEEE challenge.

Chapter 3 Prospecting a DUM: survey of ownership and hibernation of small EEE within a meso-level distinct urban mine

3.1 Chapter overview

As discussed in Chapter 2, advances in technology have led to a proliferation of electrical and electronic equipment (EEE) in recent years. This combined with an increase in globalisation, urbanisation, high levels of disposable income and consumerism, has led to a high level of EEE usage with a consequent generation of huge amounts of waste electrical and electronic equipment (WEEE) at products' end-of-life. The chapter further highlighted recycling of WEEE as the predominant pathway for WEEE management as well as the need to explore product reuse at end of use/life. Product reuse at end of life is currently under-researched as an option for management of WEEE and this chapter explores the potential for exploitation in the context of urban mining

This chapter is the presentation of the second phase of the research thesis as illustrated in the road map (Figure 3.1). The chapter begins with an overview and outline of chapter (current section). Second section provides some background on distinct urban mines (DUMs) and their potential exploitation for product reuse. In this section, levels and examples of DUMs are outlined and explained. The section also introduces Higher Education Institutions (HEIs) such as universities as potential DUM hubs for product recovery.

The third and fourth sections provide the rationale for this phase of the study, aims and objectives as well as the experimental design for the assessment of the potential of a DUM for product recovery. The results and discussion of this research phase are presented in sections 5 and 6 with a summary and conclusion provided in section 7. A modified version of this chapter titled *Prospecting reusable small electrical and electronic equipment (EEE) in distinct anthropogenic spaces* has been submitted to *Resources Conservation and Recycling* journal for publication.

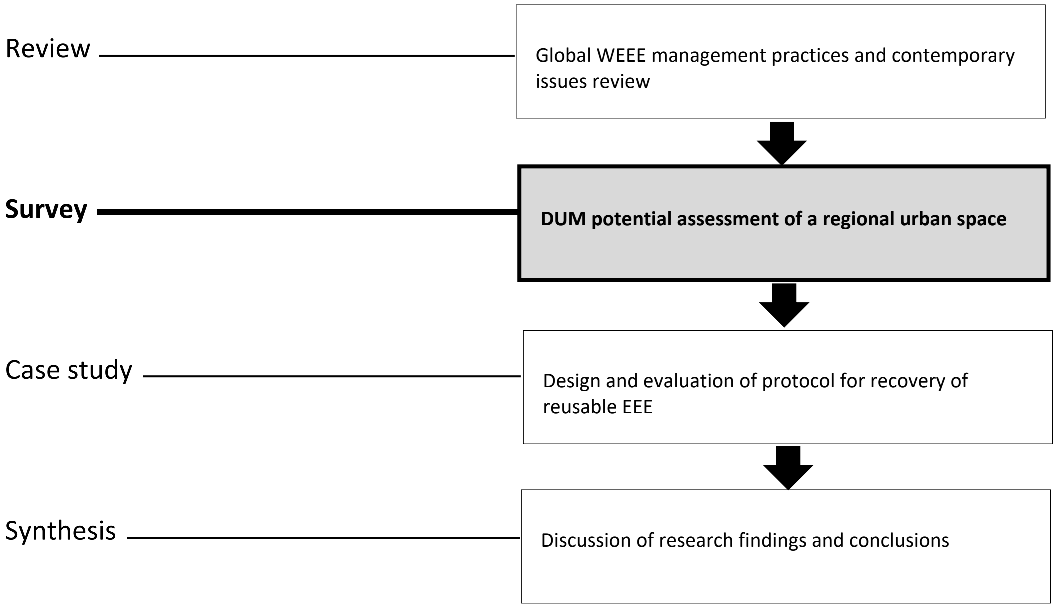

Figure 3.1. Thesis road map showing the survey phase of the research

3.2 Distinct urban mines

The concept of urban mining is closely linked to resource recovery and efficiency that aims to recover materials and resources from the anthroposphere[8]. Cossu and Williams (2015) defined urban mining as a strategy of recovering valuable materials from anthropogenic sources. They argued that resource recovery, which can be reused/recycled is fundamental to shifting towards a circular economy. This urban 'living' space is considered as a source of materials that can be recovered for recycling and reuse (Brunner, 2011; Ongondo *et al*., 2015). The materials and resources recoverable from individual urban spaces differ. The uniqueness of an urban mine, as argued by Ongondo *et al*. (2015), is due to factors such as composition and concentration of materials of interest, and material/product flow as well as the demographic profile of the urban space. This delimited space, unique in its material composition and concentration is called a Distinct Urban Mine (DUM).

Urban mining is often associated with the diversion and recovery of materials from discarded items which are then directed towards recycling (Cossu & Williams, 2015; Pierron *et al*., 2020) and

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[8] Anthroposphere is the segment of the environment that is created and modified by human beings.

previous studies have reflected this. For instance, Krook and Baas (2011) investigated the potential for copper exploitation from power grids in Sweden. They observed that the viability of urban mining is significantly dependent on ancillary factors such as system maintenance during which material exploitation can occur. This was also the subject of a similar study by Wallsten *et al*. (2015). Simoni *et al*. (2015) explored the policy aspect of urban mining in Switzerland and opined that urban mining is heavily dependent on policy-making geared towards economic viability of product recovery from this activity. This theme was also the subject of research by Gutberlet *et al*. (2015). They studied informal urban mining in Brazil and suggested that well-formulated structures were required to enhance drive towards sustainable development. On the technical side, Sun *et al*. (2015) and Tunsu *et al*. (2015) observed that WEEE, particularly ICT equipment are a valuable and strategic source of secondary materials such REE. The improvements in extraction of these materials from WEEE is the subject of the studies such Wang *et al*. 92017) and Ramanayaka *et al*. (2019). In all these studies, the focus of urban mining was on material recovery after product endo of use/life. While this is a strategically desirable outcome, ‘urban mining for reuse’ provides the opportunity to extend product lifetimes where possible before material recovery for recycling occurs. This route is the focus of the present study.

As with a traditional mine, a DUM requires prospection to determine its viability. Information such as size, concentration of materials and resources of interest and its location within the wider anthroposphere is necessary (Ongondo *et al*., 2015; Pierron *et al*., 2017., Ramanayaka *et al*., 2019). A DUM can be defined in relation to its size and boundaries. As illustrated in Figure 3.2, a DUM can be described as *micro-level*, *meso-level* or *macro-level*; a micro-level DUM being ‘small-sized’ such universities, neighbourhoods, city centres. A meso-level DUM is a larger spatial entity falling between micro-level and macro-level DUMs (e.g. a state, regional institutional clusters) while the highest level of classification (macro level) covers a much larger area such a country or nation.

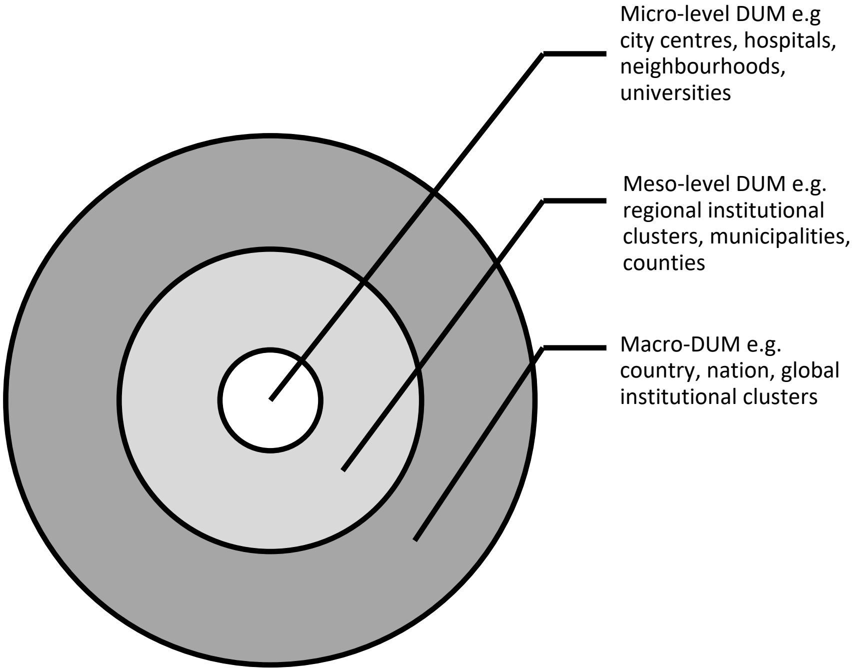

Figure 3.2. Schematic highlighting the hierarchical relationship between micro-, meso- and macro- levels of DUM classification.

There are different drivers for circularity in WEEE management including diversion of materials from landfill and economically-feasible recovery of precious metals (PM) from WEEE via recycling. Techniques used for PM recovery from WEEE have advanced in recent years and it is now possible to extract minute amounts of PM and REEE from WEEE (Tesfaye *et al*., 2017; Wang *et al*., 2018, Ramanayaka *et al*., 2019). Such recovery requires disassembly of the products to obtain the material components within. This route promotes circularity by recovering valuable materials and is desirable for EEE that have reached their end-of-life and cease to provide utility. However, not all products disposed of have reached this stage and it possible for a product to have multiple usage cycles throughout its lifetime. This presents an opportunity for product reuse and thus urban mining can be targeted at recovery of products with reuse value destined for disposal or hibernation[9] as opposed to material value.

3.2.1 EEE reuse potential in distinct urban spaces

DUMs are areas of high concentration of materials/products of interest. In recent years, there has been growing emphasis on product diversion from landfill in favour of more preferred outcomes higher up the waste hierarchy (*see* Figure 3.3). Product recovery for reuse from DUMs is

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[9] Hibernating devices/products are unused items in storage. These could be functional or non-functional.

exemplary of this shift higher up the waste hierarchy. Product reuse is the repurposing of a product/device for the purpose it was manufactured by extending its useful life through interventions such as repair, refurbishment and/or remanufacturing (Bovea *et al*., 2016). It involves the recovery of discarded end-of-use products or devices, with functional value, and its reintroduction into usage using the quickest pathway possible to achieve this (e.g. direct reuse and reuse after repair) as well as other interventions including refurbishing and remanufacturing. (Reike *et al*., 2018). This route, as illustrated in the waste hierarchy, is a more desirable outcome and urban mines can be tapped for reusable resources due to their unique composition (demographic profile, material composition and consumption). According to the definition of a DUM, places like hospitals and universities are prime examples of unique spaces (micro-level DUMs) from which materials and products can be recovered (Ongondo *et al*., 2015).

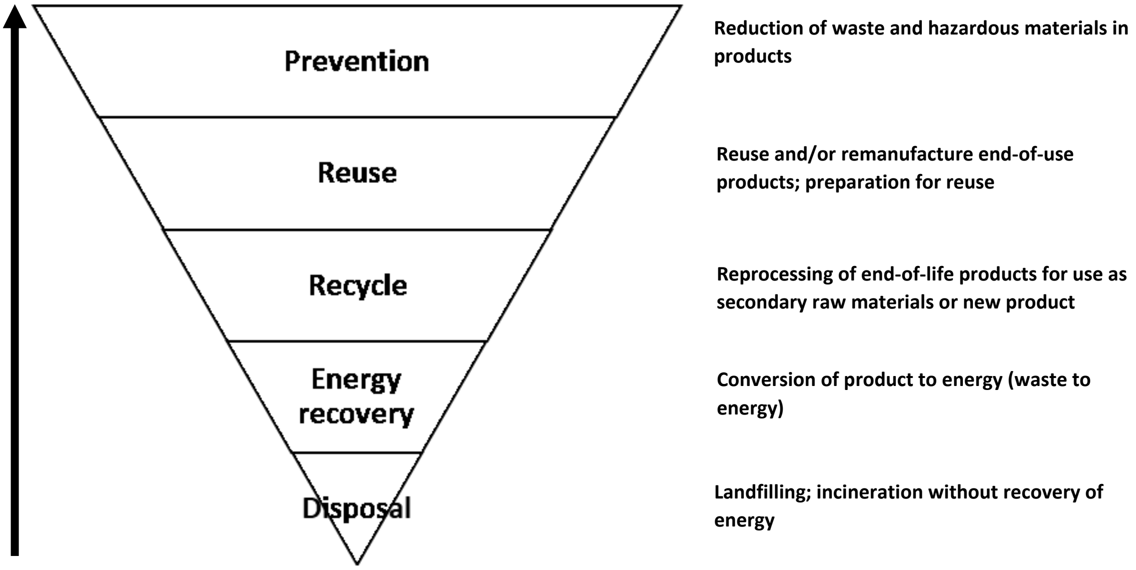

Figure 3.3. Waste Hierarchy (adapted from: OECD iLibrary, 2020); arrow indicates the direction of preferred outcome.

There has been a focus of recovery of WEEE and the recycling value obtainable is well established. Chancerel and Rotter (2009) examined the value of materials from recycling of WEEE. In their study, materials from WEEE were characterised and categorised for their recycling value and concluded that WEEE have high variability in mechanical properties and material composition. This was the theme for a similar study carried out by Oguchi *et al*. (2011) which focused on WEEE as a source of secondary metals and they identified large EEE such as refrigerators, washing machines and air conditioners as important sources of common metals such as ferrous metals while small EEE such as mobile phones, computers and video games were sources of precious metals (PM). As highlighted in section 3.2, advanced processes for rare and precious metals (RPM) recovery using hydrometallurgy and biometallurgy (Wang *et al*., 2019) and nanotechnology (Ramanayaka *et al*., 2019) have also been explored. However, these studies examined the options available for recovery of materials from end-of-life (EoL) EEE and focus on product recycling and material extraction from WEEE. In their study of the potential for circular economy in household WEEE in Denmark, Parajuly & Wenzel (2017) presented an analysis of reuse value of recovered WEEE and argued for a recovery system tailored for reclamation of reusable EEE due to reuse potential exceeding recycling potential. In relation to DUMs, there are currently few studies on recovery of reusable EEE from unique urban spaces such as Higher Education Institutions (HEI) e.g. universities. The concept of urban mining from distinct spaces was presented by Ongondo *et al*. (2015) in which they demonstrated how high-value EEE can be prospected in a university DUM. Likewise, Pierron *et al*. (2017) discussed the application of choice architecture in the enhancement of recovery of W/EEE from a university DUM after observing high level of disposal (approximately 35%) of small household items are discarded in general waste. Home entertainment devices was the focus of the study by Wilkinson and Williams (2020) in which they surveyed the ownership levels of these devices in the UK. These studies involved an evaluation of potential stocks within the DUMs of interest.

3.2.2 Higher Education Institutions as circular economy hubs

Higher Education Institutions (HEIs) are viewed as beacons of positive change and promoters of environmental sustainability (Martin & Samels, 2012; Vagnoni & Cavicchi, 2015). This reputation is achieved via knowledge creation and dissemination as well as commitment to sustainable initiatives and policies (Zhang *et al*., 2011; Tangwanichagapong *et al*., 2017), ranging from construction of ‘green’ buildings to carbon-neutral transportation systems and sustainable waste management systems with emphasis on reuse, recycling and resource conservation. With regard to waste management, one step towards achieving sustainability is to consider a HEI to constitute a distinct urban mine (Ongondo *et al*., 2015). HEIs can be viewed as small cities and provide a microcosm of the settlements within which they are situated. People within these HEI environments, like regular towns or cities, are consumers of goods and services, which make these urban spaces ideal for studying and trialling new initiatives before being implemented at broader scale.

In recent years, resource recovery from waste has been in focus in HEIs. There is growing emphasis on diversion of materials from landfill and circular economy thinking based upon application of the waste hierarchy. In a university urban mine, there is potential to divert potentially reusable items during periods of transience (e.g. when students vacate Halls of Residence) and thereby contribute to efforts to use resources more effectively. One of the categories of items recoverable during such periods is (W)EEE. With WEEE collection rates currently low in most countries and stockpiling of WEEE common, valuable and critical raw materials within these items are potentially lost (*see* Chapter 2). The loss of such critical raw materials as well as good, functional reusable products emphasizes the need to adopt circular economy approaches, as these will have a positive impact on the future management of (W)EEE. To achieve this aim, an understanding of distinct urban mines is required which will help enhance recovery of reusable EEE as well as resource recovery from WEEE via recycling, leading overall to improved WEEE management. However, for an urban mine to be considered viable, there must be detailed data and information concerning its attributes such as location, size, concentration of materials and resources to be prospected, and products flows.

3.3 Study rationale and objectives

This study was set out to examine the potential for the recovery of reusable EEE within a distinct urban mine. A university is a prime example of a DUM (at micro level; Figure 3.2), its uniqueness being largely due to its demographic profile. A typical university consists of a large, primarily transient group of people (students) and, as reported in similar studies (Ongondo *et al*., 2015: Pierron *et al*., 2017; Williams & Powell, 2019), this unique feature presents an opportunity for urban mining of EEE. It is important to have a detailed knowledge of a DUM to exploit and recover materials and products of value. This requires data on factors such as size of population and ownership levels as well as potential stocks of products of interest. These factors are the focus of this study, which aims to assess critically the potential for recovery of reusable EEE in a distinct urban mine. The objectives of this study are as follows:

- Identify, quantify and evaluate ownership levels of small EEE within the populations of micro-level DUMs that aggregate to a meso-level DUM
- Identify, quantify and evaluate frequently hibernated EEE potentially available for reuse within micro-level/meso-level DUMs
- Estimate and critically discuss the reuse potential of frequently hibernated small EEE within different types of DUM

3.4 Methods

3.4.1 Experimental design: social survey

The study is a meso-level inquiry of reuse potential at universities (micro-level DUMs) in different municipalities. The inquiry employed the use of progressive sampling which is often used in research with a well-defined research interest (Barglowski, 2018). A key feature of the technique is the identification of relevant and related cases before undertaking research. Previous work of DUMs were identified and examined (e.g. Ongondo *et al*., 2015; Pierron *et al*., 2017; Hursthouse *et al*., 2017; Williams & Powell, 2018). These studies provided a grounding for the present research and information that guided the direction of study (Patton, 1990). The direction of present study is the reuse potential of small EEE within a meso-level DUM.

The study had four major phases: *scope and boundary definition*; *design of questionnaire*, *distribution of questionnaire* and *data analysis*. The study boundary is at regional level; in this study the region of interest is the southern UK county of Hampshire with a population of approximately 1,850,000 (including the cities of Portsmouth and Southampton) (Hampshire County Council, 2021). The county has four major universities, details of which are provided subsequently (*see* Table 3.1). The cluster of four universities within this geographic region is considered a meso-level DUM (*see* Figure 3.2) and is the scope of this study. One university (Solent University in Southampton) was excluded since formal authorisation was not provided in time for its inclusion.

3.4.2 Site selection and target population

Universities, by their nature, are like small towns with definitive boundaries and distinct groups of people. The characteristics translate to a pattern of resource consumption and behaviours (Li *et al*., 2012; Ongondo *et al*., 2015). This makes such spaces ideal for prospecting products, in this case EEE, for recovery. For the present study, the target population comprised students and staff members of a university distinct urban space. As this group is unique to this type of urban space, knowledge of the levels of ownership and potential for EEE reusability is required. To achieve this, a survey of this unique population within the DUM was undertaken. The survey was guided by the approach used in previous studies such as Ongondo and Williams (2011), Ongondo *et al*. (2015) and Pierron *et al*. (2017). These studies were based on the assessment of a university (micro-level studies; Figure 3.2) for its potential for recovery of small EEE and focussed on one group of people within the DUM (students). This study expanded on the prior research by including the other group of people in a university population (staff members) and extending coverage by surveying a regional university cluster within the south of the UK. The wider coverage allows for a more meaningful and robust evaluation of ownership patterns within the population of a meso-level DUM.

Universities in the UK have populations from a diverse background and often mirror the profile of the cities/towns in which they are located. A significant portion the population (students) is transient and reside within these spaces for a limited period (Ongondo *et al*., 2015). This perhaps unique feature is key in the concept of an urban mine and formed the basis of the selection of sites for the study. As the study boundary was the county of Hampshire, the scope was the cluster of three universities (*see* Table 3.1) varying in size (medium to large campus-based institutions) and diversity of population. These universities are the Universities of Portsmouth, Southampton and of Winchester. The fourth (Solent University) was not part of the study as formal authorisation to conduct a study was not granted in time. Together, these three universities form what can be described as a '*regional distinct urban mine'* (i.e. a meso-level DUM; *see* Figure 3.2) with features of interest for this study. The total population in this DUM cluster is 65,070, which represents 2.3% of the entire UK university population (2018/2019 academic year; HESA, 2020).

3.4.3 Inclusion and exclusion criteria

Eligibility for the survey requires a respondent to be a student or staff member of the surveyed universities. Respondents are expected to be a minimum of 18 years old. As the survey targets university populations, the general population was excluded from the study. This exclusion is achieved by the distribution of the survey via channels that target the specific population required for the study only (*see* Table 3.2).

Table 3.1. Student and staff population in surveyed universities (2018/2019 academic year)

University	**Staff**	**Students**		**Total**
		Undergraduate	Postgraduate	
Southampton	5,000	17,100	7,620	29,625
Portsmouth	2,600	20,305	4,090	26,600
Winchester	1,265	6,290	1,290	8,845
Total	8,865	43,965	13,000	65,070

Source: HESA, 2020

3.4.4 Survey design

The survey was designed using iSurvey, a survey creation and distribution tool. The survey tool has a simple interface and includes logic filters that aid in answering the questionnaire (*see* Section 3.4.4.1). With Internet access widely available in the UK and the target population, online distribution of the survey for data collection was possible and considered appropriate as a means for data collection. The survey was made available between March and November 2019 (i.e. an extended period covering Easter and Summer vacation periods) and its distribution (*see* Table 3.2) was aided by information dissemination which included the publication of an article on media platforms at the respective universities. The publication provided brief information on the project as well as a link to the survey. Consent was sought and granted from each institution before data collection began. The survey was designed to collect data on (a) ownership of small EEE and (b) stockpiling/hoarding pattern within the population with view to establishing reuse potential within the DUM. The survey also included questions on demographic variables such as age, domicile and level of study (specifically for student respondents) and type of accommodation. The survey required ethical approval, and this was granted by the University of Southampton Ethics and Governance Online (ERGO) (code: ERGO/FEPS/46704). In addition to this, study approvals were granted for University of Portsmouth by the Student Survey Request Group (SSRG), and University of Winchester by the office of Energy and Environment Manager.

Table 3.2. Distribution routes of online survey at participating universities.

Route	**Target population**
SUSSED (University of Southampton student and staff portal)	Staff and Students (29,000+)
Email to University of Southampton Environmental Science students	Geography and Environmental Science students
University of Portsmouth News (online bulletin)	Staff and students (26,000+)
University of Winchester (staff and student portal)	Staff and students (8,000+)

3.4.4.1 Questionnaire design and structure

This survey was designed to inform the assessment of reuse potential in a university DUM. This involved collection of quantitative data on EEE ownership and stockpiling with the use of a questionnaire. A questionnaire is a survey tool that is carefully designed to specifically gather primary data from the field (Yusuf, 2013). Its design considers the research question(s) to be undertaken and the responses contribute towards achieving the aim(s) and objective(s) of research undertaken. Like any tool, a questionnaire needs to be tested for validity and reliability as well as ease of use. Validity is the degree to which a research tool measures what it was designed for (Messick, 1989). Reliability is the quality of a tool that ensures it can measure what it was designed for over time and in different situations (Feldt & Brennan, 1989; Adebakin, 2013).

The questionnaire design for this study was informed by previous similar surveys on EEE such as Ongondo and Williams (2011) and Pierron *et al*. (2017). Notable differences from these surveys were (1) inclusion of members of staff in the current study, and (2) a wider range of small EEE surveyed. The questionnaire featured a multiple-choice questions format and was divided into six sections requiring approximately 15 minutes completion time. The surveyed EEE were categorised into four sections:

- Small Kitchen Appliances (SKA) (56 questions)
- Personal Care Appliances (PCA) (42 questions)
- Small Household Appliances (SHA) (35 questions)
- Information and Communication Technology/ Audio-visual (ICT/AV) devices (117 questions)

Thirty-six devices were included in the questionnaire (*see* Table 3.3), each within the categories outlined above. The devices were selected from categories 2 (Screens and Monitors), 5 (Small equipment) and 6 (Small IT and Telecommunication equipment) of the EU WEEE Directive (Directive 2012/19/EU; European Union, 2012) and the internationally recognised categorisation framework described in guidelines for WEEE statistics by Forti *et al*. (2018).

The start page of the questionnaire provided a welcome statement for the participant and a brief introduction of the study. Each section was accompanied by a brief instruction paragraph to help with the completion of the questionnaire. The start page provided information on confidentiality and details of a prize draw for participants. The online questionnaire can be found in Appendix B.3.

Table 3.3. Categories of devices included for the survey.

Category of EEE	**Appliances included in questionnaire**
SKA	Electric coffee maker, electric blender, electric food mixer, electric kettle, electric juicer, electric frying pan/wok, electric rice cooker and sandwich grill/toaster
PCA	Hair curler, hair dryer, hair straightener, hair styler, electric razor/epilator and electric toothbrush

Category of EEE	Appliances included in questionnaire
SHA	Desk lamp, electric iron, home telephone, portable space heater and desk fan
ICT/AV	Digital camera, electronic tablet, laptop computer, netbook/notebook computer, headset/headphones, mobile phone, portable CD player, DVD/Blu-ray player, printer, scanner, fax machine, radio, screen/display monitor, smart watch, smart speaker, video game console and web cam

Section 1 of the questionnaire included questions on demographic information on age, level of study, degree type, domicile and household type and size. For the question on age, all respondents (both staff and students) were asked to choose the relevant age categories included (18-24; 25-44; 45-64 and 65+). This categorisation ensured ease of classification for analysis and has been used in previous similar studies such as Ongondo *et al* (2015) and Wilkinson and Williams (2020). The questions on degree type (Undergraduate/Postgraduate) level of study, domicile (Home/Overseas) were applicable to student respondents only. A logic filter ensured that only student respondents could answer questions based on these variables.

Sections 2, 3, 4 and 5 contained the main survey questions on ownership (number of device owned), replacement cycles (how often they are replaced) and hibernating stocks (number of unused functional/non-functional device(s) owned) of SKA, PCA, SHA and ICT devices respectively. The ownership level of each surveyed devices within the population is presented as a percentage of respondents reporting ownership of at least one of such devices. This also applies to stockpiled and hoarded devices[10]. To reduce completion time of the questionnaire, logic filters were used. These ensured that participants only answered questions relevant to devices they own e.g. if a respondent selects ‘0’ for the question on number of kettles owned, all follow up questions on kettle do not appear and the respondent can proceed to the next item on the questionnaire.

3.4.4.2 Questionnaire pilot and amendment

Prior to distribution of the survey, a pilot test of the questionnaire is required to ensure content validity and ease of use (Saunders *et al*., 1997; Yusuf, 2013). The pilot test for this survey was run among ten participants of different age groups from the target population and included students (both undergraduates and postgraduates) and members of staff. The pilot outcomes informed

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[10] Refined definitions of these terms have been created for this study. A **stockpiled** device is one that has functional value but is unused and kept i.e. a back-up or a spare device. A stockpiled item is potentially reusable as well as subsequently recyclable. A **hoarded** device is one that does not work but is kept. A hoarded item is thus recyclable but not reusable in its current state without some form of intervention e.g. repair and/or upgrade.

revisions to the questionnaire design, phrasing of questions and coverage of EEE as outlined in Table 3.4

Table 3.4. Questionnaire amendments made after pilot survey.

Questionnaire Section	Amendments
Section 1 (Demographics)	• Addition of 'mobile home' to response option for question on accommodation type • Inclusion of age category '65+'
Section 2 (SKA)	• Inclusion of word 'electric' to coffee maker to distinguish from non-electrical variants • Rewording of responses to question on replacement cycles • Rewording of question on electric wok ownership • Inclusion of question on ownership of non-functional SKA; this was omitted in the initial questionnaire
Section 3 (PCA)	• Inclusion of products such as hair stylers and electric hair straighteners
General layout	• General spelling errors addressed • Shortening of questions to reduce response time of survey

3.4.5 Survey analysis

3.4.5.1 EEE ownership and stockpiling/hoarding variations

Demographic variations in ownership, stockpiling and hoarding of EEE were observed. Demographic variables of interest were age, domicile, level of study and accommodation type (domicile, level of study and accommodation type apply to student respondents only).

3.4.5.2 Reuse potential estimation

Resale value of frequently stockpiled EEE was evaluated to provide an estimation of reuse value. Reuse value can be expressed as ***functional value + residual value***; residual value being the value of materials obtainable from the product via recycling at end of life. There were two assumptions made for the analyses of stockpiled devices: devices stockpiled are in good working order and are reusable/saleable without requiring repair or parts upgrade in current condition. Reuse potential was evaluated by calculating the resale value of frequently stockpiled devices. Price data[11] were obtained from online vendors www.giffgaff.com, www.preloved.com and www.gumtree.com that

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[11] Price data obtained at the following dates: 18/06/2020 (Preloved and Gumtree); 14/01/2021 (Giff Gaff)

are popular and well-established in the UK. As devices may vary in working condition and model, the resale price offered for individual device was likely to vary. To account for these variations, average sale prices were calculated from a sample of 10 randomly-selected pre-owned price data of similar devices for each analysed device. For mobile phone resale data, prices were drawn from www.giffgaff.com which is an online pre-owned and refurbished mobile phone vendor. The price data were filtered to exclude models released in 2018 or later as these are unlikely to be amongst hibernating stock. Also, the price range did not exceed the upper limit of a mid-range[12] mobile phone; mobile phone models exceeding £500 in value were excluded in order to present a modest valuation. For other devices, sample prices were drawn randomly from www.gumtree.com and www.preloved.com.

The calculated prices were expressed as averages with standard errors to represent a meaningful range of values. The valuation does not consider other variables such as geographical location of sale, cost of transportation of devices to point of resale, repair/restoration costs.

3.5 Results

The results are presented as follows:

- Demographic data
- Ownership level of devices (SKA, PCA, SHA and ICT/AV) amongst all respondents (staff and students)
- Ownership level by demographic variables: age (all respondents), domicile, degree level and accommodation type (student respondents)
- Stockpiling and hoarding levels
- Estimation of reuse potential of device stockpile

3.5.1 Demographic data

A total of 360 responses were received out of which 320 responses were usable with most of the questions completed; responses with no demographic data were excluded as these were not usable for analysis. Table 3.5 presents the demographic profile of respondents. For analysis, the age profiles used in the questionnaire were categorised into two age groups: respondents

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[12] Brand-new mid-range mobile phones generally retail between £300 - £500 in the UK (https://www.expertreviews.co.uk/mobile-phones/1408886/best-mid-range-smartphone)

between the age of 18 and 24 (18-24) and those age 25 and above (25+). In addition, for the domicile profile, EU and international students were grouped as 'overseas' while UK students were classed as 'home' students.

Table 3.5. Demographic profile of all respondents

Demographic profile (Students) (n=90)		**Number of respondents**	**Proportion of respondents (%)**	**Proportion of student nationally (2018/2019) (%)***
Age	18-24	59	65.6	69
	25+	31	34.4	31
Level of study	Undergraduate	58	64.4	75
	Postgraduate	31	34.4	25
Domicile	Home	68	75.6	80
	Overseas	22	24.4	20
Demographic profile (Staff) (n=230)		**Number of respondents**	**Proportion of respondents (%)**	**Proportion of staff nationally (%)***
Age	18-24	6	2.6	5.9
	25+	224	97.4	94.1

*****Data from HESA (2020)

A total of 94 students completed the survey out of which 90 of the responses were usable. Of this, 65.6% (n=90) were between the age of 18 and 24. This is closely comparable with the percentage share of students in this age category nationally, which is 69% according to the Higher Education Statistics Agency (HESA) (2018/2019 enrolment data) (HESA, 2020). Approximately 64% of respondents were undergraduates while 75.6% were domiciled in the UK. National students' data shows 75% of all enrolled students are undergraduates while 80% of students are home domiciled (HESA, 2020), indicating representativeness of sample.

There was a higher participation of university staff members in the survey (n=230) than students (n=90) which means there was an under-representation of student respondents; students outnumber staff members in universities in the UK (1 staff member to approximately 5 students according to data from the Higher Education Statistics Agency, HESA, 2020). Only 2.6% of respondents were between the age of 18-24 years; most staff members are 25 years and above. In comparison, the national data of staff members in universities by HESA (2019) shows approximately 5.9% are 25 years and below indicating sample was broadly representative for age distribution of university staff members.

3.5.2 Ownership level of small EEE

All respondents surveyed owned at least one item of small EEE. Every respondent owned a mobile phone; 201 respondents (67.4%) own 2 or more such devices. Most respondents owned at least one laptop (91%), a kettle (91%), a hair dryer (78%), and a lamp (77%). Two devices in the ICT category had the highest device totals (devices mobile phones: 733 devices and headset: 719 devices) with average ownership at 2.5 and 2.4 devices per person respectively; fax machines had the lowest total (4 devices) with only 3 respondents owning at least one. Headsets had the highest number of respondents reporting ownership of 4 or more (34%). Products with the highest proportion of respondents owning multiple devices (2 or more) were mostly ICT devices including headsets/headphones (70%), mobile phones (67%), laptop computers (50%) and lamps (46%). The devices with lowest proportion of respondents' ownership include juicers, electric woks and hair stylers. The SHA with highest average ownership was desk lamp (1.7) while portable space heater had the lowest (0.6). SKA blender and kettle both had average ownership of 1.1 while the same average was reported for hair dryer and electric toothbrush.

3.5.2.1 SKA ownership

Eight small kitchen devices were surveyed in the study. The data presented in Table 3.6 shows the proportion of respondents that reported owning at least one of each of the surveyed SKA. Ownership level of SKA varied from 5% for wok/electric frying pan to 91.6% for electric kettles.

Table 3.6. Small kitchen appliance ownership level of all respondents (n=320).

