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Prospecting reusable small electrical and electronic equipment (EEE) in distinct anthropogenic spaces

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Abstract:	The generation of Waste Electrical and Electronic Equipment (WEEE) continues to escalate yearly because of high demand for state-of-the-art and affordable devices. This demand is strong for small consumer electrical and electronic equipment whose usage cycle is waning due to fashion and technological obsolescence. Thus there is potentially a large 'pool' of unused, reusable devices within urban spaces. This study aimed to assess the magnitude of the reusable stock of EEE with the view to recovery/release into the circular economy. An online questionnaire survey was conducted within a regional group of universities in the United Kingdom to assess the prospects of reusable small EEE within this distinct urban mine (DUM) cluster. The study provides new, distinct definitions for types of DUM, hoarding and stockpiling, and new data for a 'meso-level' DUM on ownership levels and hibernating stocks of reusable EEE. Results show that ownership levels were high, with multiple ownership of devices common and a high degree of product stockpiling and hoarding. Estimates show a stockpile of ~400,000 small EEE within the survey zone and over 17 million devices across the UK with reuse values of >£13 million and >£571 million, respectively. The frequency of device stockpiling is likely due to perceived residual value. The study suggests that exploitation of reuse value requires prompt recovery of stockpiled items as extended periods in hibernation will result in technical obsolescence, particularly with information and communication technology (ICT) devices. Such recovery requires tailored protocols that considers DUM scale, product reusability, recyclability and redistribution.
Response to Reviewers:	Very many thanks to the reviewers for their helpful comments and time spent on this activity. See attached response for detailed text.

25 April 2021

RE: Paper for RCR.

Dear Professor Xu and Editorial Team,

We have submitted a paper to Resources Conservation & Recycling: “Prospecting reusable small electrical and electronic equipment (EEE) in distinct anthropogenic spaces.”

This study has conducted the first assessment and critical evaluation of the potential for recovery of reusable EEE from a distinct urban space at a regional (meso) level.

The circular economy is being encouraged to promote sustainable production and consumption of electrical and electronic equipment (EEE). The generation of Waste Electrical and Electronic Equipment (WEEE) continues to escalate yearly because of high demand for state-of-the-art and affordable devices. This demand is particularly strong for small consumer electrical and electronic equipment whose usage cycle is waning due to fashion and technological obsolescence. As a result, there is potentially a large ‘pool’ of unused, reusable devices within urban spaces (anthroposphere). This study has assessed the magnitude of the reusable stock of EEE with the view to recovery and release into the circular economy. The study provides new, distinct definitions for types of DUM, hoarding and stockpiling, and new data for a ‘meso-level’ DUM on ownership levels and hibernating stocks of reusable EEE. Results show that ownership levels were high, with multiple ownership of devices common and a high degree of product stockpiling and hoarding. Estimates show a stockpile of ~400,000 small EEE within the survey zone and over 17 million devices across the UK with reuse values of >£13 million and >£571 million, respectively. The frequency of device stockpiling is likely due to perceived residual value. The study suggests that exploitation of reuse value requires prompt recovery of stockpiled items as extended periods in hibernation will result in technical obsolescence, particularly with information and communication technology (ICT) devices. Such recovery requires tailored protocols that considers DUM scale, product reusability, recyclability and redistribution.

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We have checked to confirm that the paper meets the aims and scope of the journal. We have supplied all the required information in the correct format. The authors are not aware of any conflicts of interest that require declaration.

Word count = 8125 (excluding tables, list of references and acknowledgements)
Number of figures and tables = 15.

Many thanks for your attention in this matter; we look forward to hearing from you in due course.

Yours sincerely,

Professor Ian Williams

Graphical Abstract

Highlights

- Meso-level DUM survey of small EEE hibernation in the UK
- Refined definitions for DUM types, product stockpiling and hoarding
- Frequently hibernated devices include mobile phones, lamp, kettles and hair dryers
- Stockpiling of reusable EEE more common than hoarding of non-functional devices
- Estimated stockpile value across the UK is >£500 million
- Significant reuse (and subsequent recycling) potential evident in all types of DUM

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Prospecting reusable small electrical and electronic equipment (EEE) in distinct anthropogenic spaces

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ABSTRACT

The generation of Waste Electrical and Electronic Equipment (WEEE) continues to escalate yearly because of high demand for state-of-the-art and affordable devices. This demand is particularly strong for small consumer electrical and electronic equipment whose usage cycle is waning due to fashion and technological obsolescence. As a result, there is potentially a large 'pool' of unused, reusable devices within urban spaces (anthroposphere). This study aimed to assess the magnitude of the reusable stock of EEE with the view to recovery and release into the circular economy. An online questionnaire survey was conducted within a regional group of universities in the United Kingdom to assess the prospects of reusable small EEE within this distinct urban mine (DUM) cluster. The study provides new, distinct definitions for types of DUM, hoarding and stockpiling, and new data for a 'meso-level' DUM on ownership levels and hibernating stocks of reusable EEE. Results show that ownership levels were high, with multiple ownership of devices common and a high degree of product stockpiling and hoarding. Estimates show a stockpile of ~400,000 small EEE within the survey zone and over 17 million devices across the UK with reuse values of >£13 million and >£571 million, respectively. The frequency of device stockpiling is likely due to perceived residual value. The study suggests that exploitation of reuse value requires prompt recovery of stockpiled items as extended periods in hibernation will result in technical obsolescence, particularly with information and communication technology (ICT) devices. Such recovery requires tailored protocols that considers DUM scale, product reusability, recyclability and redistribution.

Keywords: small EEE, WEEE, distinct urban mine, urban mining, reuse, circular economy.

HIGHLIGHTS

- Meso-level DUM survey of small EEE hibernation in the UK
- Refined definitions for DUM types, product stockpiling and hoarding
- Frequently hibernated devices include mobile phones, lamp, kettles and hair dryers
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1. INTRODUCTION

1.1 Distinct urban mines

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. Estimates show that approximately 54 million tonnes of WEEE was generated globally in 2019 (Forti et al., 2020, Shittu et al., 2021). A significant amount of generated WEEE is not collected and processed through formal channels and is discarded or landfilled (Ongondo et al., 2011, Balde et al., 2017, Forti et al., 2020). This so-called linear economy has resulted in the loss of materials and resource inefficiency (Ongondo et al., 2015; Pierron et al., 2017; Shittu et al., 2021). The recovery of materials from the stream of end-of-life or end-of-use EEE requires a closed-loop process that allows for diversion of valuable resources from landfill (Ongondo., 2015, Ramanayaka et al., 2019).

The concept of urban mining is closely linked to resource recovery and efficiency that aims to recover materials and resources from the anthroposphere[1]. 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). 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 1, 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

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

area such a country or nation.

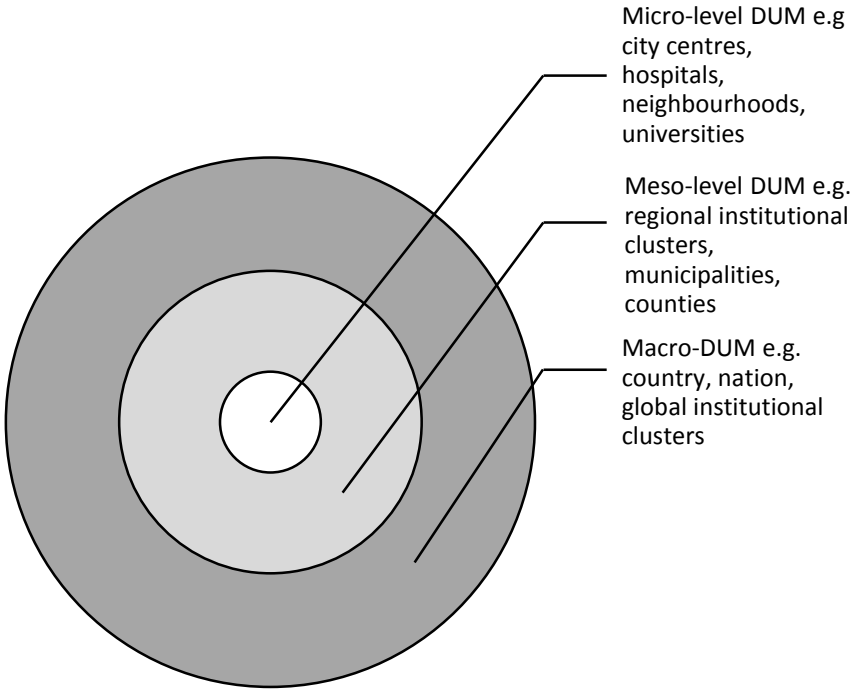

Figure 1. Schematic highlighting the hierarchical relationship between micro-, meso- and macro- levels of DUM classification.

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 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[2] as opposed to material value.

1.2 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 2). Product recovery from DUMs is exemplary of this

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

shift higher up the waste hierarchy. An urban mine can be tapped for reusable resources due to its 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).

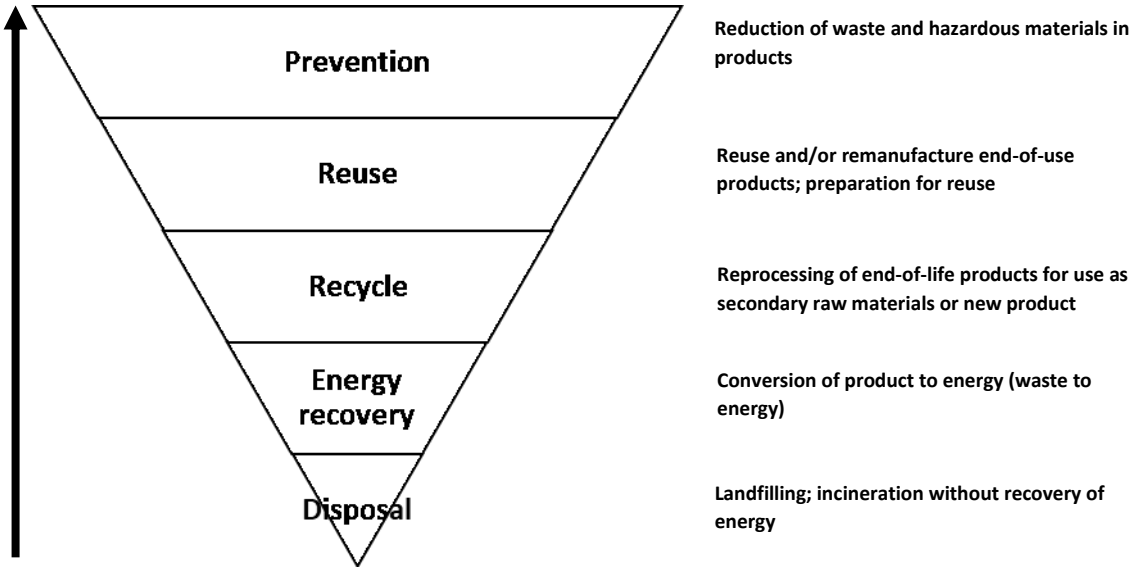

Figure 2: Waste Hierarchy (adapted from: OECD iLibrary, 2020); arrow indicates the direction of preferred outcome.

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). Advanced processes for rare and precious metals (RPM) recovery using hydrometallurgy and biometallurgy (Wang et al., 2019) and nanotechnology (Ramanayaka et al., 2019) have 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 first 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. These studies involved an evaluation of potential stocks within the DUMs of interest. In the present study, a wider perspective is presented by providing comprehensive data on reuse stocks within a university distinct urban mine population with the view of presenting product reuse as a viable option in distinct urban mining.

1.3 Study rationale and objectives

The present study sets 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 1), 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

2. METHODS

The study is a meso-level inquiry of EEE 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 and 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 in Table 1. The cluster of four universities within this geographic region is considered a meso-level DUM (*see* Figure 1) 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.

2.1 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 & 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 1) 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 representative 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 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. Together, these three universities form what can be described as a '*regional distinct urban mine'* (i.e. a meso-level DUM; *see* Figure 1) 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).

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 was achieved by the distribution of the survey via channels that target the specific population required for the study only.

Table 1. Student and staff population in surveyed universities (2018/2019 academic year) (Source: HESA, 2020).

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

2.2 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 2.2.1). 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 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.

2.2.1 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, each within the categories outlined in Table A1. 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.

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 & 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[3]. 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.

2.2.2 Survey analysis

2.2.2.1 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] 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.

2.2.2.2 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[4] were obtained from online vendors www.giffgaff.com, www.preloved.com and www.gumtree.com that 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[5] mobile phone; mobile phone models exceeding £500 in value were excluded 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 of mean to provide a representative set 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.

[4] Price data obtained at the following dates: 18/06/2020 (Preloved and Gumtree); 14/01/2021 (Giff Gaff)
[5] 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)

3. RESULTS

3.1 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 2 presents the demographic profile of respondents. For analysis, the age profiles used in the questionnaire were categorised into two age groups: respondents 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 2. Demographic profile of all respondents (*****data from HESA, 2020).

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

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 (*see* Table 2). 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.

3.2 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. Table 3 presents ownership level of all devices surveyed amongst respondents.

Table 3. Ownership levels of all devices surveyed.

SKA		PCA		SHA		ICT/AV	
Device	**Ownership level (%)**	**Device**	**Ownership level (%)**	**Device**	**Ownership level (%)**	**Device**	**Ownership level (%)**
Coffee maker	44.7	Hair curler	31.8	Desk lamp	76.9	Digital camera	72.3
Blender	76.9	Hair dryer	78	Electric iron	78.5	Electronic tablet	73.9
Food mixer	52.8	Hair straightener	50.8	Home telephone	57.6	Laptop computer	91.3
Kettle	91.6	Hair styler	5.4	Space heater	37.9	Netbook/notebook	8.4
Juicer	13.4	Electronic razor	52.2	Table fan	41.3	Headset/headphones	87.9
Wok/frying pan	5.0	Electric toothbrush	72.5			Mobile phone	100
Rice cooker	15.6					CD player	18.4
Toaster	60.9					DVD/Blu-ray	51.8
						Printer	53.8
						Scanner	7.7
						Fax machine	1.0
						Radio	51.2
						Screen/monitor	43.8
						Smart watch	38.1
						Speaker	63.9
						Video game console	48.8
						Web cam	14.7

SKA: Small kitchen appliance ownership level of all respondents (n=320).
PCA: Personal care appliance ownership level of all respondents (Hair dryer, curler and razor (n=314); hair straightener, styler and electric toothbrush (n=313).
SHA: Small household appliance ownership level of all respondents (desk lamp & table fan (n=312); electric iron, home telephone & space heater (n=311)
ICT/AV: Information and communication technology/audio-visual devices ownership level (n=299 except digital camera (n=300); headset, mobile phone (n=298).

3.2.1 SKA ownership

Eight small kitchen devices were surveyed in the study. The data presented in Table 3 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.

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 (*see* Figure 3). 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).

