An exploratory study of e-waste creation and disposal: Upstream considerations

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Abstract

This paper examines the creation and disposal of e-waste using an ecosystem framework that invites a critical examination of people (e-waste workers), business owners, consumers in communities, as well as broader policies, in order to identify the strengths and weaknesses in the transactional processes between these systems. The study is based in Pakistan, which is the 26th largest producer of e-waste, but is also the recipient of e-waste from other exporting nations. Survey results indicate local generation of electronic waste (extrapolated) is some 281 million in terms of equipment or 1,790 kilo-tonnes (2018-2019). The paper illuminates the often hard to measure and less visible 'upstream' considerations, such as volumes and attitudes of consumers that drive buying and disposing decisions. For example, consumer preference for brand-new, low quality and cheaply priced equipment traps the community in a short-term gain and unrealised long-term pain cycle, as the negative effects are felt downstream in the environment and by workers involved in disposal. The study also identifies storage as a preferred option for obsolete items, usually because of a lack of suitable disposal options. The effect however is to effectively divert discarded equipment into landfill, with attendant costs to the environment or generate another pain cycle by exposing workers to toxic materials when processing e-waste using informal methods. Identifying transactional upstream processes in the ecosystem will enable responsive action to reduce and redirect consumer contributions to the burgeoning challenge presented by e-waste. The study also reveals high levels of consumer awareness and a willingness also to pay for e-waste recycling if a formal e-waste collection and recycling system was available.

Keywords

Electronic waste (e-waste), Disposal behaviour, Consumer attitudes, Consumer awareness, Toxic waste

1. Introduction

This paper examines the creation and disposal practices of electronic products that have reached end-of-life and/or been discarded by consumers without intention to reuse. The paper uses an ecosystem framework that invites a critical examination of people (e-waste workers), business owners, consumers in communities, as well as broader policies, in order to identify the strengths and weaknesses in the transactional processes between these systems. Known variously as waste electrical and electronic equipment (WEEE), electronic waste or e-waste, this is the fastest growing stream of waste in the world

(Fu et al. 2018; Oleszek et al. 2018), estimated to be 44.7 million tonnes in 2016 for the world (Baldé et al. 2017). As this study also identifies, the volume of e-waste globally has been rising at approximately 4.2% per annum over the period 2010 to 2016. Based on indicated volumes, other studies suggest the worldwide volumes of e-waste will continue growing at the rate of 3.2% per annum, which amounts to an annual generation of around 52.2 million tonnes by 2021 (Abdelbasir et al. 2018; Alghazo et al. 2019; Baldé et al. 2017). This rising volume of waste is cause for further concern when allied to the fate of discarded electronic devices. Currently, only 15% of the e-waste is being recycled (Heacock et al. 2016; Kumar, Holuszko & Espinosa 2017; Sahajwalla & Gaikwad 2018). Conversely, these studies flag the reality that the significant majority of e-waste is undocumented and unaccounted for.

In both, developed and developing countries, management of e-waste is a challenge where stockpiling of e-waste is the dominant method of disposal (Borthakur & Govind 2018; Li, J et al. 2015; Pérez-Belis, Bovea & Simó 2015; Sarath et al. 2015; Wagner 2009). Other common methods include disposal via municipal waste (Baxter et al. 2016; Speake & Yangke 2015), formal disposal through designated collection points in some developed countries such as in European Union and Japan, while developing countries such as China, India and Pakistan are heavily reliant on informal disposal methods (Awasthi, A K, Wang, Awasthi, et al. 2018; Awasthi, A K, Wang, Wang, et al. 2018; Gu et al. 2016; Umair, Anderberg & Potting 2016). Transboundary movement of e-waste is another concerning method of disposal, where around 80% of the e-waste generated in developed countries is exported to the developing countries like China, India, Pakistan, Ghana and Nigeria (Illés & Geeraerts 2016; Sthiannopkao & Wong 2013). Considering the common ways of e-waste disposal worldwide, it is highly likely this remaining undocumented e-waste ends up as landfill in municipal waste or is exported to developing countries, where it is stockpiled and recycled, mostly using improper and hazardous methods (Bakhiyi et al. 2018; Ongondo, Williams & Cherrett 2011). In order to control the transboundary movement of e-waste, an international law called The Basel Convention was introduced in 2002 with aim to prohibit the dumping of hazardous waste from developed to developing countries (Basel Action Network 2011). At a regional level, European Union has been the first to devise and implement the e-waste management practices such as Extended Producer Responsibility (EPR) (Khetriwal, Kraeuchi & Widmer 2009). Other developed countries including Japan, Australia, Canada and USA followed and now have their e-waste management systems (Amit & Maria 2016; Mmereki et al. 2016). Moreover, developing countries are now implementing the e-waste management regulations as evident by the ban imposed by China that will force exporting developed countries to find alternate solutions.

The volume and the lack of accountability of large volumes of e-waste make e-waste management a global challenge of increasing significance. The issue is not just the volume of e-waste being generated upstream. Another under realised issue is the downstream consideration related to value of e-waste (Chancerel et al. 2015; Golev & Corder 2017; Golev, Corder & Rhamdhani 2019; Li, Z et al. 2019) and associated toxicity of associated materials in e-waste, particularly when disposal methods are informal (Huo et al. 2019; Kim et al. 2019; Stubbings et al. 2019; Wu, Gao & Wang 2019; Zhang et al. 2019; Zhou et al. 2019). E-waste material typically include high value components such as gold and lithium, but it also contains lead, arsenic and mercury that are hazardous to the environment and pose serious risks to human health (Rubin et al. 2014; Savvilotidou, Hahladakis & Gidarakos 2014; Yu, Williams & Ju 2010). The effect overall is that e-waste disposal can, on the one hand, result in often rare and valuable resources being depleted and/or wasted (Zeng et al. 2017), while on the other hand, it is contributing to a large and growing volume of e-waste being disposed or recycled using improper and hazardous methods (Ackah 2017; Moletsane & Venter 2018; Nnorom & Osibanjo 2008; Sthiannopkao & Wong 2013). As related studies also show, these improper or 'informal' methods include open burning and dumping, which in turn poses serious environmental costs, as well as equally serious risks to human health (Awasthi, Abhishek Kumar, Zeng & Li 2016; Cesaro et al. 2017).