SKA	Number of respondents	Ownership Level (%)
Coffee maker	143	**44.7**
Blender	246	**76.9**
Food mixer	169	**52.8**
Kettle	293	**91.6**
Juicer	43	**13.4**
Wok/Frying pan	16	**5.0**
Rice cooker	50	**15.6**
Toaster	195	**60.9**

Demographic variations in SKA ownership levels are presented in Figure 3.4 and Figure 3.5. There was high ownership level of products such as kettles and blenders, with over 50% of staff and students surveyed owning at least one of each of these devices. There was little difference in kettle ownership between students and staff surveyed, with staff having a higher ownership level (93%), a difference of 1.4 percentage points in comparison with overall ownership level (91.6%). The SKA with the highest variation in ownership level between staff and students was food mixers with a difference of over 45 percentage points (overall ownership level of 52.8%). Lowest variation in this regard was observed in electric wok ownership (0.8 percent points) which was also the item with lowest ownership level in the SKA category with both staff and student ownership levels less than 6% (5% ownership level overall). Ownership of all surveyed SKA was observed to be higher for staff than students except for two devices (woks and rice cookers).

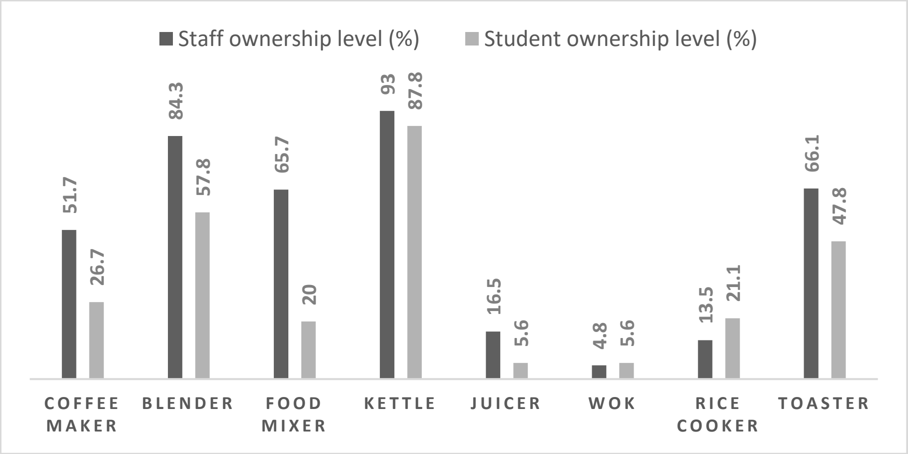

Figure 3.4. Small kitchen appliance ownership levels by respondents (staff and students) (n=320)

SKA ownership levels for respondents of age 25 and above were higher than those between age 18-24 (*see* Figure 3.5A). The only exception was rice cookers, which were observed to have a marginally higher ownership level among respondents between age 18-24 (18.5%). This represents a variation of 2.9 percentage points from the overall rice cooker ownership level (15.6%). Kettles and blenders were the most commonly owned SKA (92.5%; 87.7% and 83.1%; 52.3%) with ownership levels comparable with those observed overall (*see* Table 3.6). Variation in ownership levels between the two age groups was highest in devices such as food mixer, coffee maker and blender with percentage points differential of 43.1, 38.7 and 30.8 respectively. Woks and juicers were the least commonly owned, just as observed in the overall ownership levels.

Home (UK-based) students tend to own more SKA than overseas (which include EU) students (*see* Figure 3.5B). All SKA except kettles and rice cookers (with percentage points differential of 4.1 and 26.2 respectively) were observed to be owned by a higher proportion of home students than observed in overseas students. Devices such as electric woks and juicers were not commonly owned; no overseas student surveyed owned either. A similar trend was observed in ownership level by degree type (*see* Figure 3.5C); postgraduate level students were observed with higher ownership levels of SKA except woks, juicers and toasters. The percentage points differential in ownership levels between the levels of study were not as significant as in the first two demographic variables (age and domicile), the highest being 23.7 percentage points observed in ownership level of toasters.

Respondents living in Halls of Residence (HoR) owned fewer items of SKA in comparison with those that lived in other accommodation types (house/bungalow, flats, mobile structures and others). No staff member surveyed reported living in a HoR, so the data presented are applicable to student respondents only. All devices surveyed had higher ownership levels among respondents living in non-HoR accommodation except rice cookers (*see* Figure 3.5D). Devices such as juicers and food mixers were observed to be owned by only respondents living in accommodation other than HoR.

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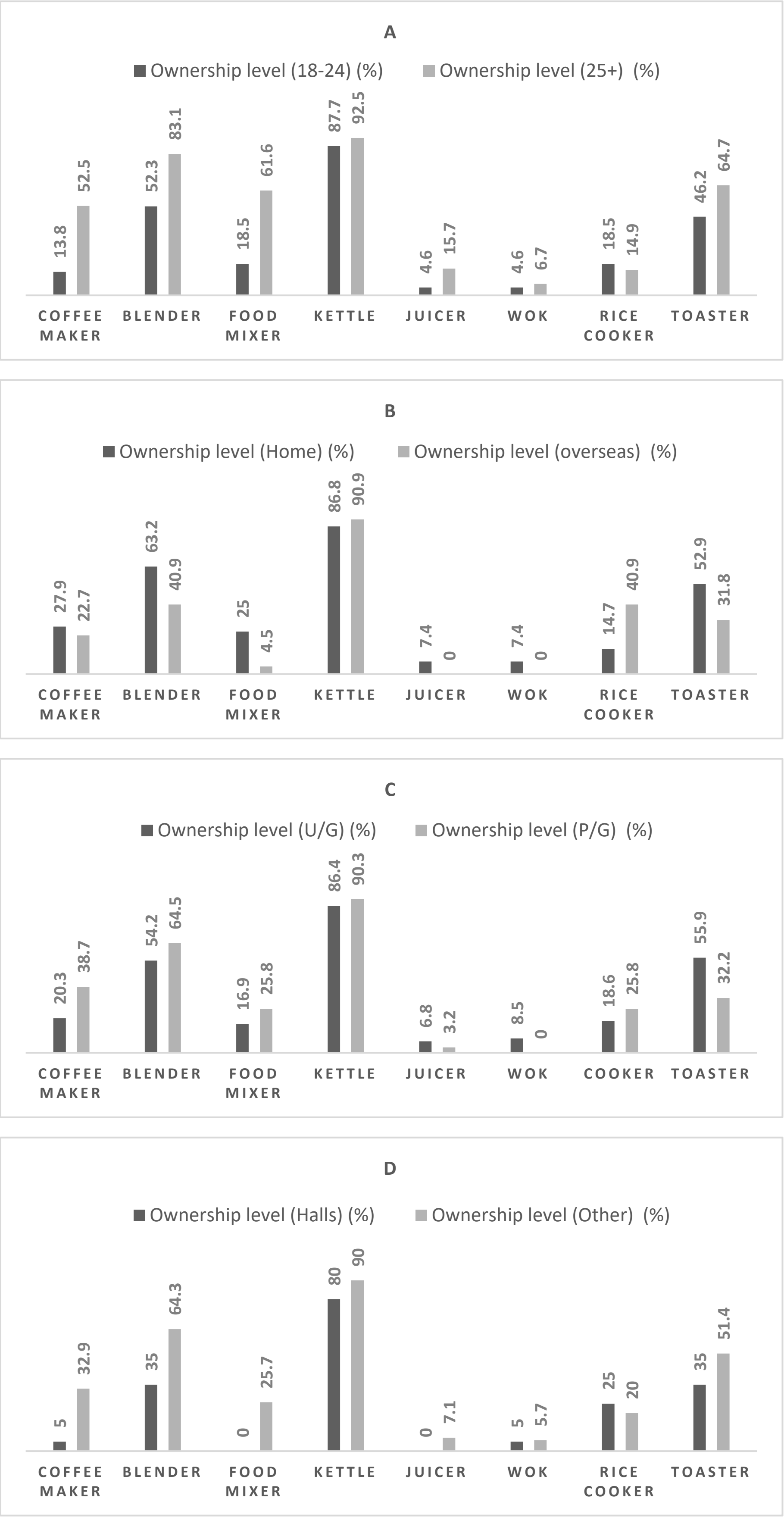


Figure 3.5. Small kitchen appliance ownership levels by the different demographic variables. **A**. ownership level by age (all respondents, n= 312); **B.** ownership by domicile (student respondents, n=90); **C**. ownership by degree type (student respondents, n=90); **D.** ownership by accommodation (student respondents, n=90).

3.5.2.2 PCA ownership

Ownership levels of the six PCA products surveyed are presented in Table 3.7. The level of PCA ownership varied from 5.4% for hair stylers to 78% observed in ownership of hair dryers. Multiple product ownership was also frequent in this product category with hair dryers the product with highest proportion of respondents owning two or more products (85 of 314 respondents). Lowest in this regard was hair stylers (5 of 313 respondents).

Table 3.7. Personal care appliance ownership level of all respondents (Hair dryer, curler and razor (n=314); hair straightener, styler and electric toothbrush (n=313).

PCA	**Number of respondents**	**Ownership level (%)**
Hair curler/curling tong	100	**31.8**
Hair dryer	245	**78**
Hair straightener	159	**50.8**
Hair styler	17	**5.4**
Electronic razor/epilator	164	**52.2**
Electric toothbrush	227	**72.5**

Staff within the surveyed population had higher ownership levels of all PCAs than students (Figure 3.6), though the percentage points differentials were not as high as those observed in SKA ownership. The highest percentage point differential was observed in ownership level of hair dryers (27.4) with staff members having an ownership level of 85.5% compared with 58.1% for students. Electric toothbrushes had a high ownership level amongst respondents (73.6% for staff; 69.8% students) and a low percentage point differential of 3.8 though the lowest differential was observed in ownership of hair stylers (2.8). This PCA was the least owned overall (5.4%) (*see* Table 3.7).

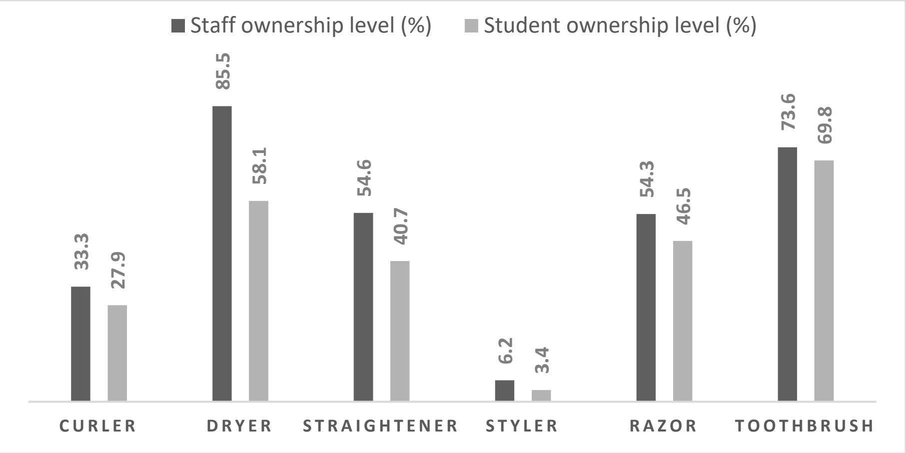


Figure 3.6. Personal care appliance ownership level by respondents (staff and students; n= 314).

As observed in ownership level of SKA, respondents 25 years and above had a higher ownership level of PCA than those between 18-24 (*see* Figure 3.7A). Percentage points differential observed between the two age groups varied from 24.8 for hair dryers to 4.8 observed in the ownership level of hair stylers. Hair dryers are the most commonly owned PCA with ownership level of 82.9% observed with respondents age 25 and above. This is 4.9 percentage points above the overall ownership level for this PCA (*see* Table 3.7). Electric toothbrush ownership also high within both age groups with 25+ respondents' ownership edging the overall ownership level with 74.5% (2 percentage points differential). Hair straighteners (46.8 % for 18-24; 51.8% for 25+) and electric razors (45.2% for 18-24; 54 for 25+), as shown in Figure 3.7A, presented similar ownership levels by age which were close to their overall ownership levels (50.8% and 52.2% respectively).

Variation in PCA ownership levels included a higher ownership level observed in home students of devices such as hair straighteners, toothbrushes and electric razors (*see* Figure 3.7B), while hair curlers, stylers and dryers had higher ownership levels amongst overseas students. Percentage points differential between the two domicile groups (home and overseas) were highest for hair dryer ownership (28.5 percentage points). This is comparable with that observed for hair dryer ownership by age *(see* Figure 3.7A). Lowest differential was observed between the two domicile categories was in ownership of hair stylers (2 percentage points). Likewise, postgraduate students had a higher ownership level of all PCA except electric razors (*see* Figure 3.7C). Highest percentage point differential was observed in hair dryer ownership (33.6 percentage points), with 80% ownership level observed in postgraduate students; a 2-percentage points differential from the overall ownership level (*see* Table 3.7). Lowest differential was observed in ownership of hair curlers (3.2 percentage points).

Respondents (students) living in Halls of Residence (HoR), as shown in Figure 3.7D, had a higher ownership levels of electric toothbrushes and high stylers (76.5% and 5.9% respectively) than those living in other types of accommodation (69.1% and 2.9% respectively). Aside from these two PCA, all other PCA devices had higher ownership levels observed amongst respondents living in other residences. Highest differential was observed in ownership level of hair straighteners (21.4 percentage points) while lowest was observed with hair stylers (3 percentage points).

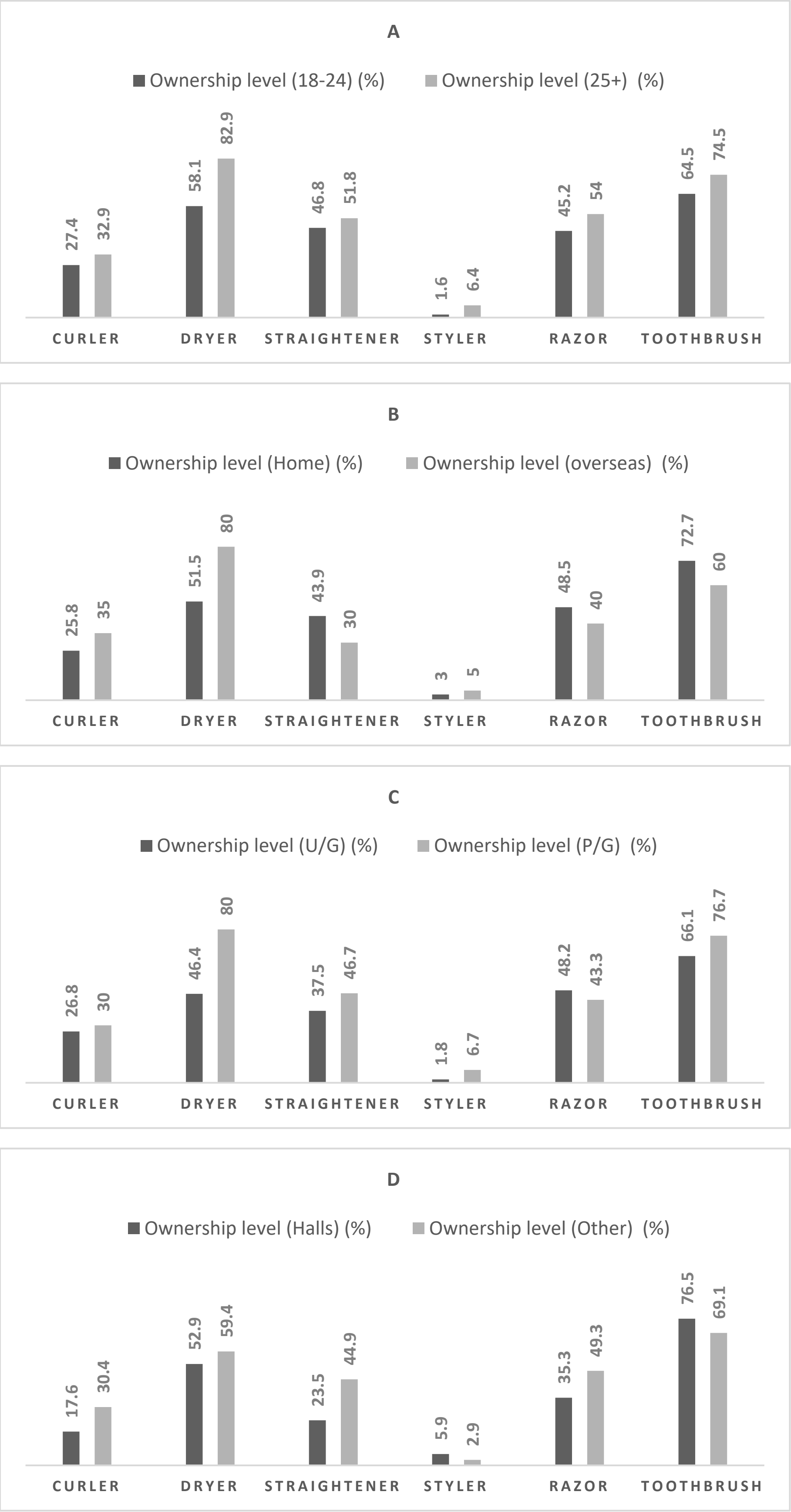


Figure 3.7. Personal care appliance ownership levels by the different demographic variables. **A**. ownership level by age (all respondents, n= 314); **B.** ownership by domicile (student respondents, n=86); **C**. ownership by level of study (student respondents, n=86); **D.** ownership by accommodation (student respondents, n=86).

3.5.2.3 SHA ownership

Ownership of SHA amongst surveyed respondents is shown in Table 3.8. Ownership level variation was from 37.9% (space heaters) to 78.5% (electric irons). Multiple ownership was highest with desk lamps with 145 of 312 respondents owning 2 or more devices while electric irons and space heaters had the lowest multiple ownership with 41 of 311 respondents owning 2 or more devices.

Table 3.8. Small household appliance ownership level of all respondents (desk lamp & table fan (n=312); electric iron, home telephone & space heater (n=311)

SHA	Number of respondents	Ownership level (%)
Desk lamp	240	**76.9**
Electric iron	244	**78.5**
Home telephone	179	**57.6**
Space heater	118	**37.9**
Table fan	129	**41.3**

Staff members within the surveyed population had a higher ownership levels of all SHA than students except for desk lamps (*see* Figure 3.8). Ownership level of lamps observed in the student population (87.1%) exceeded the overall level observed (76.9%) by percentage points of 10.2. Of the other devices surveyed, the highest percentage points differential between staff and students was observed in ownership level of home telephones (43.6 percentage points). This was closely followed by electric irons with 40 percentage points. The lowest differential observed was in ownership of table fans (5.1 percentage points).

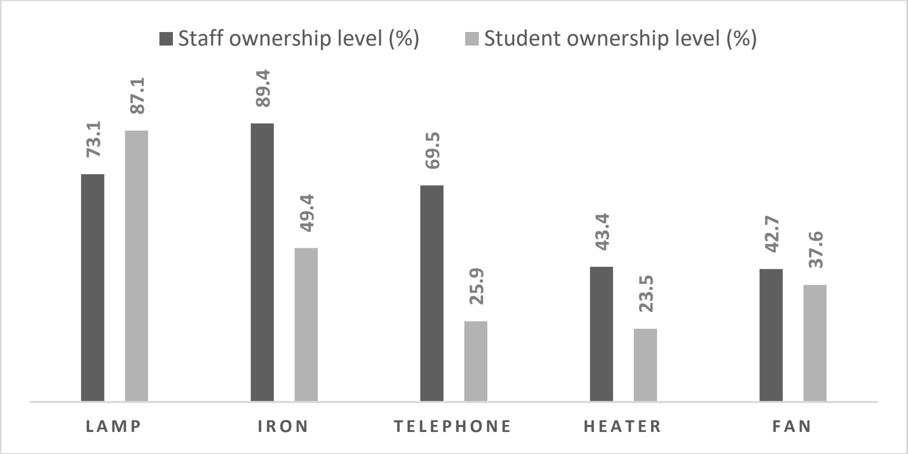


Figure 3.8. Small household appliance ownership level by respondent profile (staff and students).

There was a higher ownership level observed amongst older respondents (25 years and above) of all SHA surveyed except desk lamps with a higher ownership level observed amongst 18-24-year olds (*see* Figure 3.9A). The difference observed here represents the lowest percentage points differential of all the SHA at 2.2 percentage points with both groups having ownership levels comparable to the overall ownership level for this SHA (76.9%) (*see* Table 3.8). Electric iron ownership amongst 25+ respondents was the highest observed in all SHA (88%), a differential of 9.5 percentage points from the overall average (78.5%). The highest percentage points differential between the two age groups was also observed in the ownership of electric irons (48.7 percentage points). This is closely followed by the 45.1 percentage points differential observed in home telephone ownership between both age groups.

Students' domicile variation (*see* Figure 3.9B) shows home students had a higher ownership level of all SHA except desk lamps. A 95% ownership level of desk lamps amongst overseas students was observed with a percentage points differential of 18.1 above the overall ownership level observed for desk lamp (*see* Table 3.8). Devices such as home telephones and space heaters had a low ownership level amongst overseas students (5%) with comparable ownership levels observed for both devices amongst both domicile categories (32.3% and 29.2% respectively). Home telephone ownership also had the highest percentage points differential between the domicile categories (27.3 percentage points). The lowest was observed in the ownership level of desk fans with 10 percentage points.

Figure 3.9C shows the variation in SHA ownership level by level of study. Postgraduate respondents (students) had a higher ownership level of desk lamps, electric irons and table fans. Desk lamp ownership level was 93.3%, 16.4 percentage points higher than the overall ownership level observed. The difference observed in ownership level between postgraduates and undergraduates was lowest in space heater ownership (0.3 percentage points).

All but one SHA (table fans) had a higher ownership level amongst respondents living in other accommodation types compared with HoR residents (*see* Figure 3.9D). However, the differences observed were low; the highest percentage points differential observed in ownership level of electric irons (17.6 points). Home telephone and space heater ownership variations were comparable with percentage points differential of 10.3 and 7.4, respectively.

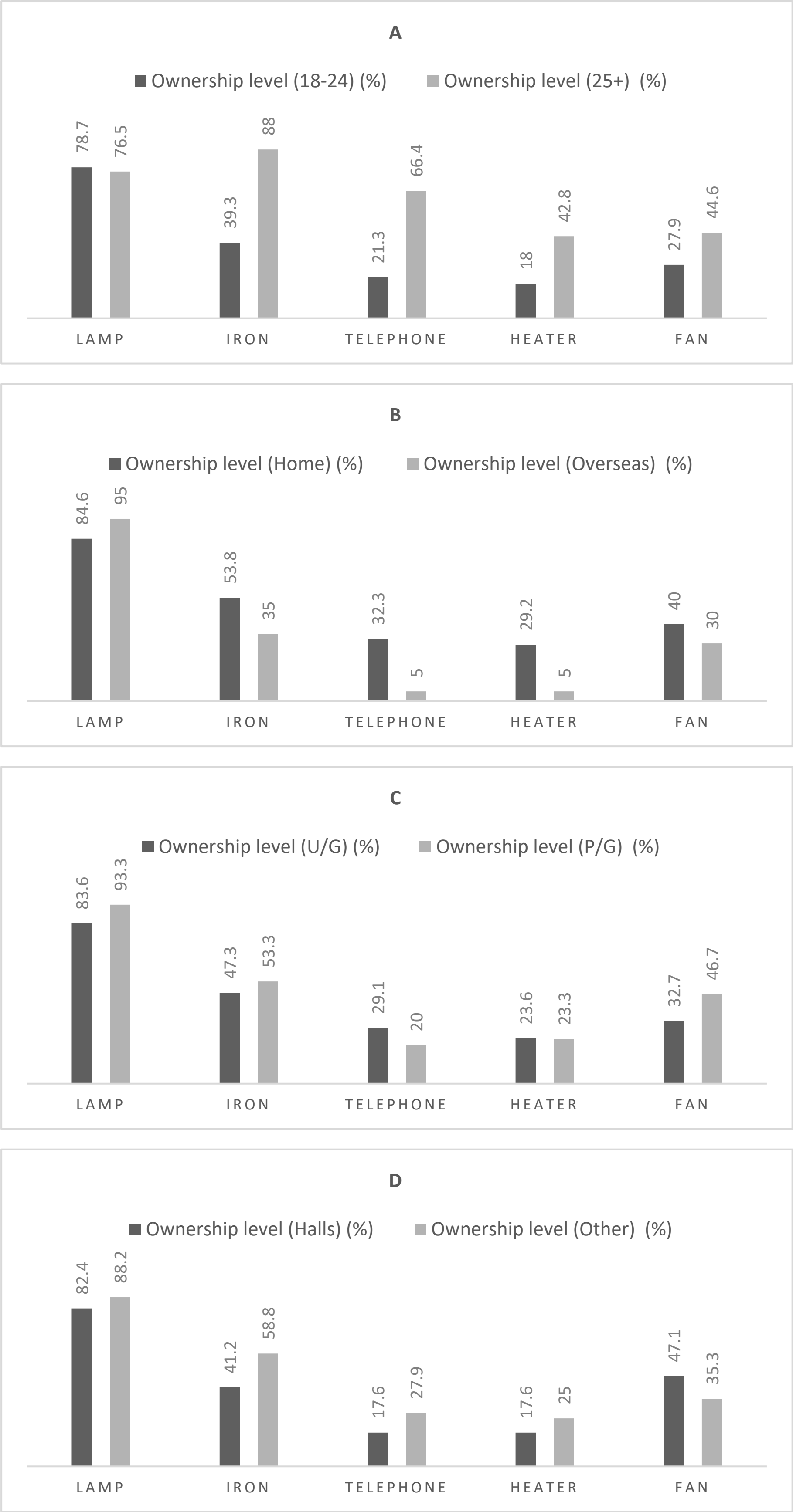


Figure 3.9. Small household appliance ownership levels by the different demographic variables. **A**. ownership level by age (all respondents, n= 312); **B.** ownership by domicile (student respondents, n=85); **C**. ownership by level of study (student respondents, n=85); **D.** ownership by accommodation (student respondents, n=85).

3.5.2.4 ICT/AV ownership

The ownership level ICT/AV devices surveyed is presented in Table 3.9. This includes the only EEE in the entire survey with a 100% ownership level (mobile phones). Level of ownership ranged from 1% observed with fax machines to 100% with mobile phone ownership. Multiple ownership of ICT/AV devices was common amongst respondents; headsets (208 of 298 respondents; 69.8%), mobile phones (201 of 298 respondents; 67.4%) and laptop computers (150 of 299 respondents; 50.2%) were the top ranked devices with multiple ownership.

Table 3.9. Information and communication technology/audio-visual devices ownership level (n=299 except digital camera (n=300); headset, mobile phone (n=298).

ICT/AV	Number of respondents	Ownership level (%)
Digital camera	217	**72.3**
Electronic tablet	221	**73.9**
Laptop computer	273	**91.3**
Netbook/Notebook	25	**8.4**
Headset/Headphones	262	**87.9**
Mobile phone	298	**100**
CD player	56	**18.4**
DVD/Blu-ray	155	**51.8**
Printer	161	**53.8**
Scanner	23	**7.7**
Fax machine	3	**1.0**
Radio	153	**51.2**
Screen/Display monitor	131	**43.8**
Smart watch	114	**38.1**
Speaker	191	**63.9**
Video game console	146	**48.8**
Web cam	44	**14.7**

There was generally a higher ownership level observed with most of devices surveyed amongst the staff respondents as shown in Figure 3.10. Notable exceptions include laptop computers and headsets/headphones, which had a marginally higher ownership level observed in the student population (7.1 and 5.3 percentage points differential, respectively). Mobile phones, as previously mentioned, was owned by every respondent and at the other end of the spectrum, ownership level of fax machines was the lowest with 1.4% observed for staff and 0% for students. Ownership level of radios was observed with the highest percentage points differential between staff and students (44.7 percentage points). This is closely followed by the ownership level of DVD/Blu-ray players (39 percentage points).

Respondents 25 years and over were observed with higher ownership level of 12 of the 17 ICT/AV devices surveyed (*see* Figure 3.11A) with the exceptions being headsets, laptop computers, notebook computers and speakers (mobile phone ownership was 100% across the board). Of these, the highest variation in ownership level was observed in speaker ownership with differential of 25.4 percentage points; lowest observed was in notebook computers (0.3 percentage points). DVD/Blu-ray players, tablets, digital cameras had higher ownership levels amongst respondents 25 years and above in comparison to those between 18-24 years with differential of 45.1, 38.2 and 31.9 percentage points respectively. No respondent between 18-24 years owned scanners and fax machines. Other devices with low ownership level amongst 18-24-year-olds were web cams (3.4%) and CD players (5.2%).

Ownership level by student domicile (*see* Figure 3.11B) showed a higher ownership level of ICT/AV devices amongst home students (12 of 17 devices). Of these, ownership of printers was observed with highest differential in ownership level between home and overseas students (31.9 percentage points). This is closely followed by the ownership of digital cameras and game consoles (29.4 and 26.9 percentage points respectively). The lowest differential observed was in ownership level of web cam (4.7 percentage points). 3 ICT/AV devices had higher ownership level in overseas students; scanners, smart watches and CD players, and these were observed with marginal differential between both groups of students (3.4, 1.9 and 0.6 percentage points respectively).

Postgraduate level respondents (students) had higher ownership levels of devices (9 of 17) in comparison to undergraduate level students (6 of 17) (*see* Figure 3.11C). Of the 9 devices, tablet computers, smart watches and digital cameras had the highest ownership differential observed between both groups (25.6, 12.6 and 11.9 percentage points respectively). Undergraduate respondents were observed to have higher ownership level of laptop computers (98.1%; overall average: 93.1%), headsets (94.4%; overall average: 87.9%) and speakers (59.3%; overall average: 63.9%) with game console ownership having the highest differential between the groups (26.7 percentage points).

Ownership variations by accommodation (*see* Figure 3.11D) included higher ownership levels by respondents (students) living in halls of residence of 5 ICT/AV devices including laptop computers with 100% ownership level (overall ownership level was 91.3%) as well as CD players, screens/monitors, game consoles and webcams. There were generally marginal differentials in ownership levels of these 5 devices between the two groups; game console ownership was observed with the highest differential (8.3 percentage points). Of the 10 devices with higher ownership levels in respondents living in other accommodation types, printers had the highest differential between both groups of respondents (27.2 percentage points) and the lowest observed was in ownership level of tablet computers (0.8 percentage points).

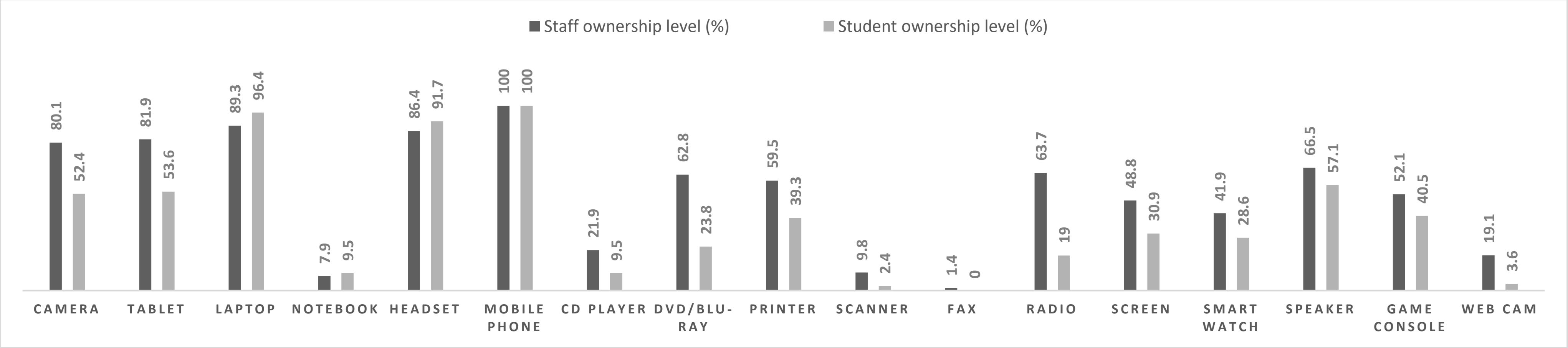
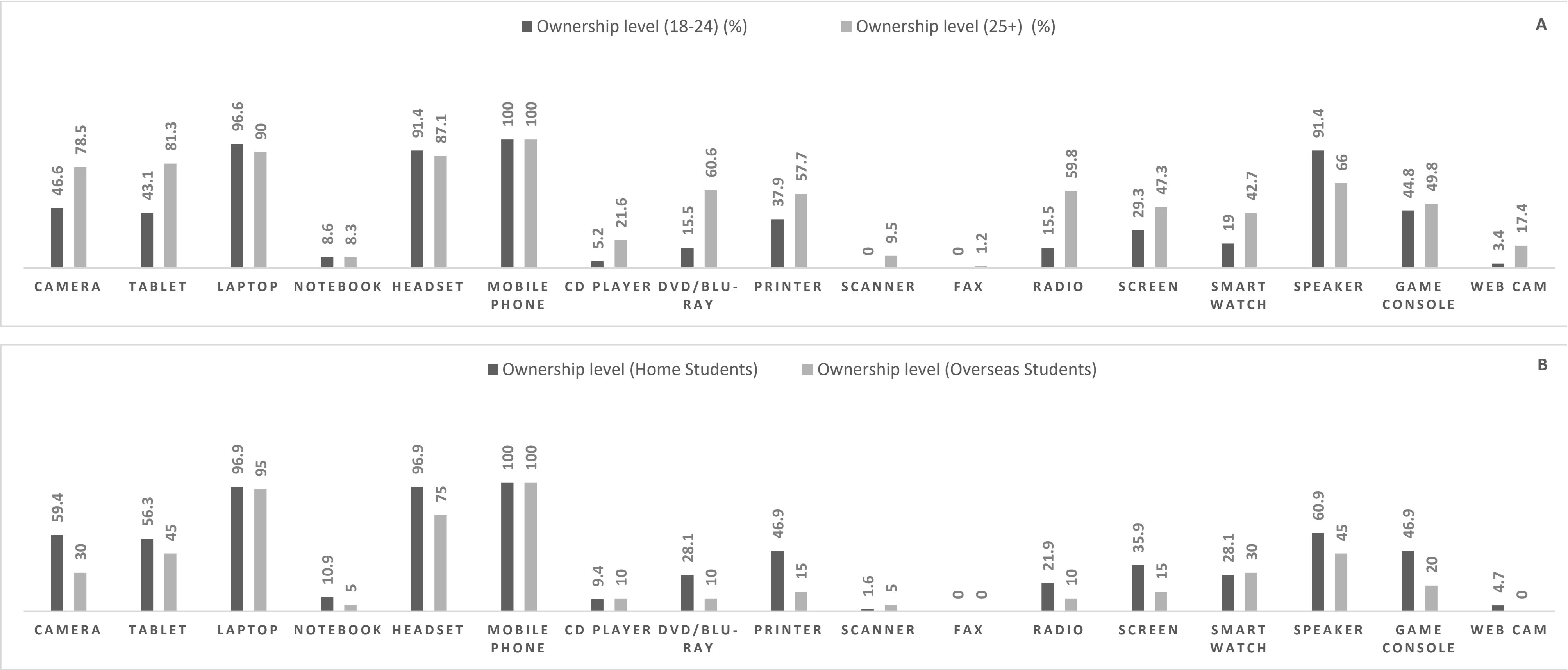


Figure 3.10. Information and communication technology/audio-visual devices ownership by respondent profile (Staff and Students).