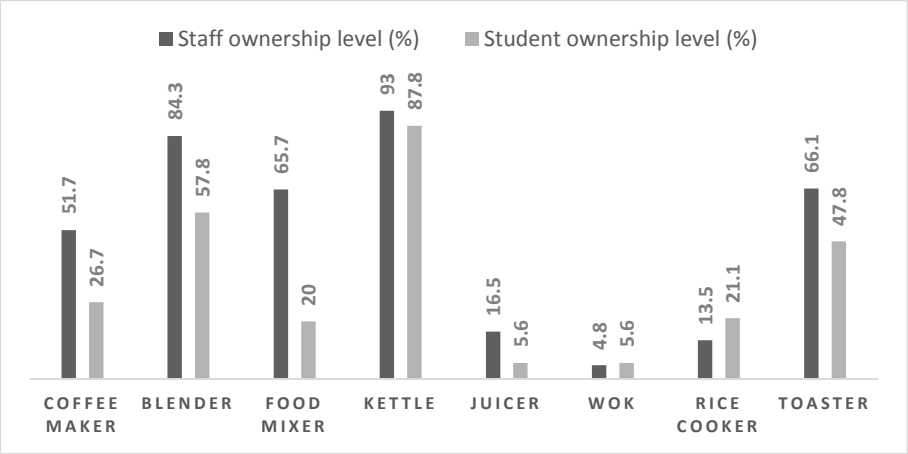

Figure 3. Small kitchen appliance ownership levels by respondents (staff and students) (n=320)

SKA ownership levels for respondents of age 25 and above were higher than those between age 18-24. 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). 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. 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; 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. Devices such as juicers and food mixers were observed to be owned by only respondents living in accommodation other than HoR.

3.2.2 PCA ownership

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).

Staff within the surveyed population had higher ownership levels of all PCAs than students (Figure 4), 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).

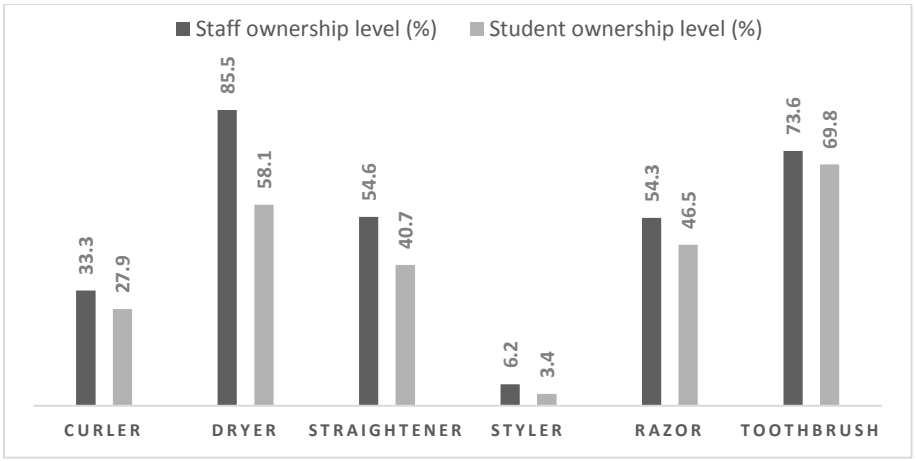

Figure 4. Personal care appliance ownership level by respondents (staff and students; n= 314).

As observed in ownership level of SKA, respondents 25 years and above had a higher ownership level of PCA than those between 18-24. 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). 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+) 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, 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. 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. 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). Lowest differential was observed in ownership of hair curlers (3.2 percentage points).

Respondents (students) living in Halls of Residence (HoR) 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).

3.2.3 SHA ownership

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.

Staff members within the surveyed population had a higher ownership levels of all SHA than students except for desk lamps (*see* Figure 5). 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).

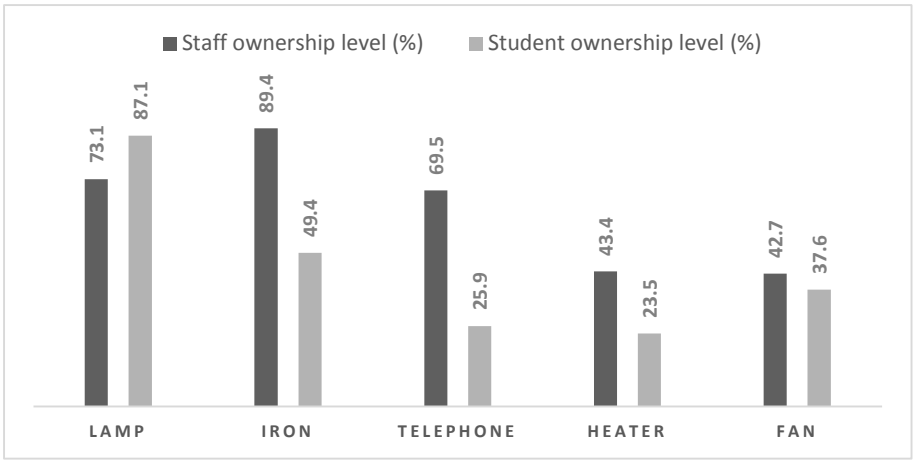

Figure 5. Small household appliance ownership level by respondent profile (staff and students).

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. 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). 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 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. 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.

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. 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.

3.2.4 ICT/AV ownership

This category 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.

There was generally a higher ownership level observed with most of devices surveyed amongst the staff respondents as shown in Figure 6. 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 (*see* Figure 6). 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 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 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). 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 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).

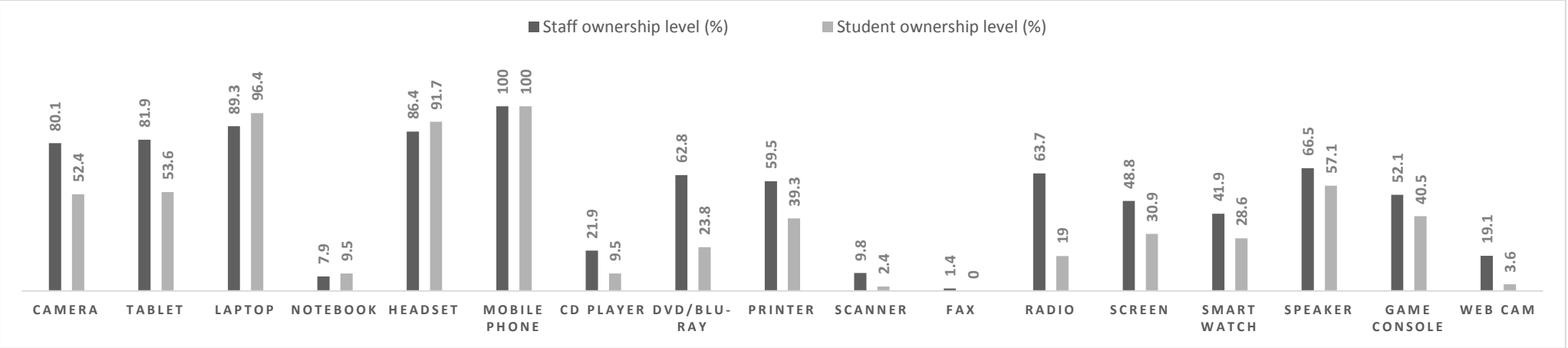

Figure 6. Information and communication technology/audio-visual devices ownership by respondent profile (Staff and Students).

3.3 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).

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). 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%. Observed percentage differential between stockpiling and hoarding levels varied from 26 percentage points (cameras) to 0.7 percentage points (fax machines).

3.3.1 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 7, 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.

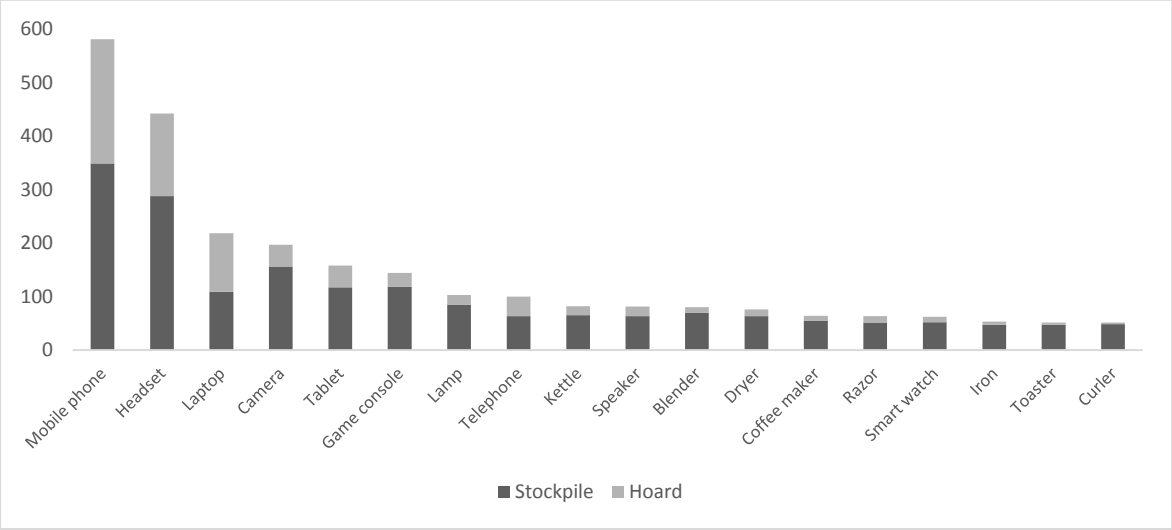

Figure 7. Total number of select device stocks with proportion of stockpiled and hoarded EEE (devices with 50 or more units observed).

3.3.2 Estimated reuse value

The reuse value of the unused functional devices owned by respondents was quantified and evaluated (*see* Tables 4 and 5). 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.

Table 4. Average sale value (*see* footnotes 4 & 5) 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 5. 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.

4. DISCUSSION

4.1 EEE ownership and hibernation

4.1.1 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 and 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 1). 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 2).

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 & 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[6] 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 6) as the few owned few devices observed in the survey belonged to older respondents.

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

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. While there is the possibility of movement of items by this group away as part of the so-called 'suitcase trade'[7], previous studies such as Williams and Powell (2019) have shown that unwanted items are likely to be left behind.

4.1.2 EEE hibernation levels

Together with ownership levels of EEE, information on devices in hibernation is essential in establishing the scope of potential of a DUM (Wilkinson and Williams, 2020). 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 and 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 present survey, there was evidence of device hibernation (stockpiles and hoards), the stockpiles being those with reuse potential. As illustrated in Figure 7, 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 6) to macro-DUM level show an estimated stockpile of over 17 million items in university DUMs across the UK. 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 and Obara, 2005; Ongondo et al., 2011; Wilkinson and 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.

[7] Suitcase trade is an informal international movement and trading of goods; such trade is generally unrecorded or under-recorded (International Monetary Fund, 1998).

Table 6. 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 (*estimation was based on total population in UK HEIs (2018/19) from Higher Education Statistics Agency; devices with 50 or more units presented).

EEE	Owned (Survey Zone)	Stockpile (Survey Zone)	Hoard (Survey Zone)	Stockpile (UK-wide) *	Hoard (UK-wide) *
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 and Williams, 2020). The survey showed that a high number of devices had long usage cycles (3 years and above) particularly SKA and SHA. 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 (2020) 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 and Powell, 2019).

4.2 Circular economy potential: opportunities and challenges

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. Stockpiling such devices would result in a loss of circularity in terms of opportunity to reuse and extending usage cycle. 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 7).

Table 7. 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 £) **	Reuse potential/capita (£/capita) *
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**	-

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

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

The survey results suggest a high potential for reuse considering that only the most frequently stockpiled devices were analysed (*see* Tables 5 and 7). 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 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 devices kept '*safety devices';* devices that are kept as back-up for as long as possible by owners due to perceived 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 device may then become dispensable due to factors including, but not limited to, technological obsolescence. At the point, the device, with little or no functionality becomes a hoarded device if it is kept by the owners. The decision to keep at this point of the device's lifecycle is likely influenced by disposal options known and/or available to the user (Wilkinson and Williams, 2020). Such devices could be made functional by repair and/upgrade after which they become reusable (*see* Figure 8).

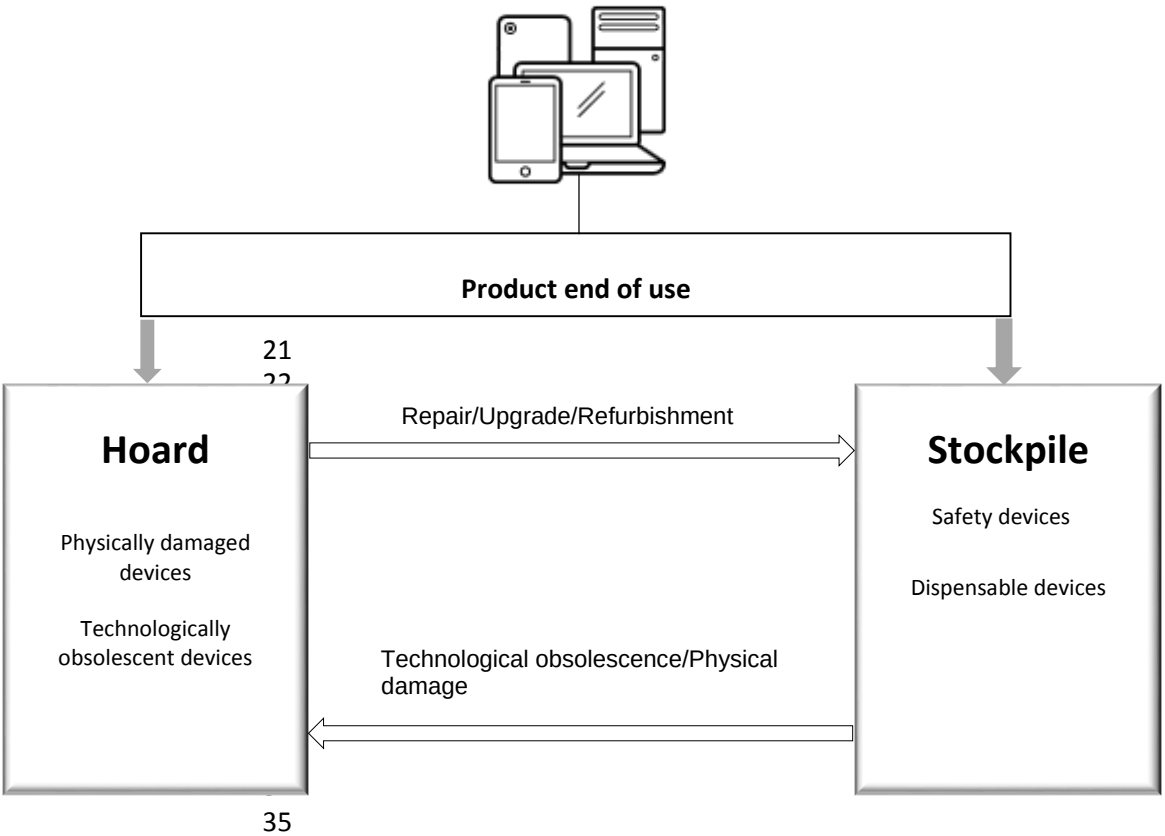

Figure 8. Illustration of product hibernation cycle showing the relationship between stockpiling and hoarding.

Attitudes towards pre-owned items is a barrier to fostering a sustainable reuse culture (Diop and Shaw, 2018; Shaw and 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 'reparability' labelling. 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, 2020).

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.

5. CONCLUSIONS

This study has successfully examined the potential for recovery of reusable EEE from university distinct urban spaces at a regional (meso) level. It provides 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 to tap into the reuse potential of the distinct urban space at micro, meso and macro levels.