1.1. The context of Pakistan

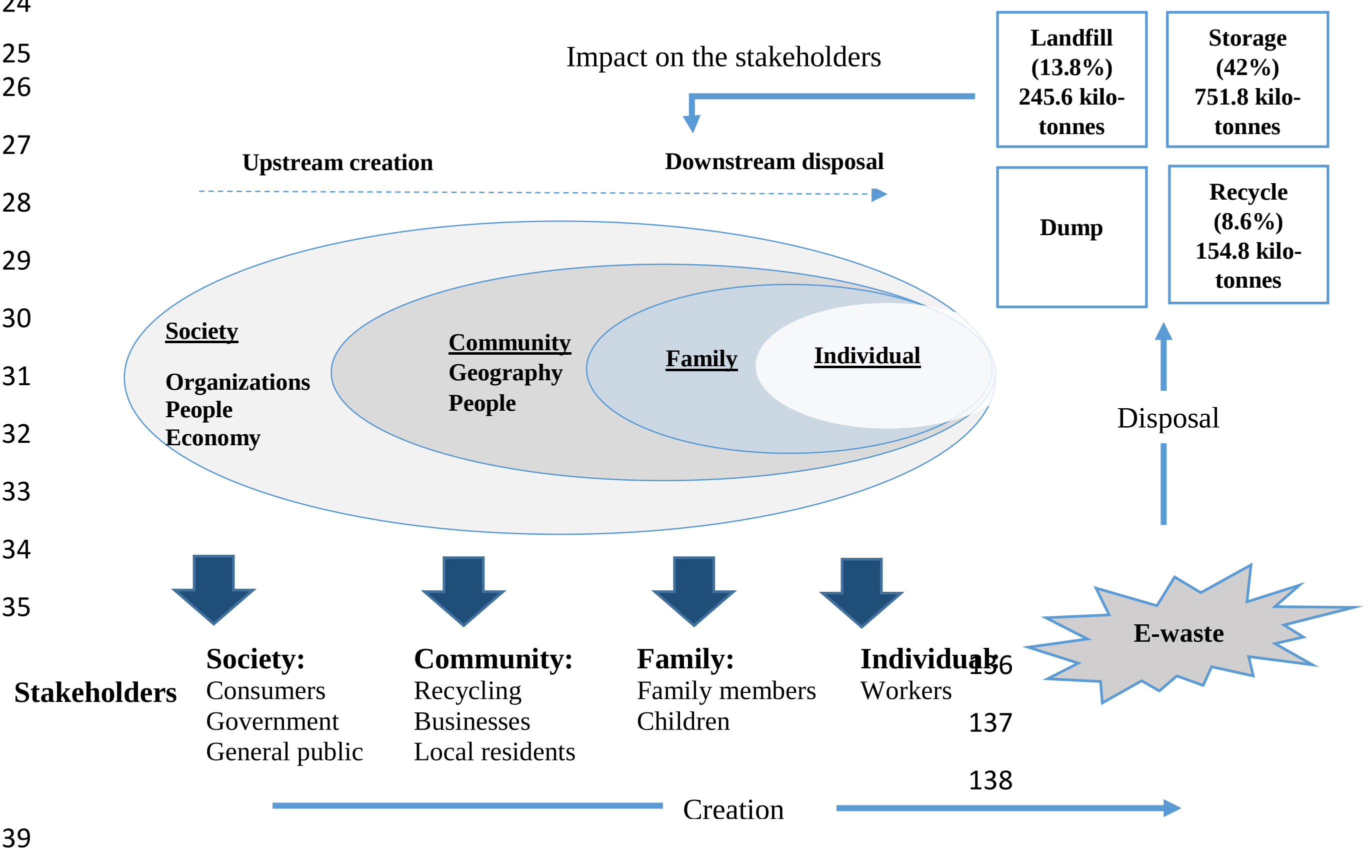
Pakistan is one of the largest producers of electronic waste. However, unfortunately, there is as yet no quantification of inventory flows of e-waste in the country (Iqbal et al. 2015). According to a UN report, Pakistan is the 26th largest producer, that generated approximately 301 kilo-tonnes of electronic waste in 2016, rising at the rate of 11% every year from 266 kilo-tonnes in 2014 (Baldé et al. 2017; Baldé et al. 2015). The surge is the result of two factors. Firstly, high technology up-take and increased consumer demand prompted by the ready availability of affordable Chinese electronic products. Secondly, the country has become an attractive destination for e-waste disposal because like other developing countries, it has cheap labour and a lack of government regulations and accountability (Awasthi, Abhishek Kumar, Zeng & Li 2016; Imran et al. 2017; Nnorom & Osibanjo 2008). Pakistan receives about 8% of the total global e-waste generated in the categories of laptops and desktop computers, while most of the trade in terms of physical goods in South Asia also flows through the country (Baldé, Wang & Kuehr 2016).

The net effect of a drastic increase in locally generated e-waste and the import of externally produced waste, plus the lack of proper disposal and recycling infrastructure in Pakistan, is an over reliance on crude and informal methods of recycling and growing hazardous environmental, social and human health impacts (Abbas 2010; Imran et al. 2017; Iqbal et al. 2015; Iqbal et al. 2017; Umair, Björklund & Petersen 2015). Proper e-waste management system is crucial to minimize these impacts, but the most important contributor to successful e-waste management systems, including take-back and recycling initiatives, is public awareness (Afroz et al. 2013; Borthakur & Govind 2018; Echegaray & Hansstein 2017; Ongondo & Williams 2011). Moreover, as related research identifies, after ICT equipment reach their end of useful life, the factor that typically hinders effective recycling most is low collection rates of these equipment, including mobile phones (Mishima & Nishimura 2016). In turn, the primary reason given for low collection rates is ignorance on how to properly dispose e-waste, which leads to many stockpiling old and unused equipment (Ongondo, Williams & Cherrett 2011; Welfens, Nordmann & Seibt 2016).

1.2. Study aim

The aim of the paper is to critically review the creation and disposal of electronic waste, using an ecosystem framework. The study is based in Pakistan, the 26th largest producer of e-waste, but is also the recipient of e-waste from other exporting nations (Baldé et al. 2017; Baldé, Wang & Kuehr 2016; Imran et al. 2017). Survey results indicate that in Pakistan, the local generation of electronic waste (extrapolated) is some 281 million in terms of equipment or 1,790 kilo-tonnes (2018-2019). The paper illuminates the often hard to measure and less visible 'upstream' considerations, such as volumes and attitudes of consumers that drive buying and disposing decisions. The proposed ecosystem framework that has been used successfully in complex health and other social interventions (Thomas 2019; World Health Organization 2002) is illustrated in Figure 1 below. The ecosystem is a well-used and recognised framework that is used to illustrate multiple stakeholders with overlapping interests, which can contribute to the complexity of many social issues.