■ Ownership level (18-24) (%)
■ Ownership level (25+) (%)
A
CAMERA 46.6 78.5
TABLET 43.1 81.3
LAPTOP 96.6 90
NOTEBOOK 8.6 8.3
HEADSET 91.4 87.1
MOBILE PHONE 100 100
CD PLAYER 5.2 21.6
DVD/BLU-RAY 15.5 60.6
PRINTER 37.9 57.7
SCANNER 0 9.5
FAX 0 1.2
RADIO 15.5 59.8
SCREEN 29.3 47.3
SMART WATCH 19 42.7
SPEAKER 91.4 66
GAME CONSOLE 44.8 49.8
WEB CAM 3.4 17.4
■ Ownership level (Home Students)
■ Ownership level (Overseas Students)
B
CAMERA 59.4 30
TABLET 56.3 45
LAPTOP 96.9 95
NOTEBOOK 10.9 5
HEADSET 96.9 75
MOBILE PHONE 100 100
CD PLAYER 9.4 10
DVD/BLU-RAY 28.1 10
PRINTER 46.9 15
SCANNER 1.6 5
FAX 0 0
RADIO 21.9 10
SCREEN 35.9 15
SMART WATCH 28.1 30
SPEAKER 60.9 45
GAME CONSOLE 46.9 20
WEB CAM 4.7 0

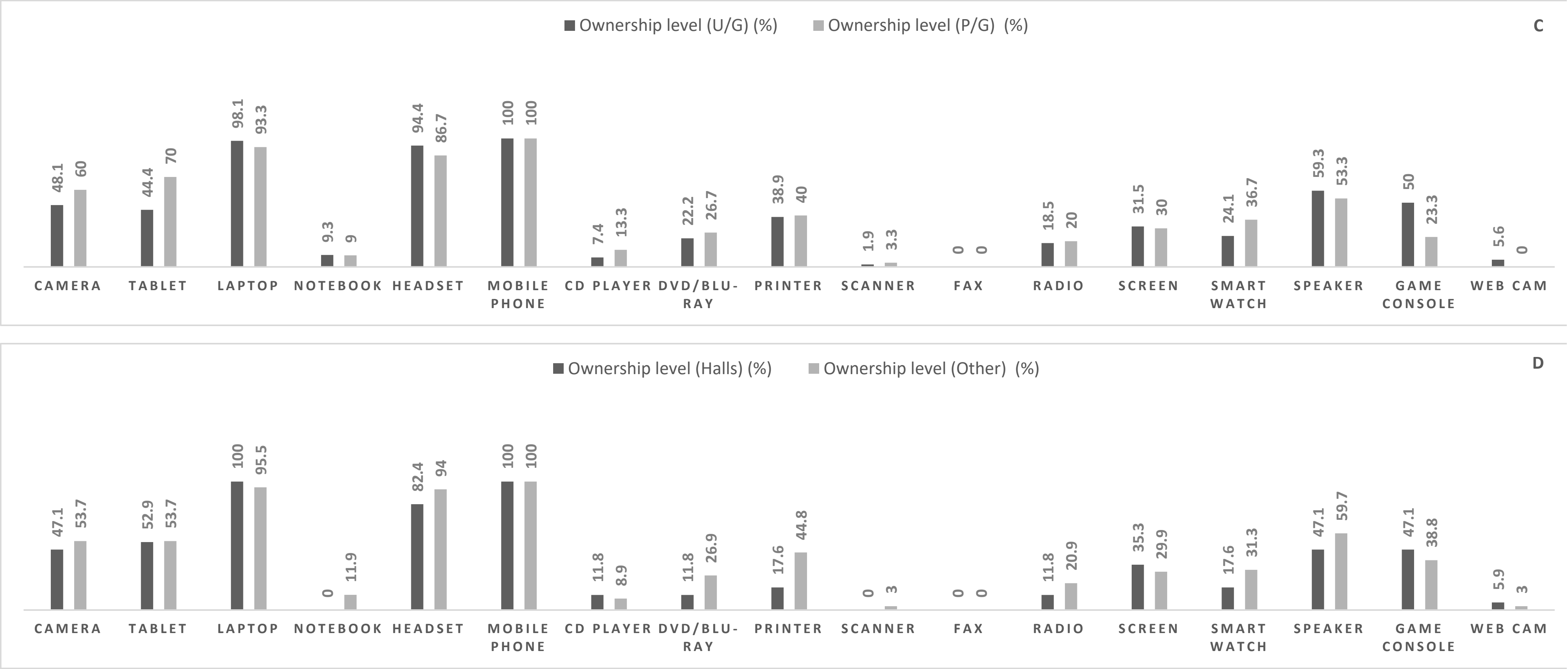


Figure 3.11. Information and communication technology/audio-visual devices ownership levels by different demographic variables. **A**: ownership level by age (all respondents); **B**: ownership level by domicile (students only); **C**: ownership level by level of study (students only); **D**: ownership level by accommodation type (students only).

3.5.3 Hibernating level of EEE

EEE stockpiling and hoarding were observed in all categories of devices surveyed. Definitions for a stockpiled/hoarded item have been outlined previously to differentiate between the two streams of devices. Overall, observed product stockpiles (functional but unused devices) were higher than product hoards (non-functional devices), as shown in Figure 3.12 and Figure 3.13.

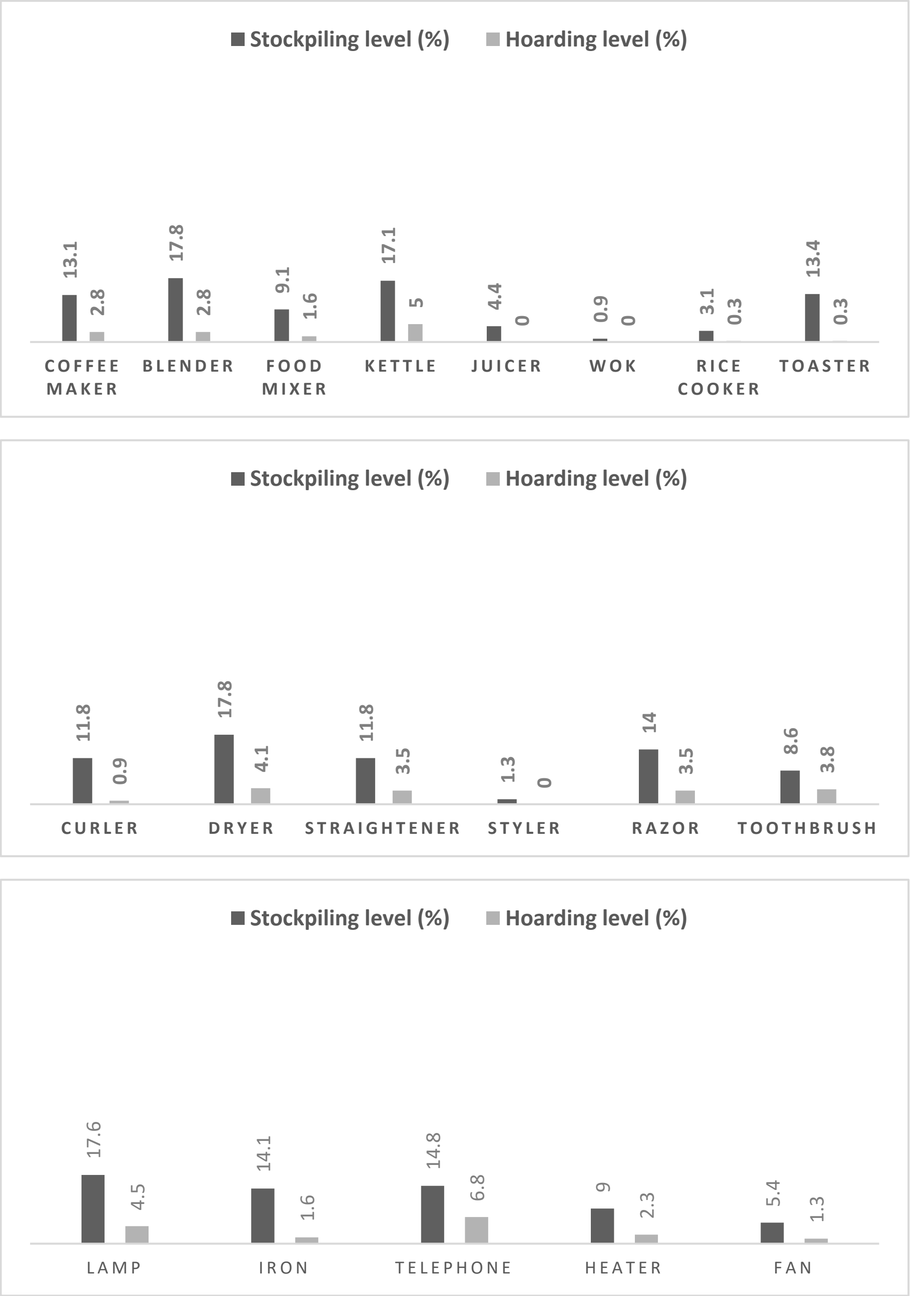


Figure 3.12. Stockpiling and hoarding levels of small kitchen appliances (n=320), personal care appliances (n=314 except for straightener, styler and toothbrush (n=313) and small household appliances (n=311 except for lamp and fan (n=312)).

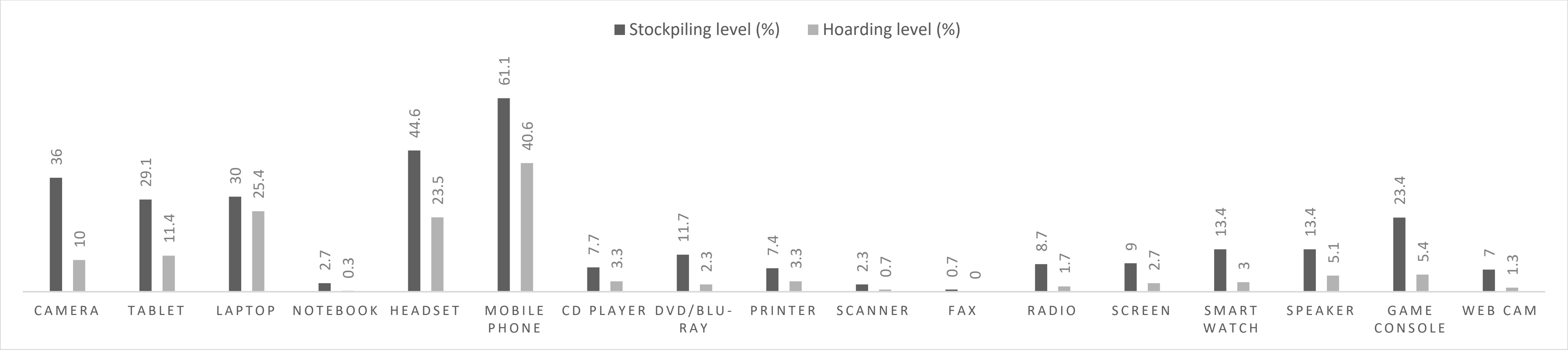


Figure 3.13. Stockpiling and hoarding levels information and communication technology/audio-visual devices amongst all respondents (n=299 except for camera (n=300) and mobile phone (n=298).

The highest stockpiling levels were observed in the ICT/AV devices categories with mobile phones and headsets with over 60% and 40% respectively. High hoarding was also observed with these two devices (40.6% and 23.5% respectively) (*see* Figure 3.13). From the other categories, devices such as kettles, blenders, toasters (SKA); hair dryers (PCA); irons and lamps (SHA) all had stockpiling level of over 15% (*see* Figure 3.12). Observed percentage differential between stockpiling and hoarding levels varied from 26 percentage points (cameras) to 0.7 percentage points (fax machines).

3.5.4 Quantification of hibernating EEE

The EEE with the largest stocks was an ICT/AV device category while the lowest was a PCA. As shown in Figure 3.14, stockpiled items were observed to generally outnumber hoarded items. The proportion of stockpiles in relation to hoards (stockpile/hoard ratio) varied from 16 for curler (1 hoarded curler for every 16 stockpiled curlers) to 1 observed with laptop (1 stockpiled to 1 hoarded). Mobile phones and headsets, with the highest number of hibernating devices, had ratios of 1.5 and 1.9 respectively. The proportions of stockpiles to hoards are illustrated in Figure 3.15

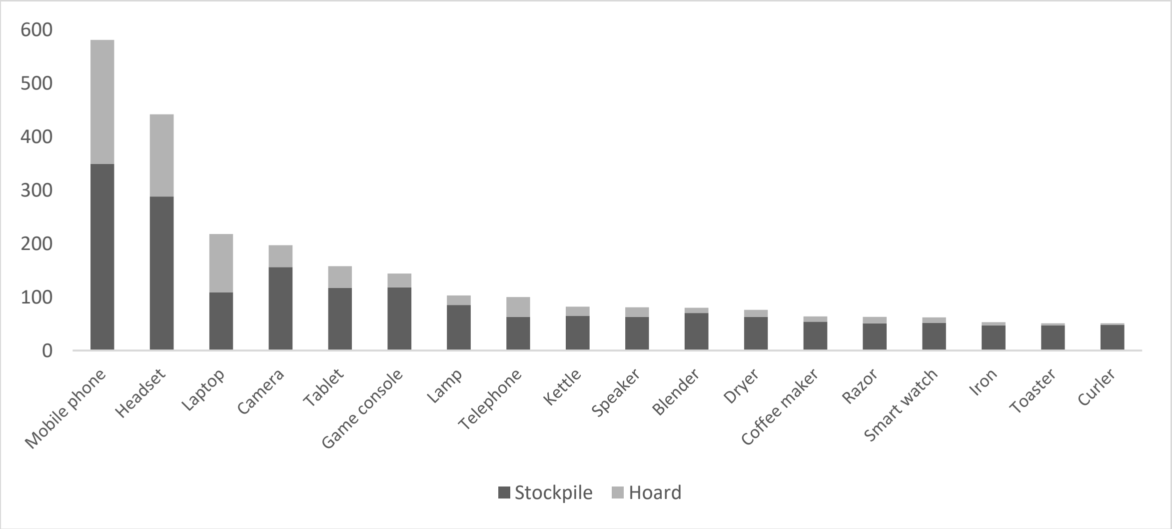


Figure 3.14. Total number of select device stocks with proportion of stockpiled and hoarded EEE (devices with 50 or more units observed).

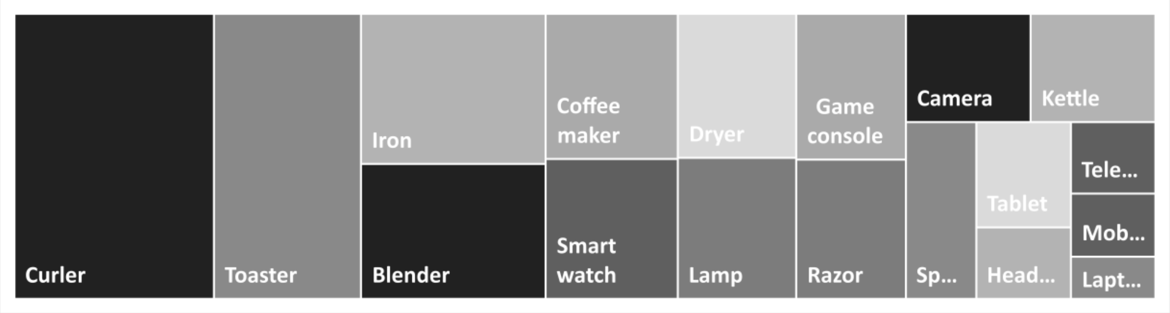


Figure 3.15. Stockpile/Hoard proportions of device stocks; (devices with 50 or more units observed) (Note: **Sp**: speaker; **Head**: headphones; **Tele**: home telephone; **Mob**: mobile phone; **Lapt**: laptop computer). Figure drawn to scale

3.5.5 Estimated reuse value

The reuse value of the unused functional devices owned by respondents was quantified and evaluated (Table 3.10 and Table 3.11). The evaluation covered the devices with the highest hibernating stocks for each EEE surveyed. In this regard, kettles (SKA), hair dryers (PCA), lamps (SHA) and mobile phones (ICT/AV) average resale value was evaluated from randomly selected price data of similar pre-owned devices (*see* section 3.4.5.2).

Table 3.10. Average sale value of selected devices. The minimum and maximum values from the randomly selected price for each device are shown together with median values and average.

Device	Minimum (£)	Median (£)	Maximum (£)	Average (£)
Kettle	6	10	15	**9.40**
Hair dryer	2.50	8	15	**7.45**
Lamp	5	17.50	50	**21.20**
Mobile phone	25	119	279	**138.60**

Table 3.11. Potential resale value of selected devices from the survey. Unit resale price expressed as average with low to high value based on devices with highest reusable stocks from each device category selected. Total hibernating EEE stock from survey as well as fraction potentially saleable shown. Average unit price presented with calculated standard error from randomly selected price samples.

Device	Total hibernating stock	Reusable stock	Reusability (%)	Average unit price (£)	Resale value (£)
Kettle	82	65	**79.3**	9.40 ± 0.80	559 – 663
Hair dryer	76	63	**82.9**	7.45 ± 1.20	393.75 – 544.95
Lamp	103	85	**82.5**	21.20 ± 5.00	1377 – 2227
Mobile phone	581	349	**60.1**	138.6 ± 24.70	39751.10 – 56991.70
Total	**842**	**562**	-	-	**42080.85 – 60426.65**

The largest proportion of ‘reusable’ EEE was observed in kettles with approximately 79% of hibernated stock reported to be in working condition. In terms of quantity, the number of reusable mobile phones was highest: 349 out of 581 devices reported to be in working order.

Mobile phones also had the highest estimated reuse value of approximately £40,000 – £57,000 based on the stockpile observed in the survey (349 devices). Overall value potentially obtainable from the 4 EEE is up to £60,000. Again, this valuation is based on the reasonable assumption that devices are saleable in their current state and require no repair and/or upgrade.

3.6 Discussion

3.6.1 EEE ownership and hibernation

3.6.1.1 EEE ownership levels

The survey results highlighted the trend of increasing ownership levels of EEE. This trend has resulted in the proliferation of urban mines that are rich in resources and potentially exploitable (Ongondo *et al*., 2015; Wilkinson & Williams, 2020). Ownership levels of small EEE were significant amongst the respondents, which represent a sample from the regional DUM cluster of three universities in the UK (meso-level DUM; Figure 3.2). The results were broadly representative since the survey was a random coverage of all constituents of a university DUM (staff and students) spread across three universities and the demographic proportions within the survey sample were closely comparable with national data (Table 3.5).

Overall, high ownership levels were observed in all categories of small EEE surveyed. Highest ownership averages were observed in the ICT/AV category and all respondents surveyed owned at least one mobile phone. Other devices in this category such as headsets, laptops and tablets also had high ownership levels with over 70% of respondents owning at least one of these devices (87.9%, 91.3% and 73.9% respectively). Kettles, hair dryers and electric irons were frequently owned, having the highest ownership levels for SKA, PCA and SHA categories respectively. This is consistent with increases in purchasing and usage of consumer ICT electronics globally, exemplified by the number of mobile phone users surpassing 3 billion in 2019 (Statista, 2021) and 95% mobile phone ownership in the UK (Statista, 2019). UK EEE consumption is rising with a generation of 23.9 kg/capita/year of WEEE generated in 2019 (Forti *et al*., 2020), second highest after Norway. The levels recorded are in line with values observed in previous studies such as Ongondo *et al* (2015), Pierron *et al* (2017) and Wilkinson and Williams (2020), the latter focusing on home entertainment EEE. The present survey results showed 100 % ownership level of mobile phones and on average, each respondent owned 2.5 mobile phones. This was closely followed by ownership of headsets (2.4 per person on average). It is worth noting that this was observed before the COVID-19 pandemic, which is likely to have increased the ownership of devices such as headsets as more people were required to work from home. Conversely, devices with low ownership levels were observed in the ICT/AV category. Legacy devices[13] such as fax machines had low ownership level (approximately 1%) and these devices were owned by older respondents (25 and above). Unsurprisingly, no student respondent reported owning a fax machine (*see* Figure 3.10) as the few owned few devices observed in the survey belonged to older respondents.

Older respondents (25 years and above; staff and students) had higher ownership levels of 28 out of 36 EEE (78%) than those between 18 – 24 years. Amongst student respondents, UK students were observed with higher ownership levels of 72% of EEE surveyed (26 of 36 devices). This may be due to the capability of home students to bring in more items from their UK permanent residences without the load restrictions students coming from overseas have to contend with if travelling by air. However, this group (students from overseas) is likely to dispose of some items including EEE at the end of their study, particularly those that would depart the UK via air travel due to baggage restrictions.

3.6.1.2 EEE hibernation levels and circular economy potential

Together with ownership levels of EEE, information on devices in hibernation is essential in establishing the scope of potential of a DUM (Wilkinson & Williams, 2019). Factors influencing device hibernation have been examined previously. Factors such as awareness of intrinsic value as well as willingness to have a backup (stockpiled) device are known to be reasons behind hibernation of EEE (Ongondo *et al*., 2015; Pierron *et al* 2017, Wilkinson & Williams, 2020; Pierron *et al*., 2020). Such devices are likely to be held on to due to due to their perceived residual value which is often over-estimated (Pierron *et al*., 2020). For hoarded (non-functional) devices, their hibernation may be due to a lack of awareness of disposal options or inaccessibility to systems for product recovery (Ongondo & Williams, 2011; Saphores *et al*., 2012, Pekarkova *et al*, 2021). Disposal routes including landfilling with general waste are frequently considered, especially for broken PCA, and recycling for SKA (Pierron *et al*., 2017). In the survey results, there was evidence of device hibernation (stockpiles and hoards), the stockpiles being those with reuse potential. As illustrated in Figure 3.14 and Figure 3.15, the survey showed there was a higher percentage of stockpiles (potentially reusable stock) relative to hoards (non-functional devices) for every device. Projections from survey data (*see* Table 3.12) to macro-DUM level show an estimated stockpile of over 17 million items in university DUMs across the UK which equates to an average of

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[13] A legacy device is one that is outdated or no longer in production (www.techopedia.com/definition/2230/legacy-device)

approximately 6.1 stockpiled devices per person. The results showed that the most frequently hibernated EEE belonged to ICT/AV category with the 6 most frequently hibernated devices belonging in this category. Outside of this, lamps were the most hibernated SHA, kettles in SKA and electric razors in PCA. These findings are comparable with those from literature (Darby & Obara, 2005; Ongondo *et al*., 2011; Wilkinson & Williams, 2020) that reported high hibernation rates of small devices. Their small sizes mean storing them is convenient for many, including students who, due to their place of abode (e.g. halls of residence), have limited storage space.

Table 3.12. Total number of devices owned, stockpiled and hoarded in the survey zone (meso-level DUM cluster) and in the UK (macro-level DUM cluster) estimated from survey data

EEE	**Owned (Survey Zone)**	**Stockpile (Survey Zone)**	**Hoard (Survey Zone)**	**Stockpile (UK-wide)** [14]	**Hoard (UK-wide)** [15]
Mobile phone	162,675	76,132	50,755	3,303,992	2,202,662
Headset	156,168	65,070	33,836	2,823,925	1,468,441
Laptop	110,619	23,425	23,425	1,016,613	1,016,613
Camera	78,084	33,836	9,110	1,468,441	395,350
Tablet	91,098	25,377	9,110	1,101,331	395,350
Game console	65,070	25,377	5,856	1,101,331	254,153
Lamp	110,619	17,569	3,904	762,460	169,436
Telephone	65,070	13,014	7,808	564,785	338,871
Kettle	71,577	13,014	3,254	564,785	141,196
Speaker	78,084	13,665	3,904	593,024	169,436
Blender	71,577	14,315	1,952	621,264	84,718
Dryer	71,577	13,014	2,603	564,785	112,957
Coffee maker	39,042	11,062	1,952	480,067	84,718
Razor	52,056	10,411	2,603	451,828	112,957
Smart watch	32,535	11,062	1,952	480,067	84,718
Iron	58,563	9,761	1,301	423,589	56,479
Toaster	45,549	9,761	651	423,589	28,239
Curler	26,028	9,761	651	423,589	28,239
Total	**1,385,991**	**395,626**	**164,627**	**17,169,465**	**7,144,533**

Ongondo *et al*. (2015) in their DUM concept study opined that having such knowledge of replacement cycles provides insight to potential product availability for recovery. However, other factors such as willingness of owners to make such devices accessible for recovery is crucial (Li *et al*., 2012, Wilkinson & Williams, 2020). The survey showed that a high number of devices had long

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[14] Estimation was based on total population in UK HEIs (2018/19) from Higher Education Statistics Agency; (devices with 50 or more hibernating units presented).

[15] Estimation was based on total population in UK HEIs (2018/19) from Higher Education Statistics Agency; (devices with 50 or more hibernating units presented).

usage cycles (3 years and above) particularly SKA and SHA (*see* Figure 3.16). Also, most respondents (approximately 91% and 83% respectively) reported replacing PCA such as hair dryers and curlers only if broken as opposed to being frequently turned over and replaced. Significant proportions of ICT/AV devices such as mobile phones, tablets and laptops are replaced within 3 years, which make them potentially exploitable within a relatively short period. The usage cycles observed are comparable with replacement cycles reported in studies such as Ongondo *et al*. (2015) and Wilkinson and Williams (2017) particularly for ICT/AV devices such as mobile phones. A unique feature of the population within a university DUM is its transient nature. A significant proportion of the population (students) turns over periodically and these periods of transition potentially present opportunities for EEE recovery, especially during move-out periods from student accommodation. This results in a 'clear-out' of belongings, some of which are discarded, and has often led to challenges with disposal of items (Williams & Powell, 2018).

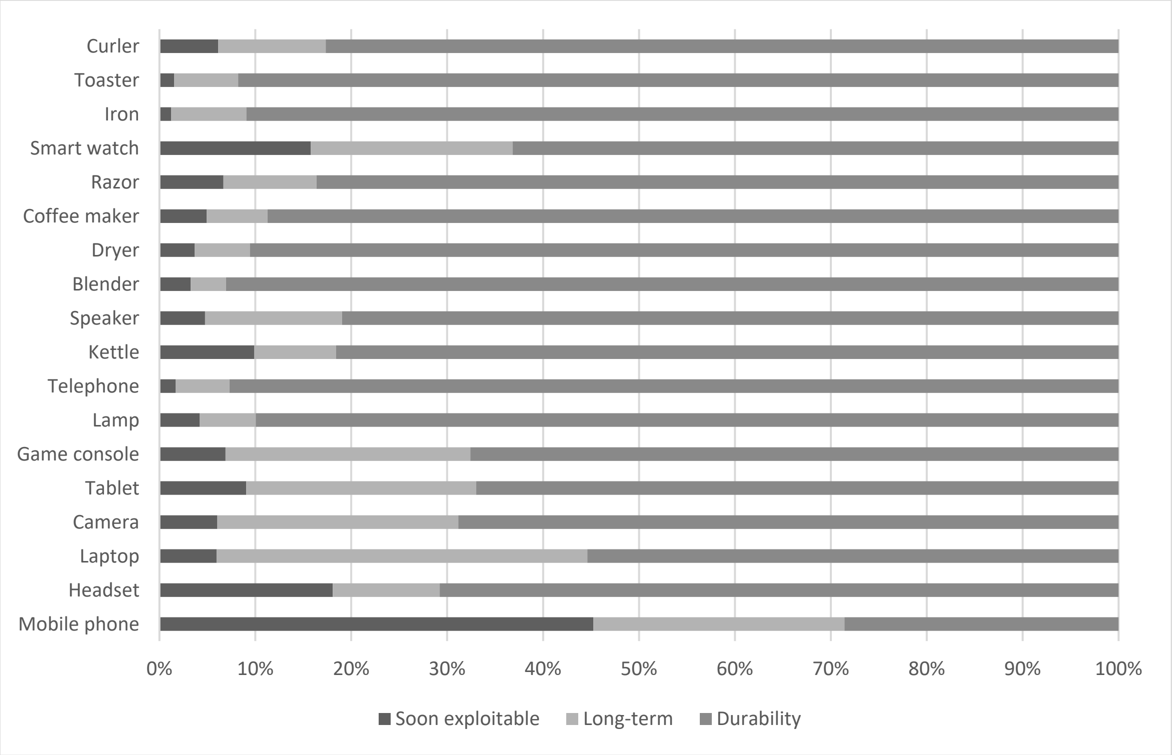

Figure 3.16. Devices usage cycles from survey; soon exploitable: 0-3 years; Long-term: 3+ years; durability: replaced only when broken/damaged (devices with 50 or more units observed).

Devices discarded before their average end-of-life cycles retain some functional (reuse) value as well as residual (material) value, making them potentially reusable and/or saleable. This, based on resource efficiency and the waste hierarchy, is a preferable outcome to recycling (Ijomah, 2019; Pekarkova *et al*, 2021). This is because recycling such devices eliminates the functional value that is lost during material recovery. Keeping a device in use for longer is a desirable route towards circularity as the functionality value of the device is enabled for longer before its residual value is exploited. Recycling is a relatively common activity, particularly in Europe and this is highlighted by a European Union survey (Eurobarometer, 2017) which showed that 65% of European citizens carry out recycling activities which suggests a desire to recycle (Pekarkova *et al*, 2021). However, more value can be derived from EEE kept in usage for longer in its current form as opposed to recycling at the end of use. For devices such as kettles, lamps, dryers and mobile phones, which, as the results show, have high stocks in hibernation, the reuse potential per person is significant (*see* Table 3.13).

Table 3.13. Estimated reuse potential in surveyed zone and UK-wide for the most frequently stockpiled devices in each category

Device	**Average stockpile**	**Reuse value (Survey Zone; in million £)**	**Reuse value (UK-wide; in million £)** [16]	**Reuse potential/capita (£/capita)** [17]
Kettle	0.20	0.11 – 0.13	4.94 – 5.85	1.75 – 2.07
Hair dryer	0.20	0.08 – 0.11	3.53 – 4.91	1.25 – 1.74
Desk lamp	0.27	0.29 – 0.46	12.45 – 20.16	4.41 – 7.14
Mobile phone	1.17	8.68 – 12.44	376.68 – 540.08	133.39 – 191.25
Total	-	**9.16 – 13.14**	**397.60 – 571.00**	-

Current systems mostly target collection of W/EEE for recycling. Such systems are neither optimised nor intended for recovery of reusable EEE. Key to establishing reuse as a genuine option is the implementation of structures and protocols designed exclusively for this stream of products. This could feature close involvement of third-party sectors such as schools, which can be used as recovery hubs, as proposed by Hursthouse *et al*. (2017), and charities. Charities, as described in Osterley and Williams (2019), can help with the redistribution of recovered devices via sales and/or donations. This can help bridge gaps in social inequality that is prevalent even in developed economies such as the UK (The Big Issue, 2021). Timlett and Williams (2011) have highlighted that behaviour-centric approaches together with informed changes to infrastructure and service provision are required to meet reuse/recycling targets. Combining these three aspects, bespoke recovery systems could, in principle, be designed with the aims of: i) recovering stockpiled EEE for reuse and ii) recovering hoarded EEE for recycling in different levels of DUM.

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[16] Projection based on UK HEI population of 2,823,925 (2018/2019 academic year)

[17] Estimate based on number of respondents that completed question on stockpiling (n): kettle 320; dryer 314; lamp 312; mobile phone 298

3.7 Chapter conclusions

The study presented in this chapter successfully examined the potential for recovery of reusable EEE from university distinct urban spaces at a regional (meso) level. It provides 'snapshot' data on device ownership and hibernation levels amongst the population of micro-level (university) DUMs (staff and students) within a meso-level (regional) DUM cluster. The data from the meso-level DUM with a population of ~65,000 show that kettles, lamps, hair dryers and mobile phones are the most stockpiled SKA, SHA, PCA and ICT/AV devices respectively. Stockpiling of reusable EEE is more common than hoarding non-functional devices with reusability of up to 80% observed. This translates to >17 million small EEE within university DUMs across the UK (macro-level DUM) with reuse value of potentially >£500 million. The study demonstrates the significant reuse potential in micro-level and meso-level DUMs and provides an indication of the extraordinary reuse (and subsequent recycling) potential at the macro-DUM level. It highlights and quantifies the huge benefits of shifting towards product reuse in financial value, materials/products recovery and pro-environmental terms within distinct urban mines at all levels.

Mobile phones were identified as the most stockpiled of the EEE surveyed and with the highest reuse value per person with an average reuse potential of up to £190 per person in a university urban mine. However, the fostering of reuse as a viable option of the waste management hierarchy will require interventions to current systems. Changes to product value chain from production to end of use decisions are required to facilitate reuse of products. Manufacturing products to last longer ensures that they can have multiple usage cycles before reaching end-of-life and going into the recycling stream. At the end user side of the value chain, informed changes that nudge towards reuse at product end of use are required. These need to be holistic and should include changes to service, infrastructure and behaviour. Timing of product recovery also of essence to reduce the incidence of technological obsolescence of unused functional devices.

The choice of reuse at product end of use needs to be made convenient and readily available. This will require encouraging the choice of reuse over buying new, which is a challenge as this will need a huge attitudinal change towards pre-owned products. For a university DUM, the transience of a significant portion of the population (students) provides a unique opportunity for reusable EEE recovery. A system of periodic collection designed to strategically coincide with periods of transience such as end of term as well as other ancillary procedures and services (e.g. awareness, product collection and sorting, product repair) is recommended in order to tap into the reuse potential of the distinct urban space at micro, meso and macro levels.