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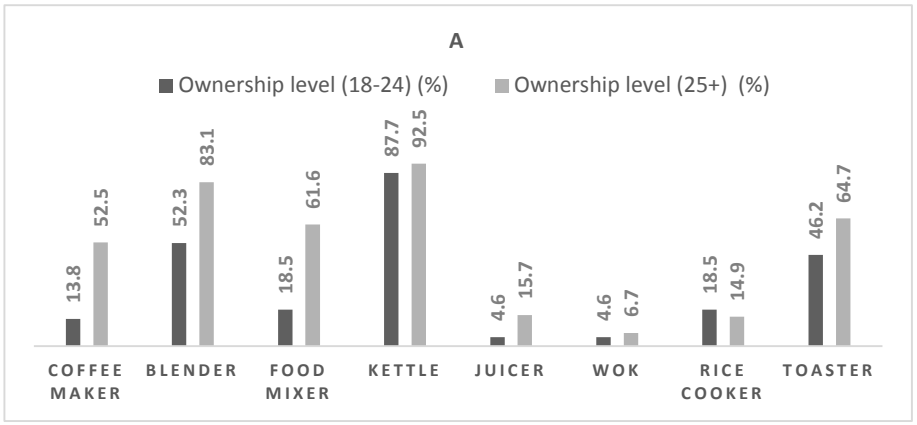
APPENDIX

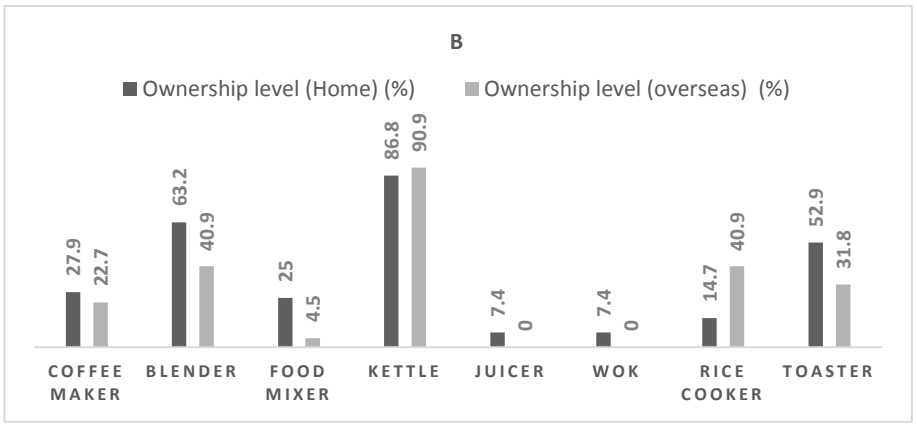
Appendix A. Small electrical and electronics equipment (EEE) categories

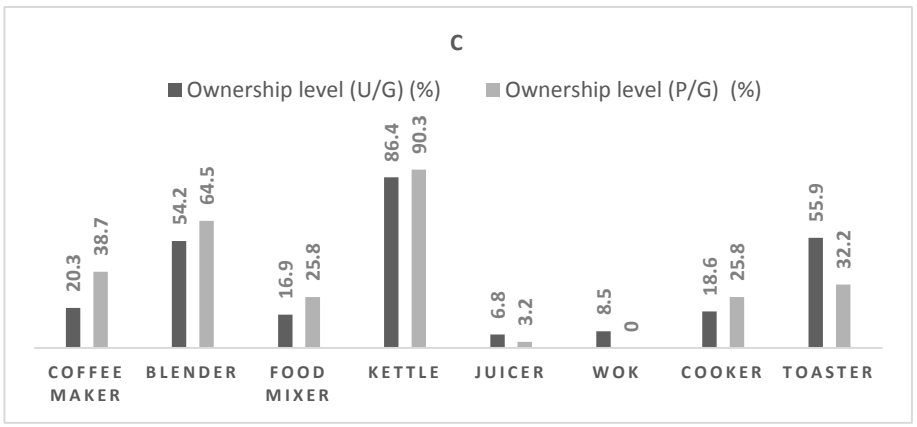
Appendix A1. Surveyed electrical and electronic equipment

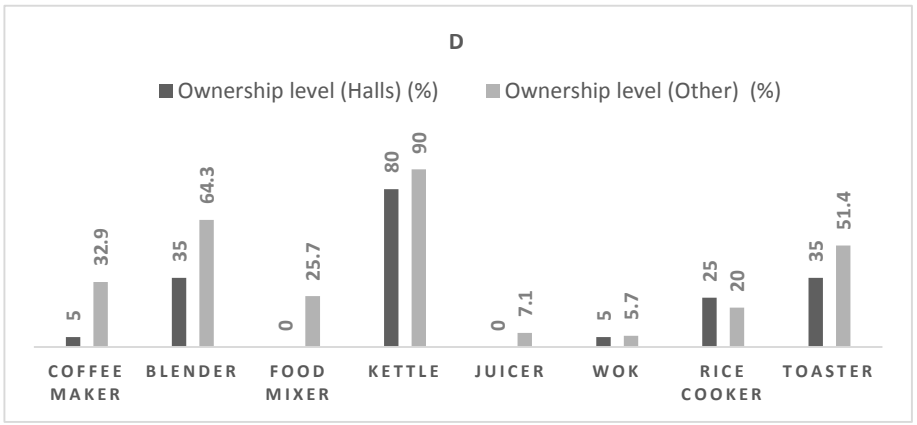
Category of EEE	Appliances included in questionnaire
SKA	Electric coffee maker, electric blender, electric food mixer, electric kettle, electric juicer, electric frying pan/wok, electric rice cooker and sandwich grill/toaster
PCA	Hair curler, hair dryer, hair straightener, hair styler, electric razor/epilator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



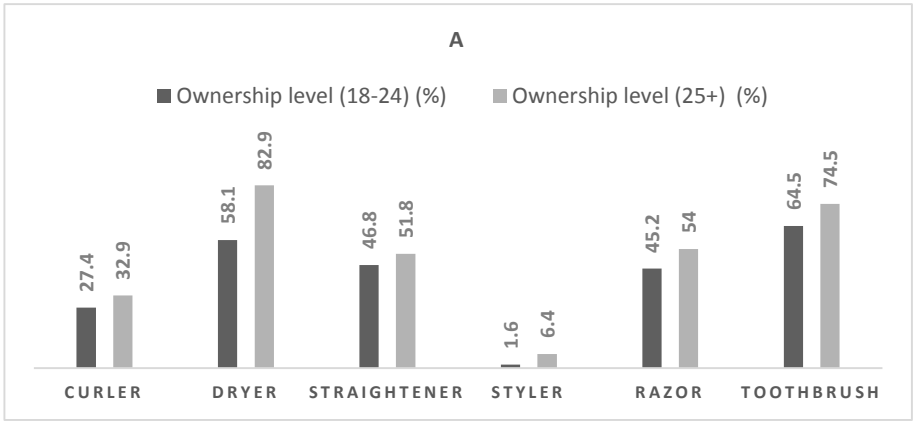
Appendix B. EEE ownership levels

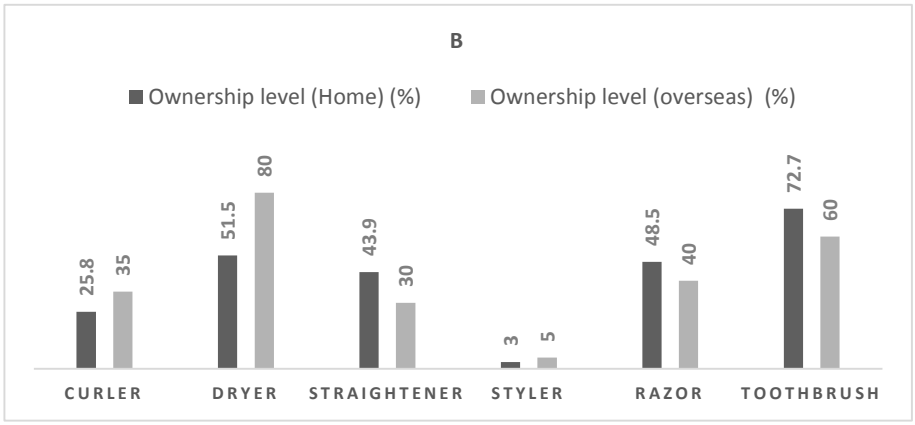


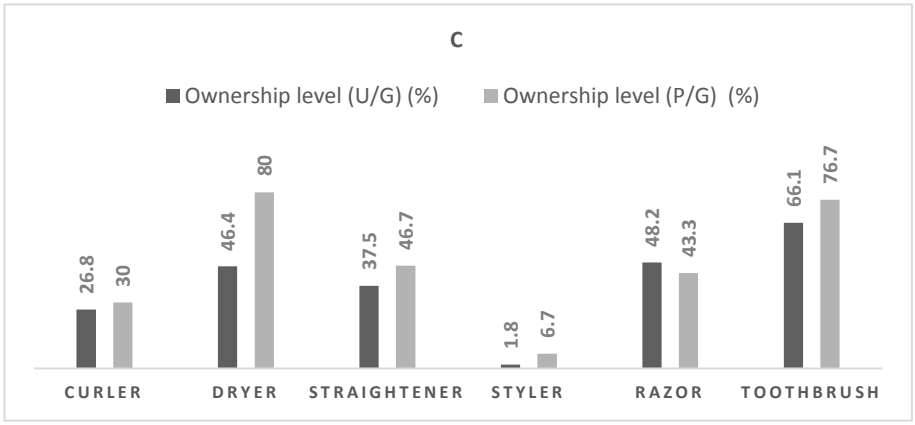


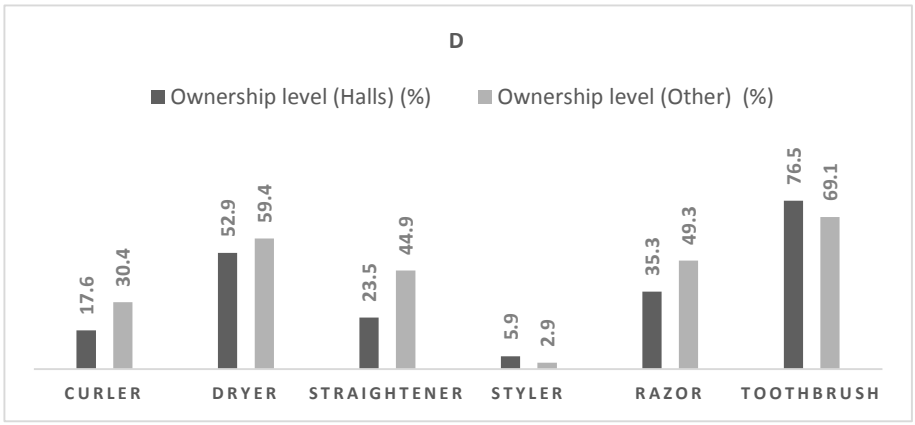


Appendix B1. Small kitchen appliance ownership levels by the different demographic variables. **A**. ownership level by age (all respondents, n= 312); **B.** ownership by domicile (student respondents, n=90); **C**. ownership by degree type (student respondents, n=90); **D.** ownership by accommodation (student respondents, n=90).

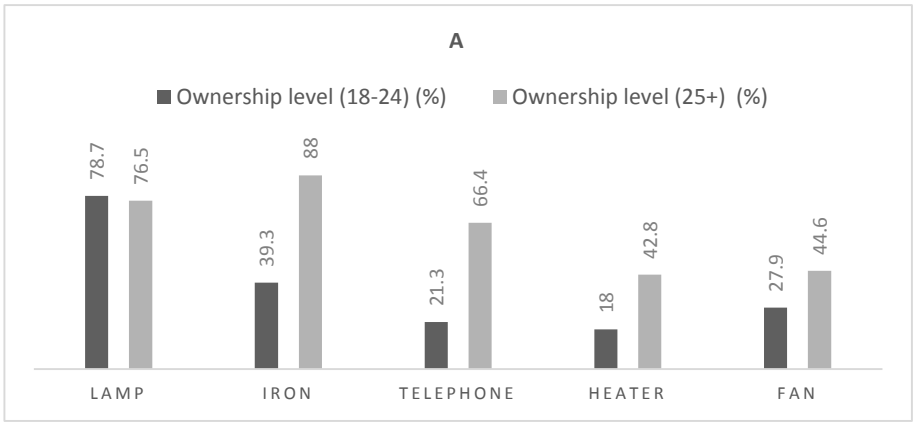


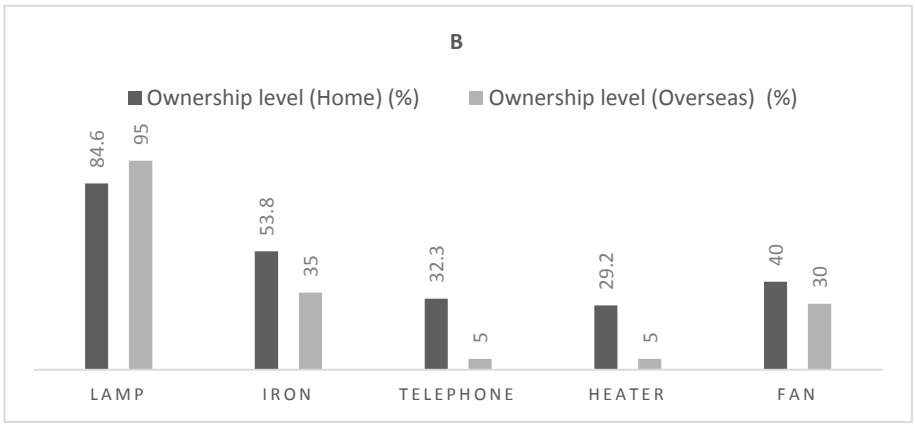


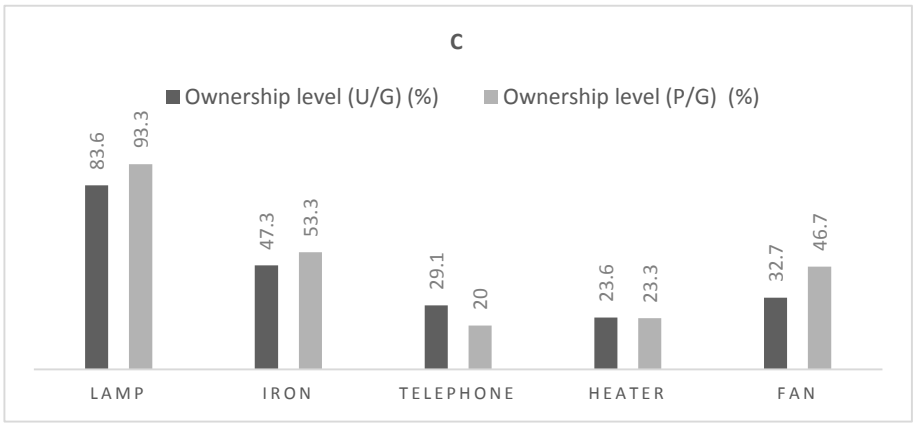


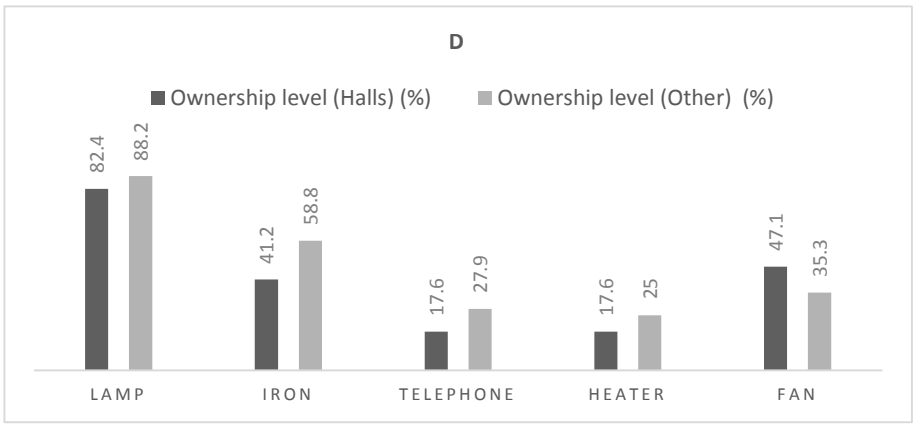


Appendix B2. Personal care appliance ownership levels by the different demographic variables. **A**. ownership level by age (all respondents, n= 314); **B.** ownership by domicile (student respondents, n=86); **C**. ownership by level of study (student respondents, n=86); **D.** ownership by accommodation (student respondents, n=86).