Figure 1: Stakeholders in an e-waste Ecosystem (with illustrative volumes)



E-waste management and its disposal from the perspective of an eco-system is contrasted by the general view of waste management (including e-waste), which emphasises the 3Rs – Reduce, Reuse and Recycle (Das et al. 2019; Ho et al. 2017; Jelić et al. 2018; Mostafa & Peters 2017). The 3R approach has worked with some types of recycling, such as plastics, where efforts are employed in terms of recycling and in new product creation (Liu, Z et al. 2018; van Heek, Arning & Ziefle 2017). However, the 3R approach is arguably not sufficient for e-waste management, which requires a collaborative and multi-disciplinary approach across national governments and between governments, non-government organisations, industry groups, including recycling businesses, and also civil society down to local levels. An eco-system framework provides this necessary multi-faceted view of the fastest growing stream of waste, with primary prevention strategies that must go upstream to influence the creation of e-waste at consumer and government policy levels. In addition, the ecosystem framework conceptually supports necessary secondary interventions related to responsible disposal and recycling of subsequent e-waste in order to minimise the downstream impact on less powerful and currently voiceless stakeholders and the general environment (Thomas 2019; World Health Organization 2002).

The rationale behind this study is that consumers are the main beneficiaries and contributors of e-waste due to their respective consumption and disposal behaviours (Afroz et al. 2013; Bovea, Pérez-Belis & Quemades-Beltrán 2017; Islam et al. 2016). Moreover, as related studies note, the purchase, use and repair patterns play an important upstream role in the creation of e-waste (Babbitt et al. 2009; Sabbaghi & Behdad 2018), while attitudes to disposal determine the subsequent fate of a large proportion of e-waste (Welfens, Nordmann & Seibt 2016). As well, collection rates will increase if there are suitable recycling or otherwise responsible disposal options via formal channels, as opposed to the current reliance on hazardous informal methods (Favot & Grassetti 2017). Consequently, given responsible disposal and recycling depends on certain attitudes highlighted by Borthakur and Govind (2017), this research will look to determine:

(i) Socio-cultural factors, such as education, age, gender, environmental awareness, ideology.
(ii) Economic factors, such as income, willingness to pay for recycling processes.
(iii) Infrastructural factors, such as familiarity with recycling, available options to disposal including door-to-door collection facility or proximity to the drop off sites.

2 will discuss the methods of empirical research, including the questionnaire design, the description of data, data collection and data analysis methods. 3 will report the results of quantitative analysis, while 4 will discuss the implications of findings and 5 will provide some concluding remarks.

2. Methods

To conduct this study, primary data was collected and a survey questionnaire was developed using factors identified by Borthakur and Govind (2017) and Schluep, Müller and Rochat (2012). This study reports quantitative findings on the creation and disposal of e-waste. As well, a parallel qualitative study exploring the downstream perspectives and experiences of recycling workers was conducted. Although not specifically reported in this paper, insights gained help to provide perspective to some of the quantitative findings in this study.

Data and variables: European Union WEEE (Waste Electrical and Electronic Equipment) Directive has classified e-waste into 6 categories based on the treatment, which include temperature exchange equipment, screens, small equipment, lamps, small IT and telecommunications equipment, and large equipment. For the purpose of this study, only two categories have been selected – "Screens" and "Small IT & telecommunications equipment". The description and corresponding UNU Key (globally comparative) of included equipment have been outlined in Table 3 (see Appendix).

The variables measured through the survey include the quantities of electrical and electronic equipment, which are then extrapolated to the population of Pakistan. Other variables include the sources and reasons of buying electrical and electronic equipment (EEE), the useful life, usage and disposal behavior, awareness about the toxic and precious elements and the willingness to pay for proper electronic waste recycling. Further details of variables are listed below:

Acquisition

- The total quantity of equipment (the quantity of equipment in use and not in use).
- The sources and preferences of buying equipment.

Usage

- Estimate the useful life of equipment

Disposal (reasons for informal disposal as opposed to formal)

- The actions (attitude/cultural norms) towards non-functioning equipment
- Available (and accessible) disposal options
- The attitude towards disposal

Awareness

- Awareness about hazardous substances
- Awareness about valuable and precious metals

Willingness to pay

- Willingness to take responsibility
- Willingness to pay a charge for disposal and recycling
- Willingness/motivation to return used/old equipment

Data collection: The questionnaire was piloted using a small sample in Melbourne, Australia. Following suitable amendments, the online version of questionnaire was distributed to consumers of electrical and electronic equipment, excluding the corporate sector, residing in Pakistan. The participants were recruited through formal (professional) and informal social media networks, and through social media groups in Pakistan. The groups respectively helped recruit participants from different socio-economic and educational backgrounds, located at different geographical regions of Pakistan. However, this method of recruitment understandably excluded a large group of consumers unable to read and complete an online questionnaire, and those who do not use social media or electronic means of communication. Therefore, to overcome the bias, questionnaires were also distributed using hard copies by the researcher to this category of typically low income and less educated consumers, who in many cases also required assistance to complete the questions.

The sample included participants based on selected demographics such as age groups (18 years and above), education level, household income level, occupation and city of residence. Some 600 questionnaires were distributed over the period September 2018 to March 2019. In all, 210 were completed, while a further 118 respondents dropped out halfway through the survey. The 210 completed questionnaires were filtered to exclude respondents under 18 years of age and those not residing in Pakistan. Subsequently, 191 questionnaires were available for analysis, which were mainly from the two cities of Karachi and Hyderabad that represent around 12.8% of Pakistan's population. The response rate is around 35%, possibly due to several reasons. Firstly, in a developing country like Pakistan, there is low motivation to participate when there is no return/benefit involved, or if the impact of the study is not immediately visible. Secondly, people are culturally more responsive to and trusting of people they personally know. Understandably, response rate was low, further impacted by possible concerns related to perceived privacy and security issues of disclosing the number of equipment (assets they own). Thirdly, since this is an environmental concern, there is reluctance to disclose and highlight the negative aspects. Lastly, there was low response rate and high drop-outs due to some questions in the survey that prompted the respondents to think deeply, such as to identify the number of equipment currently in use and not in use. Nevertheless, the sample size of 191 is deemed adequate, firstly because it is an exploratory study to unpack a highly complex and under-researched area. This study will set the groundwork for deeper, more extensive studies. Secondly, the sample size adequacy is also warranted by Sekaran (2003), who contends that sample sizes larger than 30 and less than 500 are appropriate for most research. Some of the previous studies have used similar sample size of 200 and 148 to estimate the generation and disposal behaviour (Dwivedy & Mittal 2013; Sajid et al. 2019). Each response in the survey was for a household – meaning it included data for more than one person; responses were recorded on Qualtrics and exported to MS Excel and SPSS for analysis.