Chapter 4 Demonstrating EEE recovery for reuse: a micro-level distinct urban mine case study

4.1 Chapter overview

The previous chapter discussed urban mines in the context of product recovery for reuse and presented the findings on an assessment of a meso-level DUM for potential exploitation. The results showed a high level of potentially reusable products which, if timely recovered, could be reintroduced into the circular economy for extended use. This timely recovery from a DUM would require a system specifically designed to recover reusable EEE as well as incorporate ancillary procedures and protocols for product collection, assessment and redistribution.

This chapter presents the conceptualisation and application of a reuse-centred collection and recovery protocol aimed at demonstrating the potential of a university DUM for recovery end-of-use and reusable EEE. This is an assessment and critical evaluation of an EEE recovery system based on the interventions specifically put in place for recovery of reusable EEE as a priority from a university distinct urban mine (DUM). This chapter presents the outcome of the third phase of research thesis as illustrated in Figure 4.1.

This chapter begins with a background on consumerist culture with reference to consumer electronics (Section 4.2). This is followed by an exploration of pro-environmental behaviour theories and their use in the field of environmental sustainability (Sections 4.3 and 4.4). Here the infrastructure, service and behaviour (ISB) model is introduced and with its link to this case study discussed. Section 4.5 outlines the methods and procedures used in the case study which is followed, in Section 4.6, by the results and discussion of the case study. A modified version of this chapter titled has been published in *Detritus* titled *Demonstrating EEE recovery for reuse in a distinct urban mine: a case study*.

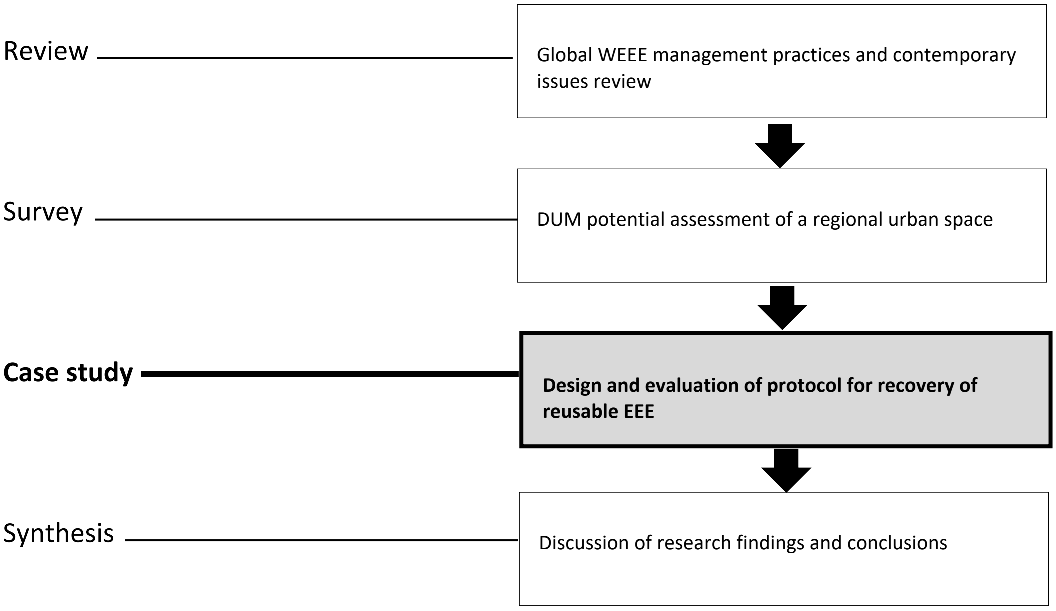


Figure 4.1. Thesis road map showing case study phase

4.2 Consumer behaviour and product end-of-use decisions

Consumerism is escalating as manufacturers create and promote new products, particularly as an outcome of the quest by producers for higher market share. At the same time, growing global affluence has resulted in an increase in “throw-away culture.” Consumption and manufacture of short-lived or disposable items rather than durable products that can be repaired inevitably leads to high turnover of items by consumers as consumers opt for newer, often trend-driven items. The linear pattern of buy-use-discard results in the relentless generation of waste that puts immense strain on resources, as there is a constant need to source raw materials to manufacture products to meet increasing demands. Contemporary high-tech EEE such as home entertainment equipment is especially rich in metals and critical raw materials (e.g. rare earth metals and platinum group metals) and constitutes a marked portion of anthropogenic stocks (Massari & Ruberti, 2013; Golev *et al*., 2016; Williams, 2016). Demand for consumer electronics is increasing and device usage cycles are shortening, which results in the generation of large quantities of discarded items. This situation has led to an increase in resource efficiency-oriented plans and strategies in the UK and Europe. These range from strategies targeting sustainable consumption such as ‘Resource Revolution’ (WRAP, 2015) to those promoting reduction in waste generation via product reuse and reparability, such as the EU Circular Economy Action Plan (Circular, 2020a).

However, some manufacturers appear to dislike these initiatives; Apple Inc., for example, took legal action against a small independent repair shop to the Supreme Court in Norway in order to prevent refurbishment of Apple's iPhones, claiming that its trademark had been "unlawfully appropriated". Apple Inc. won the Norwegian Supreme Court case in June 2020, which could be considered an impediment to reuse. Indeed, this legal decision reinforces maintenance of the *status quo* (i.e. more recycling and better management of waste disposal) at the expense of societal objectives to reduce, through reuse, the amount of waste being generated and to minimise its potential for harm to human health and the environment. In this respect, this case also raises the importance of recycling specific items (such as small WEEE) and thus highlights the importance of data on product (waste) composition to facilitate end markets for recyclates.

Purchasing decisions are influenced by several factors including, but not limited to, purchasing power (money), lifestyle, peer pressure, contemporary fashion trends, advertising, etc. These decisions often influence the duration of product use (Cox *et al*., 2013). When a product is no longer wanted or needed (e.g. broken or deemed obsolete, old or out of fashion), the owner could make one of a number of decisions for the fate of the item; decision in this context refers to what is done to the product after it is deemed by the owner to have reached its end-of-life. The decision made could either continue a linear path of production (make-use-dispose) or that of a closed loop.

End-of-use decisions remain strongly influenced by targets relating to recycling. Whilst recycling provides a "feel-good" factor to the public, it does not result in decoupling of consumption and waste generation or the correct application of principles of the waste hierarchy and circular economy. The decision to dispose, stockpile, hoard, reuse or recycle is dependent on various factors including, but not limited to, perceived intrinsic product values, availability and convenience of reuse/recycling channels, ease of repair etc.

4.3 Pro-environmental behaviour change

Many environmental challenges are intricately linked with human behaviour thus behavioural changes are required to bring about change (Steg and Vlek, 2009). Pro-environmental behaviour change is defined as behaviour that pursues the minimisation of negative impacts on the natural or built environment of one's action which can be achieved via means including resource and energy conservation, waste prevention and minimisation (Kollmuss & Agyeman, 2002). The combination of human factors such as these with other means (e.g. use of technology) goes some way in addressing environmental challenges (Bell *et al*., 2001).

Behavioural norms, according to Rimal and Real (2003), are codes of conduct that inform behaviour within a group of people. These are usually communicated between members of the group and can be described as either descriptive or injunctive. Descriptive norms are norms that are perceived or accepted as normal (Thogersen, 2006). These are generally imitated by copying others and adapting over time. On the other hand, injunctive behavioural norms are belief-oriented norms and define behaviour that is deemed moral or immoral (Cialdini *et al*., 1991). The combination of these two aspects have been shown bring about behavioural change (Schultz *et al*., 2007, Cialdini *et al*., 2003).

Behaviour is an important influence in the decision-making at the end-of-use of a product. Decisions promoting a circular economy approach require product owners to behave in a certain manner – such as de-stockpiling/de-hoarding or buying pre-owned products – to facilitate actions consistent with the desired application of the waste hierarchy (Dunlap & Jones, 2002; Ongondo *et al*., 2015, Pierron *et al*., 2017). Despite the general unpredictability and complexity of human behaviour, several theories have been developed to provide insights into human behaviours and the factors influencing them (Darnton, 2008; Parajuly *et al*., 2020). Behavioural theories have been classified into different groups; these include: *rational choice theories* and *moral theories* (Turaga *et al*., 2010). Rational choice theories are mainly based on attitudes and subjective norms (Kaiser *et al*., 1999). There are several examples of these theories from different field including psychology, sociology and economics (Parajuly *et al*., 2020). The best known of these is the Theory of Planned Behaviour (TPB). This theory centres on intention to carry out an activity and suggests that such intention is subject to attitudes towards the behaviour together with subjective norms (Ajzen, 1991). The theory considers intention to be the most significant factor in bringing about behavioural change (Parajuly *et al*., 2020). Amongst the moral theories in the field of behavioural psychology, the Value-Belief-Norm theory is the best known. It is centred around moral norms which are known to be powerful drivers of practices including pro-environmental behaviour and policies (Davies *et al*., 2018). Stern (2000) stated that beliefs and norms can be shaped by information to bring forth behaviour change.

Theory of Planned Behaviour (TPB) and the Value-Belief-Norm (VBN) model are the best-known behaviour theory/model and they have been applied to explain pro-environmental behaviour previously (Kaiser *et al*., 2005; Lopez-Mosquera & Sanchez, 2012; Botetzagias *et al*., 2015;

Bronfman *et al*., 2015; Janmaimool & Denpaiboon, 2016). Whilst pro-environmental decisions are likely to be influenced by intrinsic motivators such as beliefs, attitudes and norms (Kaiser *et al*., 2005), pro-environmental behaviours can also be influenced by extrinsic factors such as choice architecture (Thaler *et al*., 2010), which involves the modification of situational factors to bring about a desired outcome. In their study of distinct urban mining potential of a UK university, for example, Pierron *et al*. (2017) investigated ownership, stockpiling and disposal of small EEE amongst students and concluded that choice architecture can be deployed to initiate specific and desired outcomes at a product's end of use.

4.4 Reuse-oriented intervention in a university DUM

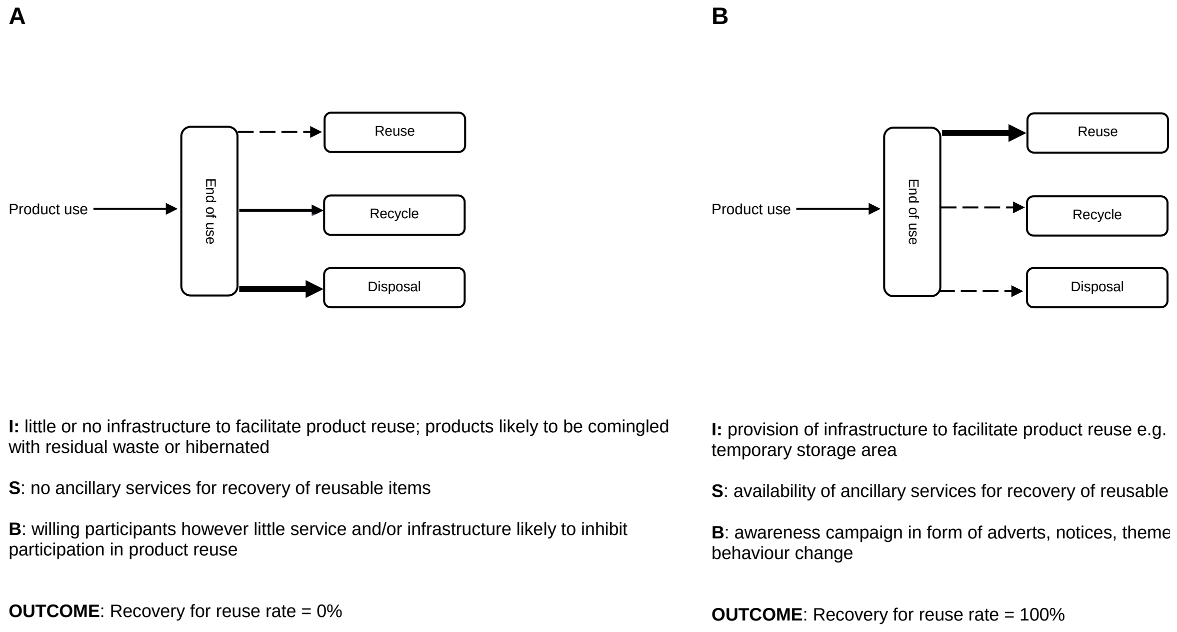
Behavioural theories have been applied when seeking to develop interventions in environmental management. Such interventions are designed such that they address intrinsic and extrinsic barriers to change (Schultz *et al*., 1995; Timlett & Williams, 2011). Intrinsic motivation for individuals to engage in pro-environmental behaviours such as reuse, and recycling can give rise to a naturally satisfying "warm-glow" effect. Such motivators include personal satisfaction, positive emotions and altruistic motives that benefit the well-being of others. Extrinsic motivators to engage in reuse and recycling may include a desire to conform to social and societal norms, enhancement of personal reputation, praise and financial rewards; several socio-psychological behavioural models have been proposed to explain waste-related behaviours (Williams, 2015). Behavioural change is also influenced by situational factors such as income and infrastructure, although the strength of these factors upon major decisions and actions may be limited (Stern, 2000). Consequently, behavioural change interventions require measures addressing both internal (psychological; intrinsic and extrinsic) and external (situational) factors. Models incorporating both intrinsic and extrinsic factors to explain behaviour in the context of waste and resource management have merit.

The Infrastructure, Service, Behaviour (ISB) model, for example, adopts this approach for planning interventions to maximise resource efficiency via consideration of situational and psychological variables (Timlett & Williams, 2011), and has been previously applied to demonstrate the impact of introducing specific and guided interventions in waste and resource management. As highlighted in Chapter 3, Higher Education Institutions (HEIs) are viewed as beacons of positive change and promoters of environmental sustainability (Martin & Samels, 2012; Vagnoni & Cavicchi, 2015). This reputation is achieved via knowledge creation and dissemination as well as commitment to sustainable initiatives and policies (Zhang *et al*., 2011; Tangwanichagapong *et al*., 2017), ranging from construction of 'green' buildings to carbon-neutral transportation systems and sustainable waste management systems with emphasis on reuse, recycling and resource conservation. With regard to waste management, one step towards achieving sustainability is to consider a HEI to constitute a distinct urban mine (Ongondo *et al*., 2015). HEIs can be viewed as small cities and provide a microcosm of the settlements within which they are situated. People within these HEI environments, like regular towns or cities, are consumers of goods and services, which make these urban spaces ideal for studying and trialling new initiatives before being implemented at broader scale.

HEIs in the UK typically provide accommodation for first year students as well as international students enrolled on foundation, pre-sessional and postgraduate courses. According to HESA (2020), approximately 15% of all enrolled students in UK HEIs in were in university accommodation during the 2018/19 academic year (>300,000 students). An academic year is typically made up of 3 terms each of around 10 weeks; the beginning of each term is accompanied by a turnover of students synchronised with teaching schedules. The first term generally comes with the highest level of enrolment in late September, while the summer term sees most student departures in June or July. These turnover periods usually result in a high number of departures from student accommodation. The university-maintained facilities thus encounter two (or sometimes three) annual "move-outs" during which students vacate their accommodation (Williams & Powell, 2019); undergraduates move out in early summer and postgraduates (and sometimes pre-sessional language) students move out during early autumn. These periods are usually associated with some products reaching their end of use. The end-of-use decision made by the owner will be largely dependent on the availability of appropriate (situational) factors. While a departing student is likely to take with them some of their personal possessions, there is always a high likelihood that some products will be discarded, some of which will retain functionality and be reusable. This pattern typically results in the generation of large quantities of discarded items, ranging from bedding, textiles and bric-a-brac to electronics and kitchenware. These regular and predictable surges in the generation of discarded items often lead to littering of streets around student dwellings and tension with the local community. There have been a few attempts by HEIs to alleviate this issue. In their review of HEIs' reuse schemes, Williams and Powell (2019) highlighted a number of schemes in UK HEIs conceived to deal better with move-outs: recovering reusable items results in diversion from landfill, aid to charitable causes and improves relationships with residents and authorities. In several of the schemes reviewed, items deemed in good condition and reusable were donated to charity organisations, sale of which generates income to support the actions of the charities.

The potential recycling value of WEEE is well established in terms of, for example, the potential value of material recycling (Chancerel & Rotter, 2009) and as a secondary metal resource (Oguchi *et al*., 2011). The concept and potential of urban mining for WEEE within distinct urban spaces (i.e. universities) has been established for WEEE (Ongondo *et al*., 2015); the collection of both WEEE and end-of-use EEE could be enhanced by the application of choice architecture (Pierron *et al.*, 2017). Relatively few studies, however, have explored the potential for recovery of reusable EEE within distinct urban spaces. Wilkinson and Williams (2020) evaluated the ownership and hoarding levels of home entertainment EEE within a DUM and found a high level of hoarding of devices that can be potentially recovered; the potential for the recovery of reusable items from students in a HEI has been demonstrated but not yet for EEE (Williams & Powell, 2019).

The potential for enhancing reuse in this context can be illustrated by comparing two scenarios, with and without opportunities for EEE reuse. Under a scenario in which HEIs provide limited opportunity for the recovery of reusable EEE discarded by students upon departure from university accommodation (Figure 4.2A), such items are either destined for recycling or commingled with residual waste. Consequently, discarded items with reuse value would be landfilled or recycled: while recycling is a preferred to landfill as an outcome, recycling does not exploit the full value of a still-functional product. A scenario in which opportunities for the recovery of reusable EEE are provided (Figure 4.2B) requires a targeted intervention and desired behavioural response. Using the ISB model (Timlett & Williams, 2011), suitable interventions can be implemented. A perfect scenario (Figure 4.2B) for a reuse-based system is one where infrastructure (I), service (S) and behaviour (B) all contribute towards achieving 100% reuse of recovered products.



I: little or no infrastructure to facilitate product reuse; products likely to be comingled with residual waste or hibernated

S: no ancillary services for recovery of reusable items

B: willing participants however little service and/or infrastructure likely to inhibit participation in product reuse

OUTCOME: Recovery for reuse rate = 0%

I: provision of infrastructure to facilitate product reuse e.g. temporary storage area

S: availability of ancillary services for recovery of reusable

B: awareness campaign in form of adverts, notices, theme behaviour change

OUTCOME: Recovery for reuse rate = 100%

Figure 4.2. Schematic illustration of extreme end-of-use scenarios. **I**nfrastructure (Aspects of the built environment such as buildings, storage bins for recycling); **S**ervices (Protocols or systems that enable patterns of behaviour e.g. weekly collection of dry recyclables); **B**ehaviour (How a person undertakes recycling/reuse) (Timlett and Williams, 2011). Panel **A** illustrates the baseline scenario before intervention. The likely destination for reusable EEE in this scenario is residual waste which goes to landfill with some recycling occurring; **B** shows the shift to recovery of products for reuse after introduction of an ISB-based recovery protocol aimed at achieving 100% recovery for reuse. Thickness of arrows indicates likelihood of product destination.

In this study, the implementation of a reuse-based EEE recovery system conceptualised using the ISB model is demonstrated for the recovery of functional reusable EEE in a university DUM. This is the first assessment and critical evaluation of the potential for recovery and redistribution of reusable EEE from a specific stream in a university urban mine using a reuse-based recovery system. The study makes the case for product reuse as the priority, targeted, most beneficial end-of-use option for sound products as opposed to an inadvertent and unconscious drift towards options that result in giving precedence to product recycling within a DUM. This study presents therefore an evaluation of the potential of a DUM for the recovery of reusable EEE as a priority, with focus on recycling only after practical options for reuse have been fully applied and exhausted. Product reuse, where possible, is presented as the preferable outcome for end-of-use EEE, thereby keeping products in the system for as long as possible.

The objectives of the study are as follows:

- Design and implementation of a reuse-based recovery protocol using the ISB model (Timlett and Williams, 2011);
- Estimation and potential value/revenue projection from products recovered for reuse (product and material value);
- Appraisal of collection and recovery protocols; and
- Recommendations on improvements to collection and preparation for reuse of EEE and recycling of WEEE from a DUM.

4.5 Methods

The study was centred on an assessment of reuse potential in a university urban mine, with focus was on students' Halls of Residence (HoR). HoR experience turnovers of student residents at specific periods, which provide a unique opportunity to investigate the potential for recovery of reusable EEE when students move out of their accommodation. Also, due to their mixed occupancy, HoR present an ideal study area to assess recovery of items from different groups of students (e.g. undergraduates/postgraduates; home/international domiciled).

The study was conducted in three phases: pre-collection, collection and sorting, and post-collection (Table 4.1). The pre-collection activities took place in the months leading to the end of summer term of the 2018/19 academic year while the collection phase took place during June, July and September 2019.

Table 4.1. Project methodology outline including phases and activities.

Study Phase	**Activities**
Pre-collection	Protocol development Meetings with representatives of residential services and selected charities Recruitment and protocol briefing of project volunteers
Collection and Sorting	Items drop and transportation to central sorting location Product inspection and data collection Product redistribution

Study Phase	Activities
Post-collection	Analysis of reuse potential Material composition analysis (using secondary data) Process analysis

4.5.1 Study area

The study took place at the University of Southampton, a large multi-campus university located in the city of Southampton, UK. It has a student population of 24,625 (HESA, 2020), most of whom are based at the main campus in Highfield. The university currently has eight institution-owned HoR offering an array of room types and sizes (University of Southampton, 2019). For this project, two HoR were selected with contrasting populations of student residents (Table 4.2). As the study set out to encompass a varied and comprehensive mix of students for representativeness, these halls provided representative samples with regard to predominant student groups they accommodate and size and layout.

Mayflower Halls is a large student complex located near Southampton city centre, approximately 3 km from the main campus. It has a room capacity of 1,105. The complex provides accommodation to students at all levels of study (foundation, undergraduate and postgraduate). By contrast, City Gateway is relatively small, located 1.6 km from the main campus and is exclusively for postgraduate and mature students (21 years or older at the start of their studies). These two HoR vary from layout to types of students accommodated which provides ideal contrast and justifies their selection for the study.

Table 4.2. Details of selected Halls of Residence

Hall of Residence	Maximum capacity	Room types	Dominant student type
City Gateway	364	Single rooms (334) Studio apartments (14) 1-bed flats (12) 2-bed flats (4)	Postgraduate students
Mayflower	1105	Single rooms (1031) Studio apartments (54) 1-bed flats (20)	Undergraduate; pre-sessional students

Source: University of Southampton Residential Services (2019).

4.5.2 Protocol development

The study was based on the assessment of outtakes from two HoR (Mayflower and City Gateway Halls; Table 4.2) in the University of Southampton using the ISB model (Timlett & Williams, 2011). Increased rate of reuse/recycling, or indeed any pro-environmental behaviour, requires a balance of situational (infrastructural, service) and psychological (behavioural) factors (*see* Figure 4.2). In this context, infrastructure is defined as aspects of the built environment such as buildings, storage bins for recycling; service refers to protocols or systems that enable a pattern of behaviour e.g. weekly collection of dry recyclates; and behaviour refers to how a person undertakes recycling/reuse, influenced by the intrinsic and extrinsic factors discussed above. The methods adopted for this project are guided by the WEEE characterisation study by Parajuly and Wenzel (2017) to evaluate the reuse value and recycling potential of collected household WEEE in Denmark.

This study formed a part of wider initiatives at the University of Southampton to improve institutional resource management (Zhang *et al*., 2011; Ongondo & Williams, 2011; Pierron *et al*., 2017; Robinson *et al*., 2015, 2018), including the collection of reusable items (clothes, homeware, and furniture) for donation to selected charities (Powell & Williams, 2019). The University of Southampton has committed to an ‘evidence-based cleaner, greener and healthier future, bringing students, staff and residents together to improve sustainability across our estate’ (University of Southampton, 2020). In the days leading up to the move-out periods, each collection room at the selected HoR was provided with red plastic bags to enable the deposition of functional but unwanted EEE. Students were instructed to deposit filled bags at designated areas in their accommodation complex. Pamphlets containing information on what was suitable for donation were provided as well as strategically deployed posters and TV screens that displayed relevant information.

There were three survey periods, which were tailored to coincide with the students’ departure dates at the HoR in June, July and September 2019. The June period covered students on 38-week accommodation contracts, which is usually the choice for undergraduate students. The majority of students leaving accommodation at this time are final-year undergraduates who have completed their studies, or continuing students seeking accommodation elsewhere. The July period covered students on 40-week contracts whilst the September period involved a mixture of postgraduate (Masters) students and “pre-sessional” students improving their English language skills at a summer school before commencing their subject studies.

4.5.3 Participating charities

The UK charity sector is large and varied, comprising over 160,000 charities with an income of approximately £39 billion (NCVO, 2014). They are quite unique to the UK and their activities and impacts on society are extensively discussed by Osterley and Williams (2019). There are currently several schemes and collaborations between UK HEIs and charities involving student donations (Williams & Powell, 2019). The donations help to support causes ranging from education advancement and poverty alleviation to funding medical research. The British Heart Foundation collaborates with over 80 UK universities (Williams & Powell, 2019) via its 'Pack for Good' campaign and the revenue generated from donations helps to fund research into the cure and treatment of heart conditions (BHF, 2020). This charity collects, amongst other items, donated EEE which are sold in their outlets nationwide. The BHF was one of three charities involved in the project (Table 4.3). Debra is also a national charity which supports epidermolysis bullosa research. Scratch is a regional charity based in Southampton which provides relief effort within the city and surrounding areas and caters for the needs of deprived communities by redistributing reusable items donated such as furniture and small EEE to those in need.

Table 4.3. Charities involved in the project.

Charity	Mission	Coverage	Annual Income (£'000)
British Heart Foundation	Support for cardiovascular research	National	138,000 (2018)[18]
Debra	Funding Epidermolysis Bullosa research	National	16,138 (2018)[19]
Scratch	Poverty relief	Southampton/Hampshire	N/A

4.5.4 Product collection and transportation

Collection and transfer of donated items occurred over a period of 4 – 5 days during which the donated bags were transferred to a central location (Wessex Lane Complex). The logistics

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[18] https://www.bhf.org.uk/what-we-do/where-your-money-goes

[19] https://www.debra.org.uk/downloads/trustees-annual-report-2018.pdf

(collection, transport and sorting) were planned to cater to the needs of the HoR studied. Due to the varied layout and sizes of both halls, transport arrangements differed slightly. For Mayflower Halls, the initial storage area (where students dropped bags) was a large bicycle shed, which acted as a central location for storage before the bags were moved to the sorting area. The arrangement at City Gateway was slightly different due to the lack of a large storage area. Instead, two vehicles were stationed at the hall, which were used to collect the items before transporting to the central sorting area, at which the team of volunteers inspected each bag and sorted items accordingly. The set-up (*see* Figure 4.3) included a dedicated skip to hold unsorted items, gazebos to shelter project crew and equipment and a 1100L storage container (Figure 4.3A) to hold sorted items awaiting collection by participating charities.

Figure 4.3. **A**. 1100L storage container used for storage; **B.** Storage container with bagged contents; **C.** volunteers sorting and inspecting donated items; **D.** EEE donation examples: printer and computer display monitor; **E.** EEE donation examples: ICT devices; **F.** EEE donation examples: small kitchen appliances.

4.5.5 Sorting and product characterisation

A crew of volunteers was recruited to sort the donated EEE over five days in June, July and September 2019. The contents of each bag were visually inspected, weighed using digital scales and graded according to their physical condition (Table 4.4). Functionality testing of items was not carried out as it was beyond the scope of the study.

Table 4.4. Grading system for product sorting. Product rating determined the fate of each item after sorting with products rated “Good” and “Reusable” recovered for reuse while those rated “Broken” were put aside for recycling. Note that products rated ‘Good’ and ‘Reusable’ are ultimately reusable and the distinction between the two ratings is based on the physical condition of item.

Condition	**Definitions and examples**
Good	Good as new; saleable (e.g. a printer with all accessories present; kettle with plug in tact)
Reusable	Requires repair/component replacement or upgrade (e.g. kettle with a broken plug; LED TV without remote control)
Broken	Broken/parts missing (e.g. laptop with shattered screen)

Items that were rejected (“broken”; Table 4.4) were collected separately for recycling. Each donated bag was also weighed, and numbers of commingled items were recorded to evaluate the success rate of the scheme.

The following information was collected for each inspected item:

- Device type
- Device category (small kitchen appliances (SKA), small home appliances (SHA), personal care appliances (PCA) and information and communication technology devices (ICT/AV)
- Product brand (where identifiable)
- Product condition (visual inspection of products was carried out and each item was given a grade based on its physical condition (Good, Reusable or Broken; Table 4.4)
- Product weight (in kg). Products that could not be weighed were assigned weights of similarly sized variants/models.

4.5.6 Potential for product reuse

The potential reusability of EEE is largely dependent on the physical condition and functionality of the items collected. Items rated as “Good” (Table 4.4) are likely to be valued higher due to their condition. Values will also be dependent on other factors such as an item’s model, demand and platform/vendor. As done for reuse evaluation in Chapter 3 (Section 3.4.5.2), estimation of the resale value was based on average prices of commonly-traded EEE, which were obtained from online pre-owned goods trading platforms (www.preloved.com and www.gumtree.com). Prevalent items in the recovery stream were selected for this analysis. In order to account for price variations for each item, 10 price listings were randomly drawn from the aforementioned online platforms to estimate the average price of each item as well as the standard error to account for product price range.

4.5.7 Material composition analysis

In parallel with the evaluation of product reusability and redistribution, a material composition analysis was carried out to estimate the value of materials contained within the EEE collected. This provided a comparison between reuse and recycling scenarios for recovered items. EEE are known to be a rich source of materials such as ferrous and non-ferrous metals (WRAP, 2012; Meloni, 2020). Products that occurred most commonly in the items collected were selected for material composition analysis. For this analysis, secondary data (average material composition of common household EEE) were used (Parajuly & Wenzel, 2017). Minor materials accounting for less than 5% of an item’s weight were excluded in the analysis.

4.6 Results and discussion

4.6.1 Students' departures from Halls of Residence

A total of 1,885 student departures were recorded during the study period (Table 4.5). Mayflower Hall saw significantly more departures in June than City Gateway. The reason for this is partly due to size difference: Mayflower Hall accommodates more students (1105 at full capacity). City Gateway Hall houses mostly postgraduate students many of whom opt for longer letting contracts (51 weeks) that end in September. July showed the lowest overall departures (199) whilst September saw the highest (1058).

Table 4.5. Student departures for Mayflower and City Gateway Halls in 2019.

Hall of Residence	Month	Home (UK) students	International students	Total
Mayflower	June	437	177	614
	July	30	77	107
	September	14	795	809
City Gateway	June	1	13	14
	July	40	52	92
	September	41	208	249

Source: University of Southampton Residential Services (2019)

Seventy percent of overall departures during the study period were international students. This contrasts with the demographic profile of the entire university (30% international students, 70% home students) (HESA, 2020). September saw the highest international student departures (53% of total departures) while the lowest count of international student departures was in July (0.07% of total departures). This profile indicates a high proportion of postgraduate international students' departures in this period, many of whom tend to stay longer due to the duration (a full year) of their degree programmes. Pre-sessional students' departures are also numerous at this period. Mayflower Hall saw a high number of home students' departures in June (71% of Mayflower departures) while a single home student departure from City Gateway was recorded in the same period.

4.6.2 Collection output

In total 128 bags were collected and sorted (Table 4.6). From these, 447 electrical and electronic items with total weight of 447.67 kg were inspected and sorted. This equates to approximately

0.24 kg of donated items per departing student. The June collection saw the highest number of bags (77), despite having the second highest number of departures (661). June also accounted for the highest number of donated items of EEE (234) with a total weight of 242.37 kg. This constituted 52% of the number of all items collected and 54% by weight.

Table 4.6. EEE donation bag collections from Mayflower and Gateway halls of residence in 2019.

Month	Number of donation bags collected
June	77
July	19
September	32
Total	**128**

With 52 items received, July saw the lowest number of donated items by number and weight (67 kg). This corresponds with the number of departures as the fewest departures (67) at this time. However, July saw the highest collection per student departure at 0.52 kg/student compared with 0.39 kg/student and 0.19 kg/student for June and September, respectively. The overall average collection rate was 0.24 kg/student.

A summary of the items inspections and their condition is presented (Table 4.7& Table 4.8). Of the 234 items inspected in June, 101 items were rated as “Good” (43%) while 14 items were rated as “Broken” (6%). A similar trend was recorded in July with 21 out of 52 items rated as ”Good” (40%) while 54% of items inspected were rated as “Reusable”. September saw the highest percentage of items rated as “Good” (66%; 106 out of 161 items inspected).

Table 4.7. Numbers of items collected during surveys in 2019 and their condition (*see* Table 4.4).

Month	Number of items	Good	Reusable	Broken
June	234	101	119	14
July	52	21	28	3
September	161	106	55	0
Total	**447**	**228**	**202**	**17**

Table 4.8. Weights of items collected during surveys in 2019 and their condition (*see* Table 4.4).

Month	**Weight (kg)**	**Good**	**Reusable**	**Broken**
June	242.4	100.7	132.2	9.5
July	55.3	22.4	30.8	2.1
September	150	90.8	59.2	0
Total	**447.7**	**213.9**	**222.2**	**11.6**

The EEE collected were categorised into: SHA, SKA, ICT and PCA. The volumes collected for each category varied, however, a greater volume of SHA was collected in June (40%) and September (35%) than other categories. This category includes items such as desk lamps, fans and extension cables. June also saw a high proportion of SKA items (37%). However, the highest proportion of SKA was recorded in July (Figure 4.4). Approximately 61% of all items collected during this period were SKA. Regarding ICT, 41 and 43 devices were collected in June and September respectively, including some high-value devices in good condition: three LED TVs and six printers. The September collection also included higher-value ICT items: six printers (two Good and four Reusable) and six laptops (five Good and one Reusable).