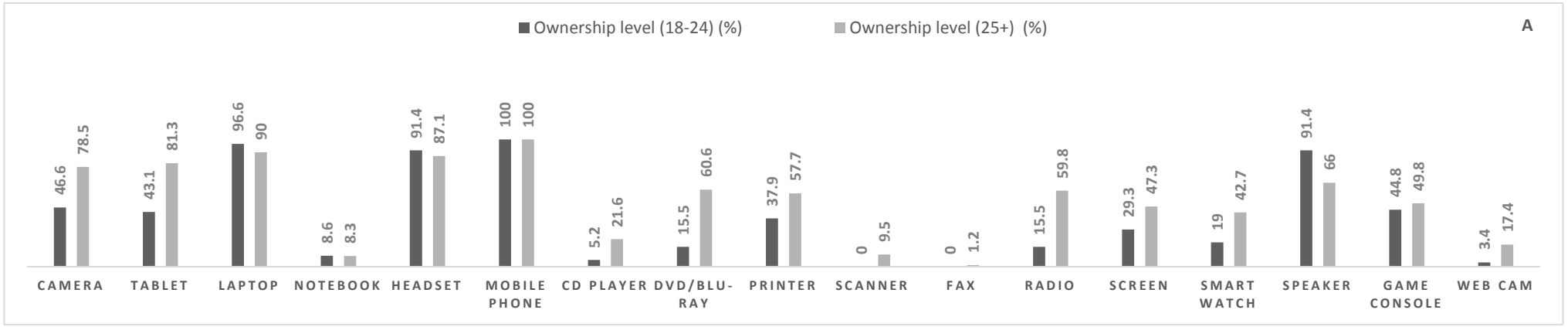


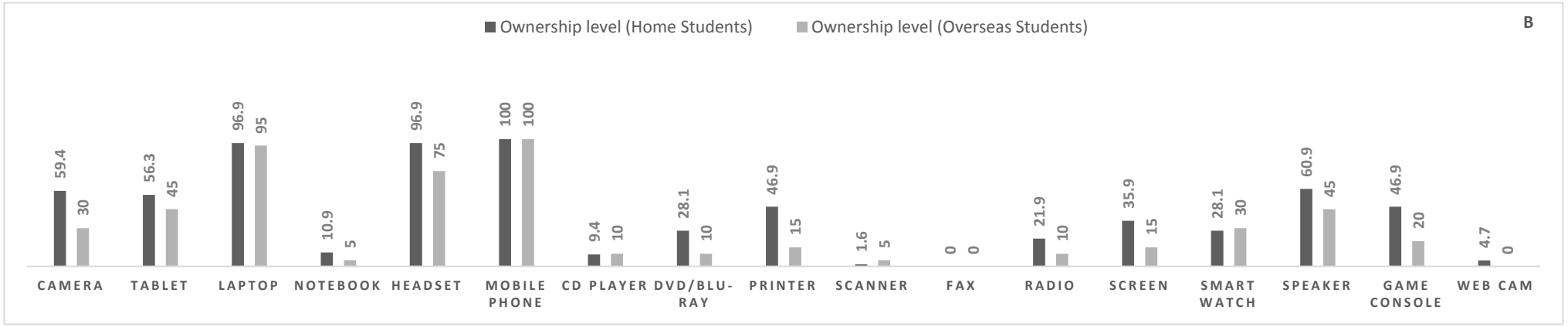


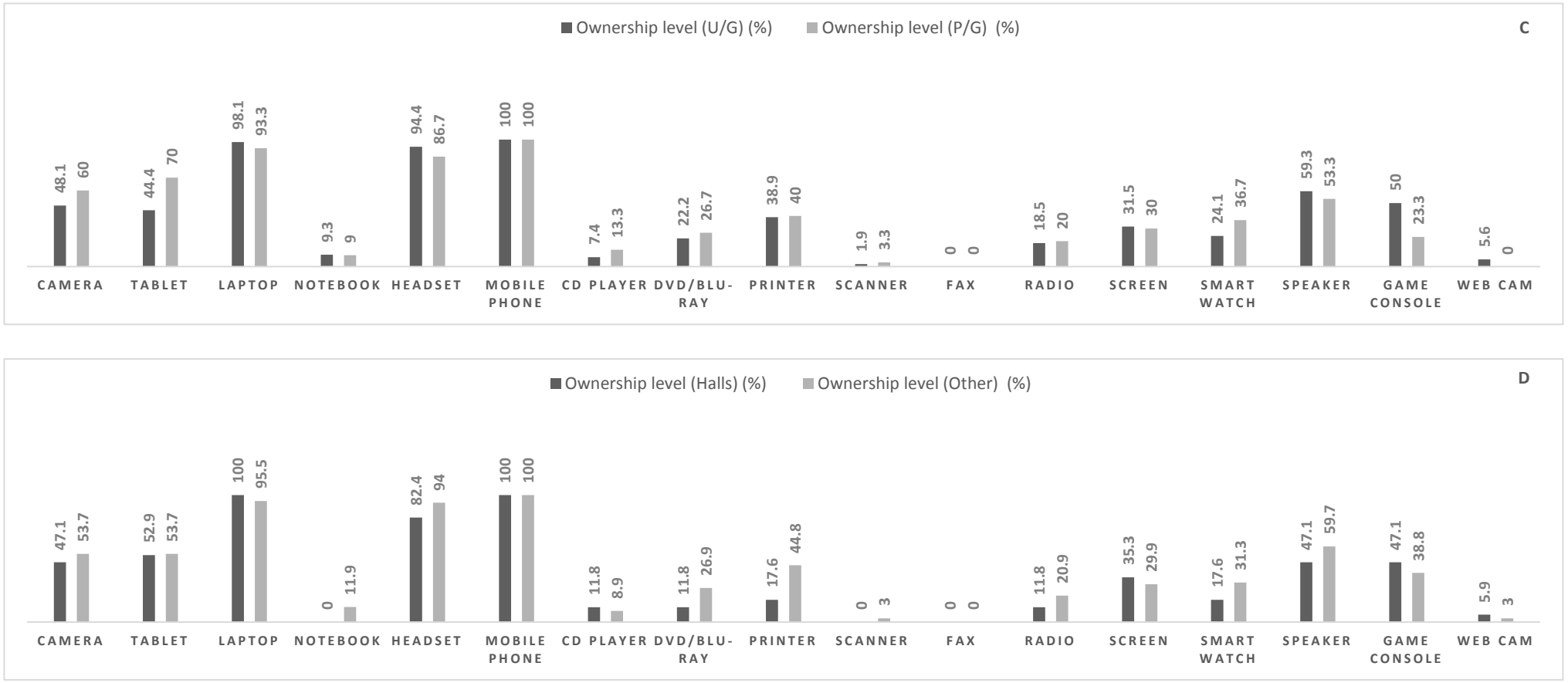




Appendix B3. Small household appliance ownership levels by the different demographic variables. **A**. ownership level by age (all respondents, n= 312); **B.** ownership by domicile (student respondents, n=85); **C**. ownership by level of study (student respondents, n=85); **D.** ownership by accommodation (student respondents, n=85).

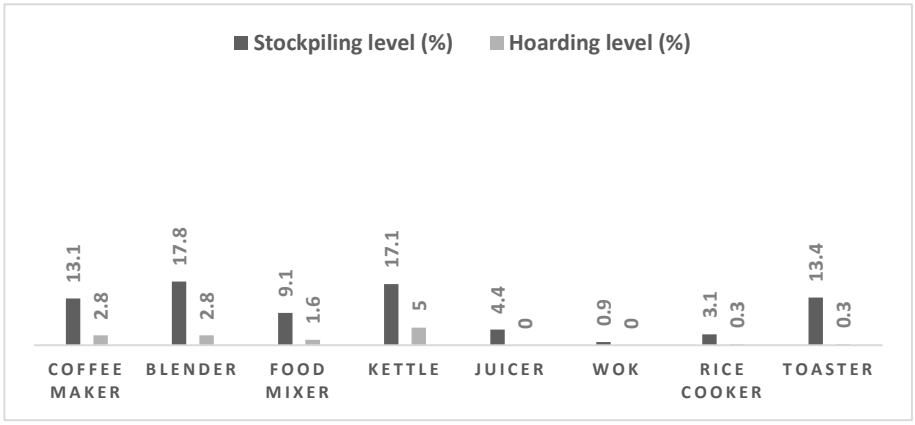

A
Ownership level (18-24) (%)
Ownership level (25+) (%)
46.6
78.5
43.1
81.3
96.6
90
8.6
8.3
91.4
87.1
100
100
5.2
21.6
15.5
60.6
37.9
57.7
0
9.5
0
1.2
15.5
59.8
29.3
47.3
19
42.7
91.4
66
44.8
49.8
3.4
17.4
CAMERA
TABLET
LAPTOP
NOTEBOOK
HEADSET
MOBILE PHONE
CD PLAYER
DVD/BLU-RAY
PRINTER
SCANNER
FAX
RADIO
SCREEN
SMART WATCH
SPEAKER
GAME CONSOLE
WEB CAM

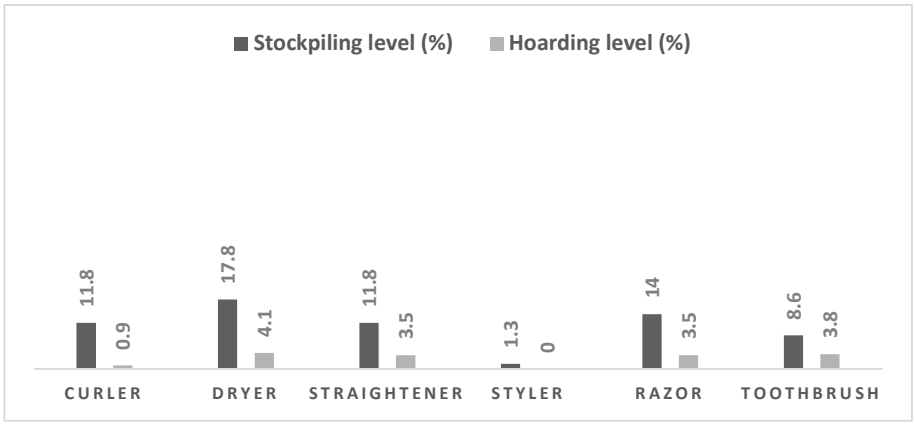

B
Ownership level (Home Students)
Ownership level (Overseas Students)
59.4
30
56.3
45
96.9
95
10.9
5
96.9
75
100
100
9.4
10
28.1
10
46.9
15
1.6
5
0
0
21.9
10
35.9
15
28.1
30
60.9
45
46.9
20
4.7
0
CAMERA
TABLET
LAPTOP
NOTEBOOK
HEADSET
MOBILE PHONE
CD PLAYER
DVD/BLU-RAY
PRINTER
SCANNER
FAX
RADIO
SCREEN
SMART WATCH
SPEAKER
GAME CONSOLE
WEB CAM

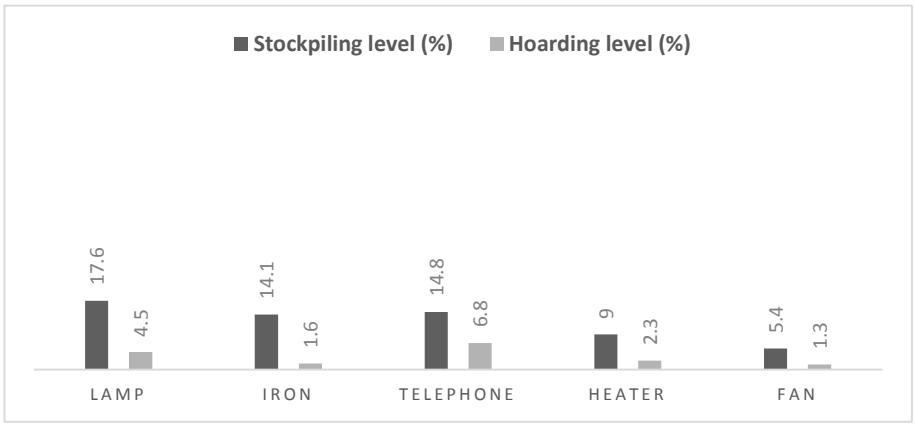


Appendix B4. Information and communication technology/audio-visual devices ownership levels by different demographic variables. **A**: ownership level by age (all respondents); **B**: ownership level by domicile (students only); **C**: ownership level by level of study (students only); **D**: ownership level by accommodation type (students only).