Data Analysis: The collective data is quantitative and non-normal in nature, even though efforts have been made to include participants from all socio-economic backgrounds. The data has been summarised using descriptive statistics. Extrapolation for the quantities has been made based on income levels of the sample and the population. Further, correlation and statistical analysis has been carried out based on demographic factors, where comparisons were made with behaviour and practices. For instance, the significance of relationships between the behaviour and demographic factors has been studied using non-parametric statistical tests, such as Pearson Chi-square test of independence, Goodman and Kruskal's Gamma (ordinal by ordinal) and Phi/ Cramer's V (Nominal by Nominal). The Pearson Chi-square is a non-parametric test used to analyse group differences when the dependent variable is measured at the nominal level (McHugh 2013). It does not require the equality of variance among the study groups or homoscedasticity in the data. Therefore, it is a rich tool in estimating the significance in relationships for non-normal data sets. The analysis has been conducted based on the equipment type.

3. Results

3.1. Demographics

The data was collected principally from two cities – Karachi and Hyderabad, in Sindh province. Data from all other cities are grouped into one category for analysis. Survey participants were aged 18 years and above, with the majority of participants young, in the age group of 25-34. The respondents were male (76%) and female (24%), respectively. Participants from different socio-economic background were included, based on education and income levels. The majority of participants had completed an undergraduate or postgraduate degree. Monthly household income for the majority of respondents was above Rs.50,000, which represents the top 20% of Pakistan's population. For the purpose of analysis, household income groups were categorised into 3 groups. The first group (less than Rs.24,000 or USD 170.43 per month[1]) represents 40% of Pakistan's population, the second group (Rs.25,000 to Rs50,000 or USD 177.5 to USD 355.06 per month) represents another 40% of total population, while the third group (more than Rs.50,000 or USD 355.06 per month) corresponds to some 20% of the total population of Pakistan. Table 4 (in Appendix) presents the detailed demographic information of participants.

3.2. Equipment Quantities

The total quantities of each type of equipment (in use and not in use) were calculated to be 2810 equipment for the sample as detailed in Table 6 (Appendix). The total family members in the sample include 867 adults (above 18 years) and 332 children (below 18 years). Based on these numbers, there are 17 equipment per household, with each adult estimated to own about 4 equipment each. With children included, there are 3 equipment per person in Pakistan.

Mobile phones (including smart phones and pagers) were found to be the dominant type of equipment in numbers, comprising some 27% of the total number of equipment. Interestingly, the consumers identified some 15% of the total number of equipment as not in use. Since the high-income category was over-represented in the sample, these quantities might be overstated, and usage related attitudes might be biased. Therefore, subsequent analysis will need to distinguish responses based on the income level, rather than the sample as a whole.

Comparing the quantities of equipment according to the levels of income, it can be observed that the lowest income category (earning less than Rs.25,000) representing 12% of the sample, owned just 5.8% of the total equipment. The second category (earning Rs.25,001-Rs.50,000) representing around 18%

[1] Equivalent income in USD has been calculated using the exchange rate of PKR 140.82/USD as of 31 March 2019.

of the population had around 9.5% of the total equipment. Therefore, the number of equipment (total proportion) owned by the two low-income categories was half their sample size proportion. On the contrary, the highest income category (earning above Rs.50,000) was 61.7% of the sample and owned around 84.7% of the total equipment.

Quantity estimates for the population of Pakistan

The total number of equipment for the population of Pakistan were extrapolated based on the proportion of income groups and the number of equipment owned by each income group in the sample (see Table 8). First, population size was estimated to be 184 million, based on the number of mobile phone subscribers, which were 160 million, adjusted for total equipment not in use (15% of the total equipment). Second, population had to be divided based on income levels. So, the data of population across income categories was obtained from Table 11 (Pakistan Bureau of Statistics 2017b) of Household Integrated Economic Survey (2015-2016) (Pakistan Bureau of Statistics 2017a). The survey reported the population and average monthly income (Rs.) in quintiles as shown in the first row of Table 5.

Based on the average monthly income and percentage of population in each quintile, sample income categories were adjusted from seven to just three categories. Then, corresponding percent of population was calculated for each income category. According to the calculations, 40% of Pakistani population earns less than Rs.25,000 per month, 40% population earns between Rs.25,001 to Rs.50,000 per month and only 20% population earns more than Rs.50,000 per month. The population size was adjusted and divided according to percentage population in three income categories. Extrapolated total number of equipment was calculated using the number of equipment per person and adjusted population in each income category (see Table 7 for calculations). The extrapolated total number of equipment (e-waste) was also calculated by type of equipment (Table 8). Finally, the number of equipment was converted to weights based on the typical weights of each equipment. The typical weight was estimated (see Table 9) from the data on the websites of respective manufacturers and retailers (Dell, HP, Lenovo, Apple, LG, Harvey Norman, Amazon).

Results of this extrapolation suggest that there are presently 281 million equipment (1,790 kilo-tonnes) in Pakistan, out of which 15% (42.15 million equipment or 268 kilo-tonnes) are not in use and could be described as deferred waste. It is important to highlight that these estimates are valid just for personally owned and used equipment/e-waste, as no data was collected from the commercial or corporate sector. The equipment currently in use will become e-waste after the end of useful life. The annual growth in e-waste can be expected to be near 11% based on the growth rates exhibited by the estimates of Baldé et al. (2017) for Pakistan as opposed to the global growth rate of 3.2%.

3.3. Acquisition:

This sub-section identifies the upstream motivation and attitudes reported by consumers towards technology uptake and acquisition. This behaviour determines the rate of creation of electronic waste.

3.3.1. Why people buy new equipment?

According to the results (Table 10 in Appendix), most commonly, people in Pakistan purchase new equipment if and when their current device gets damaged or otherwise rendered non-functional. The second most common reason was when the equipment was lost or stolen. The third ranked reason was to upgrade due to outdated functionality, and the least important reason was an upgrade due to outdated style. These reasons suggest that Pakistani consumers usually tend to buy new equipment based on needs and not as a luxury item or in order to get a new model, whenever this newer item was introduced in the market.

To explore if the reasons for new purchase decisions depend on demographic factors, a comparison was made with income levels, age groups, the city of residence and gender.