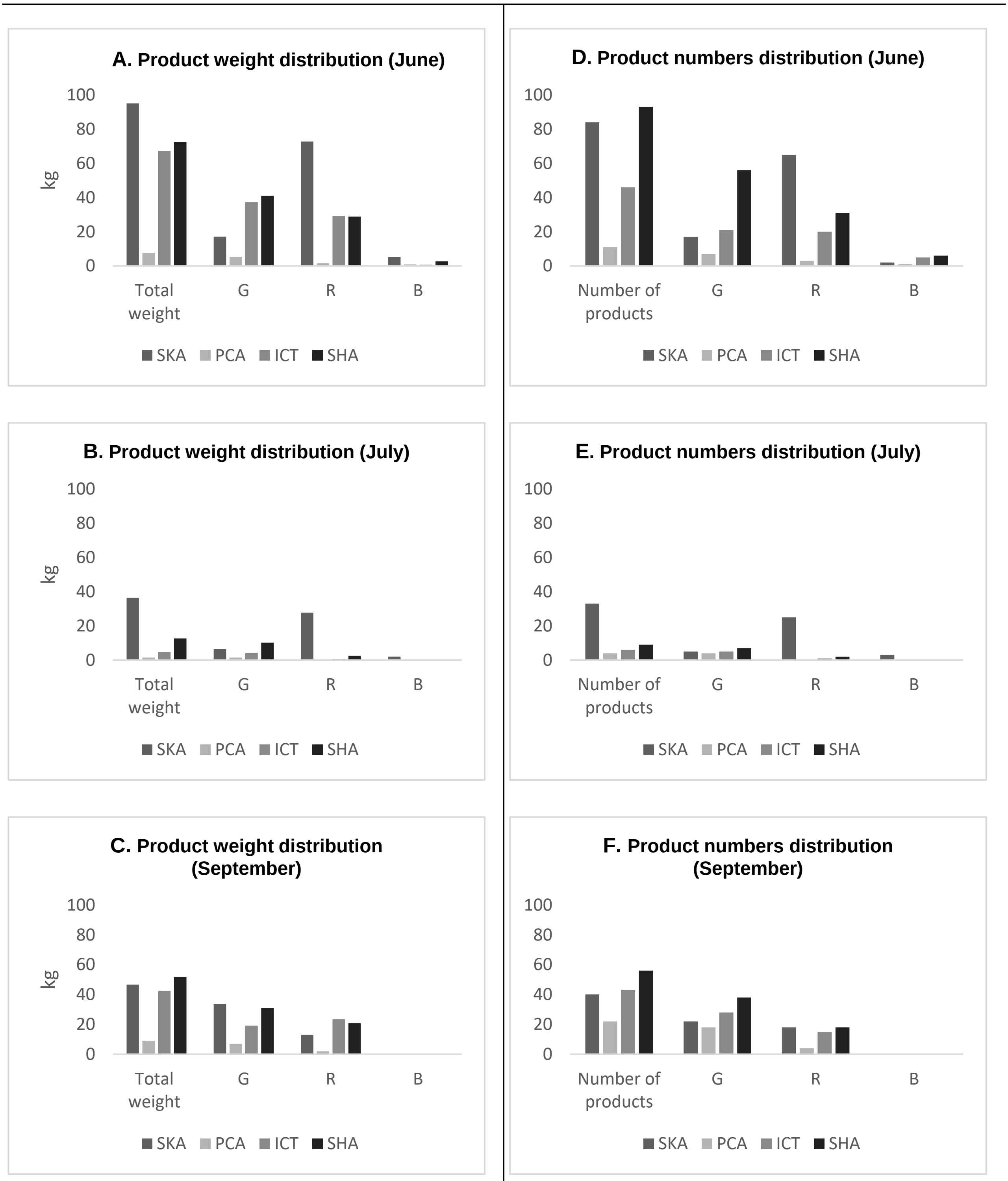

Figure 4.4. Distributions of collected and assessed items and associated grading (*see* Table 4.4).

4.6.3 Reuse potential

A total of 430 out of 447 items collected during the project were either rated as ”Good” or “Reusable”. For each category, over 90% of the items inspected were rated either as “Good” or “Reusable” (Table 4.9). SKA and SHA products constituted most of the items collected (152 items per category), each with reusability of 97% and 96% respectively. Though the total number of items collected in PCA category was the lowest, this category had the highest reuse rate (Good or Reusable items) at just over 97%. Hair grooming products such as hair dryers and stylers featured prominently in this category.

Table 4.9. Product grading by category. Items in each category assessed and graded using grading system adopted (*see* Table 4). Reusability (%) is the proportion of assessed items that were reusable (products rated ‘Good’ or ‘Reusable’).

Product category	**Total**	**Good or Reusable**	**Reusability (%)**
SKA	157	152	96.8
PCA	37	36	97.2
ICT	95	90	94.7
SHA	158	152	96.2

The resale value was estimated for selected items collected during the study. The potential resale value of the items selected is presented in Table 4.10

Table 4.10. Estimated product reuse value of select items collected. Items selected featured heavily in stream assessed. Resale value estimates are based on average price of similar products on online resale platforms ± standard error.

Item	**Average price (pre-owned) (£)**	**Number of Good or Reusable items collected)**	**Estimated potential resale value (£)**
Iron	9.70 ± 2.00	14	108 – 164
Kettle	9.40 ± 0.80	74	636 – 755
Lamp	21.20 ± 5.00	59	956 – 1546
Toaster	8.80 ± 1.20	39	257 – 390
Printer	51.3 ± 9.50	12	502 – 730
Hair dryer	7.45 ± 1.20	20	125 – 173
Total		**218**	**2584 - 3758**

The resale value of an item is dependent on its physical condition and functionality. The resale values (Table 4.10) show a range of values of similar items from reuse platforms. From the analysis, the items were estimated to be worth between £2584 and £3758. We note that this estimate is for a subsample of items collected (~36%) and the items collected and assessed for this were from only two HoR in a single HEI (University of Southampton).

4.6.4 Material composition analysis

A material composition analysis was carried out to estimate the quantities of materials contained in the items collected. EEE are a rich source of materials such as ferrous metals, non-ferrous metals and plastics (WRAP, 2012; Meloni, 2020). A selection of products was analysed based on their prevalence in the stream of items collected (Table 4.11 and

Table 4.12). Products rated as "Broken" were also included for the material composition analysis.

Table 4.11. EEE average material composition (%).

Product	**Iron (%)**	**Copper (%)**	**Aluminium (%)**	**Plastic (%)**
Iron	21.6	7.1	19.3	51.0
Kettle	4.7	5.6	22.0	62.2
Toaster	36.8	3.3	27.3	30.4
Printer	26.1	1.8	0	60.2
Hair dryer	15.7	15.3	0	63.5

Data from Parajuly and Wenzel (2017).

Table 4.12. Number and average material composition (kg) of select products collected.

Product	**Number collected**	**Total weight (kg)**	**Iron (kg)**	**Copper (kg)**	**Aluminium (kg)**	**Plastic (kg)**
Iron	14	10.3	2.22	0.73	1.99	5.25
Kettle	77	52.5	2.47	2.94	11.55	32.56
Toaster	39	49.1	18.07	1.62	13.40	14.93
Printer	12	52.2	13.62	0.94	0	31.42
Hair dryer	21	9.4	1.48	1.44	0	5.97
Total	**163**	**173.5**	**37.86**	**7.67**	**26.94**	**90.13**

Using compositional analysis data (Table 4.11), the material composition of a selected group of EEE from the collection was estimated (

Table 4.12). These five products accounted for 36% of the 447 items collected and sorted. From the analysis, 162.6 kg of these four materials were recovered (Fe, Cu, Al and plastics) and constituted 94% of the total weight of these five products. Table 4.13 presents the value of metals in the prevalent items evaluated. The residual weight is for materials with trace quantities which were not considered in the analysis. Plastics form the bulk of material component (55%) which is expected as small EEE are typically made of over 15 different plastic polymers (Martinho *et al.*, 2012). Copper is the least abundant material fraction in the EEE sampled though at $5,763/tonne (LME, 2020), it is the most valuable material per unit weight.

Table 4.13. Material value of subsample of items (*see* Table 4.11 and Table 4.12). Metal values based on London Metal Exchange average prices per tonne at three months forward as of 18/6/2020 (LME, 2020).

Metal	**Weight (kg)**	**£/tonne[20]**	**Material value (£)**
Fe	37.86	212	80.3
Cu	7.67	4,591	35.2
Al	26.94	1,274	34.3
Total	**72.47**		**149.8**

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[20] Metal values converted to £ sterling using OANDA currency converter (Oanda, 2020)

4.6.5 Variation in products collected

The study demonstrates the substantial potential for recovering small EEE for reuse and recycling from students departing from two university HoRs at the University of Southampton. With 447 items weighing approximately 450 kg (Table 4.7 and Table 4.8) collected from just two HoR in one academic year, there is a huge potential for the recovery of reusable from this stream if more HoR are involved. The study observed the peak month for collection to be June. This is despite more students departing in September (*see* Table 4.5). The higher proportion of 'Good' items recorded in September may be indicative of better information assimilation by the students on type and condition of items suitable for donation as the students that moved out at this time had more time to prepare.

Small kitchen appliances and small household appliances constituted the bulk of overall EEE recovered (157 and 158 items respectively out of a total of 447 items). This suggests that such items are purchased or brought in by students moving into halls at high numbers. While the HoR studied provide basic kitchen and household items for shared use, the high level of recovery of items in these categories suggests that students opt to bring in or purchase their own. This may be more common amongst international students (70% of total departures) who may have brought with them items like kettles, sandwich makers; some of the product brands were from outside the UK. While it is difficult to attribute items donated to individual students, it is safe to assume, due to large percentage of international students in the sample population, that departing international students are more likely to donate items deemed excess, making them a potentially viable group to target for a reuse scheme (Williams and Powell, 2019). The case study observed a high level of compliance from students regarding the condition of items collected; only a small fraction of items collected did not meet criteria as specified in the guidance and were deemed unsuitable for reuse. Most of these unsuitable items were received in June (*see* Table 4.14) and were mostly SHA. The level of compliance resulted in a contamination rate[21] of less than 5% during each month of collection (with an overall contamination rate of 2.6%). These products, while not available for reuse, retain resource value and material recovery can occur via recycling.

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[21] Contamination rate is a measure of the level of recycling compliance often used in waste management. For this study, it is used to assess level of reuse compliance. It is expressed as a proportion of contaminants in total items collected i.e. contaminants (kg)**/**total items(kg) as %. Contaminants in this study comprise items rated 'Broken'

Table 4.14. Contamination rate of EEE collection

Month	Total weight (kg)	Weight (Good & Reusable) (kg)	Weight (Broken) (kg)	Contamination rate (%)
June	242.4	232.9	9.5	4.1
July	55.3	53.2	2.1	4.0
September	150	150	0	0
Overall	**447.67**	**435.87**	**11.6**	**2.6**

The HoR studied provide facilities for WEEE recycling in form of storage bins and yards which may have contributed to the low rates of contamination since students already have an option to recycle broken/non-functional EEE. Studies have shown that without such facilities, such items are likely to be disposed of in general waste (Ongondo & Williams, 2011; Pierron *et al*., 2017). Pierron *et al*. (2017) also observed high likelihood of end-of-use PCA disposal as opposed to being recycled. This may explain the low prevalence of PCA collection observed during this study.

4.6.6 Reuse and recycling potential

The UK has over 150 HEIs and each HEI, in principle, is potentially an urban mine rich in items and resources that can be reintroduced into the circular economy (Pierron *et al*., 2017). According to the Higher Education Statistics Agency (2020), 351,605 students live in university-owned HoR/accommodation (2018/2019 data) across the UK. Assuming a reusable EEE recovery rate of 0.24 kg/student as observed in this study, there is a UK-wide potential for recovery of 84 tonnes of EEE for reuse annually. This potential value excludes other students living outside HoR who constitute the majority; of the over 2 million students enrolled at universities during 2018/19 academic year, only 17.5% students resided in HoR (HESA, 2020).

The observed subsample of items (Table 4.10) was estimated to yield potentially an estimated resale value of £2,600 - £3,700. This equates to £1.30 - £1.90 per student (from a student population of 1,885). If this figure is assumed to be broadly representative of UK university students, this represents a monetary value of up £485,000 - £690,000 for all students living in UK university accommodation nationwide in the 2018/19 academic year. Scaling this up for total student population, assuming the same monetary value per student, and that students in other accommodation undergo periodic clear-out, the student population at University of Southampton (24,625 students) and UK universities (2,383,970 students), the monetary potential is up to

£46,000 and £4,500,000 respectively (using average value of £1.90 per student). On the other hand, the material value of the same subsample was estimated to be £27,942 for a student population of 361,605 and £189,453 for entire student population in the UK. These data suggest a high potential for reuse as these estimates cover a subset of all items recovered and assessed. This potential could be higher considering that the products, apart from their reuse value, also possess material value which can be exploited via recycling at their end of life. While resale value is likely to plummet with each product usage cycle, the materials contained (especially metals) will retain their value.

4.7 Chapter conclusions

This chapter presented a study that provides evidence that a reuse-based recovery system for small EEE significantly increases the urban mining potential of a university DUM while creating an avenue to provide a platform for extending the life time of small EEE. While there were logistical challenges, the project demonstrates a workable proof-of-concept for a reuse-based recovery and redistribution system within a university DUM.

The study presented product reuse as a priority for end-of-use EEE for sound but unwanted products within a DUM as opposed to an inadvertent and unconscious drift towards less desirable options. It provides an important insight into the significant potential for recovering reusable small EEE from a DUM, in this case, students within a university urban mine. The study presents, for the first time, data on recovery of reusable small EEE from departing students from university HoR. Through applying a protocol informed by the ISB model (Timlett & Williams, 2011), the transfer of items from donors (students) to beneficiaries (participating charities) has been demonstrated to support the case for reuse as the preferred end-of-use decision for products with good functionality and, in so doing, result in positive environmental, economic and social impacts. As this was a demonstration project, the potential for impact if replicated nationwide is highly significant in terms of increased diversion from landfill, resource efficiency, materials recovery at end-of-life, reduction of adverse environmental effects, and social and economic benefits. This study also highlights the role individual young people can play when they act in concert for societal benefit and the global replicability of the reuse-based system as a viable route to circularity of EEE.

This study was aided by a communication campaign, which elicited a positive behavioural response from the students, as well as provision of necessary infrastructure and service. This demonstrates that the ISB model can bring about desired changes in addressing waste management issues. This strongly suggests that the adoption of similar systems in universities and other HEIs within the UK and globally has tremendous potential to recover hibernating EEE as well as divert several tonnes of reusable EEE from landfill as well as providing social and economic benefits.

Chapter 5 General discussion, recommendations and conclusions

5.1 Chapter overview

This chapter presents a synthesis of outcomes of the research presented in the previous chapters. It brings forward the main points from Chapters 2, 3 and 4 with the results integrated and discussed. This chapter is the final part of the research thesis (*see* Figure 5.1) and begins with a summary of the WEEE management practices and scenarios and the important role urban mining plays within it. This chapter concludes with some future perspectives in WEEE management and a proposed reuse-oriented system for periodic recovery of reusable EEE. A modified version of the discussions in this chapter has been published as an editorial in *Resources, Conservation and Recycling* journal titled *The 'WEEE' challenge: is reuse the new "recycling"?*.

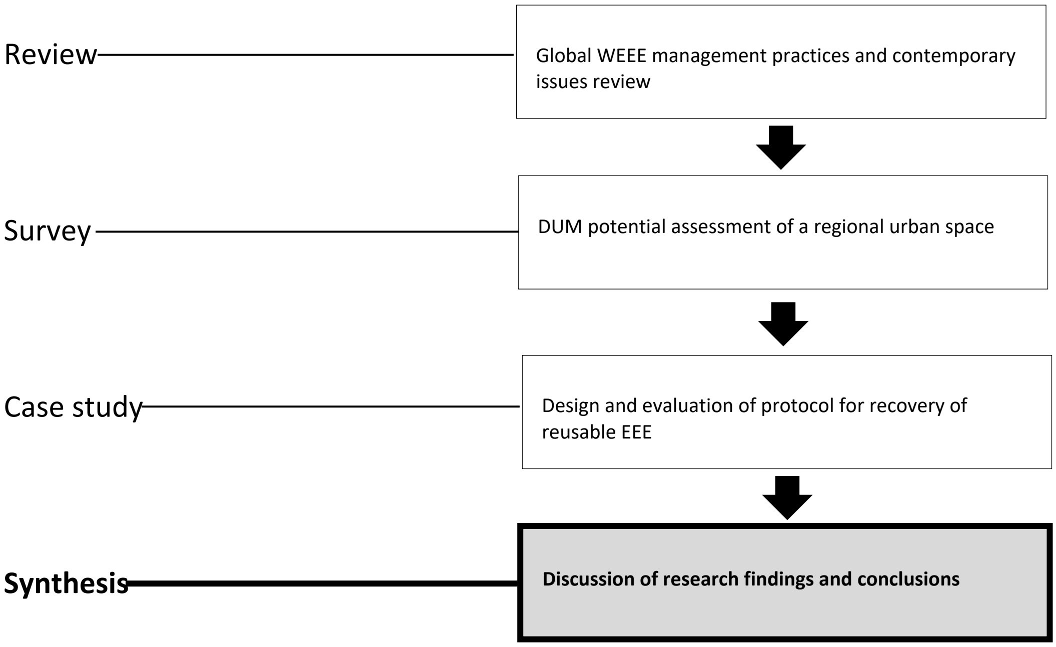


Figure 5.1. Thesis road map showing the placements of the discussion, recommendations and conclusions chapter

5.2 Global WEEE picture

The review in Chapter 2 provided a contemporary and comprehensive profile of current trends and insights to established and emerging issues relating to WEEE. The upward trend of global EEE usage, with accompanying increase in WEEE generation, is expected to continue and with the advent of new and emerging technologies, services and systems, and space exploration and travel. Economic growth in developing and emerging regions will ensure continued increase in the global usage of ICT and consumer electronics penetration due to more of the global population being able to afford electrical and electronic goods. WEEE recycling rates remain low, even in many economically developed countries with established WEEE management systems, and informal, unregulated recycling persists in many economically developing and emerging countries, especially in Africa and Asia.

Four typical WEEE management scenarios have been identified. Efficient and environmentally-sound WEEE management is largely dependent on the availability of data on EEE products put on the market, consumption and WEEE generation; this forms the basis of strategic planning regarding establishing infrastructure necessary for WEEE management. Data reporting using commonly-agreed and harmonised methodology is essential in monitoring WEEE generation and flows. Just over 40 countries globally currently officially report WEEE statistics using harmonised methodology. As a result, the final treatment and destinations of WEEE are mostly uncertain in the majority of countries; uncertainty in this regard is likely higher where informal sector activities are prevalent. It is proposed that more countries will need to adopt and implement formal WEEE data reporting to ensure sound and effective management. Another important issue is enforcement of regulations and policy to ensure that WEEE is managed in an environmentally and ethically sound manner. This can be enabled by enacting relevant legal and regulatory frameworks for WEEE management. Whilst approximately 66% of the world's population is covered by WEEE regulations and law, lack of effective enforcement remains a hindrance to proper WEEE management; this situation is not limited to less economically developed countries.

The review (Shittu *et al*., 2021) highlighted the current dominance and importance of the activities in the informal recycling sector for WEEE management. These activities are the sources of livelihood for many involved, despite the known potential for human health hazards and environmental pollution. A possible solution in the future is regulation of these activities, together with improving the activities to comply with appropriate safety standards. This will involve the introduction of regulatory frameworks, where absent, and enforcement where related regulation already exists.

There is an increasing emphasis on resource recovery from waste (including space debris) as well as recovering reusable EEE, particularly in Europe. This creates the avenue for the urban mining of WEEE and UEEE from defined anthropogenic spaces. WEEE is a potential source of a myriad of valuable materials, which can be prospected to obtain secondary raw materials. With collection rates currently low in most countries (and non-existent in space) and the stockpiling of WEEE common, valuable and critical raw materials within these items are potentially lost. Loss of such critical raw materials may compromise the future production of EEE. It is essential that circular economy approaches be adopted, as these will have a positive impact on the future management of WEEE. A clear understanding of distinct urban mines is essential for achieving this aim by enhancing recovery of EEE with reuse value as well as resource recovery from WEEE, which will improve WEEE/UEEE management. However, for an urban mine to be considered viable, there must be detailed and meaningful data and information about its attributes such as location, size, concentration of materials and resources to be prospected and products flows.

5.3 Urban mining for reuse: opportunities and challenges

The survey results in Chapter 3 suggest a high potential for reuse considering that only the most frequently stockpiled devices were analysed (*see* Table 3.11 and Table 3.13). The scenario is particularly applicable to devices with little or no built-in technological obsolescence. However, exploiting ICT devices in this manner can be potentially challenging due to short timescales within which they become obsolescent (programmed obsolescence). With rapid evolution in technological and computing power/demands, older/legacy devices are reaching obsolescence quicker. Also, issues like ‘back-compatibility’ of new software and firmware may be an issue when attempting to keep such devices in use for longer. An example is the recent preference for the use of Universal Serial Bus (USB-C) ports on newer ICT devices such as mobile phones and laptops (Tech Advisor, 2021). Despite its technological advantage, this trend could potentially speed up the obsolescence of older peripherals such as headsets due to incompatibility with the USB-C connectivity interface. This illustrates the importance of timing in recovery of reusable devices. An unused device with functional value at the point of hibernation would lose its reuse value and become technologically obsolescent within a few years. This can occur with ‘*safety devices’;* that are kept as back-up by owners due to the perceived value (monetary and/or back-up value) of such devices (Pierron *et al.*, 2020). For instance, the purchase of a new mobile phone may result in the previous device being kept as a safety device by owner. Such a device may then become dispensable due to factors including, but not limited to, technological obsolescence. At this point, the device, with little or no functionality becomes a hoarded device if it is kept by the owners. The decision to keep a device at this point of its lifecycle is likely influenced by disposal options known and/or available to the user (Wilkinson & Williams, 2019). Such devices could be made functional by repair and/upgrade after which they become reusable (*see* Figure 5.2).

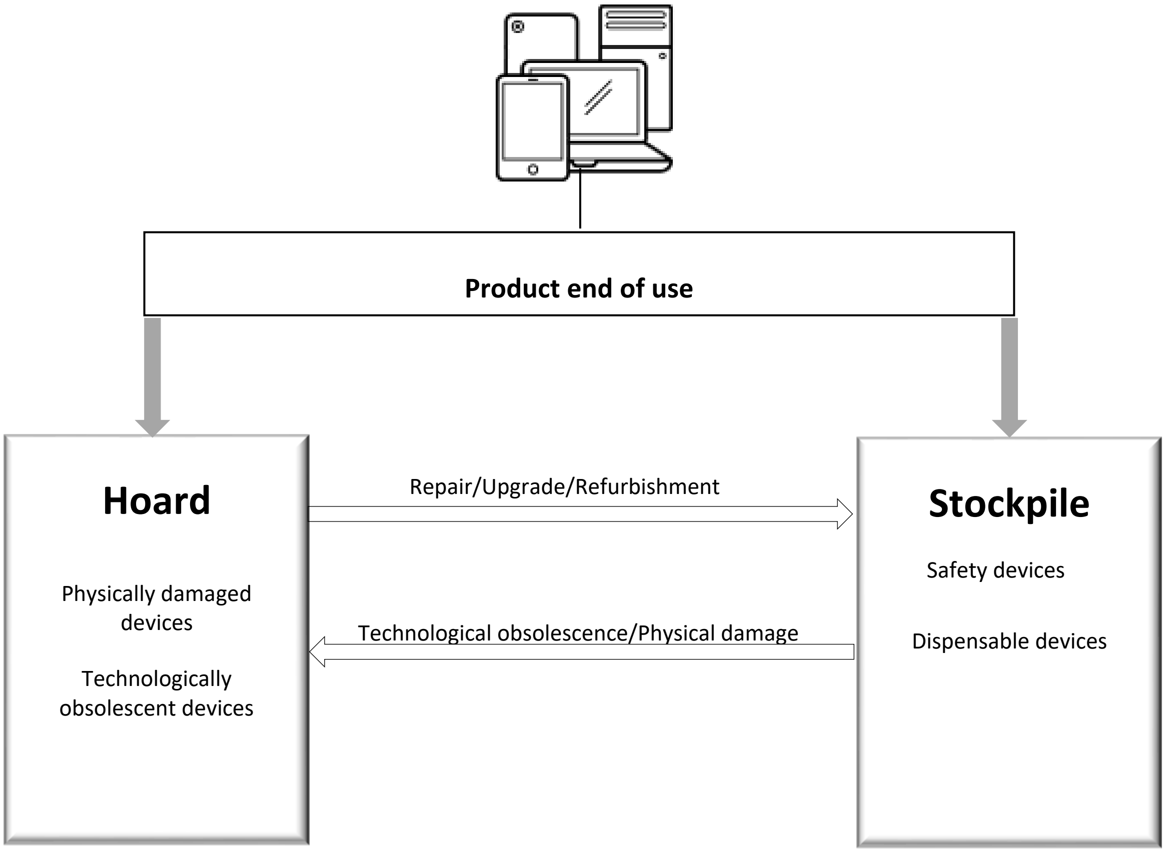
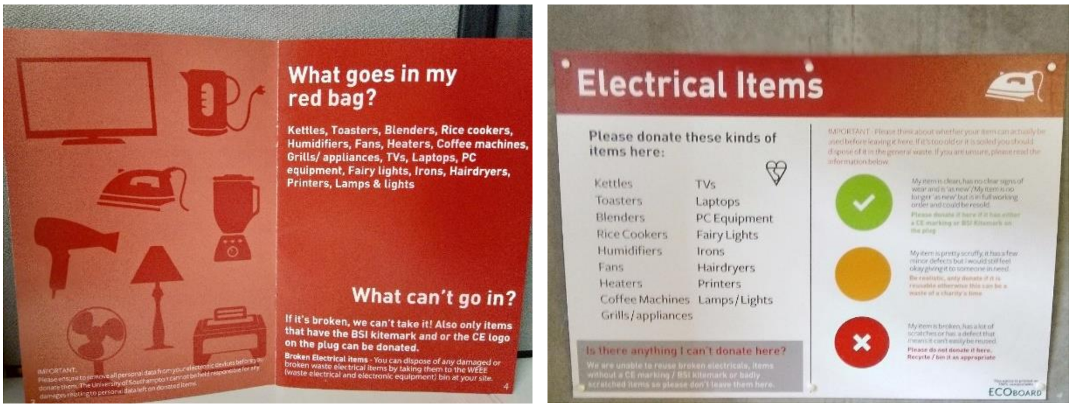


Figure 5.2. Illustration of product hibernation cycle showing the relationship between stockpiling and hoarding.

Attitudes towards pre-owned items is a known barrier to fostering a sustainable reuse culture (Diop & Shaw, 2018; Shaw & Williams, 2018). Setting reuse standards for EEE will potentially contribute to reducing these barriers. These range from standardisation of reuse protocols of end-of-use devices such as those proposed by Dietrich *et al*. (2014), to measures that tackle planned obsolescence such as design for repair and reuse as well as 'reparability' labelling to provide information. The latter involves inclusion of labels on devices to give information on its durability and ease of repair. This move is gaining traction, especially in Europe, where France has announced mandatory labelling of EEE that provides information on estimated usage life and repair rating (Circular, 2020b). This, of course, brings into play issues such as availability of skills and competence needed to carry out repairs, and availability of spare parts for repair/refurbishment.

5.3.1 EEE recovery process analysis

As highlighted in Chapter 4, schemes involving donation of unwanted and/or end of use items with reuse value are commonplace in UK HEIs. Schemes such as 'Shift your Stuff' organised by the Students' Union at the University of Southampton, for example, have been planned to coincide with the departure periods of students and encourage the donation any unwanted items when they move out. Schemes run in the past by Students' Union collected items such as clothing, homeware and other bric-a-brac but excluded collection of reusable EEE. The study presented in Chapter 4 is the first of its kind that specifically studied the outcome of source-segregated EEE donations. Comingling with broken EEE was minimal as observed in the contamination rate (*see* Table 4.12), indicating that information provided was largely understood. As stated previously, the study was preceded by a period in which information was disseminated using different media, including strategically-located posters and pamphlets (*see* Figure 5.3)



What goes in my red bag?

Kettles, Toasters, Blenders, Rice cookers, Humidifiers, Fans, Heaters, Coffee machines, Grills/ appliances, TVs, Laptops, PC equipment, Fairy lights, Irons, Hairdryers, Printers, Lamps & lights

What can't go in?

If it's broken, we can't take it! Also only items that have the BSI kitemark and or the CE logo on the plug can be donated.

Broken Electrical items - You can dispose of any damaged or broken waste electrical items by taking them to the WEEE (waste electrical and electronic equipment) bin at your site.

IMPORTANT.
Please ensure to remove all personal data from your electronic devices before you donate them. The University of Southampton cannot be held responsible for any damages relating to personal data left on donated items.

Electrical Items

Please donate these kinds of items here:

Kettles	TVs
Toasters	Laptops
Blenders	PC Equipment
Rice Cookers	Fairy Lights
Humidifiers	Irons
Fans	Hairdryers
Heaters	Printers
Coffee Machines	Lamps/Lights
Grills/appliances	

Is there anything I can't donate here?
We are unable to reuse broken electricals, items without a CE marking / BSI kitemark or badly scratched items so please don't leave them here.

IMPORTANT - Please think about whether your item can actually be used before leaving it here. If it's too old or it is soiled you should dispose of it in the general waste. If you are unsure, please read the information below.

✓ My item is clean, has no clear signs of wear and is 'as new' / My item is no longer 'as new' but is in full working order and could be resold.
Please donate it here if it has either a CE marking or BSI Kitemark on the plug

● My item is pretty scruffy, it has a few minor defects but I would still feel okay giving it to someone in need.
Be realistic, only donate it if it is reusable otherwise this can be a waste of a charity's time

✗ My item is broken, has a lot of scratches or has a defect that means it can't easily be reused.
Please do not donate it here. Recycle / bin it as appropriate

Figure 5.3. Some examples of media used to influence behaviour change by providing information on the project (Source: University of Southampton Residential Services, 2019).

The case study had three major components; collection/recovery of EEE from departing students, sorting and characterisation of the items received, and the redistribution which involved select charities (*see* Figure 5.4). Interventions made for the collection/recovery component included provision of bags as well as temporary storage areas to hold the EEE. With this, the protocol differed between the two HoR studied. Mayflower Halls has a large sheltered bicycle shed which doubled as a temporary storage (Infrastructure aspect of ISB model; Timlett & Williams, 2011) hold for the EEE collected. The situation was different at City Gateway Hall, which lacks an adequate storage area; instead, the collected items were stored temporarily in vans. This is an example of infrastructure differences which required different interventions as postulated by the ISB model (Timlett & Williams, 2011).

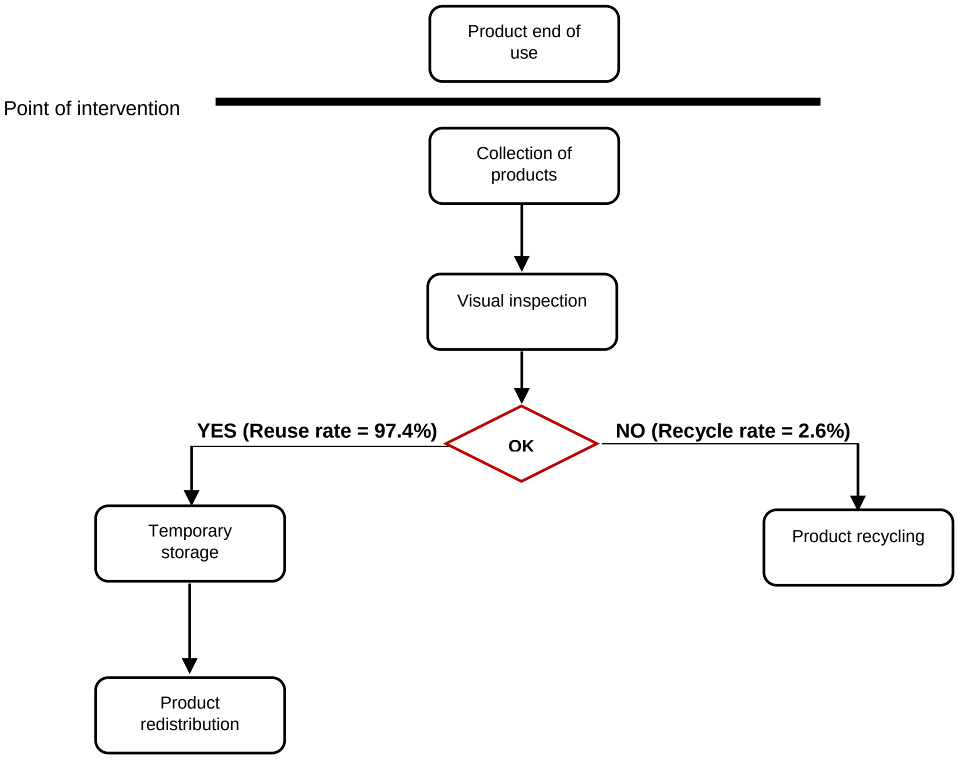


Figure 5.4. Project protocol and processes including the interventions made using ISB model (**I**: temporary storage; **S**: collection and inspection of products; **B**: products are redirected and made to pass through the system which recovers items with residual reuse value).

The EEE collected went through a process of screening and sorting. The activities could not be feasibly carried out at the sites of collection (HoR) for logistical reasons. While the Mayflower Halls complex has a storage space which, in principle, could have been used for product sorting, City Gateway lacks such a facility and the small number of volunteers recruited for the project were necessarily co-located. As a result, all items collected were moved to another location where sorting took place. The process required careful handling of the devices collected to minimise likelihood of damage during transport to sorting area.

The case study presented in Chapter 4 recorded a high reuse rate overall (*see* Table 4.9). The assessment of products received was necessarily based on visual inspection. Several items received required cleaning while some others were missing minor components. However, a more robust assessment such as functionality testing was not carried out as it was beyond the scope of the project. Whilst there is merit in undertaking robust functionality tests (Parajuly and Wenzel, 2017), addition of a testing stage to the protocol would incur additional resources and costs. It is probable that a functionality test would have resulted in a higher rejection/contamination rate. However, a recovery system based on reuse can still accommodate items not deemed for this purpose (reuse) as such items still possess some value especially if they can be repaired and those deemed irreparable can be recycled.

For this study, the involvement of charities proved effective in the redistribution and reuse of products collected. As previously noted, there are national charities that have partnered with HEIs in schemes involving product recovery and redistribution, diverting reusable products from landfill or recycling. Future collaborations in such schemes, as demonstrated in this project, will yield positive environmental, social and economic impacts. Examples of such impacts are highlighted in Table 5.1.