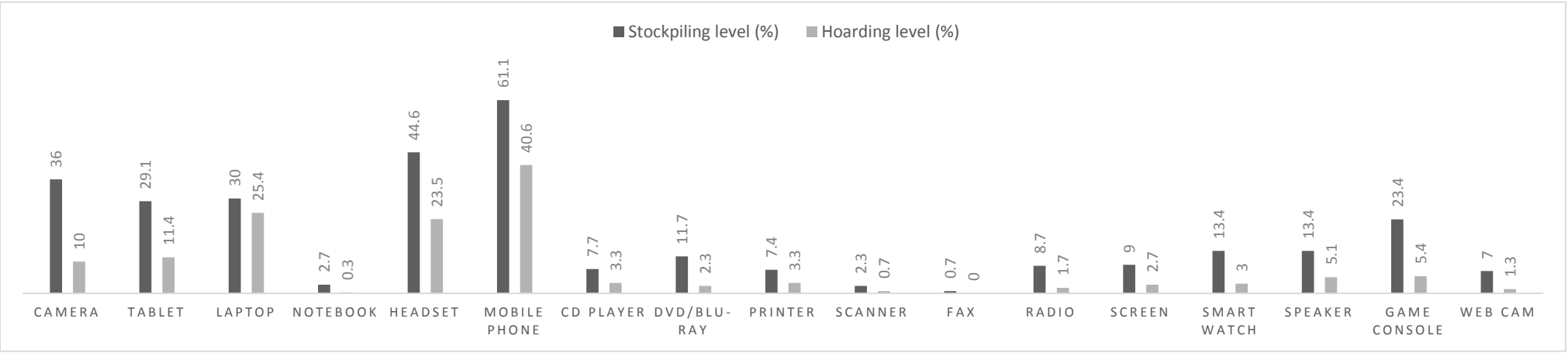
Appendix C. Device hibernation levels





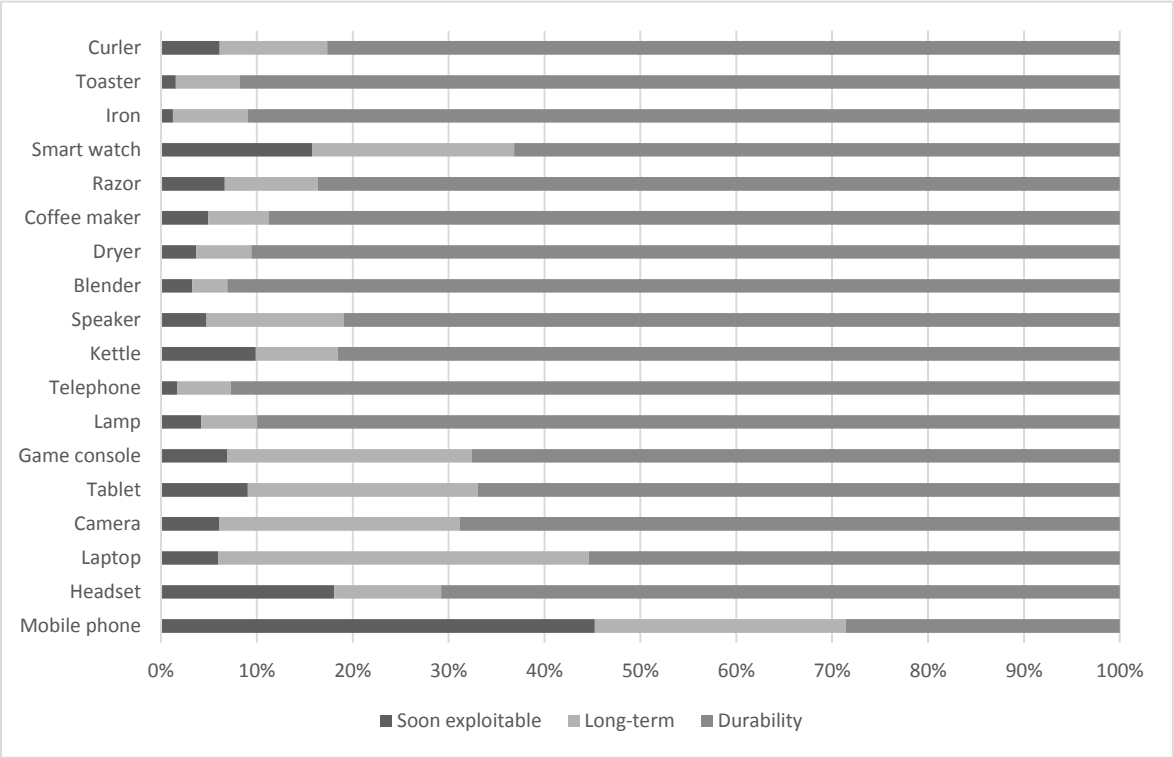


Appendix C1. Stockpiling and hoarding levels of small kitchen appliances (n=320), personal care appliances (n=314 except for straightener, styler and toothbrush (n=313) and small household appliances (n=311 except for lamp and fan (n=312)).



Appendix C2. 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).

Appendix D. Device usage cycles



Appendix D1. 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).

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Table 1. Student and staff population in surveyed universities (2018/2019 academic year) (Source: HESA, 2020).

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

Table 2. Demographic profile of all respondents (*****data from HESA, 2020).

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

Table 3. Ownership levels of all devices surveyed.

SKA		PCA		SHA		ICT/AV	
Device	**Ownership level (%)**	**Device**	**Ownership level (%)**	**Device**	**Ownership level (%)**	**Device**	**Ownership level (%)**
Coffee maker	44.7	Hair curler	31.8	Desk lamp	76.9	Digital camera	72.3
Blender	76.9	Hair dryer	78	Electric iron	78.5	Electronic tablet	73.9
Food mixer	52.8	Hair straightener	50.8	Home telephone	57.6	Laptop computer	91.3
Kettle	91.6	Hair styler	5.4	Space heater	37.9	Netbook/notebook	8.4
Juicer	13.4	Electronic razor	52.2	Table fan	41.3	Headset/headphones	87.9
Wok/frying pan	5.0	Electric toothbrush	72.5			Mobile phone	100
Rice cooker	15.6					CD player	18.4
Toaster	60.9					DVD/Blu-ray	51.8
						Printer	53.8
						Scanner	7.7
						Fax machine	1.0
						Radio	51.2
						Screen/monitor	43.8
						Smart watch	38.1
						Speaker	63.9
						Video game console	48.8
						Web cam	14.7

SKA: Small kitchen appliance ownership level of all respondents (n=320).

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

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

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

Table 4. 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 5. 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**

Table 6. 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 (*estimation was based on total population in UK HEIs (2018/19) from Higher Education Statistics Agency; devices with 50 or more units presented).

EEE	Owned (Survey Zone)	Stockpile (Survey Zone)	Hoard (Survey Zone)	Stockpile (UK-wide) *	Hoard (UK-wide) *
Mobile phone	162675	76132	50755	3303992	2202662
Headset	156168	65070	33836	2823925	1468441
Laptop	110619	23425	23425	1016613	1016613
Camera	78084	33836	9110	1468441	395350
Tablet	91098	25377	9110	1101331	395350
Game console	65070	25377	5856	1101331	254153
Lamp	110619	17569	3904	762460	169436
Telephone	65070	13014	7808	564785	338871
Kettle	71577	13014	3254	564785	141196
Speaker	78084	13665	3904	593024	169436
Blender	71577	14315	1952	621264	84718
Dryer	71577	13014	2603	564785	112957
Coffee maker	39042	11062	1952	480067	84718
Razor	52056	10411	2603	451828	112957
Smart watch	32535	11062	1952	480067	84718
Iron	58563	9761	1301	423589	56479
Toaster	45549	9761	651	423589	28239
Curler	26028	9761	651	423589	28239
Total	**1385991**	**395626**	**164627**	**17169465**	**7144533**

Table 7. Estimated reuse potential of stockpiles 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 £) ****	**Reuse potential/capita (£/capita) ***
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**	-

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

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

Prospecting reusable small electrical and electronic equipment (EEE) in distinct anthropogenic spaces

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ABSTRACT

The generation of Waste Electrical and Electronic Equipment (WEEE) continues to escalate yearly because of high demand for state-of-the-art and affordable devices. This demand is particularly strong for small consumer electrical and electronic equipment whose usage cycle is waning due to fashion and technological obsolescence. As a result, there is potentially a large 'pool' of unused, reusable devices within urban spaces (anthroposphere). This study aimed to assess the magnitude of the reusable stock of EEE with the view to recovery and release into the circular economy. An online questionnaire survey was conducted within a regional group of universities in the United Kingdom to assess the prospects of reusable small EEE within this distinct urban mine (DUM) cluster. The study provides new, distinct definitions for types of DUM, hoarding and stockpiling, and new data for a 'meso-level' DUM on ownership levels and hibernating stocks of reusable EEE. Results show that ownership levels were high, with multiple ownership of devices common and a high degree of product stockpiling and hoarding. Estimates show a stockpile of ~400,000 small EEE within the survey zone and over 17 million devices across the UK with reuse values of >£13 million and >£571 million, respectively. The frequency of device stockpiling is likely due to perceived residual value. The study suggests that exploitation of reuse value requires prompt recovery of stockpiled items as extended periods in hibernation will result in technical obsolescence, particularly with information and communication technology (ICT) devices. Such recovery requires tailored protocols that considers DUM scale, product reusability, recyclability and redistribution.

Keywords: small EEE, WEEE, distinct urban mine, urban mining, reuse, circular economy.

HIGHLIGHTS

- Meso-level DUM survey of small EEE hibernation in the UK
- Refined definitions for DUM types, product stockpiling and hoarding
- Frequently hibernated devices include mobile phones, lamp, kettles and hair dryers
- Stockpiling of reusable EEE more common than hoarding of non-functional devices
- Estimated stockpile value across the UK is >£500 million
- Significant reuse (and subsequent recycling) potential evident in all types of DUM

1. INTRODUCTION

1.1 Distinct urban mines

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. Estimates show that approximately 54 million tonnes of WEEE was generated globally in 2019 (Forti et al., 2020, Shittu et al., 2021). A significant amount of generated WEEE is not collected and processed through formal channels and is discarded or landfilled (Ongondo et al., 2011, Balde et al., 2017, Forti et al., 2020). This so-called linear economy has resulted in the loss of materials and resource inefficiency (Ongondo et al., 2015; Pierron et al., 2017; Shittu et al., 2021). The recovery of materials from the stream of end-of-life or end-of-use EEE requires a closed-loop process that allows for diversion of valuable resources from landfill (Ongondo., 2015, Ramanayaka et al., 2019).

The concept of urban mining is closely linked to resource recovery and efficiency that aims to recover materials and resources from the anthroposphere[1]. 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). 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 1, 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

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

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area such a country or nation.

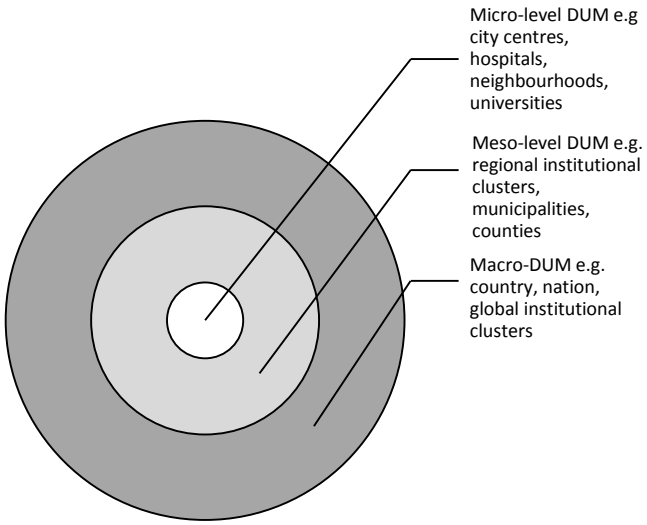

Figure 1. Schematic highlighting the hierarchical relationship between micro-, meso- and macro- levels of DUM classification.

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 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[2] as opposed to material value.

1.2 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 2). Product recovery from DUMs is exemplary of this

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

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shift higher up the waste hierarchy. An urban mine can be tapped for reusable resources due to its 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).

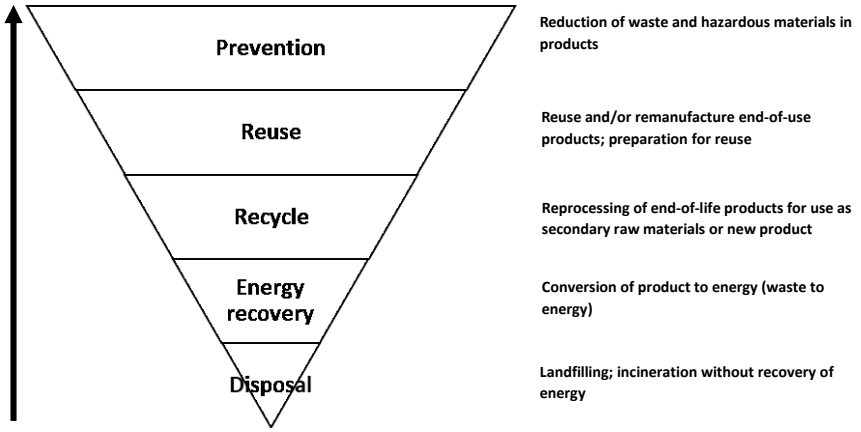

Figure 2: Waste Hierarchy (adapted from: OECD iLibrary, 2020); arrow indicates the direction of preferred outcome.

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). Advanced processes for rare and precious metals (RPM) recovery using hydrometallurgy and biometallurgy (Wang et al., 2019) and nanotechnology (Ramanayaka et al., 2019) have 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 first 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. These studies involved an evaluation of potential stocks within the DUMs of interest. In the present study, a wider perspective is presented by providing comprehensive data on reuse stocks within a university distinct urban mine population with the view of presenting product reuse as a viable option in distinct urban mining.

1.3 Study rationale and objectives

The present study sets 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 1), 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

2. METHODS

The study is a meso-level inquiry of EEE 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 and 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 in Table 1. The cluster of four universities within this geographic region is considered a meso-level DUM (*see* Figure 1) 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.

2.1 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 & 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 1) 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 representative 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 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. Together, these three universities form what can be described as a '*regional distinct urban mine'* (i.e. a meso-level DUM; *see* Figure 1) 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).

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 wais achieved by the distribution of the survey via channels that target the specific population required for the study only.

Table 1. Student and staff population in surveyed universities (2018/2019 academic year) (Source: HESA, 2020).

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

2.2 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 2.2.1). 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 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.

2.2.1 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, each within the categories outlined in Table A1. 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.

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 & 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[3]. 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.

2.2.2 Survey analysis

2.2.2.1 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] 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.

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2.2.2.2 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[4] were obtained from online vendors www.giffgaff.com, www.preloved.com and www.gumtree.com that 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[5] mobile phone; mobile phone models exceeding £500 in value were excluded 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 of mean to provide a representative set 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.

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

[5] 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)

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3. RESULTS

3.1 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 2 presents the demographic profile of respondents. For analysis, the age profiles used in the questionnaire were categorised into two age groups: respondents 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 2. Demographic profile of all respondents (*data from HESA, 2020).

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

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 (*see* Table 2). 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.

3.2 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. Table 3 presents ownership level of all devices surveyed amongst respondents.

Table 3. Ownership levels of all devices surveyed.

SKA		PCA		SHA		ICT/AV	
Device	**Ownership level (%)**	**Device**	**Ownership level (%)**	**Device**	**Ownership level (%)**	**Device**	**Ownership level (%)**
Coffee maker	44.7	Hair curler	31.8	Desk lamp	76.9	Digital camera	72.3
Blender	76.9	Hair dryer	78	Electric iron	78.5	Electronic tablet	73.9
Food mixer	52.8	Hair straightener	50.8	Home telephone	57.6	Laptop computer	91.3
Kettle	91.6	Hair styler	5.4	Space heater	37.9	Netbook/notebook	8.4
Juicer	13.4	Electronic razor	52.2	Table fan	41.3	Headset/headphones	87.9
Wok/frying pan	5.0	Electric toothbrush	72.5			Mobile phone	100
Rice cooker	15.6					CD player	18.4
Toaster	60.9					DVD/Blu-ray	51.8
						Printer	53.8
						Scanner	7.7
						Fax machine	1.0
						Radio	51.2
						Screen/monitor	43.8
						Smart watch	38.1
						Speaker	63.9
						Video game console	48.8
						Web cam	14.7

SKA: Small kitchen appliance ownership level of all respondents (n=320).
PCA: Personal care appliance ownership level of all respondents (Hair dryer, curler and razor (n=314); hair straightener, styler and electric toothbrush (n=313).
SHA: Small household appliance ownership level of all respondents (desk lamp & table fan (n=312); electric iron, home telephone & space heater (n=311)
ICT/AV: Information and communication technology/audio-visual devices ownership level (n=299 except digital camera (n=300); headset, mobile phone (n=298).

3.2.1 SKA ownership

Eight small kitchen devices were surveyed in the study. The data presented in Table 3 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.