Income level and the reasons for purchase decisions

Comparing the reasons for purchase according to income levels, all income groups are equally likely to change devices due to damage, loss/theft and interestingly in order to upgrade the equipment if perceived as being updated in style. However, a significant difference was found for upgrades due to outdated function, whereby the highest income group is more likely to change the equipment for upgraded functionality (80%) as compared to the low-income groups (15.4%) who tended to regard it as unimportant (Table 1 below).

Age groups and the reasons for purchase decisions

There are no significant differences noted in reasons for purchase decisions across different age groups. Rather, all age groups tend to have similar reasons for buying new equipment.

City of residence and the reasons for purchase decisions

Comparisons of the reasons across the city of residence and income groups were not found to be significantly different (Table 11 in Appendix). It can be concluded that the reasons for purchase do not depend on the city of residence and are similar.

Gender and the reasons for purchase decisions

Comparing the importance of each reason for both genders, it is found that male and female find the reasons of “damage”, “lost/stolen” and “upgrade due to outdated function” equally important. However, for the least important reason of “upgrade due to outdated style”, a moderately significant relationship/difference is found between the two genders (Table 1 below). The relationship is significant at 0.05 level. Male tend to be more tech savvy and are more likely than female to change their electronic devices because of a new model and associated features. Around 84% male respondents ranked the upgrade due to outdated function as an important reason to buy a new equipment, as opposed to 15.6% female.

Table 1: The reasons for purchase based on gender and income levels

The reasons for purchase based on gender							
		Important		**Not important**		**Total**	
Damage	Male	71	71.00%	59	83.10%	130	76%
	Female	29	29.00%	12	16.90%	41	24%
	Total	100	100.00%	71	100.00%	171	100%
	Pearson Chi-square 3.334 (0.068)						
Lost/stolen	Male	64	71.90%	66	80.50%	130	76%
	Female	25	28.10%	16	19.50%	41	24%
	Total	89	100.00%	82	100.00%	171	100%
	Pearson Chi-square 1.723 (0.189)						
Upgrade – outdated function	Male	62	77.50%	68	74.70%	130	76%
	Female	18	22.50%	23	25.30%	41	24%
	Total	80	100%	91	100.00%	171	100%
	Pearson Chi-square 0.180 (0.672)						
Upgrade – outdated style	Male	54	84.40%	76	71.00%	130	76.02%
	Female	10	15.60%	31	29.00%	41	23.98%
	Total	64	100.00%	107	100.00%	171	100.00 %
	Pearson Chi-square 3.914* (0.048)						
The reasons for purchase based on income levels							
		Important		**Not important**		**Total**	
Damage	Less than Rs.25,000	13	13.00%	7	9.90%	20	11.70%
	Rs.25,001 to Rs.50,000	20	20.00%	12	16.90%	32	18.70%
	More than Rs.50,000	67	67.00%	52	73.20%	119	69.60%
	Total	100	100%	71	100%	171	100%
	Pearson Chi-square 0.769 (0.672)						
Lost/stolen	Less than Rs.25,000	10	11.20%	10	12.20%	20	12%
	Rs.25,001 to Rs.50,000	19	21.30%	13	15.90%	32	19%
	More than Rs.50,000	60	67.40%	59	72.00%	119	70%
	Total	89	100%	82	100%	171	100%
	Pearson Chi-square 0.848 (0.654)						
Upgrade – outdated function	Less than Rs.25,000	6	7.50%	14	15.40%	20	12%
	Rs.25,001 to Rs.50,000	10	12.50%	22	24.20%	32	19%
	More than Rs.50,000	64	80.00%	55	60.40%	119	70%
	Total	80	100 %	91	100%	171	100%
	Pearson Chi-square 7.075* (0.021)						
Upgrade – outdated style	Less than Rs.25,000	10	15.60%	10	9.30%	20	11.70%
	Rs.25,001 to Rs.50,000	11	17.20%	21	19.60%	32	18.71%
	More than Rs.50,000	43	67.20%	76	71.00%	119	69.59%
	Total	64	100%	107	99.90%	171	100%
	Pearson Chi-square 1.562 (0.458)						
*Significant at 0.05 level							

3.3.2. What condition?

In order to determine the preference for buying used equipment, the consumers were asked about the condition of products they preferred when buying a new equipment. A large majority (73%) preferred to buy brand new equipment, as opposed to second-hand or used equipment (Table 12 in Appendix). These results might be dependent on demographic factors such as income level, age groups, gender and the city of residence.

Preferred condition according to income level and age groups

The preference for new equipment is seen to significantly depend on the income level for almost all of the equipment types. High-income groups bought more new equipment, while low-income groups preferred used equipment. Similarly, the preference significantly depended on age groups, wherein young participants (18-34) preferred new equipment, while older participants relied on used equipment.

Preferred condition according to the gender

Comparing the preference of equipment condition according to gender, there is no significant relationship noted, implying that majority of the people prefer to buy new equipment, irrespective of the gender (Table 13 in Appendix).

Preferred condition according to the city of residence

A significant difference was found in the preferred condition of Cathode Ray Tube monitors across different cities (Table 14 in Appendix). A large number of respondents in Karachi had no preference about the condition, presumably because it is obsolete technology and not bought frequently. In addition, across cities, new CRT TV is preferred in Karachi, while used equipment (for relative cost benefits) is more preferred in Hyderabad.

3.3.3. Where do consumers buy equipment?

Majority of the respondents buy their equipment from a local electronics market, where both new and second-hand equipment are readily available. The second most common source of purchase is direct from the company. There is a lesser tendency noted by consumers to buy equipment online possibly because of low trust in online vendors and quality on delivery.

3.4. Lifecycle

The expected useful life for each type of equipment was determined by how frequently consumers change each product. Results are presented in Table 16 (Appendix). A large proportion of sample reports never buying CRT televisions and CRT monitors or they buy new after using the old CRT televisions or monitors for more than 10 years. The life of CRT televisions and monitors is longer as compared to flat panel televisions and monitors, which is up to 10 years. In contrast, smaller equipment like mobile phones and the computer mouse are turned over after 2 years, while routers, modems, keyboards remain in use up to typically 5 years. For impact of demographic factors on useful life or equipment, comparisons were made across the levels of income, age, gender and the city of residence.