Table 5.1. Cross-sectoral benefits of a reuse-based EEE recovery system.

Stakeholder	**Benefit**	**Benefit category**
Charities/NGOs or other recipients	Receipt of good quality reusable items at little cost; redistribution of items	Economic; Social
Universities/HEIs	Lower disposal expenditure; enhancement of 'green' credentials	Economic; Environmental
Students	'Warm glow' (intrinsic factor) of contributing towards environmental sustainability	Psychological
Waste/environmental manager	Carbon savings, resource conservation; circularity	Environmental; Economic

These benefits are universally derivable irrespective of location. While this study was undertaken in the UK, adoption of a similar strategy elsewhere will potentially yield similar outcomes. The UK, due to its well-established charity sector, provides a platform through which recovered reusable products can be redistributed for resale/reuse. Similar organisations elsewhere in the form of NGOs (non-governmental organisations) are potential benefactors and can perform similar roles. A key factor of the reuse-based recovery system is the transient nature of university/HEI student population. Due to periodic turnover of students, there will be predictable and repeated opportunities for recovery of reusable EEE from departing students or those changing accommodation. While the frequency of this annual turnover within an academic year may vary from country to country, this unique factor allows for global replicability of the reuse-based EEE recovery system.

5.4 Future perspectives and implications

The demand for, and production of, EEE is expected to continue to rise in the future. With technological advances and increased accessibility and penetration of electronics, WEEE generation is expected to rise substantially; globally it is expected to exceed 54 MT by 2030 (Forti *et al*., 2020). New developments such as in artificial intelligence (AI), Nano-electronics, bio-technology, automated agriculture, clean and renewable energy technologies and space systems are expected to contribute to WEEE generation in the near future. WEEE generation will also grow with increasing penetration of products such as 3D TVs, 5G cellular communications, virtual reality systems and electric vehicles. These new streams of EEE will reach obsolescence at some point and will require end-of-life or end-of-use management. Technological convergence (especially via media and digital convergence), changes in design and miniaturisation of EEE will increasingly make older and bulkier electronics less fashionable and hence they will be discarded in larger quantities. The advent of Internet of Things (IoT) devices and systems means that products will evolve to seamlessly interface with one another and there will be huge redundancy of older devices that lack such integrative functionality.

With the introduction of newer products, recycling of emerging WEEE streams may become challenging as existing facilities may become redundant. For instance, a recycling facility designed to process CRT TVs would need a wholesome revamp to handle LCD/LED/OLED TVs or it will rapidly become redundant. This also applies to preparation for reuse of discarded but functional EEE as refurbishment may require the use of spare parts that may no longer exist. This may prove to be an obstacle for promoting the reuse of discarded devices in the future. Designing devices with the view of recycling will help alleviate this challenge. The use of modular design, as used in

Fairphone[22] mobile phones, promotes easier disassembly and recovery of materials that can then be recycled. This will only be achieved by putting pressure on manufacturers to adopt design for repair, refurbishment, reuse/recycling (D4R) in the design and manufacture of EEE (Hickey *et al*., 2014; Meloni, 2020).

Developing and emerging countries will continue to record increases in EEE penetration, particularly with ICT devices. With internet connectivity increasing, countries in Africa and Asia will further enhance mobile telephony and usage of consumer electronics. This is expected to increase as the use of renewable energy and electrification, especially from photovoltaic (solar) panels - which themselves will increasingly contribute to future WEEE streams - become more widespread in countries with limited electrical power distribution. One-off events such as the digital switchovers for TVs (and potentially for radios), as occurred in the UK and other European countries in recent years (Ongondo *et al*., 2011), significantly add to the WEEE stream as older products reach obsolescence rapidly. This will become more prevalent, particularly in Africa in the near future where countries such as Nigeria have started the switch over from analogue to digital media transmissions.

The coverage of WEEE legislation is expected to accelerate as more countries and regions adopt legal frameworks to regulate WEEE management officially. Currently, some form of legislation covers over 66% of the world population, whether WEEE-specific or WEEE-related. Europe leads the way in this regard; the Member States of the EU all have legislative coverage and North America also has 100% WEEE legislation (Baldé *et al.*, 2017). Regions like the EU are expected to increase recycling rates in accordance to the provisions of the Recast EU WEEE Directive, while developing countries in Africa and Asia will be pushing to adopt, improve and enforce legal frameworks for efficient and environmentally friendly WEEE management. The USA and Australia may eventually increase the coverage of their current collection and recycling schemes to include more product categories. It is also noteworthy to say that WEEE legislation globally will need to evolve to accommodate new EEE and future WEEE streams.

A key measure to ensure better WEEE management in the future is a unified understanding of WEEE terminologies and standardisation of WEEE data. This can be achieved by adopting a harmonised set of definitions and methodologies in data collection. Currently, only the EU

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[22] Fairphone is a social enterprise company based in Amsterdam. It aims to develop smartphones that are designed and produced with minimal environmental impact https://www.fairphone.com/de/

implements WEEE management using a defined framework as specified in Directive 2012/19/EU (EU, 2014). Within this framework, key WEEE-related definitions are provided as well as the roles of all parties in a product's lifecycle. Adoption of a unified framework in other regions would help to standardise data reporting and likely lead to better management of WEEE. Such measures will also need to consider the importance of informal WEEE management to ensure data capture of these activities as well as standardising recycling to reduce negative environmental impacts.

The exploration for and strain on natural resources for WEEE production will continue to rise, particularly if the current open-loop economic model persists (Mueller *et al*., 2015). With new electronic devices requiring the use of REM such as terbium and yttrium – currently mined actively in China, Korea and Japan - demand for these will increase. Cobalt, which is commonly used by mobile phone and electric vehicles (EV) manufacturers for producing batteries, is increasingly becoming essential. Future use of recovered cobalt from recycled mobile phones to produce batteries for EVs has been mooted (Sanderson, 2018). Other metals such as nickel are likely to be in higher demand as well, as the production of electric vehicles increases. Urban mining for secondary raw materials, especially from unique anthropogenic spaces, is expected to increase as separation and extraction techniques of PM and REE improve.

5.4.1 Towards product reuse becoming a mainstay of EEE and WEEE management

Circular economy approaches are becoming more popular and widely embraced to promote strategic waste minimisation and resource management, although there is some way to go before it is fully understood (Circular, 2021a). Studies by Mueller *et al.* (2015, 2017; Parajuly and Wenzel (2017) and Huisman *et al.* (2017) suggest that there is a potential for circular economy and resource recovery from WEEE. For end-of-use products/devices with residual functional value, recovery for reuse is desirable. Such potential is a subject of ongoing research, including the present study, which investigate the prospects of exploiting distinct and defined urban mines in order to recover more value from WEEE as well as discarded EEE with reuse value (UEEE); this is likely to have a significantly positive effect on the environment and human health by promoting circular economy (Pierron *et al*., 2017; Wilkinson and Williams, 2020). These spaces, such as universities/HEIs, provide a unique opportunity for this to occur. The present study provides an exemplar in this regard.

The projections presented in Chapter 3 (Table 3.12) illustrates the scale of potentially recoverable EEE within university DUMs in the UK. Assessing the scale globally, there are 30,586 universities[23] across the world (as of June 2020) with millions of members (staff and students). In theory, the universities, particularly those with physical campuses, are potential micro-level DUMs for EEE recovery. As the case study in Chapter 4 shows, the timed intervention allowed for the recovery of good quality reusable EEE which were then put back in the circular economy by providing an opportunity for another usage cycle before reaching end of life.

Extending beyond university (micro level) DUMs, the potential for EEE recovery at meso and macro levels are enormous. From the review in Chapter 2, the global generation of WEEE provides an illustration of the scale of reuse potential (*see*

Table 5.2). This potential can be estimated using the simple equation {$\mathbf{S_{country} = P \times S_{person}}$} where $\mathbf{S_{country}}$ is the estimated stockpile volume in a country, $\mathbf{P}$ is the population of the country and $\mathbf{S_{person}}$ is the average stockpile per capita which was estimated to be 6.1 devices from the survey (*see* Section 3.6.1.2). These projections are speculative as the assumptions are based on survey data from a specific context (i.e. UK university DUMs) and a select group of EEE (i.e. small EEE with frequent stockpiling level; *see* Table 3.12).

Table 5.2. Total number of devices potentially recoverable from top 10 countries by WEEE generation (as of 2019)

Country	**Population[24]**	**WEEE generation (kg/capita/year)**	**Stockpile (rounded)[25]**
United Kingdom	68,217,623	23.9	416,127,500
Switzerland	8,714,339	23.4	53,157,468
Australia	25,781,155	21.7	157,265,045
United States of America	332,829,358	21	2,030,259,084
Japan	126,117,722	20.4	769,318,104
Hong Kong	7,554,449	20.2	46,082,139
Canada	38,055,180	20.2	232,136,598

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[23] https://www.webometrics.info/en/distribution_by_country

[24] https://www.worldometers.info/world-population/ (accessed 7/6/21)

[25] Estimates based on stockpile ratio from DUM survey i.e. 1 person owning approximately 6.1 stockpiled devices

Country	Population[24]	WEEE generation (kg/capita/year)	Stockpile (rounded)[25]
Singapore	5,893,796	19.9	35,952,155
Finland	5,548,760	19.8	33,847,436
Germany	84,034,891	19.4	512,612,835

Also, it is worth noting that this projection is based on assumption of uniform stockpiling levels in the countries shown. This would be influenced by a myriad of factors. Recovery rates would vary significantly between countries depending on situational factors including level of W/EEE management. A country like Switzerland, for example, has an advanced management system with developed infrastructure for EEE recovery and would be expected to perform better than others with less advanced management systems.

An increase in recovery of reusable EEE will need to be matched with well-defined reuse standards for products (Dietrich *et al.*, 2014; Circular 2020a, Circular, 2021b). Circularity provides a means to keep products (including EEE) and materials in use for extended periods and presents an opportunity to reduce negative environmental impacts. A successful implementation of the circular economy model will be dependent on factors such as product design and reverse logistics as well as having an enabling environment (Meloni, 2020). Product reuse can become a mainstay, with adequate interventions, from production to end of use. Products designed with ease of disassembly and/or repair are likely to be in a closed loop longer as such products can retain functionality for longer periods, potentially changing owners during their lifetime. Going forward, interventions such as using modular designs would become crucial for incorporating circular economy principles in product design.

Reverse logistics is another crucial element of the circular economy model. As this study has shown, providing the means to recover and redistribute reusable items can provide economic, societal and environmental gains (*see* Table 5.1). With organisations such as charities available to absorb and aid redistribution of such items, they provide solutions within a circular economy by either selling or donating to potential new owners. As noted by Meloni (2020), movement of products between different categories of users, e.g. high-end users to lower/emerging users, ensures that products can be made available to cater to the needs and constraints of different users during their lifetime. While such movements have been labelled as 'dumping,' particularly when involving product movement from developed to developing countries, providing a high-quality reuse standard for pre-owned items would ensure that such products undergo rigorous testing and certification before being moved on to new owners.

Attitudes towards pre-owned EEE are a potential barrier to reuse. Improving perceptions of product reuse could be a significant step towards circularity. The improvement in perception is required upstream and downstream (product purchase to end-of-use decisions). Again, a high-quality reuse standardisation and certification provides an opportunity to alter perceptions by, for instance, instilling confidence in pre-used products. This post-use quality assurance system such as that used in studies such as Hickey *et al*. (2014) and Dietrich (2014) involves testing, upgrading and certifying pre-owned EEE before redistribution to new owners. At the other end of the value chain, behaviour and attitudes, well as an awareness of circularity, are significantly influencing in determining the fate of EEE. A good understanding of these factors is key in the design phase of EEE as well as the planning and execution of interventions for product recovery at the end of use to maximise reuse potential.

In the UK, a publicly available specification (PAS) for the reuse of EEE (PAS 141) was developed to provide guidance on preparing discarded EEE/WEEE for reuse. This paved the way for a Europe-wide standard (EN 50614) developed by the European Committee for Electrotechnical Standardisation which provides guidance on preparing EEE for reuse (Circular, 2021b). Adopting the use of such standard alongside the recovery system presented in Chapter 4 provides a ‘seal of quality’ which will help alter perception on pre-owned but functional EEE. For EEE recovery in a university DUM, this could involve the services of repair shops/cafés to provide visual inspection, product testing, repair/upgrade and certification for reuse. This is likely to incur extra costs on the institution however institutions can forge partnerships with local repair shops/reuse centres especially if the prevailing conditions are favourable. In the UK, the introduction of legal right to repair in 2021 provides an opportunity to push product reuse up the agenda (Restart, 2021). This together with product design for repair/reuse, favourable economic conditions for reuse centres, repair shops and easy access to spare parts will help to make product reuse a preferable and desirable action.

5.4.2 Recommendations: shifting from a material-oriented to product-oriented management approach

The management of EoL EEE is often approached from a material recovery perspective via recycling. This was evidently shown in the of management practices in the countries reviewed with emphasis on collection for recycling (Chapter 2). While recycling is desirable from a waste hierarchy point of view, product reuse is more favourable especially when/where there is residual reuse value in the product. This shift in approach requires wholesale changes regarding attitudes and infrastructure as many EoL systems are designed for material recycling which treats discarded EEE as waste. This study has demonstrated the potential for reuse as a viable end-of-use/life option for EEE. Alongside other EoL outcomes such as recycling, products and materials can be kept in a resource loop for extended periods in line with circularity. As demonstrated in the case study (Chapter 4), such outcome would require specific interventions at different levels. These interventions can be described according to the levels of DUMs described in this study (micro, meso and macro levels).

A key component of any policy or scheme is the availability of associated legislative instruments and framework. This is important for coordination of reuse activities at macro level and it is at this level the most significant changes can be brought about which can influence activities at meso and micro levels. In the UK, strategies such as the Circular Economy Plan and Right to Repair provide relevant legislative framework for the implementation of reuse-centred product recovery. Such implementation will need to be driven by a robust and rigorous sensitisation campaign to raise awareness on the benefit of reuse and timely recovery of reusable products in hibernation. A national campaign similar to that by the Waste and Resources Action Programme’s (WRAP) *Love Food Hate Waste* for EEE would go a long way in influencing citizen behaviour change and educate consumers regarding the importance of releasing hibernating reusable EEE stocks promptly.

Meso-level interventions could help coordinate a unified approach at meso level. Using the UK as an example, meso-level coordination should involve municipal/county councils (e.g. Hampshire County Council) and/or institutional clusters (e.g. Russell Group[26]of universities) collaborating with regional/national third-party sectors such as the Charity Retail Organisation and pro-reuse and repair organisations such as the Restart Project for the publicity and execution of timed recovery events. For EEE, such events may be planned to coincide with ‘theme’ days such as Earth Day (22 April) or the International E-waste Day (14 October).

At micro level, interventions should be geared towards providing local solutions to EEE recovery within a micro-level DUM. Using a university DUM as an example, integrating product recovery for

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[26] The Russell Group is a group representing 24 research-intensive UK universities www.russellgroup.ac.uk

reuse into an institutions strategy will help promote and foster this outcome. Many universities in the UK have environmental/sustainability policies to help drive their desire to reduce their negative environmental impacts. For example, the University of Southampton recently published its Sustainability Strategy in which it highlights environmental and sustainability targets (University of Southampton, 2020). Part of the strategy involves reduction of emissions and promotion of sustainability through research and education. Product recovery for reuse ties into this strategy as a way to promote circular economy and environmental sustainability. As shown in the case study (Chapter 4), timed and targeted interventions will be required to help drive this policy. This can be put into practice by having collection events using optimised recovery systems (illustrated in Figure 5.5) during which students and staff can bring in their unused reusable items. The events could be planned in collaboration with local charity retailers, repairers (for EEE) and could also involve participation of student volunteers to help with collection and sorting. As the collection trials (Chapter 4) showed, such timely intervention has the potential to facilitate recovery of items of high reuse value.

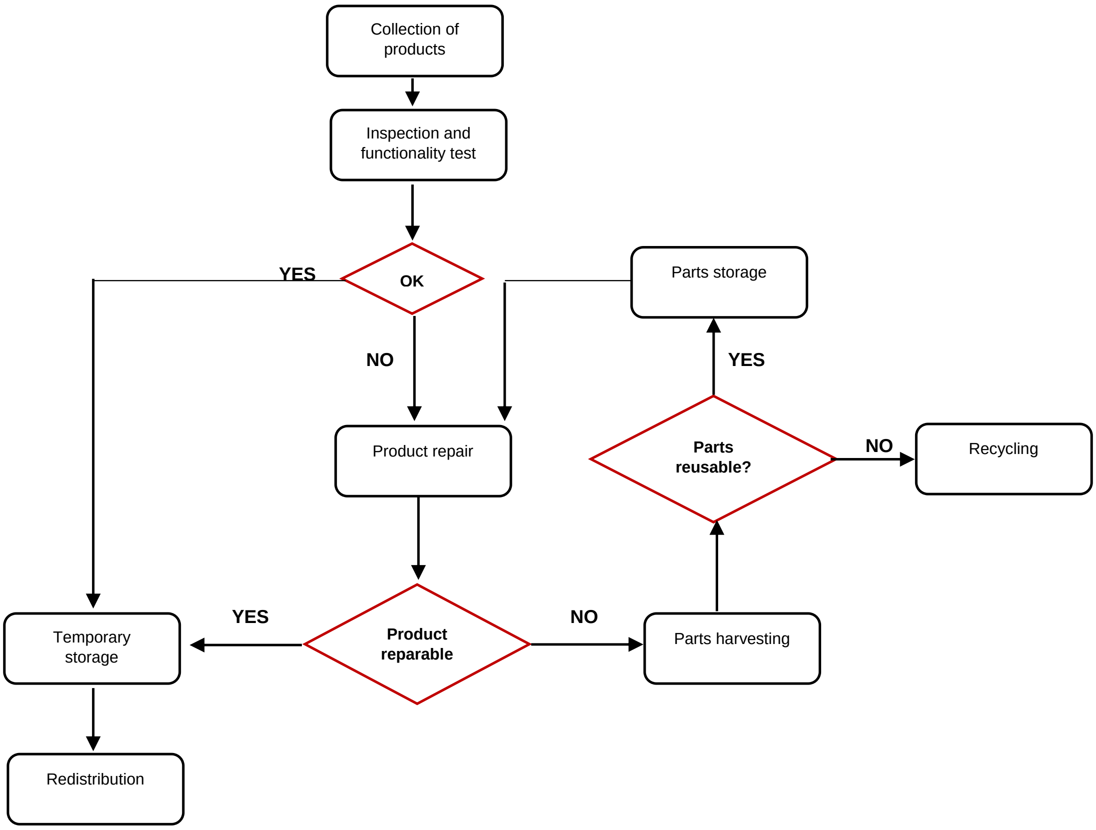

Figure 5.5. Proposed reuse-based recovery system that incorporates ancillary services such as product testing and certification for reuse

5.5 Concluding remarks

The digital revolution has brought with it a corresponding increase in production, availability and consumption of electrical and electronic equipment. Devices such as personal computers, mobile phones and electrical kitchen equipment have become ubiquitous and their usage is likely to increase in the future. With increase in ownership of these devices come an increase in electronic waste generation. As usage cycles become shorter, products come to their end of life sooner and are discarded, further fuelling the mounting WEEE challenge. This mounting challenge was the subject of the first part of this study (Chapter 2) where the global picture of WEEE was examined. WEEE has been identified as an important waste stream globally with an annual growth of 3 – 5%. This makes it imperative to have in place management strategies to address its generation. As discussed in the review, this is important for a number of reasons including resource efficiency and progression towards a circular economy. Four main management scenarios were identified in the review. This ranges from formal collection and recycling of WEEE observed in countries with formal WEEE legislation to informal collection and scavenging. The review also identified and highlighted contemporary and emerging issues on current and future WEEE management.

The circular economy model prioritises end of use/life options such as reuse. This route as an option towards circularity was the subject of investigation in Chapter 3 of this thesis. A unique urban space was surveyed to explore the potential for circularity of small EEE with reuse value. This space, which was described as meso-level distinct urban mine, provided an insight into hibernating levels of small EEE in this type of DUM cluster. Accessing these stocks will involve properly timed interventions and situational factors that target recovery of reusable EEE. This was demonstrated in in the study presented in Chapter 4 which investigated a conceptual product-oriented and reuse-centred recovery system for EEE recovery within an exemplar DUM. The outcome demonstrated the importance of systemic alterations and timed interventions in the product recovery for reuse. Overall, the study shows that in order to progress towards circularity, current systems for EoL management of EEE will need to incorporate fundamental changes including:

- Treating EoL EEE as a resource by targeting extension of useful usage cycle of recovered products. This will involve timely recovery of products with reuse value and would require a significant shift in attitude and relevant infrastructure to enable recovery of EEE for reuse

- A synergy between stakeholders in a product's lifecycle at all levels from 'cradle to grave' which will help guide implementation of relevant procedures geared towards product recovery for reuse and subsequent recycling
- Relevant legislative framework and mechanisms to support product reuse and other ancillary activities such as product recovery and repair.

5.5.1 Research limitations and future research

The study identified key issues in EoL management of EEE and investigated and demonstrated recovery of EEE within distinct anthropogenic spaces. This was achieved by a series of research work presented in previous chapters. However, some limitations were identified which can be considered in future research work.

The review in Chapter 2 presented a comprehensive coverage of management activities of W/EEE across different regions with the aim of providing a global picture of WEEE management. Due to time constraints and access/availability of data, the review was limited to 40 countries. Also, the review presented an analysis of contemporary issues evaluated using an importance/urgency matrix. This analysis was done solely by the researcher and thus the results were based on their subjectivity. A future analysis of this nature could be done using a more rounded approach such as a Delphi[27] study in which an expert panel can be constituted to provide an in-depth analysis and evaluation.

The meso-level DUM survey in Chapter 3 provided an insight into hibernating stocks of reusable EEE within a DUM cluster. However, the sample obtained from the survey was not fully representative of the wider UK staff and student population; sample was skewed by the higher proportion of staff respondents relative to student respondents. Further research on the subject matter could aim to obtain a representative sample. Also, the survey provided questions on a pre-determined group of 36 small EEE. While comprehensive, this group is in no way exhaustive; future surveys may allow for inclusion of more EEE options.

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[27] A Delphi study involves an aggregation of expert knowledge involving the constitution of an expert panel that provides insight and analyses on the subject matter.

The case study demonstrated the implementation of a reuse-centred recovery system in a micro-level DUM (University of Southampton) and the results shows the potential viability of such intervention. The process involved collection, visual inspection and sorting before recovered items were redistributed via donations to charity retailers. This system, while successful, was without a through product inspection via product functionality testing. The majority of items received and visually inspected were in good condition as the results showed however, a functionality test would provide a more comprehensive assessment of the products before redistribution. Such tests would have to be carried out by qualified and licenced professionals. The viability and economic implication of this should be the subject of future research.

Appendix A WEEE review literature

The review presented in Chapter 1 was a synthesis from a desk study which involved the use of publications ranging from academic to grey literature. Table below presents a summary of the countries reviewed together with relevant citations.

Table A1. Summary of global WEEE management scenarios

Region	**Country example**	**Generation rate (MT/year)**	**Remarks**
Europe	Finland	0.11 (Forti *et al*., 2020)	Finland had a producer responsibility scheme prior to the existence of the WEEE Directive for the management of waste tyres, waste paper and packaging (Ylä-Mella *et al.*, 2014). The WEEE Directive was harmonised with existing legislation (Finnish Waste Act [1072/1993]) to establish a framework for WEEE management. The amended legislation (Finnish Waste Act 452/2004) requires producers to facilitate the management (including re-use and recovery) of EEE they put on the market, including bearing the costs incurred (Ylä-Mella *et al.*, 2014).
	Germany	1.60 (Forti *et al*., 2020)	The WEEE Directive was transposed into Germany via the Act Governing the Sale, Return, and Environmentally Sound Disposal of Electrical and Electronic Equipment (ElektroG) (Walther *et al.*, 2009). Producers are required to register with the Elektro-Altgeraete Register (National Register for Waste Electrical Equipment) (Rotter *et al.*, 2011).

Region	**Country example**	**Generation rate (MT/year)**	**Remarks**
	Switzerland	0.20 (Forti *et al*., 2020)	Switzerland was the first country in the world to inaugurate a formal WEEE management system (Duygan and Meylan, 2015). The S.E.N.S, also known as the Swiss Foundation for Waste Management, is the first WEEE management EPR scheme in Switzerland which collects WEEE on behalf of manufacturers and retailers. Initially with a limited scope of just refrigerators and freezers collection, it expanded to collect a wider range of household EEE (Ongondo *et al.*, 2011).
	United Kingdom	1.59 (Eurostat, 2017; Forti *et al*., 2020)	The Environment Agency (EA) is responsible for the oversight of WEEE management in England (Ongondo *et al.*, 2011; Environment Agency, 2017), and until 2013, Wales (Natural Resources Wales, 2017); in Scotland, the Scottish Environmental Protection Agency is responsible (SEPA, 2017). The WEEE Directive was transposed in the United Kingdom (UK) as the WEEE Regulation, which was fully implemented in January 2007 (Ongondo *et al.*, 2011; WRAP, 2017).
	Other	-	The Balkan sub-region in Europe has, in the past, been a destination of WEEE from developed countries (Baldé *et al.*, 2015). This, in addition to internally-generated WEEE, has led to challenges in WEEE management in the region. A few countries in the region have WEEE legislation including Albania, Bosnia, Slovenia and Bulgaria, the latter two being EU Member States. Albania generates 20KT of WEEE annually with 0.6Kg generated per person per year (Baldé *et al.*, 2017), making it one of the lowest generators of WEEE in Europe. At the higher end of per capita generation is Slovenia which generates 16.1Kg/person/year and a total of 33KT annually. Bulgaria and Bosnia & Herzegovina generate 79KT and 25KT of WEEE respectively (Baldé *et al.*, 2017). WEEE collection and recycling in

Region	**Country example**	**Generation rate (MT/year)**	**Remarks**
			relatively low in this region compared with western Europe, although Bulgaria reportedly collects over 60% of WEEE generated annually (Baldé *et al.*, 2015).
Africa	Ghana	0.05 (Forti *et al*, 2020)	WEEE legislation was passed in Ghana in 2016. Known as the Hazardous and Electronic Waste Control Management Bill, 2016, it aims to bring some control to the WEEE management sector (Campen and Enders, 2016). It aims to regulate and restrict the influx of WEEE from abroad, as stipulated by the Basel Convention, and manage WEEE generated internally (Campen and Enders, 2016; Baldé *et al.*, 2017).
	Kenya	0.05 (Forti *et al*, 2020)	Kenya is a signatory to both Basel and Bamako Conventions that restrict the transboundary movement of WEEE (Ongondo *et al.*, 2011). The Kenyan E-waste Act is the most recent WEEE related legislation but is yet to be formally approved and it stipulates the end-of-life management of WEEE as the responsibility of manufacturers (Baldé *et al.*, 2017).
	Nigeria	0.3 (UNEP, 2019)	Nigeria banned the importation of used electronics in 2011. WEEE/near end-of-life EEEs are often mixed with used electrical and electronic equipment (UEEE) (Ogungbuyi *et al.*, 2012; Li *et al.*, 2013). The NESREA regulation (National Environmental [Electrical/Electronic Sector] Regulations 2010 S.1.No 23) requires importers of UEEE to register with the National Environmental Standards and Regulations Enforcement Agency (NESREA) before commencing with importation (NESREA, 2016). EPRON (Extended Producer Responsibility Organisation of Nigeria) was set up in 2018 and it involves companies such as Dell and Microsoft (Forti *et al*., 2020).

Region	**Country example**	**Generation rate (MT/year)**	**Remarks**
	South Africa	0.41 (Forti *et al*., 2020)	The Basel Convention is ratified by South Africa, although it is notably not a signatory to the Bamako Convention which places a complete ban on hazardous substances including WEEE. This is to ensure possible hazardous waste trading and recycling in the country (Snyman *et al.*, 2015). There is a National Waste Management Strategy, under which WEEE is classified as hazardous waste (Snyman *et al.*, 2015; Salhofer *et al.*, 2017). The WEEE management plan developed by the electronics industry has been forwarded to the Department of Environmental Affairs, which is planning to introduce an EPR tax to be collected from producers of WEEE and used to fund producer compliance schemes (PCS) (Campen and Enders, 2016).
	Other	-	In North Africa and the Maghreb sub-region, Algeria generates 252 KT of WEEE with per capita generation of 6.2 kg/person/year (Baldé *et al.*, 2017), making it one of the biggest contributors of WEEE in Africa (Campen and Enders, 2016; Baldé *et al.*, 2017). Algeria currently has no WEEE-specific legislation and no recorded official collection of WEEE. Libya has a very high rate of annual WEEE generation per capita at 11 kg (Baldé *et al.*, 2017); this rose from a reported 8.3 kg/person/year in 2014 (Baldé *et al.*, 2015). There is little information on collection and recycling as formal recording does not take place. Mauritania is on the lower end of the generation trend as it produces 1.3 kg/person/year, lower than the continental average. The total amount generated in Mauritania in 2016 was approximately 5.1 KT (Baldé *et al.*, 2017). Morocco is not known to have WEEE legislation; it produced 127 KT of WEEE in 2016 (3.7 kg/person/year). Tunisia has mooted plans to introduce a tax system believed to be for funding compliance schemes (Campen and Enders, 2016). Total WEEE generation is 63 KT (Baldé *et al.*, 2017).