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 (*see* Figure 3). 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).

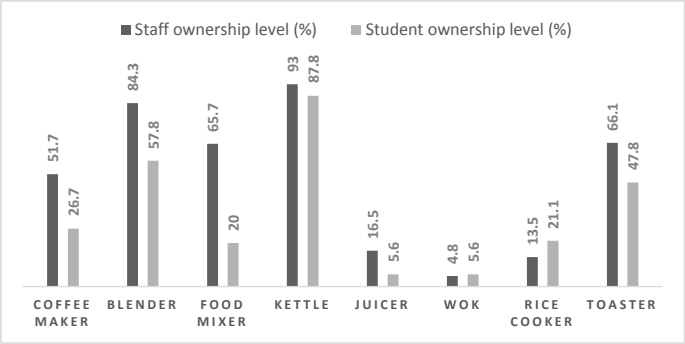

Figure 3. Small kitchen appliance ownership levels by respondents (staff and students) (n=320)

SKA ownership levels for respondents of age 25 and above were higher than those between age 18-24. 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). 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. 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; 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. Devices such as juicers and food mixers were observed to be owned by only respondents living in accommodation other than HoR.

3.2.2 PCA ownership

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).

Staff within the surveyed population had higher ownership levels of all PCAs than students (Figure 4), 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).

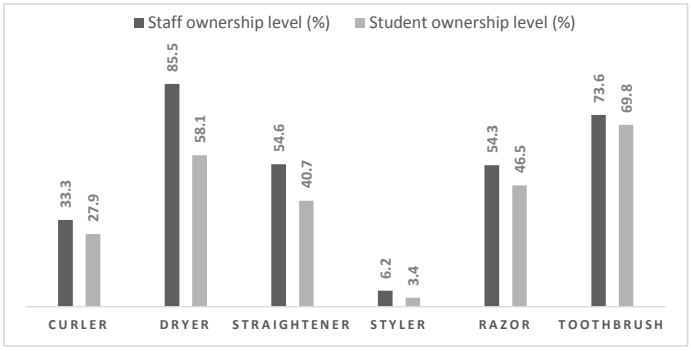

Figure 4. Personal care appliance ownership level by respondents (staff and students; n= 314).

As observed in ownership level of SKA, respondents 25 years and above had a higher ownership level of PCA than those between 18-24. 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). 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+) 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, 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. 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. 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). Lowest differential was observed in ownership of hair curlers (3.2 percentage points).

Respondents (students) living in Halls of Residence (HoR) 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).

3.2.3 SHA ownership

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.

Staff members within the surveyed population had a higher ownership levels of all SHA than students except for desk lamps (*see* Figure 5). 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).

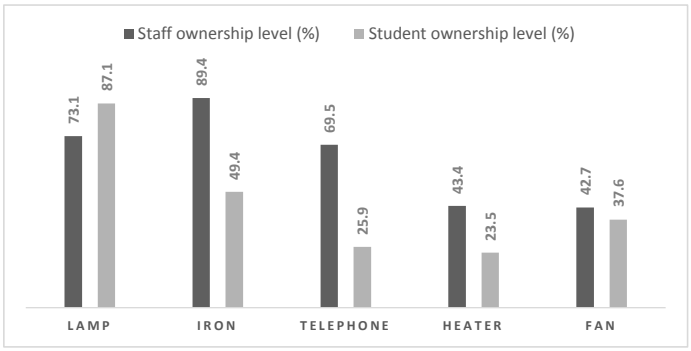

Figure 5. Small household appliance ownership level by respondent profile (staff and students).

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. 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). 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 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. 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.

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. 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.

3.2.4 ICT/AV ownership

This category 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.

There was generally a higher ownership level observed with most of devices surveyed amongst the staff respondents as shown in Figure 6. 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 (*see* Figure 6). 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 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 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). 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 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).

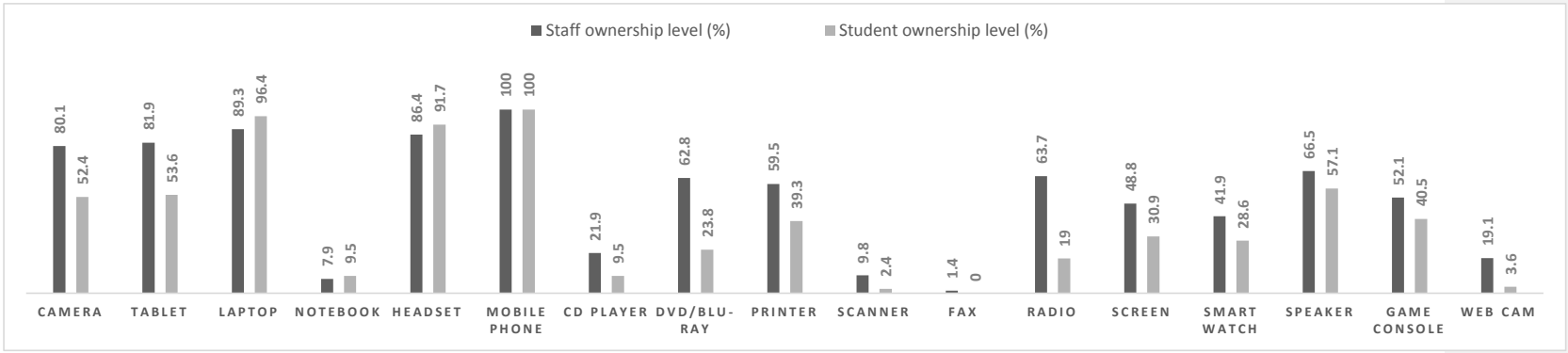

Figure 6. Information and communication technology/audio-visual devices ownership by respondent profile (Staff and Students).

3.3 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).

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). 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%. Observed percentage differential between stockpiling and hoarding levels varied from 26 percentage points (cameras) to 0.7 percentage points (fax machines).

3.3.1 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 7, 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.

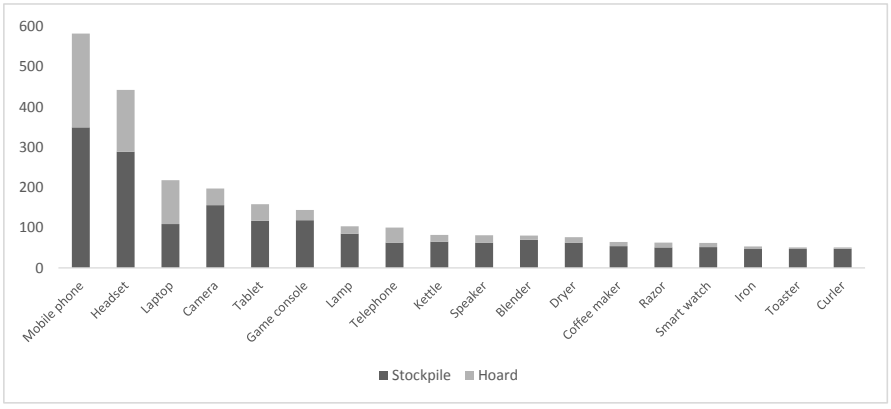

Figure 7. Total number of select device stocks with proportion of stockpiled and hoarded EEE (devices with 50 or more units observed).

3.3.2 *Estimated reuse value*

The reuse value of the unused functional devices owned by respondents was quantified and evaluated (*see* Tables 4 and 5). 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.

Table 4. Average sale value (*see* footnotes 4~~5~~ &~~—~~ 5~~7~~) 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 5. 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.

4. DISCUSSION

4.1 EEE ownership and hibernation

4.1.1 EEE ownership levels

The survey results highlighted the trend of increasing ownership levels of EEE~~, particularly in developing countries~~. This trend has resulted in the proliferation of urban mines that are rich in resources and potentially exploitable (Ongondo et al., 2015; Wilkinson and 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 1). 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 2).

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 & 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[6] such as fax machines had low ownership level (approximately 1%) and these devices were owned by older respondents (25 and above). Unsurprisingly, no student

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

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respondent reported owning a fax machine (*see* Figure 6) 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. While there is the possibility of movement of items by this group away as part of the so-called 'suitcase trade'[7], previous studies such as Williams and Powell (2019) have shown that unwanted items are likely to be left behind.

4.1.2 EEE hibernation levels

Together with ownership levels of EEE, information on devices in hibernation is essential in establishing the scope of potential of a DUM (Wilkinson and Williams, 2020). 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 and 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 present survey, there was evidence of device hibernation (stockpiles and hoards), the stockpiles being those with reuse potential. As illustrated in Figure 7, 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 6) to macro-DUM level show an estimated stockpile of over 17 million items in university DUMs across the UK. 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 and Obara, 2005; Ongondo et al., 2011; Wilkinson and Williams, 2020) that reported high hibernation rates of small devices. Their small sizes mean storing them is

[7] Suitcase trade is an informal international movement and trading of goods; such trade is generally unrecorded or under-recorded (International Monetary Fund, 1998).

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convenient for many, including students who, due to their place of abode (e.g. halls of residence), have limited storage space.

Table 6. 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 (*estimation was based on total population in UK HEIs (2018/19) from Higher Education Statistics Agency; devices with 50 or more units presented).

EEE	Owned (Survey Zone)	Stockpile (Survey Zone)	Hoard (Survey Zone)	Stockpile (UK-wide) *	Hoard (UK-wide) *
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 and Williams, 2020). The survey showed that a high number of devices had long usage cycles (3 years and above) particularly SKA and SHA. 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 (2020) 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 and Powell, 2019).

4.2 Circular economy potential: opportunities and challenges

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. ~~Reuse value can be expressed as ***functional value + residual value***; residual value being the value of materials obtainable from recycling~~. 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. Stockpiling such devices would result in a loss of circularity in terms of opportunity to reuse and extending usage cycle. 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 7).

Table 7. 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 £) **	Reuse potential/capita (£/capita) *
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**	-

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

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

The survey results suggest a high potential for reuse considering that only the most frequently stockpiled devices were analysed (*see* Tables 5 and 7). 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 ~~the obsolescence~~programmed obsolescence. ~~factor~~. 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 devices kept '*safety devices';* devices that are kept as back-up for as long as possible by owners due to perceived 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 device may then become dispensable due to factors including, but not limited to, technological obsolescence. At the point, the device, with little or no functionality becomes a hoarded device if it is kept by the owners. The decision to keep at this point of the device's lifecycle is likely influenced by disposal options known and/or available to the user (Wilkinson and Williams, 2020). Such devices could be made functional by repair and/upgrade after which they become reusable (*see* Figure 8).

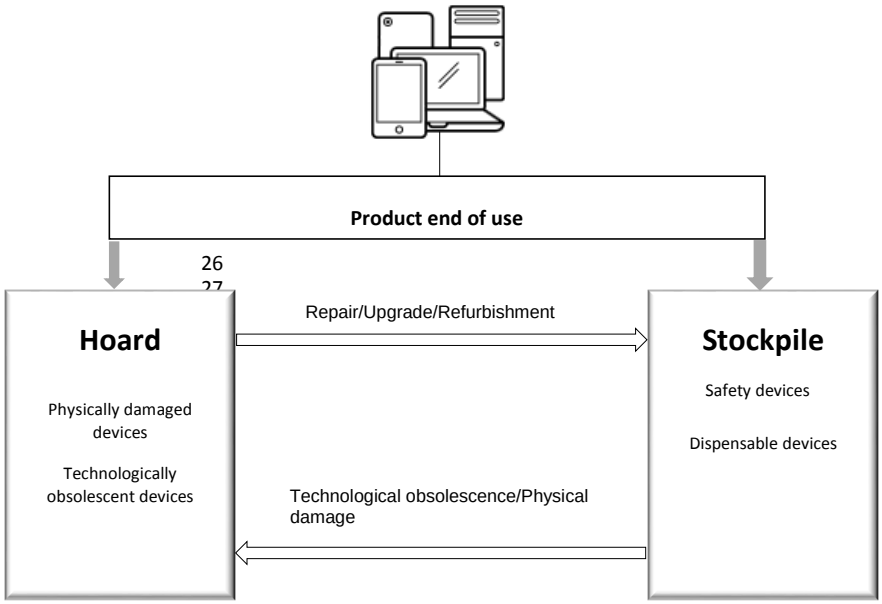

Figure 8. Illustration of product hibernation cycle showing the relationship between stockpiling and hoarding.

Attitudes towards pre-owned items is a barrier to fostering a sustainable reuse culture (Diop and Shaw, 2018; Shaw and 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 'reparability' labelling. 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, 2020).

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.

5. CONCLUSIONS

This study has successfully examined the potential for recovery of reusable EEE from university distinct urban spaces at a regional (meso) level. It provides 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 to tap into the reuse potential of the distinct urban space at micro, meso and macro levels.

ACKNOWLEDGEMENT

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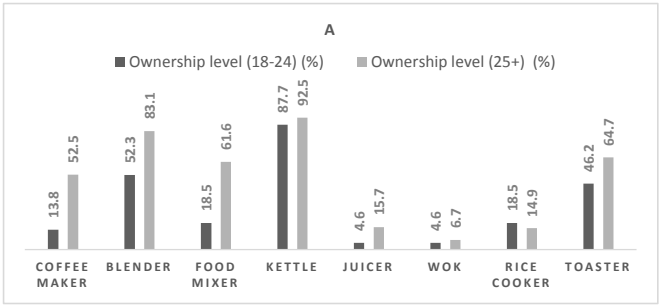
APPENDIX

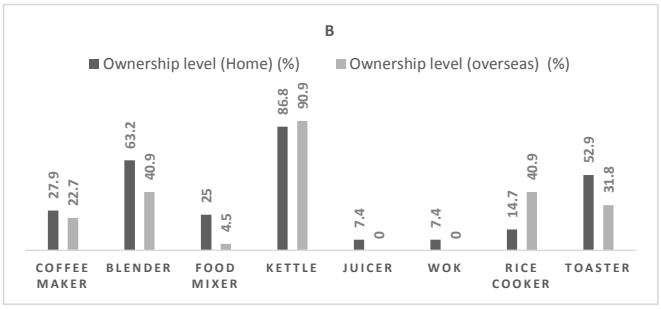
Appendix A. Small electrical and electronics equipment (EEE) categories

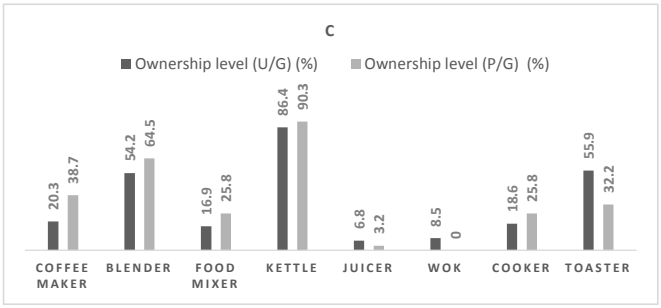
Appendix A1. Surveyed electrical and electronic equipment

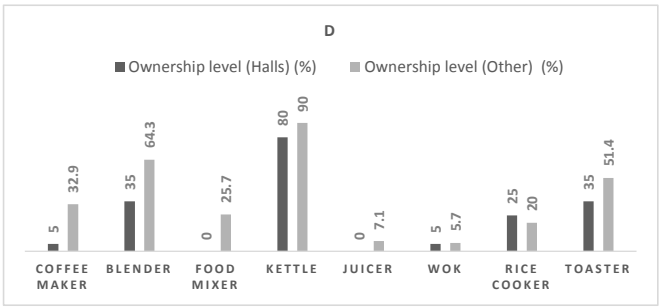
Category of EEE	Appliances included in questionnaire
SKA	Electric coffee maker, electric blender, electric food mixer, electric kettle, electric juicer, electric frying pan/wok, electric rice cooker and sandwich grill/toaster
PCA	Hair curler, hair dryer, hair straightener, hair styler, electric razor/epilator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