Table 2: Impact of income level and age on the expected useful life

Income and age with the expected useful life (Goodman and Kruskal's Gamma)					
		Value (Gamma)	**Asymptotic Standard Error[a]**	**Approximate T[b]**	**Approximate Significance**
Television (Cathode Ray Tube)	Income	-0.350*	0.139	-2.494	0.013
	Age	0.239	0.132	1.755	0.079
Flat panel televisions (LCD, LED, Plasma)	Income	-0.150	0.229	-0.659	0.510
	Age	0.030	0.014	0.206	0.837
Desktop PCs (excluding monitors & accessories)	Income	-0.057	0.275	-0.208	0.835
	Age	-0.045	0.181	-0.246	0.806
Monitors (Cathode Ray Tube)	Income	-0.079	0.338	-0.233	0.815
	Age	0.146	0.275	0.054	0.593
Flat panel monitors (LCD, LED, Plasma)	Income	-0.017	0.272	-0.062	0.951
	Age	0.155	0.161	0.952	0.341
Routers & modems	Income	-0.134	0.282	-0.471	0.637
	Age	-0.053	0.153	-0.351	0.725
Keyboards	Income	0.039	0.230	0.170	0.865
	Age	0.008	0.160	0.050	0.960
Mouse	Income	-0.044	0.251	-0.174	0.862
	Age	-0.022	0.156	-0.139	0.890
External drives	Income	0.573	0.257	1.294	0.195
	Age	0.180	0.190	0.928	0.354
Printers, scanners, faxes, multi-functional	Income	0.090	0.286	0.309	0.757
	Age	-0.235	0.208	-1.124	0.261
Laptops, notebooks & tablets	Income	0.187	0.229	0.803	0.422
	Age	0.277*	0.124	2.158	0.031
Telephones, cordless, answering machines	Income	0.029	0.277	0.104	0.917
	Age	-0.083	0.160	-0.525	0.600
Mobile phones, smart phones, pagers	Income	0.119	0.132	0.906	0.365
	Age	-0.096	0.111	-0.856	0.392
GPS (Global Positioning System)	Income	-	-	-	-
	Age	-0.600	0.296	-1.628	0.104
Pocket calculators	Income	0.361	0.255	1.180	0.238
	Age	-0.007	0.184	-0.041	0.968
Game consoles	Income	-1.000	0.000	-1.039	0.299
	Age	-0.137	0.258	-0.523	0.601

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.
*Significant at 0.05 level

Expected useful life according to income level

All income groups are likely to buy all types of equipment with similar frequency except CRT Televisions (Table 2). There is negative relationship between the frequency of buying CRT TVs and the income level. The relationship is significant at 0.05 level. Higher income groups are less likely to buy any CRT TV, while people from the low-income group buy CRT TVs after more than every 2-5 years. For instance, 89% of the highest income group respondents never buy a CRT. In contrast, around 40% of the lowest-income category group respondents report they buy a CRT TV any time after between 2- 5 years of use.

Expected useful life according to age groups

All age groups are likely to buy all types of equipment with similar frequency, except laptops, notebooks and tablets (Table 2). A positive relationship is noted between the age group and useful life of laptops. The relationship is significant at 0.05 level. The majority of respondents between the ages of 18-34 years tend to change their laptops within 2-5 years. In contrast, older respondents in the age group of 45-55 years use their laptops for longer periods and change equipment after 5-10 years.

Expected useful life according to the gender and city of residence

Comparisons across the categories of gender revealed significant differences in the expected useful lives of flat panel television, routers and modems, laptops, notebooks and tablets. Women tend to use this equipment for longer periods than men. Similarly, the results of comparisons of cities did not have significant differences.

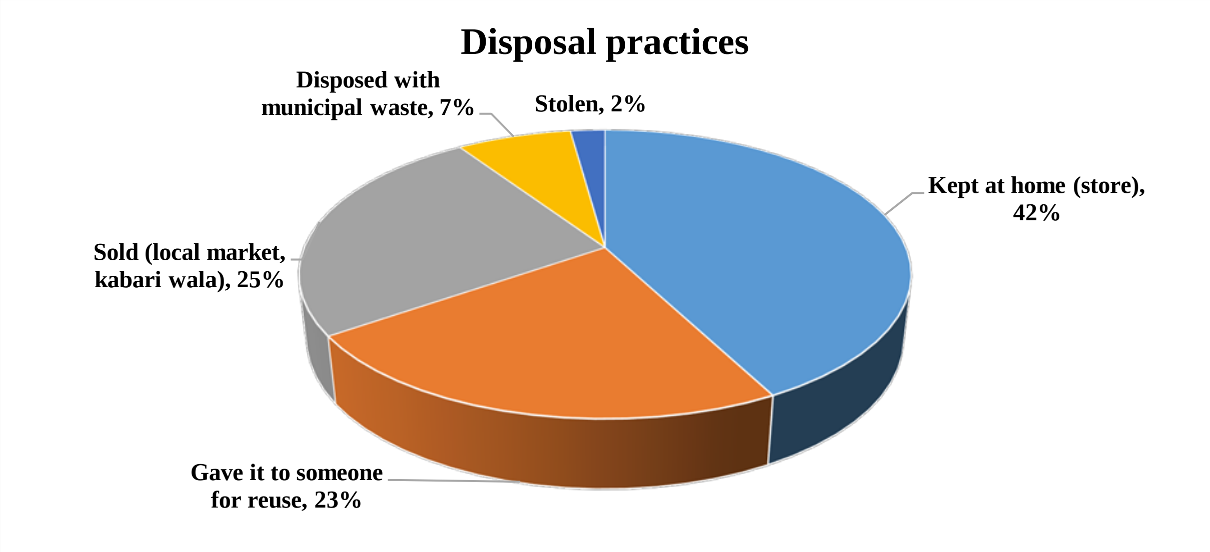
3.5. Disposal

After (or even before) the completion of useful life, if the equipment stops working for any reason, the first instinct for the majority is to try to get it repaired (Table 17 in Appendix). This suggests that Pakistan is arguably not (as yet) a throwaway society. However, if it cannot be repaired or getting it repaired is inconvenient, consumers tend to discard the old equipment and buy a new one. Continuing to use the equipment even if it is damaged is the least popular action, assuming continuing functionality, possible only in situations where it is difficult to afford new equipment.

Exploring possible disposal methods of used equipment (e-waste) in Pakistan, it was found that stockpiling or storage was very prevalent (42%), followed by selling equipment (25%) because it is usually deemed valuable. The third common method was to give the equipment away for reuse (23%), while 7% of equipment went to the landfill via municipal waste and 2% were reported as lost or stolen.

Figure 2 below shows the percentages for each disposal method. Extrapolating for the population, out of the total 281 million equipment (1,790 kilo-tonnes), 42% or 118 million equipment (751.8 kilo-tonnes) are likely to be stored, while 7% or 19.67 million equipment (125.3 kilo-tonnes) are likely to end up in the landfill, with consequent downstream negative impacts on the environment and possibly on human health too.