Region	Country example	Generation rate (MT/year)	Remarks
			In eastern and southern Africa, Tanzania generated 38 KT of WEEE in 2016 (Baldé *et al.*, 2017). There is no legislation on WEEE management and there is significant informal sector focused on collection and recycling. A partnership between Finland and Tanzania is in place for knowledge and skills transfer involving the assembling of 3D printers using material fractions from recycled WEEE (Gale, 2015). Rwanda drafted a policy on WEEE management in 2012 (Campen and Enders, 2016); the proposed WEEE management scheme is to be based on the EPR principle and the framework development is still ongoing. Madagascar generated 14 KT of WEEE in 2016 (Baldé *et al.*, 2017). It put in place a decree in 2015 to develop a national electronic waste management plan based on EPR principle on historic and future WEEE streams (Campen and Enders, 2016). The Seychelles generated the highest per capita WEEE generation in Africa in 2016 (11.5 kg/person/year) (Baldé *et al.*, 2017). This could be partly attributed to its high GDP and per capita income. WEEE in the Seychelles is reported to be generally commingled with general waste. Mauritius also on the high end with regards to WEEE generation estimates (8.5 kg/person/year) and currently has no WEEE-related legislation.
Asia	China	10.1 (Forti *et al*., 2020)	WEEE-related legislation in China has been developed over the last decade, providing the legal framework for official collection and treatment of WEEE. The national legislation encompasses the collection and treatment of small and large electrical equipment such as TVs, refrigerators, washing machines; screen/monitors and ICT equipment (Wang *et al.*, 2013) – 18% of total generated WEEE was reportedly collected in 2016, amounting to

Appendix A

Region	Country example	Generation rate (MT/year)	Remarks
			1.3MT (Baldé *et al.*, 2017). There is a system of formal WEEE collection in China which comprises licensed collection stations and recyclers. These entities are in direct competition for WEEE with informal collectors who are more prevalent and easily accessible. Informal collection is mainly carried out by door-to-door pick-ups, mostly by street peddlers. The WEEE collected via these channels is rarely destined for official treatment systems (Cao et al., 2018), but goes to repair shops or dismantling houses, depending on the condition of the items.
	Hong Kong	0.15 (Forti *et al*., 2020)	Hong Kong recently established its first formal recycling plant for processing WEEE. The facility, which is government-supported in partnership with a German waste management company, handles large and small WEEE under strict and controlled conditions (Bland, 2018). This has been followed up with plans to impose a levy on imported EEE, with the income generated from this being used to fund the recycling facility (Bland, 2018). However, there remains illegal WEEE recycling sites still in operation and their impact on the environment is poorly understood due to a paucity of data (Lin *et al*., 2020).
	India	3.2 (Forti *et al*., 2020)	India introduced a WEEE-related legislation (E-waste Management and Handling Rules) which came into force in 2012 (Turaga and Bhaskar, 2017). In common with other WEEE legislation, it is based on an EPR framework. This regulation requires producers to attain set collection targets in an effort to boost collection and recycling rate in a country that still has a predominant informal WEEE sector (Turaga and Bhaskar, 2017); 95% of recycling is carried out in the informal sector (Awasthi *et al.*, 2016). Under the regulation, producers (including recyclers and dismantlers) are required to register with state-controlled environmental regulators. The regulators-known as State Pollution Control Boards (SPCBs) are responsible for the issuance of permits for WEEE collection and

Region	**Country example**	**Generation rate (MT/year)**	**Remarks**
			treatment (Turaga and Bhaskar, 2017). The regulation has been amended to promote higher recycling rates. The amendment, similar to the changes made to the EU WEEE Directive, sets collection targets as a percentage of EEE put on market (Turaga and Bhaskar, 2017). The regulation has resulted in an increase in the number of registered WEEE treatment facilities (Turaga and Bhaskar, 2017).
	Japan	2.1 (Balde *et al*., 2017)	Japan was amongst the first countries in Asia and globally to develop and implement a WEEE management system based on EPR (Baldé *et al.*, 2015; Sugimura and Murakami, 2016, Forti *et al*., 2020). In 2001, a law on WEEE recycling was introduced called Home Appliance Recycling Law (HARL) that specifically targets consumer electronics (Zhang and Kimura, 2006; Ongondo *et al.*, 2011). Consumer electronics such as washing machines, air conditioners and TVs constitute the highest percentage of WEEE by volume and weight (Ongondo *et al.*, 2011). The HARL law underwent amendment to include new and emerging consumer products such as LCD (Liquid Crystal Display) and Plasma TVs. The HARL law also requires producers of EEE to take back products that have reach end of life (EoL) and treat, with materials recovered reused or recycled (Aizawa *et al.*, 2008; Ongondo *et al.*, 2011).
	South Korea	0.8 (Forti *et al*., 2020)	WEEE generated in South Korea is managed using an EPR based system under the Waste Management Act (Act on the Promotion of Conservation of Resources) (Hyunmyung and Yong-Chul, 2006; Kim, Jang and Lee, 2013), which was introduced in 2003. There are collection networks within municipalities involving either kerbside drop-off

Region	**Country example**	**Generation rate (MT/year)**	**Remarks**
			points or door-to-door collection (Kim *et al.*, 2013). Collected WEEE is then transported by authorised transporters to designated recycling facilities (Turaga and Bhaskar, 2017). Under the Korean WEEE Act, six hazardous substances are regulated (lead, cadmium, mercury, poly-brominated diphenyl ethers, hexavalent chromium & poly-brominated biphenyls). Coverage of EEE under the Act is limited to 10 types of EEE including refrigerators, washing machines, mobile phones and TVs (Kim *et al.*, 2013).
	Vietnam	0.25 (Forti *et al*., 2020)	Vietnam's WEEE-related policy, the Prime Ministerial Decision on E-waste, came into effect in 2016, with huge dominance of informal recycling and transboundary importation persisting (Baldé *et al.*, 2017; Borthakur and Govind, 2017). EEE producers are presently responsible for only discarded EEE that originate from the production line, not consumer-generated WEEE (Borthakur and Govind, 2017).
	United Arab Emirates	0.16 (Forti *et al*., 2020)	There is currently no formal WEEE legislation in UAE, however a partnership with Switzerland is to deliver a recycling plant in Dubai which, when commissioned, will handle 39 KT of WEEE annually (Gulf Today, 2017).
North America	Canada	0.7 (Balde *et al*., 2017; Forti *et al*., 2020)	Canada has no federal WEEE legislation. However, the Ministry of Environment is responsible for WEEE management. The management of WEEE in Canada is predominately handled by the private sector under a Stewardship Programme: Electronic Product Stewardship Canada (EPSC) (Kumar and Holuszko, 2016; Baldé *et al.*, 2017). Eight provinces have product stewardship programs in Canada - Alberta, British Columbia, Manitoba, Newfoundland & Labrador Nova Scotia, Ontario, Quebec and Saskatchewan (Kumar and Holuszko, 2016; Borthakur

Region	Country example	Generation rate (MT/year)	Remarks
			and Govind, 2017). These programmes have resulted in proliferation of WEEE management organisations in the provinces. These organisations require operating licences, which are issued subject to an audit carried out by the Recycler Qualification Office (RQO). The RQO runs the national Recycler Qualification Programme, which ensures that WEEE is recycled in an environmentally safe manner (Recycler Qualification Office, 2015). The recyclers mainly collect and recycle laptops, personal computers, together with other associated peripherals and small household appliances.
	United States of America	6.9 (Forti *et al*., 2020)	WEEE management in the USA varies between states as there is no federal legislation on WEEE. California, in 2003, adopted a management system which laid financial responsibility by the consumers of EEE for EoL management (Li, 2011). The state of Maine followed up with an EPR-based e-waste law in 2004, which is based on involvement of all stakeholders (producer, consumer & municipality) in shared responsibility of WEEE management (Ongondo *et al.*, 2011; Borthakur and Govind, 2017). Different schemes and initiatives exist in the USA for WEEE management. One of such is the National Strategy for Electronics Stewardship (NSES). The programme enables the promotion of environmentally safe EoL management of WEEE, reduction of WEEE exports to developing countries as well as encouraging concepts such as eco-design in electronics manufacturing (USEPA, 2017c). Its framework has been adopted widely for the development of action plans for WEEE management across different states in the USA (Baldé *et al.*, 2017). Another initiative is the US-EPA managed Sustainable Materials Management (SMM) program. This involves the partnership between the USEPA and original equipment manufacturers (OEMs) for the collection of WEEE from consumers. It also advocates for the purchase of certified 'green' electronics, particularly by federal

Region	**Country example**	**Generation rate (MT/year)**	**Remarks**
			agencies and to recycle generated WEEE at certified recycling facilities, including in states without WEEE takeback regulations (Baldé *et al.*, 2017). There are two certification programs for the recycling of WEEE in the USA; the Responsible Recycling Standard for Electronic Recyclers (R2) Standard, which is run by the Sustainable Electronics Recycling International (SERI), and the E-Stewards certification programme, by Basel Action Network (BAN). The programmes provide accreditation to electronic recycling facilities, subject to auditing and meeting set criteria. Over 550 recyclers in the US across different states are accredited by one or both schemes (US-EPA, 2017b).
Latin America	Argentina	0.46 (Forti *et al*., 2020)	Argentina is a signatory to the Basel Convention, but it currently has no national WEEE legislation. Laws on hazardous waste treatment exist and currently cover the handling and treatment of WEEE (Torres *et al.*, 2016). The national government is currently collaboration with the National Institute of Industrial Technology on a programme that will establish WEEE recycling facilities and provide necessary training for relevant stakeholders (Torres *et al.*, 2016). The primary objective of the programme is to increase collection and recycling rates, currently only 3% (Torres *et al.*, 2016), and divert WEEE away from landfill.
	Brazil	2.1 (Forti *et al*., 2020)	Brazil has regulations and policies aimed at the management of WEEE. The National Solid Waste Policy (Waste Law) mandates every single stakeholder within the lifecycle of EEE to be responsible for its EoL management (Torres *et al.*, 2016); the policy aims to promote reverse logistics of WEEE. There are recycling companies operating in Brazil, specialising in dismantling and recovery of materials such as aluminium, plastics and wires. Despite the significant

Region	Country example	Generation rate (MT/year)	Remarks
			increase in WEEE generation rate in Brazil, few authorised WEEE management systems are present, with large quantities of WEEE commingled with household waste and landfilled (de Souza *et al*., 2016).
	Bolivia	0.04 (Forti *et al*., 2020)	There is no WEEE legislation currently in Bolivia, but the government has a partnership with United Nations Industrial Development Programme (UNIDO) on tackling persistent organic pollutants (POPs) emitted from uncontrolled WEEE recycling
	Chile	0.18 (Forti *et al*., 2020)	Chile introduced a WEEE-specific law in 2016 which provides a legal framework for WEEE management via extended producer responsibility (Silva and Baigorrotegui, 2020). The law is unique as, unlike other legislation in Latin American countries, it incorporates informal recyclers such as waste pickers into the WEEE management system (Silva and Baigorrotegui, 2020).
	Colombia	0.31 (Forti *et al*., 2020)	A regulation on WEEE is being developed that encompasses EPR principle for all categories of EEE including integrated management of WEEE (Forti *et al*., 2020).
	Mexico	1.2 (Forti *et al*., 2020)	According to waste legislation in Mexico, WEEE is classified as special handling waste and there is a framework in place that sets out the responsibilities of various players (from manufacturers to consumers) (Cruz-Sotelo *et al.*,

Region	**Country example**	**Generation rate (MT/year)**	**Remarks**
			2016). Columbia generates an estimated 250 KT of WEEE annually (Kuehr *et al*., 2015; World Resources Forum, 2017). The first WEEE-related guidelines were set in 2013 which provided a framework for WEEE compliance schemes (Kuehr *et al*., 2015). This was followed up with a national policy on WEEE management in 2017 with key objectives including responsible consumption and proper end of life management of WEEE (World Resources Forum, 2017).
	Other	-	In Paraguay, a significant amount of the 44 KT of WEEE it generates is destined for open dumps, as there is currently no WEEE legislation. Peru, with rapid ICT penetration in recent years, generates 182 KT of WEEE mainly from ICT devices (Torres *et al.*, 2016). WEEE-related legislation – the National Regulation for the Management of Waste Electrical and Electronic Equipment - specifies the roles of producers, retailers. Official collection occurs with planned capacity enhancements. Nicaragua's generation of WEEE is estimated to be 2kg/person/year (Central America Data, 2020) with total generation estimated at 11 KT in 2014 (Kuehr *et al*., 2015). There are no known official treatment channels for WEEE management (Central America Data, 2020). Uruguay currently has no WEEE-specific legislation to deal with the 32 KT of WEEE it generates annually (Kuehr *et al*., 2015). Collected WEEE is dealt with mostly by manual disassembly and recovery of metals.
Oceania	Australia	0.57 (Balde *et al*., 2017; Forti *et al*., 2020)	Australia has regulations that cover WEEE management; the National Waste Policy (2009); Product Stewardship Act (2011); Product Stewardship (for TVs and computers) regulations and the National Television and Computer Recycling Scheme (NTCRS) (Morris and Metternicht, 2016). These regulations have led to the introduction of

Region	Country example	Generation rate (MT/year)	Remarks
			schemes for EoL management of WEEE. The Product Stewardship (TVs and computers) regulation that came into force in 2011 provides a legal framework for the establishment of the NTCRS for recycling services. These privately-funded schemes, supported by the national government, provide services for the collection and recycling of computers and TVs (Morris and Metternicht, 2016; Baldé *et al.*, 2017). While the scheme does not cover other WEEE categories, it aims to attain 80% collection rate of computers and TVs (Australian Government, 2018). The Australia Mobile Telecommunications Association (AMTA) coordinates discarded mobile phones collection and recycling. It carries out collection and recycling through its accredited programme, Mobile Muster, which are then recycled (AMTA, 2018).
	New Zealand	0.09 (Balde *et al*., 2017; Forti *et al*., 2020)	There is currently no WEEE legislation in New Zealand. However, the government has explored the possibility of creating a product stewardship scheme by undertaking stakeholder consultations and WEEE data collection and analysis (Baldé *et al.*, 2017).
	Other	-	WEEE management in the Pacific Island countries and territories (PICTs) is mostly informal. The Pacific Regional Waste Pollution Management Strategy was recently adopted to facilitate waste management in the sub-region (Baldé *et al.*, 2017). Current and future WEEE management, alongside other waste streams, are included in this strategy. Another project backed by the European Union known as PacWaste, which is based in Samoa, is ongoing

Region	Country example	Generation rate (MT/year)	Remarks
			to collect relevant data on WEEE management, including generation data and current management practices in the Pacific Island Countries (Baldé *et al.*, 2017).

Appendix B Survey supporting information

This section contains supporting information on the EEE survey conducted between March and November 2019

B.1 Email correspondence (Universities of Portsmouth and Winchester)

Hello,

Hope this meets you well.

My name is Lanre. I am a 2nd year PhD student at the University of Southampton working on a piece of research on waste electrical and electronic equipment. My supervisors are Professor Ian Williams and Dr. Pete Shaw. I wish to seek consent to recruit participants at the Universities of Portsmouth and Winchester.

The survey aims to collect data on ownership and generation patterns of EEE/WEEE amongst staff members and students of universities within Hampshire (Portsmouth, Southampton and Winchester). Data from the survey will provide baseline data on EEE/WEEE generation in unique urban spaces like universities, which in turn would help guide end-of-life management of WEEE generated in such environments. The survey is proposed to commence in March 2019, subject to relevant Risk Assessment and Ethics approval. The survey will be conducted using an online questionnaire-based survey. This information will help each university to better manage their own WEEE and also input into strategies and policies that help to deal with the so-called “end-of-year clear out” that can cause tensions between local residents and university students every May/June.

Thanking you in advance of your cooperation.

With regards,

Lanre

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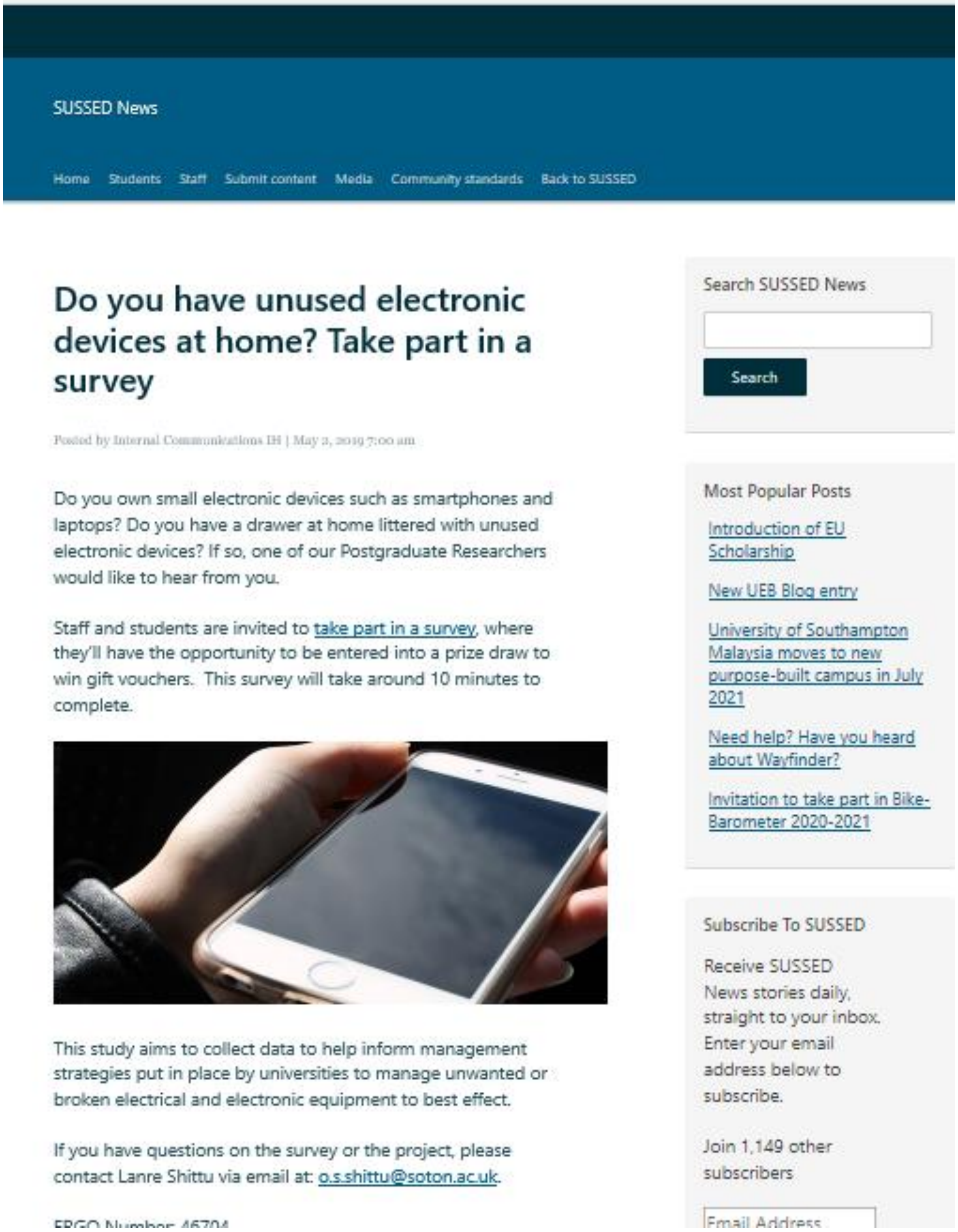
SO17 1BJ

B.2 EEE Survey news bulletin (University of Southampton SUSSSED webpage) Link



Do you have unused electronic devices at home? Take part in a survey

Posted by Internal Communications IH | May 2, 2019 7:00 am

Do you own small electronic devices such as smartphones and laptops? Do you have a drawer at home littered with unused electronic devices? If so, one of our Postgraduate Researchers would like to hear from you.

Staff and students are invited to take part in a survey, where they'll have the opportunity to be entered into a prize draw to win gift vouchers. This survey will take around 10 minutes to complete.

This study aims to collect data to help inform management strategies put in place by universities to manage unwanted or broken electrical and electronic equipment to best effect.

If you have questions on the survey or the project, please contact Lanre Shittu via email at: o.s.shittu@soton.ac.uk.

ERGO Number: 46704

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B.3 Survey questionnaire including Participant Information Sheet

Ownership and stockpiling of small Electrical and Electronic Equipment Survey

Researchers: Olanrewaju Shittu, Professor Ian Williams & Dr Pete Shaw

ERGO number: ERGO/FEPS/46704

Please read this information carefully before opting to take part in this research.

What is the survey about?

The primary focus of this survey is an evaluation of ownership and stockpiling of small electrical and electronic equipment amongst staff and students in universities within Hampshire. This will involve collection of data on ownership, replacement and displacement cycles and stockpiling of small electrical and electronic appliances. The survey will focus on these devices:

- Small kitchen appliances
- Personal care appliances
- Information and communication technology/audio-visual devices
- Small household appliances

Why have I been asked to participate?

You have been chosen to participate through an online survey circulated via the host institution's intranet. The target population for the survey are university staff members and students.

What will happen to me if I take part?

You will be asked to fill out the online questionnaire titled '*Ownership and stockpiling of small electrical and electronic appliances survey'.* The survey will take less than 15 minutes to complete.

Are there any benefits in my taking part?

You will be contributing to data that will inform end of life and management of electrical and electronic appliances. For completing this survey, you will be entered into a prize draw. First prize will be a £100 gift card; 2nd prize will be £50 gift card.

Are there any risks involved?

There are no risks involved when taking part in this questionnaire.

Will my participation be confidential?

All the information you provide will be in line with the Data Protection Act and confidentiality policies of the University of Southampton. Information will be stored securely in a password-protected computer and will not be disclosed to third parties.

What should I do if I want to take part?

If you decide to take part in this online survey, the next steps are easy. Simply indicate your interest by ticking the consent box at the bottom of this page and proceed to completing the survey. **Please note that the questionnaire is easily accessible with a mobile device (e.g. smart-phones, tablets, etc.)**

What happens if I change my mind?

You have the right to withdraw at any time without affecting your legal rights.

What will happen to the results of the research?

This project will be written up in the form of a scientific report. The research data will be remain anonymously stored at the University of Southampton for a minimum of 10 years, in line with our university policy.

Where can I get more information?

If you have any questions after reading this information sheet, please feel free to contact the principal researcher Olanrewaju Shittu (o.s.shittu@soton.ac.uk), or Professor Ian Williams, who is part of the research team (023 8059 8755, idw@soton.ac.uk).

What happens if something goes wrong?

In the unlikely case of concern or complaint, please feel free to contact the Research Integrity and Governance Manager (023 8059 5058, rgo-info@soton.ac.uk).

Thank you for taking the time to read this information sheet and considering taking part in this research.

---

1. Demographics

Question 1.

Are you a staff member or student?

Question 2.

Select your age category

Question 3.

Select your University

Question 4.

Select type of household you currently live in

Question 5.

How many people, including you, live in current household?

Question 6.

Please indicate how this survey is being completed.

---

2. Small Kitchen Appliances

This section asks questions on ownership of small kitchen appliances. Do not include appliances/devices owned by others in the household. **Shared appliances should be included only if you are the primary user.** For the first question, please select number of **ALL** appliances you own, including those that are not in use and/or non-functional e.g. if you own two kettles and one is non-functional, indicate you own **TWO** kettles.

Question 1.

How many electric coffee maker(s) do you own?

Please select

Where is the primary location of the electric coffee maker? (Please select location of most frequently used appliance if you own more than one)

Please select ▾

How often do you replace your electric coffee maker?

Please select ▾

Do you own (a) functional but unused electric coffee maker(s)?

Please select ▾

Do you own (a) non-functional electric coffee maker(s)?

Please select ▾

Question 2.

How many electric blender(s) do you own?

Please select ▾

Where is the primary location of the electric blender? (Please select location of most frequently used appliance if you own more than one)

Please select ▾

How often do you replace your electric blender?

Please select ▾

Do you own (a) functional but unused electric blender(s)?

Please select ▾

Do you own (a) non-functional electric blender(s)?

Please select ▾

Question 3.

How many electric food mixer(s) do you own?

Please select ▾

Where is the primary location of the electric food mixer? (Please select location of most frequently used appliance if you own more than one)

Please select ▾

How often do you replace your electric food mixer?

Please select ▾

Do you own (a) functional but unused electric food mixer(s)?

Please select ▾

Do you own (a) non-functional electric food mixer(s)?

Please select ▾

Question 4.

How many electric kettle(s) do you own?

Please select ▾

Where is the primary location of the electric kettle? (Please select location of most frequently used appliance if you own more than one)

Please select ▾

How often do you replace your electric kettle?

Please select ▾

Do you own (a) functional but unused electric kettle(s)?

Please select ▾

Do you own (a) non-functional electric kettle(s)?

Please select ▾

Question 5.

How many electric juicer(s) do you own?

Please select ▾

Where is the primary location of the electric juicer? (Please select location of most frequently used appliance if you own more than one)

Please select ▾

How often do you replace your electric juicer?

Please select ▾

Do you own (a) functional but unused electric juicer(s)?

Please select ▾

Do you own (a) non-functional electric juicer(s)?

Please select ▾

Question 6.

How many electric wok(s)/electric frying pan(s) do you own?

Please select ▾

Where is the primary location of the electric wok/electric frying pan? (Please select location of most frequently used appliance if you own more than one)

Please select ▾

How often do you replace your electric wok/frying pan?

Please select ▾

Do you own (a) functional but unused electric wok(s)/electric frying pan(s)?

Please select ▾

Do you own (a) non-functional electric wok(s)/frying pan(s)?

Please select ▾

Question 7.

How many rice cooker(s) do you own?

Please select ▾

Where is the primary location of the rice cooker? (Please select location of most frequently used appliance if you own more than one)

Please select ▾

How often do you replace your rice cooker?

Please select ▾

Do you own (a) functional but unused rice cooker(s)?

Please select ▾

Do you own (a) non-functional rice cooker(s)?

Please select ▾

Question 8.

How many sandwich grill(s)/toaster(s) do you own?

Please select ▾

Where is the primary location of the sandwich grill/toaster? (Please select location of most frequently used appliance if you own more than one)

Please select ▾

How often do you replace your sandwich grill/toaster?

Please select ▾

Do you own (a) functional but unused sandwich grill(s)/toaster(s)?

Please select ▾

Do you own a non-functional sandwich grill(s)/toaster(s)?

Please select ▾

---

3. Personal Care Appliances

This section asks questions on personal care products. Do not include appliances/devices owned by others in the household. **Shared appliances should be included only if you are the primary user.** For the first question, please select number of **ALL** appliances you own, including those that are not in use and/or non-functional e.g. if you own two hair dryers and one is non-functional/not in use, indicate you own **TWO** hair dryers.

Question 1.

How many hair curler(s)/curling tong(s) do you own?

Please select ▾

Where is the primary location of the hair curler/curling tong? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your hair curler/curling tong?

Please select ▾

Do you own (a) functional but unused hair curler(s)/curling tong(s)?

Please select ▾

Do you own (a) non-functional hair curler(s)/curling tong(s)?

Please select ▾

Question 2.

How many hair dryer(s) do you own?

Please select ▾

Where is the primary location of the hair dryer? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your hair dryer?

Please select ▾

Do you own (a) functional but unused hair dryer(s)?

Please select ▾

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Do you own (a) non-functional hair dryer(s)?

Please select ▼

Question 3.

How many hair straightener(s) do you own?

Please select ▼

Where is the primary location of the hair straightener? (Please select location of most frequently used device if you own more than one)

Please select ▼

How often do you replace your hair straightener?

Please select ▼

Do you own (a) functional but unused hair straightener(s)?

Please select ▼

Do you own (a) non-functional hair straightener(s)?

Please select ▼

Question 4.

How many hair styler(s) do you own?

Please select ▼

Where is the primary location of hair styler? (Please select location of most frequently used device if you own more than one)

Please select ▼

How often do you replace your hair styler?

Please select ▼

Do you own (a) functional but unused hair styler(s)?

Please select ▼

Do you own (a) non-functional hair styler(s)?

Please select ▼

Question 5.

How many electronic razor(s)/epilator(s) do you own? **(Epilators are small electric hair removal devices)**

Please select ▼

Where is the primary location of the epilator? (Please select location of most frequently used device if you own more than one)

Please select ▼

How often do you replace your epilator?

Please select ▼

Do you own (a) functional but unused epilator(s)?

Please select ▼

Do you own (a) non-functional epilator(s)?

Please select ▼

Question 6.

How many electric toothbrush(es) do you own?

Please select ▼

Where is the primary location of the electric toothbrush? (Please select location of most frequently used device if you own more than one)

Please select ▼

How often do you replace your electric toothbrush?

Please select ▼

Do you own (a) functional but unused electric toothbrush(es)?

Please select ▼

Do you own (a) non-functional electric toothbrush(es)?

Please select ▼

4. Small Household Appliances

This section asks questions on the ownership of small household appliances. Do not include appliances/devices owned by others in the household. **Shared appliances should be included only if you are the primary user.** For the first question, please select number of **ALL** appliances you own, including those that are not in use and/or non-functional e.g. if you own two desk lamps and one is non-functional, indicate you own **TWO** desk lamps

---

Question 1.

How many desk lamp(s) do you own?

Please select ▼

Where is the primary location of the desk lamp? (Please select location of most frequently used device if you own more than one)

Please select ▼

How often do you replace your desk lamp?

Please select ▼

Do you own (a) functional but unused desk lamp(s)?

Please select ▼

Do you own (a) non-functional desk lamp(s)?

Please select ▼

Question 2.

How many electric iron(s) do you own?

Please select ▼

Where is the primary location of the electric iron? (Please select location of most frequently used device if you own more than one)

Please select ▼

How often do you replace your electric iron?

Please select ▼

Do you own (a) functional but unused electric iron(s)?

Please select ▼

Do you own (a) non-functional electric iron(s)?

Please select ▼

Question 3.

How many home telephone(s) do you own?

Please select ▼

Where is the primary location of the home telephone? (Please select location of most frequently used device if you own more than one)

Please select ▼

How often do you replace your home telephone?

Please select ▼

Do you own (a) functional but unused home telephone(s)?

Please select ▼

Do you own (a) non-functional home telephone(s)?

Please select ▾

Question 4.

How many portable space heater(s) do you own?

Please select ▾

Where is the primary location of the portable space heater? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your portable space heater?

Please select ▾

Do you own (a) functional but unused portable space heater(s)?

Please select ▾

Do you own (a) non-functional portable space heater(s)?

Please select ▾

Question 5.

How many table/desk fan(s) do you own?

Please select ▾

Where is the primary location of the table/desk fan? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your table/desk fan?

Please select ▾

Do you own (a) functional but unused table/desk fan(s)?

Please select ▾

Do you own (a) non-functional table/desk fan(s)?

Please select ▾

5. Audio-visual/ICT devices

Questions in this section are on ownership of audio-visual/information technology devices. Do not include appliances/devices owned by others in the household. **Shared appliances should be included only if you are the primary user.** For the first question, please select number of **ALL** appliances you own, including those that are not in use and/or non-functional e.g. if you own two CD players and one is non-functional, indicate you own **TWO** CD players.

Question 1.

How many digital camera(s) (excluding mobile phones; tablets) do you own?

Please select ▾

Where is the primary location of the digital camera? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your digital camera?

Please select ▾

Do you own (a) functional but unused digital camera(s)?

Please select ▾

Do you own (a) non-functional digital camera(s)?

Please select ▾

Question 2.

How many electronic tablet(s) do you own?

Please select ▾

Where is the primary location of the electronic tablet? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your electronic tablet?

Please select ▾

Do you own (a) functional but unused electronic tablet(s)?

Please select ▾

Do you own (a) non-functional electronic tablet(s)?

Please select ▾

Question 3.

How many laptop computer(s) do you own?

Please select ▾

Where is the primary location of the laptop computer? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your laptop computer?

Please select ▾

Do you own (a) functional but unused laptop computer(s)?

Please select ▾

Do you own (a) non-functional laptop computer(s)?

Please select ▾

Question 4.

How many netbook(s)/notebook computer(s) do you own?

Please select ▾

Where is the primary location of netbook/notebook computer? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your netbook/notebook computer?

Please select ▾

Do you own (a) functional but unused netbook(s)/notebook computer(s)?

Please select ▾

Do you own (a) non-functional netbook(s)/notebook computer(s)?

Please select ▾

Question 5.

How many headset(s)/headphone(s) do you own?

Please select ▾

Where is the primary location of the headset/headphones? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your headset/headphones?

Please select ▾

Do you own (a) functional but unused pair(s) of headset(s)/headphones?

Please select ▾

Do you own (a) non-functional headset(s)/headphones?

Please select ▾

Question 6.

How many mobile phone(s) do you own?

Please select ▾

How often do you replace your mobile phone?

Please select ▾

Do you own (a) functional but unused mobile phone(s)?

Please select ▾

Do you own (a) non-functional mobile phone(s)?

Please select ▾

Question 7.

How many portable CD player(s) do you own?

Please select ▾

Where is the primary location of the portable CD player? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your portable CD player?

Please select ▾

Do you own (a) functional but unused portable CD player(s)?

Please select ▾

Do you own (a) non-functional portable CD player(s)?

Please select ▾

Question 8.

How many DVD/Blu-ray player(s) do you own?

Please select ▾

Where is the primary location of DVD/Blu-ray player? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your DVD/Blu-ray player?

Please select

Do you own (a) functional but unused DVD/Blu-ray player(s)?

Please select

Do you own (a) non-functional DVD/Blu-ray player(s)?

Please select

Question 9.

How many printer(s) do you own? **(Stand-alone printers, excluding Multi-Functional Devices)**

Please select

Where is the primary location of the printer? (Please select location of mostly frequently used device if you own more than one)

Please select

How often do you replace your printer?

Please select

Do you own (a) functional but unused printer(s)?

Please select

Do you own (a) non-functional printer(s)?

Please select

Question 10.

How many scanner(s) do you own? **(Stand-alone scanners, excluding Multi-Functional Devices).**

Please select

Where is the primary location of the scanner? (Please select location of most frequently used device if you own more than one)

Please select

How often do you replace your scanner?

Please select

Do you own (a) functional but unused scanner(s)?

Please select

Do you own (a) non-functional scanner(s)?

Please select

Question 11.

How many fax machines(s) do you own?

Please select ▾

Where is the primary location of fax machine? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your fax machine?

Please select ▾

Do you own (a) functional but unused fax machine(s)?

Please select ▾

Do you own (a) non-functional fax machine(s)?

Please select ▾

Question 12.

How many radio(s) (analogue or digital) do you own?

Please select ▾

Where is the primary location of the radio? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your radio?

Please select ▾

Do you own (a) functional but unused radio(s)?

Please select ▾

Do you own (a) non-functional radio(s)?

Please select ▾

Question 13.

How many screen(s) (20" and below) do you own? **(Including flat-panel computer monitors)**

Please select ▾

Where is the primary location of the screen? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your screen?

Please select ▾

Do you own (a) functional but unused screen(s)?

Please select ▾

Do you own (a) non-functional screen(s)?

Please select ▾

Question 14.

How many smart/digital watch(es) do you own?

Please select ▾

How often do you replace your smart/digital watch?

Please select ▾

Do you own (a) functional but unused smart/digital watch(es)?

Please select ▾

Do you own (a) non-functional smart/digital watch(es)?

Please select ▾

Question 15.

How many small speaker(s) (including smart speakers) do you own? **(Dual speakers should be counted as one unit)**

Please select ▾

Where is the primary location of small speaker(s)? (Please select location of most frequently used device if you own more than one pair)

Please select ▾

How often do you replace your small speaker(s)?

Please select ▾

Do you own (a) functional but unused small speaker(s)?

Please select ▾

Do you own (a) non-functional small speaker(s)?

Please select ▾

Question 16.

How many video game console(s) do you own?

Please select ▾

Where is the primary location of video game console? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your video game console?

Please select ▾

Do you own (a) functional but unused video game console(s)?

Please select ▾

Do you own (a) non-functional video game console(s)?

Please select ▾

Question 17.

How many webcam(s) do you own?

Please select ▾

Where is the primary location of webcam? (Please select location of most frequently used device if you own more than one)

Please select ▾

How often do you replace your webcam?

Please select ▾

Do you own (a) functional but unused webcam(s)?

Please select ▾

Do you own (a) non-functional webcam(s)?

Please select ▾

6. Finally...

Question 1.

Would you be interested in participating in further research involving a trial of collection of small electrical and electronic equipment?

▾

Question 2.

Would you like to be entered into a prize draw?