Appendix B. EEE ownership levels

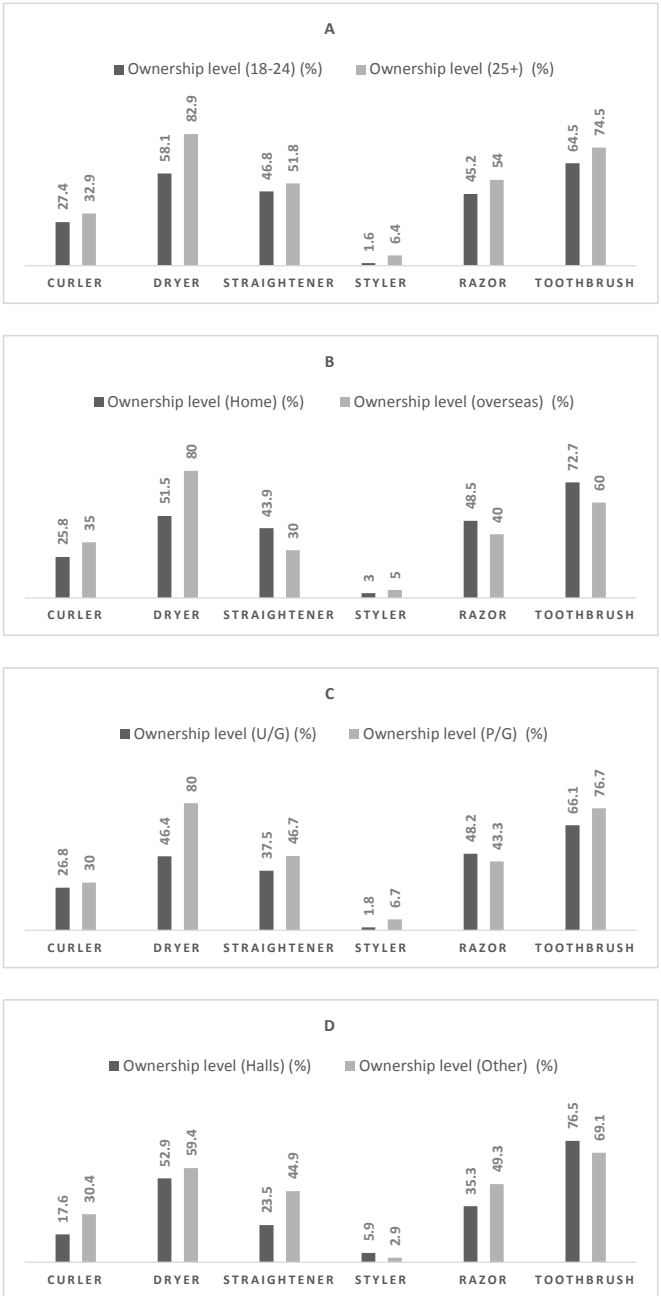




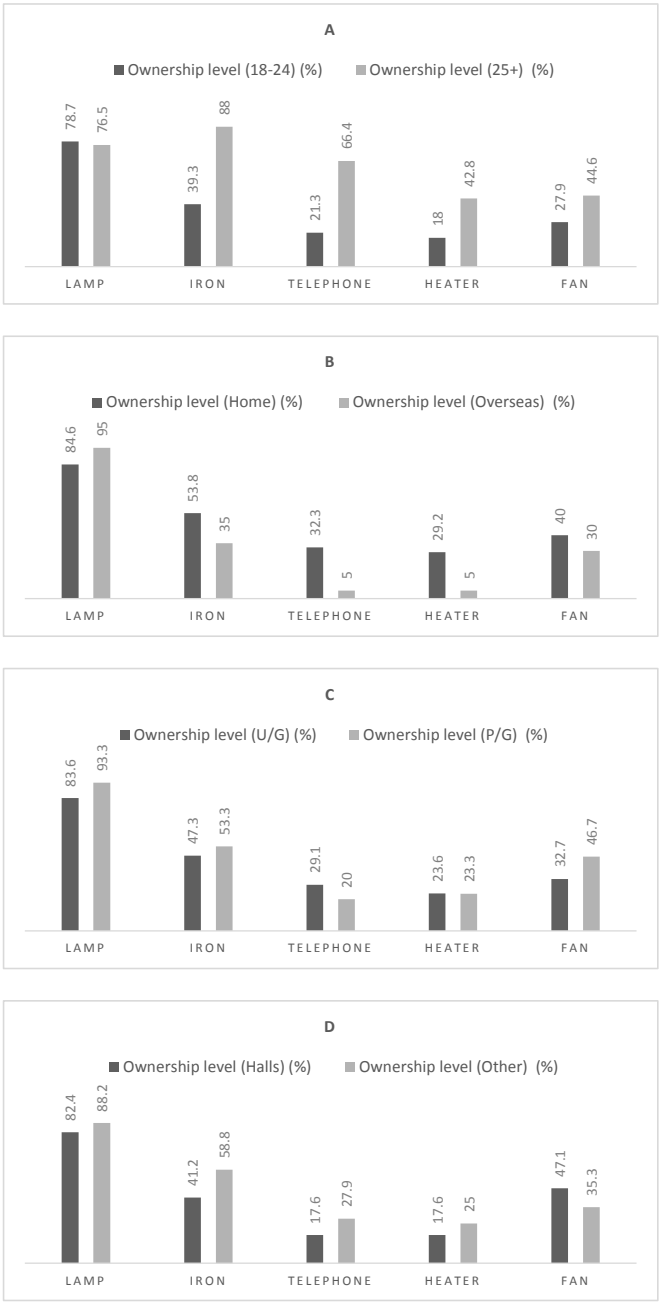




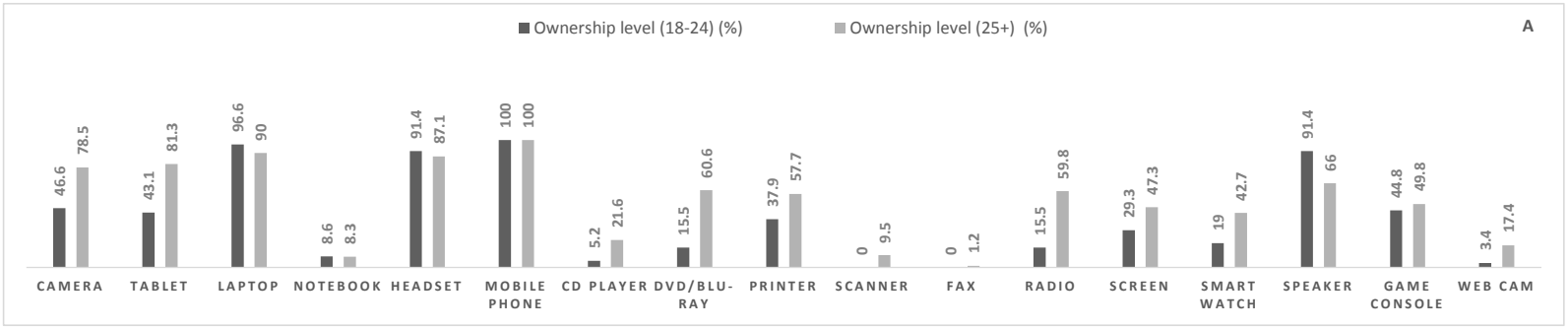
Appendix B1. Small kitchen appliance ownership levels by the different demographic variables. **A**. ownership level by age (all respondents, n= 312); **B.** ownership by domicile (student respondents, n=90); **C**. ownership by degree type (student respondents, n=90); **D.** ownership by accommodation (student respondents, n=90).

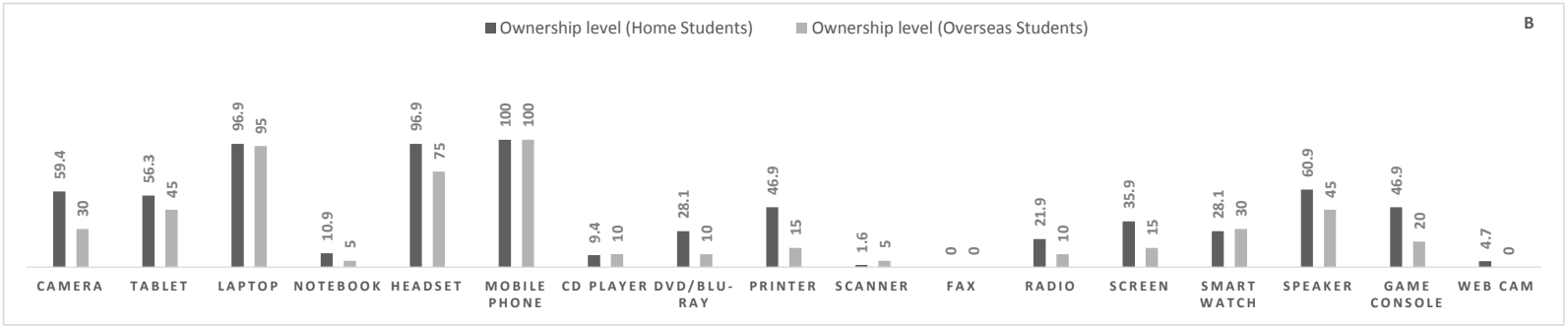


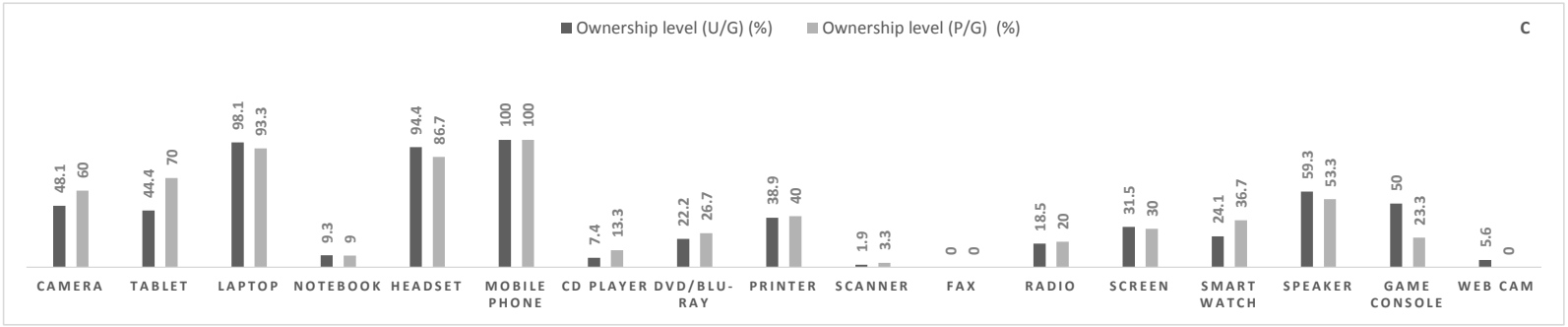
Appendix B2. Personal care appliance ownership levels by the different demographic variables. **A**. ownership level by age (all respondents, n= 314); **B.** ownership by domicile (student respondents, n=86); **C**. ownership by level of study (student respondents, n=86); **D.** ownership by accommodation (student respondents, n=86).

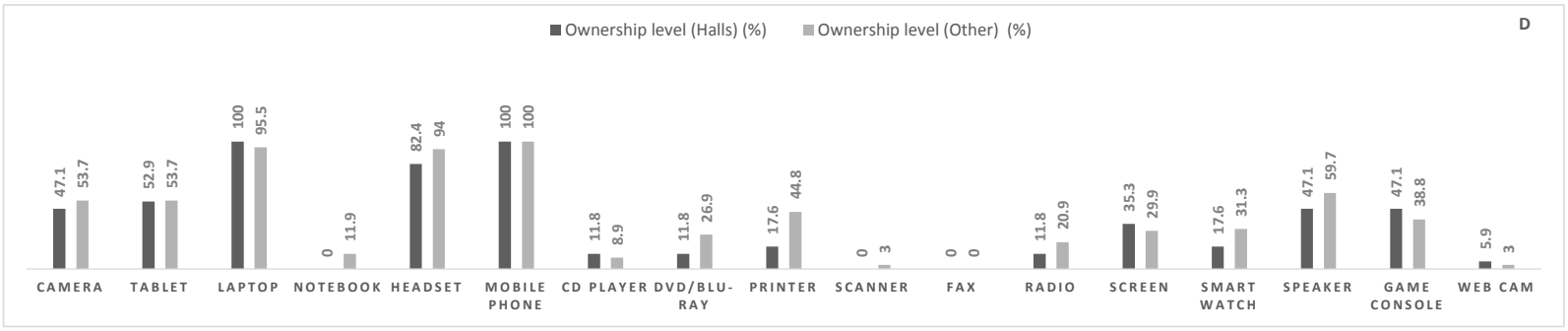


Appendix B3. Small household appliance ownership levels by the different demographic variables. **A**. ownership level by age (all respondents, n= 312); **B.** ownership by domicile (student respondents, n=85); **C**. ownership by level of study (student respondents, n=85); **D.** ownership by accommodation (student respondents, n=85).


Ownership level (18-24) (%)
Ownership level (25+) (%)
A
46.6
78.5
43.1
81.3
96.6
90
8.6
8.3
91.4
87.1
100
100
5.2
21.6
15.5
60.6
37.9
57.7
0
9.5
0
1.2
15.5
59.8
29.3
47.3
19
42.7
91.4
66
44.8
49.8
3.4
17.4
CAMERA
TABLET
LAPTOP
NOTEBOOK
HEADSET
MOBILE PHONE
CD PLAYER
DVD/BLU-RAY
PRINTER
SCANNER
FAX
RADIO
SCREEN
SMART WATCH
SPEAKER
GAME CONSOLE
WEB CAM

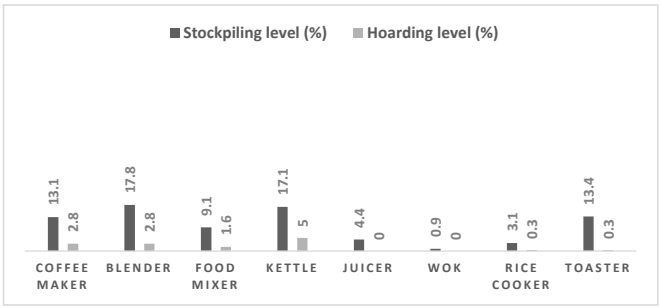

Ownership level (Home Students)
Ownership level (Overseas Students)
B
59.4
30
56.3
45
96.9
95
10.9
5
96.9
75
100
100
9.4
10
28.1
10
46.9
15
1.6
5
0
0
21.9
10
35.9
15
28.1
30
60.9
45
46.9
20
4.7
0
CAMERA
TABLET
LAPTOP
NOTEBOOK
HEADSET
MOBILE PHONE
CD PLAYER
DVD/BLU-RAY
PRINTER
SCANNER
FAX
RADIO
SCREEN
SMART WATCH
SPEAKER
GAME CONSOLE
WEB CAM

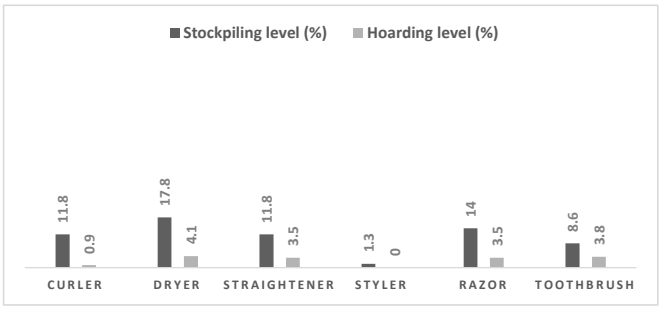


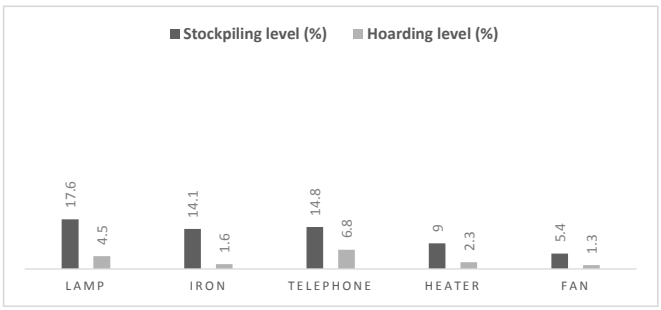


Appendix B4. Information and communication technology/audio-visual devices ownership levels by different demographic variables. **A**: ownership level by age (all respondents); **B**: ownership level by domicile (students only); **C**: ownership level by level of study (students only); **D**: ownership level by accommodation type (students only).