Figure 2: Disposal practices in Pakistan

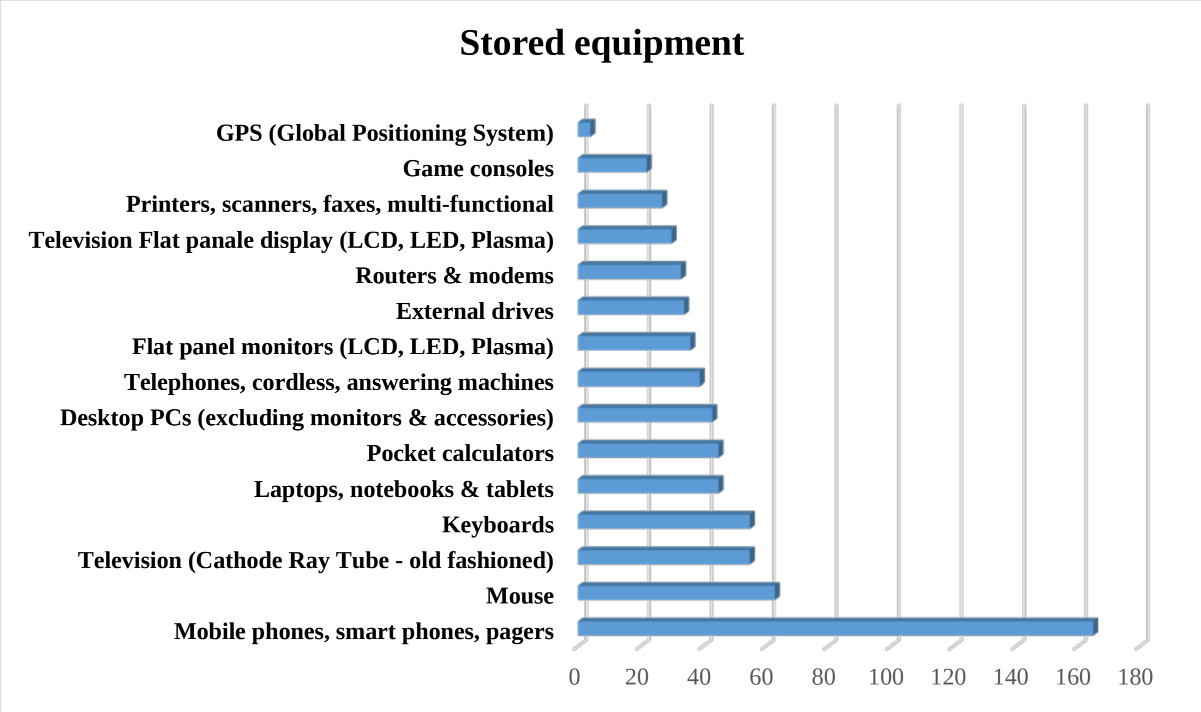


Why people store old electrical equipment

Investigation of the reasons for storage of old electronic equipment highlighted that people tend to hoard equipment as a backup or spare in case they need it later. Another reason was unavailability of (easy access to) any disposal option, so people do not know where and how to dispose electronic waste. This is a major challenge in Pakistan where proper collection systems for e-waste or even municipal waste are non-existent. Other reasons for storage included concerns about the security of data, emotional attachment or perceived intrinsic value of the equipment, general apathy or the feeling that disposal action was troublesome. The reasons have been detailed in Table 19 (Appendix).

Since storage or stockpiling was the dominant disposal method, we further investigated the categories of equipment stored the most. Figure 3 is a summary of the most stored categories of e-waste. Mobile phones were the single widely stored category of equipment, followed by computer mouse. The tendency to store small equipment like mobile phones and the mouse is explained by the fact that they do not take up much space in the drawers or storerooms, and that they have intrinsic value. In addition, mobile phones hold data and there is residual monetary value attached to these equipment, which cannot be recovered if the phones were marked for disposal.

Figure 3: The most stored categories of e-waste



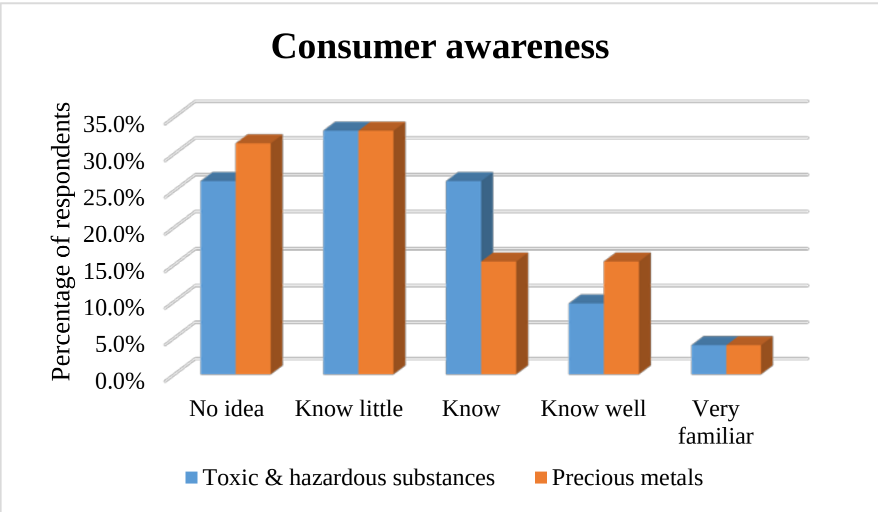
Disposal after storage: Why and how

Stored equipment is typically finally disposed after years when space in the house runs out and nothing more can be stored or when people move houses. However, even after years of storage, some participants reported still wanting to continue storing their e-waste. That said, when some event compels people to dispose the stored equipment, most of the people give their e-waste to someone for re-use or they sell it in the local market or sell to the local waste collector (*kabari wala* in local language) (details in Table 20 and Table 21). The local waste collector, who is a convenient and deeply habituated social feature of life on the sub-continent, typically on-sells these equipment to recyclers, who use informal and usually high-risk toxic methods when recycling electronic waste in order to extract precious metals. Disposal using municipal waste is also a popular choice in the absence of availability of other disposal options, which unfortunately however takes e-waste directly to landfill. The risks from toxic waste by disposal via landfill and informal recycling practices are hard to see, but also certain.