B.4 Tables of results

B.4.1 Ownership levels

Small household appliances

SHA	No of respondents	0	1	2	3	4	Average	Ownership level (%)
Desk lamp	312	72	95	62	32	51	**1.7**	**76.9**
Electric iron	311	67	203	35	4	2	**0.9**	**78.5**
Home telephone	311	132	94	41	27	17	**1**	**57.6**
Portable space heater	311	193	77	28	6	7	**0.6**	**37.9**
Table/desk fan	312	183	82	28	11	8	**0.7**	**41.3**

Small kitchen appliances

SKA	No of respondents	0	1	2	3	4	Average	Ownership Level (%)
Electric coffee maker	320	177	109	26	7	1	**0.6**	**44.7**
Electric blender	320	74	170	58	14	4	**1.1**	**76.9**
Electric food mixer	320	151	137	29	3	0	**0.6**	**52.8**
Electric kettle	320	27	232	51	8	2	**1.1**	**91.6**

SKA	**No of respondents**	**0**	**1**	**2**	**3**	**4**	**Average**	**Ownership Level (%)**
Electric juicer	320	277	41	2	0	0	**0.1**	**13.4**
Electric wok/frying pan	320	304	13	2	0	1	**0.1**	**5**
Rice cooker	320	270	44	4	2	0	**0.2**	**15.6**
Sandwich/toaster	320	125	163	28	3	1	**0.7**	**60.9**

Personal care appliances

PCA	**No of respondents**	**0**	**1**	**2**	**3**	**4**	**Average**	**Ownership Level (%)**
Hair curler/curling tong	314	214	77	13	6	4	**0.4**	**31.8**
Hair dryer	314	69	160	73	10	2	**1.1**	**78**
Hair straightener	313	154	115	39	5	0	**0.7**	**50.8**
Hair styler	313	296	12	5	0	0	**0.1**	**5.4**
Electronic razor/epilator	314	150	107	40	8	9	**0.8**	**52.2**
Electric toothbrush	313	86	156	39	17	15	**1.1**	**72.5**

Appendix B

Information and communication technology/audio-visual devices

ICT	No of respondents	0	1	2	3	4	Average	Ownership Level (%)
Digital camera	300	83	106	74	29	8	**1.2**	**72.3**
Electronic tablet	299	78	107	67	19	28	**1.4**	**73.9**
Laptop computer	299	26	123	90	37	23	**1.7**	**91.3**
Netbook/Notebook	299	274	24	1	0	0	**0.1**	**8.4**
Headset/Headphones	298	36	54	60	47	101	**2.4**	**87.9**
Mobile phone	298	0	97	60	48	93	**2.5**	**100**
CD player	299	244	44	10	1	0	**0.2**	**18.4**
DVD/Blu-ray	299	144	111	39	5	0	**0.7**	**51.8**
Printer	299	138	142	19	0	0	**0.6**	**53.8**
Scanner	299	276	21	2	0	0	**0.1**	**7.7**
Fax machine	299	296	2	1	0	0	**0**	**1**
Radio	299	146	74	37	23	19	**1**	**51.2**
Screen	299	168	65	38	13	15	**0.8**	**43.8**
Smart watch	299	185	78	24	10	2	**0.5**	**38.1**
Speaker	299	108	92	47	28	24	**1.2**	**63.9**
Video game console	299	153	63	38	17	28	**1**	**48.8**
Web cam	299	255	39	2	2	1	**0.2**	**14.7**

B.4.2 Stockpiling and hoarding levels

Small household appliances (functional)

SHA	No of respondents	Respondents	1	2	3	4	Stockpiles	Stockpiling level (%)
Desk lamp	312	55	33	16	4	2	**85**	**17.6**
Electric iron	311	44	42	1	1	0	**47**	**14.1**
Home telephone	311	46	34	9	1	2	**63**	**14.8**
Portable space heater	311	28	20	7	0	1	**38**	**9**
Table/desk fan	312	17	12	3	0	2	**26**	**5.4**

Small household appliances (non-functional)

SHA	No of respondents	Respondents	1	2	3	4	Hoards	Hoarding level (%)
Desk lamp	312	14	10	4	0	0	**18**	**4.5**
Electric iron	311	5	4	1	0	0	**6**	**1.6**
Home telephone	311	21	13	4	0	4	**37**	**6.8**
Portable space heater	311	7	6	1	0	0	**8**	**2.3**
Table/desk fan	312	4	4	0	0	0	**4**	**1.3**

Appendix B

Small kitchen appliances (functional)

SKA	No of respondents	Respondents	1	2	3	4	Stockpiles	Stockpiling level (%)
Electric coffee maker	320	42	31	10	1	0	**54**	**13.1**
Electric blender	320	57	44	13	0	0	**70**	**17.8**
Electric food mixer	320	29	27	2	0	0	**31**	**9.1**
Electric kettle	320	55	47	6	2	0	**65**	**17.1**
Electric juicer	320	14	13	1	0	0	**15**	**4.4**
Electric wok/frying pan	320	3	3	0	0	0	**3**	**0.9**
Rice cooker	320	10	9	1	0	0	**11**	**3.1**
Toaster	320	43	40	2	1	0	**47**	**13.4**

Small kitchen appliances (non-functional)

SKA	No of respondents	Respondents	1	2	3	4	Hoards	Hoarding level (%)
Electric coffee maker	320	9	8	1	0	0	**10**	**2.8**
Electric blender	320	9	8	1	0	0	**10**	**2.8**
Electric food mixer	320	5	5	0	0	0	**5**	**1.6**
Electric kettle	320	16	15	1	0	0	**17**	**5**
Electric juicer	320	0	0	0	0	0	**0**	**0**
Electric wok/frying pan	320	0	0	0	0	0	**0**	**0**
Rice cooker	320	1	1	0	0	0	**1**	**0.3**
Toaster	320	1	0	0	0	1	**4**	**0.3**

Personal care appliances (functional)

PCA	No of respondents	Respondents	1	2	3	4	Stockpiles	Stockpiling level (%)
Hair curler/curling tong	314	37	28	7	2	0	**48**	**11.8**
Hair dryer	314	56	49	7	0	0	**63**	**17.8**
Hair straightener	313	37	36	1	0	0	**38**	**11.8**
Hair styler	313	4	3	1	0	0	**5**	**1.3**
Electronic razor/epilator	314	44	38	5	1	0	**51**	**14**
Electric toothbrush	313	27	27	0	0	0	**27**	**8.6**

Personal care appliances (non-functional)

PCA	No of respondents	Respondents	1	2	3	4	Hoards	Hoarding level (%)
Hair curler/curling tong	314	3	3	0	0	0	**3**	**0.9**
Hair dryer	314	13	13	0	0	0	**13**	**4.1**
Hair straightener	313	11	11	0	0	0	**11**	**3.5**
Hair styler	313	0	0	0	0	0	**0**	**0**
Electronic razor/epilator	314	11	10	1	0	0	**12**	**3.5**
Electric toothbrush	313	12	7	3	1	1	**20**	**3.8**

Appendix B

Information and communication technology/audio-visual devices (functional)

ICT	No of respondents	Respondents	1	2	3	4	Stockpiles	Stockpiling level (%)
Digital camera	300	109	71	31	5	2	**156**	**36**
Electronic tablet	299	87	66	14	5	2	**117**	**29.1**
Laptop computer	299	90	73	15	2	0	**109**	**30**
Notebook/netbook	299	8	8	0	0	0	**8**	**2.7**
Headset/headphones	298	133	45	43	23	22	**288**	**44.6**
Mobile phone	298	182	75	66	22	19	**349**	**61.1**
CD player	299	23	22	1	0	0	**24**	**7.7**
DVD/Blu-ray	299	35	31	4	0	0	**39**	**11.7**
Printer	299	22	21	1	0	0	**23**	**7.4**
Scanner	299	7	6	1	0	0	**8**	**2.3**
Fax	299	2	2	0	0	0	**2**	**0.7**
Radio	299	26	20	5	1	0	**33**	**8.7**
Screen	299	27	18	8	0	1	**38**	**9**
Smart watch	299	40	30	9	0	1	**52**	**13.4**
Speaker	299	40	26	8	3	3	**63**	**13.4**
Video game console	299	70	45	10	7	8	**118**	**23.4**
Web cam	299	21	19	2	0	0	**23**	**7**

Information and communication technology/audio-visual devices (non-functional)

ICT	No of respondents	Respondents	1	2	3	4	Hoards	Hoarding level (%)
Digital camera	300	31	23	6	2	0	**41**	**10**
Electronic tablet	299	34	30	2	1	1	**41**	**11.4**
Laptop computer	299	76	53	16	4	3	**109**	**25.4**
Netbook/Notebook	299	1	1	0	0	0	**1**	**0.3**
Headset/Headphones	298	70	28	16	10	16	**154**	**23.5**
Mobile phone	298	121	56	35	14	16	**232**	**40.6**
CD player	299	10	7	3	0	0	**13**	**3.3**
DVD/Blu-ray	299	7	6	1	0	0	**8**	**2.3**
Printer	299	10	9	1	0	0	**11**	**3.3**
Scanner	299	2	2	0	0	0	**2**	**0.7**
Fax machine	299	0	0	0	0	0	**0**	**0**
Radio	299	5	2	3	0	0	**8**	**1.7**
Screen	299	8	8	0	0	0	**8**	**2.7**
Smart watch	299	9	8	1	0	0	**10**	**3**
Speaker	299	15	13	1	1	0	**18**	**5.1**
Video game console	299	16	9	5	1	1	**26**	**5.4**
Web cam	299	4	3	1	0	0	**5**	**1.3**

B.5 Randomly-selected price data

Price data used for estimation of reuse value of EEE were randomly selected from online sources as described in Chapters 3 and 4. Prices shown in pounds (£)

EEE	Price #1	Price #2	Price #3	Price #4	Price #5	Price #6	Price #7	Price #8	Price #9	Price #10	Average	St. Error
Iron	10	10	25	10	15	5	5	7	5	5	**9.7**	**2**
Kettle	15	10	6	10	8	10	7	10	10	8	**9.4**	**0.8**
Lamp	35	50	5	8	25	10	20	15	5	39	**21.2**	**5**
Toaster	12.5	5	12	10	4	9	10	5	15	5	**8.75**	**1.2**
Printer	60	120	15	50	50	18	75	40	50	35	**51.3**	**9.5**
Dryer	2.5	3	9	15	5	10	7	4	10	9	**7.45**	**1.23**
Mobile Phone	25	79	89	99	109	129	139	199	239	279	**138.6**	**24.7**

Appendix C Case study supporting information

C.1 Copy of EEE collection and sorting data sheet

W/EEE Characterisation Sheet

Date: ________________________

Site: ________________________

Sheet No: ____________________

S/N	Product type	Product category	Weight (kg)	Physical condition	Brand (if available)	Model year (if available)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						

C.2 Collection output data

C.2.1 Collection output (June 2019)

Product Type	Product Category	Weight (Kg)	Physical Condition
Toaster	SKA	1.1	G
Kettle	SKA	0.8	G
Kettle	SKA	0.8	G
Lamp	SHA	0.8	G
Headphones	ICT/AV	0.3	B
Lamp	SHA	0.9	G
Table fan	SHA	0.9	G
Toaster	SKA	1	G
Lamp	SHA	0.8	G
Décor light	SHA	0.5	G
Hair styler	PCA	0.4	G
Lamp	SHA	1.1	G
Extension Plug	SHA	0.7	G
Radio	SHA	0.3	G
Adapter	SHA	0.05	G
Kettle	SKA	0.8	G
Lamp	SHA	0.6	G
Bathroom scale	SHA	1.1	G
Toaster	SKA	1.7	G
Speaker	ICT/AV	0.9	G
Lamp	SHA	0.8	G
Space heater	SHA	3	R
Laptop charger	ICT/AV	0.4	R
Fan	SHA	5.2	R
Mouse	ICT/AV	0.1	B
Kettle	SKA	0.8	G
Kettle	SKA	0.8	G
Fan	SHA	1.6	G
Fan	SHA	0.9	G
Charger	ICT/AV	0.1	G
Charger	ICT/AV	0.1	R
Kettle	SKA	1.4	R
Cable	ICT/AV	0.1	B
Cable	ICT/AV	0.1	R
Electric mirror	SHA	0.5	R
Hard drive	ICT/AV	0.2	R
Toaster	SKA	2.7	R
Kettle	SKA	0.8	R
Adapter	SKA	0.1	R
Adapter	SKA	0.1	R
Hard drive	ICT/AV	0.2	R

Product Type	Product Category	Weight (Kg)	Physical Condition
Rice cooker	SKA	2.7	B
Printer	ICT/AV	5.5	R
Lamp	SHA	1.1	G
Hair dryer	PCA	0.8	G
Toaster	SKA	1.2	G
Lamp	SHA	0.8	G
Extension Plug	SHA	0.4	G
Extension Plug	SHA	0.4	G
Shaver	PCA	0.5	R
Lamp	SHA	0.8	R
Mouse	ICT/AV	0.1	B
Watch	ICT/AV	0.1	R
Headphones	ICT/AV	0.1	G
Thermometer	SHA	0.1	G
Toaster	SKA	1.2	G
Speaker	ICT/AV	0.5	R
Lamp	SHA	0.8	G
Extension box	SHA	0.2	G
Watch	ICT/AV	0.1	G
Lamp	SHA	0.8	G
Lamp	SHA	0.1	G
Décor light	SHA	0.1	G
Charger	SHA	0.1	G
Charger	SHA	0.1	G
Bath scale	SHA	1	B
Kettle	SKA	0.8	R
Blender	SKA	1.8	R
Lamp	SHA	0.8	G
Headphones	ICT/AV	0.3	G
Iron	SHA	1.2	G
Lamp	SHA	0.6	G
Iron	SHA	0.6	R
Iron	SHA	0.6	R
Headphones	ICT/AV	0.2	R
Hot rollers	PCA	2	G
Piano	ICT/AV	0.7	G
Décor light	SHA	0.1	G
Charger	ICT/AV	0.2	G
Phone Charger	ICT/AV	0.2	G
Phone Charger	ICT/AV	0.1	R
Phone Charger	ICT/AV	0.1	R
Cable	ICT/AV	0.1	G
Hard drive	ICT/AV	0.5	G

Appendix C

Product Type	Product Category	Weight (Kg)	Physical Condition
LCD TV	ICT/AV	5	R
Rice cooker	SKA	2	R
Lamp	SHA	0.8	G
Lamp	SHA	0.8	G
Lamp	SHA	0.8	G
Kettle	SKA	0.8	R
Dryer	PCA	0.5	G
Steamer	PCA	0.7	G
Dryer	PCA	0.5	R
Toaster	SKA	1.4	R
Fan	SHA	1	G
Lamp	SHA	0.8	R
Game controller	ICT/AV	0.2	R
Washing	SHA	4.4	G
Lamp	SHA	0.8	G
Décor light	SHA	0.2	R
Décor light	SHA	0.2	R
Mini projector	ICT/AV	0.9	G
Vacuum cleaner	SHA	6.8	R
Electric guitar	ICT/AV	2.7	R
Adapter	SHA	0.1	G
Mixer	SKA	0.9	G
Lamp	SHA	3	G
Décor light	SHA	0.2	R
Décor light	SHA	0.2	R
Décor light	SHA	0.2	R
Diffuser	SHA	0.1	R
Dryer	PCA	0.9	B
Blender	SKA	0.8	R
Face cleaner	PCA	0.5	R
Headphones	ICT/AV	0.1	R
Hair dryer	PCA	0.4	G
Lamp	SHA	0.8	G
Lamp	SHA	0.8	B
Extension box	SHA	0.3	G
Smoke alarm	SHA	0.2	R
Coffee maker	SKA	2.5	R
Kettle	SKA	0.8	R
Toaster	SKA	0.5	R
Blender	SKA	1.7	R
Kettle	SKA	0.8	R
Lamp	SHA	0.5	G
Hand blender	SKA	1.4	G
Iron	SHA	0.8	G
Toaster	SKA	1.2	R

Product Type	Product Category	Weight (Kg)	Physical Condition
Kettle	SKA	0.8	R
Blender	SKA	1.8	G
Kettle	SKA	0.7	R
Lamp	SHA	0.5	B
Lamp	SHA	0.5	R
Lamp	SHA	0.6	R
Lamp	SHA	0.6	R
Lamp	SHA	0.5	R
Lamp	SHA	0.5	R
Toaster	SKA	0.8	R
Lamp	SHA	0.7	G
Kettle	SKA	0.8	G
Toaster	SKA	1	R
Toaster	SKA	0.9	R
Kettle	SKA	1	G
Bath Scale	SHA	1.2	G
Blender	SKA	1.7	R
Headphones	ICT/AV	0.2	G
Space heater	SHA	2	G
Set box	ICT/AV	1	G
Lamp	SHA	0.5	R
Cable	ICT/AV	0.1	B
Kettle	SKA	0.4	R
Extension box	SHA	0.1	R
Extension box	SHA	0.1	B
Toaster	SKA	1.4	R
Rice cooker	SKA	2.8	R
Lamp	SHA	0.7	R
Extension box	SHA	0.1	B
Kettle	SKA	0.8	R
Printer	ICT/AV	5	G
Printer	ICT/AV	5	G
Lamp	SHA	0.8	G
Lamp	SHA	0.8	G
Kettle	SKA	1	R
Toaster	SKA	1.3	R
Toaster	SKA	1.3	R
Toaster	SKA	1.3	R
Rice cooker	SKA	2.5	B
Kettle	SKA	0.4	R
Kettle	SKA	0.7	R
Kettle	SKA	0.7	R
Game controller	ICT/AV	2	G

Appendix C

Product Type	Product Category	Weight (Kg)	Physical Condition
Toaster	SKA	2.5	R
Toaster	SKA	2	R
Toaster	SKA	1.5	R
Kettle	SKA	0.4	R
Kettle	SKA	0.4	R
Printer	ICT/AV	4.2	G
Lamp	SHA	0.5	G
Adapter	SHA	0.1	G
Charger	SHA	0.2	B
Speaker	ICT/AV	0.3	R
Mouse	ICT/AV	0.1	R
Lamp	PCA	0.5	G
Hair dryer	SKA	0.2	G
Rice cooker	SHA	2	R
Lamp	SHA	0.2	G
Iron	SKA	0.5	R
Toaster	SHA	1	R
Iron	SHA	0.5	R
Iron	SHA	0.8	R
Lamp	SHA	0.5	G
Décor light	SHA	0.2	G
Kettle	SKA	0.8	R
Kettle	SKA	0.8	R
Toaster	SKA	1.2	R
Iron	SHA	1.4	R
Toaster	SKA	1.2	R
Adapter	SHA	0.02	G
Kettle	SKA	1	R
Blender	SKA	1	R
Kettle	SKA	0.8	R
Toaster	SKA	1.2	R
Toaster	SKA	1.4	R
Lamp	SHA	0.4	G
LED TV	ICT/AV	6.2	G
Printer	ICT/AV	4.5	G
Rice cooker	SKA	2.1	R
Kettle	SKA	0.8	G
Kettle	SKA	0.8	R
Kettle	SKA	0.8	R
Toaster	SKA	1	R
Kettle	SKA	0.7	R
Rice cooker	SKA	1.9	R
Kettle	SKA	0.8	R
Kettle	SKA	0.8	R
Toaster	SKA	1.4	R

Product Type	Product Category	Weight (Kg)	Physical Condition
Rice cooker	SKA	1.8	R
Kettle	SKA	0.8	R
Kettle	SKA	0.8	R
Desk fan	SHA	2.8	R
Lamp	SHA	0.6	G
Rice cooker	SKA	1.8	R
Kettle	SKA	0.7	R
Kettle	SKA	0.8	R
Printer	ICT/AV	5	G
Calculator	ICT/AV	0.1	R
Calculator	ICT/AV	0.1	R
Calculator	ICT/AV	0.1	G
Lamp	SHA	0.6	R
Bath Scale	SHA	1.2	R
Light bulb	SHA	0.1	G
LED TV	ICT/AV	8	R
Kettle	ICT/AV	0.8	R

C.2.2 Collection output (July 2019)

Product Type	Product Category	Weight (Kg)	Physical Condition
Kettle	SKA	1	G
Kettle	SKA	0.7	B
Toaster	SKA	0.9	R
Mouse	ICT/AV	0.2	G
Toaster	SKA	0.9	R
Kettle	SKA	0.7	R
Sandwich grill	SKA	2.3	R
Mattress Heater	SHA	1.7	R
Kettle	SKA	0.7	B
Kettle	SKA	0.7	R
Toaster	SKA	0.9	R
Kettle	SKA	0.7	R
Kettle	SKA	0.7	R
Kettle	SKA	0.7	R
Rice cooker	SKA	1.7	R
Hair dryer	PCA	0.5	G
Toaster	SKA	1.1	R
Toaster	SKA	0.9	R
Kettle	SKA	1	G
Toaster	SKA	1.3	R
Toaster	SKA	2.4	R

Product Type	Product Category	Weight (Kg)	Physical Condition
Kettle	SKA	0.7	R
Kettle	SKA	0.7	R
Toaster	SKA	2.6	R
Kettle	SKA	0.7	R
Toaster	SKA	0.9	R
Iron	SHA	0.8	R
Toaster	SKA	0.9	R
Kettle	SKA	0.7	R
Blender	SKA	1.9	G
Speaker	ICT/AV	0.6	R
Kettle	SKA	0.7	B
Kettle	SKA	0.7	G
Light bulb	SHA	0.1	G
Vacuum cleaner	SHA	5	G
Toaster	SKA	0.9	R
Electric shaver	PCA	0.4	G
Lamp	SHA	2.2	G
Lamp	SHA	1.3	G
Plug	SHA	0.3	G
Sandwich grill	SKA	2.3	R
Oral sprayer	PCA	0.3	G
Kettle	SKA	0.7	R
Kettle	SKA	0.7	R
Extension cable	SHA	0.3	G
Phone charger	ICT/AV	0.1	G
Iron	SHA	1	G
Coffee maker	SKA	2	G
Laptop fan	ICT/AV	0.7	G
Keyboard	ICT/AV	0.5	G
Laptop	ICT/AV	2.6	G
Electric toothbrush	PCA	0.3	G

C.2.3 Collection output (September 2019)

Product Type	Product Category	Weight (Kg)	Physical Condition
Water filter	SKA	0.5	G
Lamp	SHA	0.1	G
Blender	SKA	0.5	G
Fan	SHA	1.5	G
Fan	SHA	1.5	G
Hair dryer	PCA	0.3	G
Printer	ICT/AV	3.4	G
Kettle	SKA	0.5	G
Lamp	SHA	0.3	G

Product Type	Product Category	Weight (Kg)	Physical Condition
Lamp	SHA	1	G
Kettle	SKA	0.5	G
Hair dryer	SHA	0.5	G
Headphones	ICT/AV	0.2	G
Lamp	SHA	0.8	G
Lamp	SHA	0.8	G
Headphones	ICT/AV	0.1	G
USB Cable	ICT/AV	0.1	G
USB Cable	ICT/AV	0.1	G
USB Cable	ICT/AV	0.1	G
USB Cable	ICT/AV	0.1	G
Vacuum	SHA	1.2	G
Lamp	SHA	0.8	G
Hair dryer	PCA	0.5	G
Mouse	ICT/AV	0.2	G
Coffee maker	SKA	0.5	G
Lamp	SHA	0.5	G
Iron	SHA	0.6	G
Printer	ICT/AV	3.4	R
Fan	SHA	1.5	G
Sandwich grill	SKA	1.5	G
Bath Scale	SHA	1.1	R
Kettle	SKA	0.5	R
Rice cooker	SKA	3.7	G
Kettle	SKA	0.3	G
USB Cable	ICT/AV	0.2	R
Fan	SHA	1.5	R
Laptop	ICT/AV	1.8	R
Keyboard	ICT/AV	0.5	G
Fan	SHA	0.5	G
Kettle	SKA	0.5	R
Rice cooker	SKA	1	R
Fan	SHA	1.1	G
Lamp	SHA	0.5	G
Lamp	SHA	0.3	G
Kettle	SKA	0.5	G
Lamp	SHA	1.2	G
Calculator	ICT/AV	0.2	G
Lamp	SHA	0.2	G
Lamp	SHA	0.2	G
Fan	SHA	1.1	G
Printer	ICT/AV	3.4	R
Plug	SHA	0.2	G

Appendix C

Product Type	Product Category	Weight (Kg)	Physical Condition
Rice cooker	SKA	1.5	G
Humidifier	SHA	1.5	R
Electric air pump	SHA	0.2	G
Kettle	SKA	0.5	R
Keyboard	ICT/AV	0.8	R
Kettle	SKA	0.5	R
Lamp	SHA	0.5	G
Cable	ICT/AV	0.5	G
Kettle	SKA	0.5	G
Alarm clock	SHA	0.4	R
Plug	SHA	0.5	G
Mouse	ICT/AV	0.2	G
Kettle	SKA	0.5	G
Fan	SHA	0.5	G
Cable	SHA	0.3	G
Vacuum	SHA	0.7	G
Kettle	SKA	0.5	R
Hair dryer	PCA	0.3	G
Electric shaver	PCA	0.2	G
Printer	ICT	5.4	G
Microwave	SKA	12	G
Blender	SKA	2	G
Fan	SHA	2.5	G
Hair dryer	PCA	0.5	G
Steamer	PCA	0.5	G
Lamp	SHA	0.8	G
Lamp	SHA	0.8	R
Fan	SHA	1.1	G
Mouse	ICT/AV	0.2	R
Fan	SHA	0.5	R
Hair dryer	PCA	0.3	G
Hair dryer	PCA	0.3	G
Bath Scale	SHA	0.5	G
Electric toothbrush	PCA	0.4	G
Game controller	ICT/AV	0.3	G
Power bank	ICT/AV	0.2	G
Cable	SHA	0.2	G
Kettle	SHA	0.5	G
Lamp	SHA	0.2	G
Hair Straightener	PCA	0.5	G
Power bank	ICT/AV	0.2	R
Phone charger	ICT/AV	0.3	G
Fan	SHA	1.1	G
Vacuum cleaner	SHA	4.7	R
Vacuum cleaner	SHA	4.7	R

Product Type	Product Category	Weight (Kg)	Physical Condition
Hair Straightener	PCA	0.3	G
Curler	PCA	0.3	G
Fan	SHA	2.3	G
Kettle	SKA	0.5	R
Kettle	SKA	0.5	R
Kettle	SKA	0.3	R
Rice cooker	SKA	0.5	R
Kettle	SKA	0.3	R
Cable	SHA	0.3	R
Fairy lights	SHA	0.2	R
Blender	SKA	1	R
Toaster	SKA	0.5	R
Rice cooker	SKA	2	G
Set box	SHA	2.8	G
Cable	SHA	0.1	G
Hair dryer	PCA	0.5	G
Iron	SHA	0.5	G
Fan	SHA	1.3	G
Kettle	SKA	0.5	G
Hair dryer	SHA	0.5	R
Hair dryer	SKA	0.3	G
Iron	SHA	0.5	R
Oral spray	PCA	0.3	R
Fan	SHA	1.2	G
Fan	SHA	1.2	R
Hair dryer	PCA	0.3	G
Printer	ICT/AV	3.7	R
Lamp	SHA	0.7	G
Mouse	ICT/AV	0.2	G
Hair dryer	PCA	0.3	G
Lamp	SHA	0.7	G
Rice cooker	SKA	3.5	G
Lamp	SHA	0.5	R
Lamp	SHA	0.7	R
Laptop docking station	ICT/AV	1	R
Rice cooker	SKA	3.5	R
Hair curler	PCA	0.5	R
Laser hair removal	PCA	0.7	R
Water filter	SKA	0.7	G
Hair remover	PCA	0.5	G
Extension box	SHA	0.5	R
Kettle	SKA	0.2	G
Mouse	ICT/AV	1.1	R

Appendix C

Product Type	Product Category	Weight (Kg)	Physical Condition
Fan	SHA	0.5	R
Kettle	SKA	0.7	G
Lamp	SHA	0.5	G
Lamp	SHA	0.7	R
Kettle	SKA	0.5	G
Extension cable	SHA	0.3	G
Torch	SHA	0.5	R
Printer	ICT/AV	3.7	R
Electrical fixtures	SHA	0.3	R
Mouse	ICT/AV	0.2	R
Keyboard	ICT/AV	0.7	G
Lamp	SHA	0.7	G
Kettle	SKA	0.7	R
Hair dryer	PCA	0.5	G
Hair dryer	PCA	0.5	R
Keyboard	ICT/AV	0.5	G
Kettle	SKA	0.5	R
Iron	SHA	0.5	G
Toaster	SKA	0.5	R
Sandwich grill	SKA	0.7	R
Speaker	ICT/AV	2.9	R

Appendix D Published papers

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Global E-waste management: Can WEEE make a difference? A review of e-waste trends, legislation, contemporary issues and future challenges

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A B S T R A C T

Waste electrical and electronic equipment (WEEE) comprises a globally important waste stream due to the scarcity and value of the materials that it contains; annual generation of WEEE is increasing by 3–5% per annum. The effective management of WEEE will contribute critically to progress towards (1) realisation of the United Nations' Sustainable Development Goals, (2) a circular economy, and (3) resource efficiency. This comprehensive review paper provides a critical and contemporary examination of the current global situation of WEEE management and discusses opportunities for enhancement. Trends in WEEE generation, WEEE-related policies and legislation are exemplified in detail. Four typical future WEEE management scenarios are identified, classified and outlined. The European Community is at the forefront of WEEE management, largely due to the WEEE Directive (Directive 2012/19/EU) which sets high collection and recycling targets for Member States. WEEE generation rates are increasing in Africa though collection and recycling rates are low. WEEE-related legislation coverage is increasing in Asia (notably China and India) and in Latin America. This review highlights emerging concerns, including: stockpiling of WEEE devices; reuse standards; device obsolescence; the Internet of Things, the potential for collecting space e-debris, and emerging trends in electrical and electronic consumer goods. Key areas of concern in regard to WEEE management are identified: the partial provision of formal systems for WEEE collection and treatment at global scale; further escalation of global WEEE generation (increased ownership, and acceleration of obsolescence and redundancy); and absence of regulation and its enforcement. Measures to improve WEEE management at global scale are recommended: incorporation of circular economy principles in EEE design and production, and WEEE management, including urban mining; extension of WEEE legislation and regulation, and improved enforcement thereof; harmonisation of key terms and definitions to permit consistency and meaning in WEEE management; and improvements to regulation and recognition of the informal WEEE management sector.

Contents

Appendix D

detritus
Multidisciplinary Journal for Waste Resources & Residues

DEMONSTRATING EEE RECOVERY FOR REUSE IN A DISTINCT URBAN MINE: A CASE STUDY

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ABSTRACT

At the heart of the circular economy model is the reorientation of consumer behaviours away from disposing of items before they reach end of their functional life as a step towards resource efficiency and reduction of environmental impacts. One way to facilitate this change is to enable proactive redistribution of electrical and electronic equipment (EEE) with reuse value from urban spaces followed by high quality recycling at end-of-life. We have conducted the first assessment and critical evaluation of a model for the recovery of reusable EEE from a distinct urban mine (DUM) - in this case, a university. The Infrastructure, Service and Behaviour (ISB) model was used as a guide for interventions. Small EEE recovered from two Halls of Residence at the University of Southampton were characterised, visually inspected and sorted. From the items inspected visually, 97% was reusable and were donated to participating charities for redistribution via reuse/sale. The results show that an ISB Model system designed using choice architecture to recover reusable EEE from a DUM contributes strongly to extending products' lifetimes and promotes circular economy ambitions. The study provides strong evidence of a viable reuse-based recovery system for small EEE in a university DUM and with a potential for replicability at global scale. It is recommended that a carefully planned and tailored system based on the ISB model should be put in place in universities for the recovery and redistribution of reusable EEE (ReEEE) and that recycling is implemented only after practical options for reuse have been exhausted.

1. INTRODUCTION

Waste Electrical and Electronic Equipment (WEEE) is one of the fastest growing waste streams globally; over 53 million tonnes are generated annually (Forti et al., 2020; Shittu et al., 2021). In 2019, the world generated 53.6 million metric tonnes of WEEE, and only 17.4% of this was officially documented as properly collected and recycled (Forti et al., 2020). Further growth is expected with the rapid expansion of the digital economy, especially during the COVID-19 pandemic and its anticipated consequences, and the emergence of new technologies in areas such as artificial intelligence, biomedical engineering, renewable energy, space travel, e-textiles and smart agriculture (Shittu et al., 2021). A large proportion of this waste currently comprises personal and consumer electronics such as laptop computers, mobile 'phones and TVs. Around 20% of WEEE generated globally is recycled but the fate of much WEEE is undocumented (Balde et al., 2017; World Economic Forum, 2019; Forti et al., 2020); tracking the flows of end-of-life electrical and electronic equipment (EEE) is thus challenging. Europe currently has the highest reported WEEE recycling rate at 35%, due to the implementation of the WEEE Directive in European Union (EU) Member States (WEEE Forum, 2019; Forti et al., 2020; Shittu et al., 2021).

The increasing quantities generated have brought WEEE to global attention (Zhang et al., 2019). Studies of WEEE range from the ill-effects on health and environment of poorly-managed WEEE to global recycling practices. There is some, if limited, focus and emphasis on reusability of discarded EEE, aligned with the promotion of a circular economy. Distinct Urban Mining (Ongondo et al., 2015; Pierron et al., 2017; Parajuly et al., 2017; Wilkinson & Williams, 2019) offers much in this regard. As an example

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Perspective

The 'WEEE' challenge: Is reuse the "new recycling"?

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Waste Electrical and Electronic Equipment (WEEE, also known as e-waste) is the fastest growing solid waste stream globally with annual growth rate of 3–5%; global WEEE generation is predicted to exceed 75 million tonnes by 2030 (Forti et al., 2020). This colossal generation rate is largely fuelled by a rapid turnover rate of electrical and electronic equipment (EEE) such as laptops, mobile 'phones and other Information and Communication Technology (ICT) devices plus other small consumer electronics (Forti et al., 2020). This situation has global ramifications; many countries do not have the capacity and capability to handle this waste stream in an environmentally safe manner.

In the UK, annual WEEE generation is approximately 1.5 million tonnes; less than 40% is collected via official channels for end-of-life WEEE management (Forti et al., 2020). End-of-life management is ranked using the Waste Hierarchy (see Fig. 1) with prevention and minimisation being preferred due to their lower levels of environmental impact.

The officially-documented items of WEEE collected are mostly recycled using mechanical processes such as manual disassembly and shredding to extract constituent components – mostly ferrous metals and non-ferrous metals, glass and plastics. However, product recycling does not make use of the potential residual reuse value of products at their end of use/life. For this to be made use of, product recovery for reuse is required.

Urban mining as a concept is often discussed in the context of material recovery from products. EEE with residual functionality is sometimes discarded in favour of newer, trendier versions (fashion/technological obsolescence). These products retain residual functional value, making recovery for reuse the most desirable outcome. Recycling, while a desirable route towards circularity of materials and resources, should be preferred as a management option but only when opportunity for product reuse has been exhausted.

The recovery of high value EEE from distinct spaces has been shown to be workable solution for the management of products that are no longer required by an individual but retain functionality (Ongondo et al., 2015). Achieving this requires timely recovery of EEE with reuse value to prevent a loss of opportunity for reuse and enable extension of product lifecycles. This, as demonstrated in a case study at the University of Southampton (UoS), requires infrastructural, service and behavioural (ISB) interventions that target timely recovery of reusable EEE (Shittu et al., 2021). The result of this is potential recovery of good quality and functional devices that can then be donated or redistributed. The study at the UoS achieved this by collaborating with accommodation service providers and charitable organisations. The recovery effort promotes charitable causes and can help to bridge societal gaps.

Product reuse provides a route to extending the usage cycle of devices with residual reuse value hence providing a viable option in the transition from linearity to circularity of materials and products. UK retailers (e.g. CeX and Cash Converters) have demonstrated that this is a viable business on the high street and online, recognising that reuse requires deliberately well-timed interventions to work effectively. This route should become the public's habitual default ahead of recycling to prevent loss of reuse value, particularly as a result of hoarding. A product retains recycling value as long as constituent components are intact whereas reuse value is time-sensitive and dependent on factors such as physical condition, reparability and availability of spare parts/components for repair/upgrade. However, recovering devices in this manner – especially ICT devices – can be challenging due to short timescales within which they become obsolescent (i.e. programmed obsolescence). With rapid evolution in technological and computing power and demands, older – "legacy" –devices are reaching obsolescence quicker. In addition to this, devices are often not designed to be repaired and their reusability is diminished.

An increase in recovery of reusable EEE will need to be matched with well-defined reuse standards for products. Product reuse can become a mainstay, with adequate interventions, from production to end of use. Products designed with built-in ease of disassembly and/or repair are likely to be in a closed loop longer as their functionality is extended, potentially changing owners several times during their lifetime. Going

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