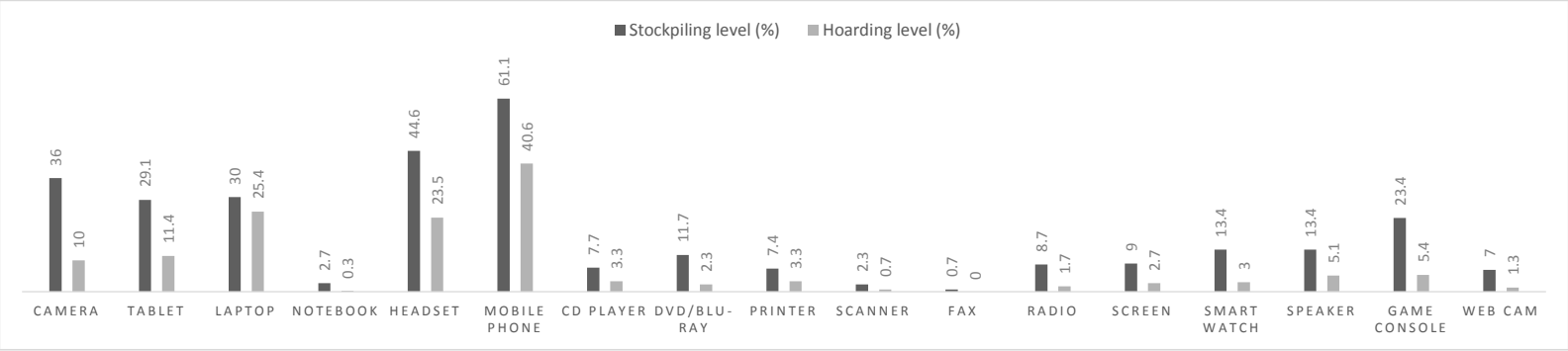
Appendix C. Device hibernation levels





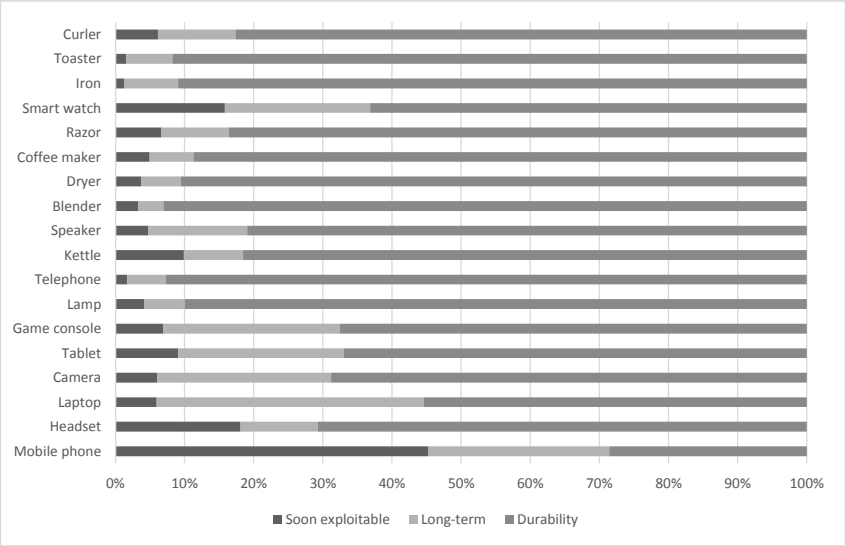


Appendix C1. Stockpiling and hoarding levels of small kitchen appliances (n=320), personal care appliances (n=314 except for straightener, styler and toothbrush (n=313) and small household appliances (n=311 except for lamp and fan (n=312)).



Appendix C2. 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).

Appendix D. Device usage cycles



Appendix D1. 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).

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Table 1. Student and staff population in surveyed universities (2018/2019 academic year) (Source: HESA, 2020).

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

Table 2. Demographic profile of all respondents (*****data from HESA, 2020).

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

Table 3. Ownership levels of all devices surveyed.

SKA		PCA		SHA		ICT/AV	
Device	**Ownership level (%)**	**Device**	**Ownership level (%)**	**Device**	**Ownership level (%)**	**Device**	**Ownership level (%)**
Coffee maker	44.7	Hair curler	31.8	Desk lamp	76.9	Digital camera	72.3
Blender	76.9	Hair dryer	78	Electric iron	78.5	Electronic tablet	73.9
Food mixer	52.8	Hair straightener	50.8	Home telephone	57.6	Laptop computer	91.3
Kettle	91.6	Hair styler	5.4	Space heater	37.9	Netbook/notebook	8.4
Juicer	13.4	Electronic razor	52.2	Table fan	41.3	Headset/headphones	87.9
Wok/frying pan	5.0	Electric toothbrush	72.5			Mobile phone	100
Rice cooker	15.6					CD player	18.4
Toaster	60.9					DVD/Blu-ray	51.8
						Printer	53.8
						Scanner	7.7
						Fax machine	1.0
						Radio	51.2
						Screen/monitor	43.8
						Smart watch	38.1
						Speaker	63.9
						Video game console	48.8
						Web cam	14.7

SKA: Small kitchen appliance ownership level of all respondents (n=320).

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

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

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

Table 4. 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 5. 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**

Table 6. 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 (*estimation was based on total population in UK HEIs (2018/19) from Higher Education Statistics Agency; devices with 50 or more units presented).

EEE	Owned (Survey Zone)	Stockpile (Survey Zone)	Hoard (Survey Zone)	Stockpile (UK-wide) *	Hoard (UK-wide) *
Mobile phone	162675	76132	50755	3303992	2202662
Headset	156168	65070	33836	2823925	1468441
Laptop	110619	23425	23425	1016613	1016613
Camera	78084	33836	9110	1468441	395350
Tablet	91098	25377	9110	1101331	395350
Game console	65070	25377	5856	1101331	254153
Lamp	110619	17569	3904	762460	169436
Telephone	65070	13014	7808	564785	338871
Kettle	71577	13014	3254	564785	141196
Speaker	78084	13665	3904	593024	169436
Blender	71577	14315	1952	621264	84718
Dryer	71577	13014	2603	564785	112957
Coffee maker	39042	11062	1952	480067	84718
Razor	52056	10411	2603	451828	112957
Smart watch	32535	11062	1952	480067	84718
Iron	58563	9761	1301	423589	56479
Toaster	45549	9761	651	423589	28239
Curler	26028	9761	651	423589	28239
Total	**1385991**	**395626**	**164627**	**17169465**	**7144533**

Table 7. Estimated reuse potential of stockpiles 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 £) ****	**Reuse potential/capita (£/capita) ***
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**	-

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

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

Reviewer 1		
Reviewer Comment	**Authors' Response**	**Revised Text**
Reviewer #1: This is a well-researched paper that is clearly written and has immediate relevance for managing W/EEE and associated devices in the UK university sector. In my view, the paper could be strengthened by some acknowledgement of the political-economic context in which the authors situate their study. I realize that this paper is not focused on political-economy and that is fine. However, there are a number of places in the manuscript where claims are made or conclusions drawn that imply they are value-neutral when, arguably, they include latent value judgements or assumptions built-in. Said differently, there are places in the manuscript where statements about what ought to be are presented as merely what is. Having such values built-in is not a bad thing, but it is also not neutral. What follows is a non-exhaustive list of examples from the manuscript. I recommend that the authors return to these and other examples as they revise the manuscript and offer some very brief commentary or acknowledgements about the values ('oughts') assumed by the authors:	We thank Reviewer 1 for the comprehensive observations and comments. The focus of the study was to present the potential for recovery of high-value devices from a distinct urban mine. We agree that different contextual and prevailing factors would affect the implementation of DUM recovery from place to place. Such factors (the assessment of which is outside the scope of this study) need to be considered in order to maximise the potential for recovery of EEE. Re. comment on 'loss' to the circular economy, we are not sure there was any reference to loss to the circular economy. A product/material loop, as the reviewer rightly observed, can be achieved irrespective of location. However, with the emphasis of this study on product reuse, we believe that recovery of products with residual reuse value is desirable in a circular economy and this recovery needs to be timely due to reasons highlighted in Section 4.2 of the manuscript. A device that could be recovered for reuse in the UK may end up elsewhere where this route is	**Revised text: Page 28, Line 14 – 15.**

1/ References to the circular economy in this manuscript implicitly assume that any device leaving the UK (or, perhaps, the EU) is a 'loss' to 'the' circular economy. This is a questionable assumption since its validity largely depends on the geograph(y)ies assumed to make up 'the circle'. Devices leaving the UK for reuse elsewhere in the EU or, indeed, overseas are not lost in any absolute sense (they travel for reuse and/or material recovery and, yes, disposal at some later date elsewhere). The issue is only partially captured by the authors' use of the nested scales of DUMs (micro, meso, macro in Figure 1) since it's hard to imagine how a 'loss' could occur from something scaled as 'global'. The issue being described in this example points up the political-economy of circular economies in more pragmatic, realpolitik ways with respect to resource security. The circular economy can be put to use as a 'ring fence' around critical materials embodied in W/EEE and be used to enclose those resources. So some key questions to ask about worries over 'losses' of materials would include: Lost from whom? Where? When? Under what conditions? The latter questions are merely possible prompts for the authors and I am not suggesting the manuscript needs to delve into detail on them. I would, however, like to see the authors at least acknowledge that the idea of 'loss'	not unavailable. This is the 'loss' referred to in the context of the study.	

from the circular economy is a value-laded assumption. The authors may find the following useful on these points: Kama, Kärg. "Circling the Economy: Resource-Making and Marketization in EU Electronic Waste Policy." Area, 2015, n/a-n/a. https://doi.org/10.1111/area.12143.		
2/ Assumptions built-in to claims about 'overseas' students and the likelihood of leaving devices behind. For some categories of devices, the authors' assumptions may be correct. For other categories it may be much more likely that overseas students take things with them, particularly examples of ICT/AV (especially phones, tablets, and laptops). I urge the authors to give a bit of consideration to what some researchers call the suitcase trade or suitcase economy. Again, I recognize that the paper is not about this trade, but it is likely that it impinges on some of the conclusions drawn by the authors. The authors' survey results (probably) will not be able to say anything directly about this issue (and that is fine). However, I do think there is analytical value in the authors considering how the suitcase trade might impinge on the conclusions they offer about	We acknowledge that departing students may take with them items in use at the time of departure which, as the reviewer noted, may contribute to the suitcase economy. However, as previous studies (e.g. Williams and Powell, 2018) have shown, items that are unwanted are likely to be left behind and such items can be recovered if the means are available to do so. While we acknowledge its existence, we believe that suitcase trade is minimal in this context.	**Revised text: Page 26, Line 10 – 12**.

overseas students.		
Reviewer 2		
Discussion section, Line 4 This sentence can easily be misunderstood. The survey was developed in the UK and does not highlight the trend in developing countries. I recommend rephrasing this sentence.	We thank the reviewer for their thoughtful observations. Opening statement of the discussion section (Line 4 – 5) rephrased as recommended.	**Page 25, Line 4 – 5**
Conclusions section, Line 19 – 21 For some type of products, in particular from the ICT/AV category, more than on changes to manufacturing, the focus should lie on how to prevent programmed obsolescence and products getting slower by more recent software updates. It might be worth mentioning this in the discussion as well.	We agree with this; programmed obsolescence is a huge barrier to reuse particularly with ICT devices. This was highlighted in the discussion (Page 28, Line 26-29). This text has been slightly modified to emphasise this point.	**Page 28, Line 27**
Reviewer 3		
This manuscript provides a case study on potential assessment of reusable small EEEs from three universities in UK, with the "DUM" concept. This	We thank the reviewer for the comments. We agree that the DUM concept is the basis of the study and this was acknowledged by	-

topic fits the scope of resources, conservation and recycling very well, but it requires more amendment until publishment. 1. In line 22 of part 1.1, as the concept DUM is a key word in this manuscript, if it is from literature, the source should be provided; if not, more explanations for this word are necessary.	dedicating an entire section (Section 1.1) for the explanation of the concept e.g. Page 3, line 21 – 28. The concept in relation to WEEE was conceived by Ongondo et al., (2015) and reference to this was made on Page 3, Line 19 – 22 i.e. "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)".	
2. The composition of population in UK HEIs should be given. Otherwise, the data in Table 6 should be in a scope, but not a certain value.	We believe this information was provided in Table 2 (Demographic Profile) in which the compositions of the survey respondents were compared with the UK HEI population.	-
3. The formula of Reuse value in part 4.2 and related method introduction part should be moved to part 2.	We agree with this observation and relevant revisions have been made.	**Section 2.2.2.2 (Page 11, Line 3 – 4).**
4. The line numbers in the Figure 8 should be deleted.	Comment has been noted. This change will be made on the final (clean) version of the manuscript.	-

5. The expression "tailored protocols" doesn't appear in the main body of this manuscript. Further, in nowadays, some resale activities can happen through internet across one country, especially for second-hand ICT products. So why the tailored protocols are necessary in the DUM?	While the term 'tailored protocol' wasn't used in the main body, it was implied in the conclusion (Page 31, Line 30 – 33) i.e. "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 to tap into the reuse potential of the distinct urban space at micro, meso and macro levels". It was also implied on Page 30, Lines 16 – 21 i.e. "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". We agree that product resale is commonplace via the Internet nowadays. However, the protocol proposed in the study provides a viable option for product redistribution and extension of usage lifecycles.	-

CRediT author statement

O. S. Shittu: Data curation, Investigation, Methodology; Formal analysis, Writing- Original draft preparation, Validation; Visualisation.

Ian Williams: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Writing - review & editing.

P. J. Shaw: Supervision; Methodology; Writing- review & editing; Visualisation.