3.6. Awareness

Awareness is a key to responsible usage and disposal, as it can make an e-waste management system effective. The awareness of the presence of *toxic and hazardous substances* such as lead, mercury and arsenic in e-waste is high (Figure 4 below). The results show that 75% of the respondents reported at least some knowledge and the remaining 25% have no knowledge at all. The awareness of the presence of *precious metals* in e-waste is also high overall (70% have at least some knowledge, while 30% have no knowledge). The majority of the people also agree that improper disposal of e-waste can have negative impacts on the environment, and also on human health (Figure 6 in Appendix). The current level of awareness appears improved through education, which was found to have a significant impact (at 0.05 level) on awareness. Highly educated respondents were found to have better awareness of the toxic content, as well as presence of precious metals and negative impact on the environment and human health, as compared to less educated respondents. Results of the statistical tests have been illustrated in Table 22 and Table 23 (in Appendix), respectively.

Figure 4: Consumer awareness about toxic, hazardous and precious elements in e-waste



3.7. Responsibility and Willingness

In order to support the introduction of e-waste management policy, it is important to identify the stakeholders who should and who are willing to take the responsibility. Most of the consumers identified the government as a responsible stakeholder to introduce e-waste management policy and systems (Table 24 in Appendix). Many consumers also believed it was their own or a common responsibility to have proper e-waste disposal and management systems. Therefore, being the ultimate beneficiary of electronic equipment, most of them (65%) were willing to pay a charge for recycling, and most preferred a recycling charge to be embedded in the price of product, so they could pay for it when buying the new equipment (Table 25 in Appendix). A significant minority (35%) disagree with taking financial responsibility. However, noting people are willing to contribute financially to e-waste recycling systems, it is important to explore if this willingness depends on the level of income.

Examining this issue, the differences across income categories was noted as insignificant, implying that people who are in low-income group are equally willing, as much as the people who fall in the high-income group. Therefore, income level appears not to influence the willingness of people to pay for a proper e-waste management system. Further analysis (Table 26) on the willingness to pay according to income levels shows that about 60% of the people are willing to pay up to about 10% of the product price in order to support proper e-waste recycling and management.

Incentive to return/dispose e-waste (take-back)

As discussed earlier, collection rates plays an important role in determining the recycling rates. Therefore, if a take-back system was in place that paid some amount of money to the consumers for returning their e-waste, results indicate that around 87% of respondents were willing to participate and return their e-waste (Figure 7 in Appendix). The remaining 13% appear unwilling to return used equipment due to a lack of trust in the systems and authorities or security of the data/private information. Out of those willing to participate, a payback of up to 10% can motivate around 40% of the consumers to return their e-waste through the take-back system, while a payback of up to 20% was identified as able to motivate around 76% of consumers (Figure 8 in Appendix).

4. Discussion

As noted earlier, this paper set out to illuminates the often hard to measure and less visible ‘upstream’ considerations, such as volumes and attitudes of consumers that drive buying and disposing decisions. The results and statistical inference suggest that Pakistan generates around 281 million equipment’s that can be classified as e-waste each year. This is equivalent to 1,790 kilo-tonnes in the period 2018-2019. These quantities include just two categories of e-waste out of six categories under EU-6. Previous studies estimated the total e-waste in Pakistan to be 301 kilo-tonnes in 2016 (Baldé et al. 2017) and 114-138 kilo-tonnes in 2014 (Sajid et al. 2019). The difference between current and previous estimates is due to several reasons. Firstly, the differences could arise because of including different categories of e-waste. This study includes two categories of e-waste, which include screens and small IT equipment. List of the specific equipment in these categories has been provided in Table 3 (Appendix). However, estimation by Sajid et al. (2019) was just for desktop computers and laptops that fall in the category of screens. Baldé et al. (2017) estimate the quantities for all six categories of e-waste. Secondly, the differences in methodology could lead to different estimates. Previous studies mostly base their estimation on trade or sales data; however, in many developing countries such as Pakistan, not all imports are registered. For instance, estimation of Baldé et al. (2017) is based on the sales data, derived from the imports and exports data. Imran et al. (2017) estimated the flow of e-waste using the imports data. Similarly, in order to estimate the e-waste, Sajid et al. (2019) used the sales data, imports (quantity estimated in a news report), e-waste in three cities (Peshawar, Rawalpindi/Islamabad and Lahore) based on the quantities imported, whereby 20-40% of the total quantities was assumed to be the e-waste. Moreover, it was also assumed that the rest of Pakistan, including Karachi generated the same quantities of e-waste as the three cities surveyed. The current study employs a more comprehensive approach of extrapolation using primary data, which is based on the income groups and the population. Finally, the estimates could also be dissimilar due to the different time in which estimates were made.

Acquisition

Viewing consumers as stakeholders in the upstream sector of the e-waste ecosystem helps quantify the creation and disposal challenge of e-waste. Focusing on the acquisition phase, the main source of electrical and electronic equipment in Pakistan is the local electronics markets. These markets source new as well as second-hand equipment from Dubai, the United Arab Emirates, and developed countries such as the USA, UK, Canada and Singapore. New equipment are sourced directly from international electronic manufacturing companies. Assessing the reasons that drive consumer purchase behaviour, it was found that most people bought new equipment if their existing device was damaged, became non-functional, or was lost/stolen. Equipment retention and turnover rates vary, but overall it suggests that Pakistan at large is not a trend- or consumer-driven society that buys new technology simply to upgrade for new style. However, the higher income group tends to upgrade equipment for functionality reasons. This group is cause for concern in terms of the overall contribution to rising e-waste volumes because although representing just 20% of the population, this high-income group appears to generate around 40% of the total e-waste volume. It is also noticeable that the male population is more likely to upgrade for new style than the female, in part because men are more tech savvy but also because advanced equipment is considered to be a status symbol. As technology advances, these factors are likely to accelerate the future growth of e-waste in Pakistan.

A less obvious consideration in more recent times is the trend towards acquiring larger quantities of technology products from China at cheaper prices. However, also a less appreciated reality reported by the recycling workers in the qualitative study suggest that electronic goods are now being made with materials that yield less valuable metals but generate the same levels of toxicity and also require the same efforts to extract the metals. The net effect, consequently, is to make new equipment more affordable for consumers and so more attractive, but also presenting greater downstream costs to both workers and the environment. For instance, Singh et al. (2019) found that technical innovations in the mobile phone designs has not reduced the toxicity during fifteen years from 2001 to 2015. This study suggests, rather, that the relative mass of toxic in waste mobile phones increased (statistically significantly) over this period. As a result of technological innovation and cost reductions, the markets are now flooded with electronic equipment from companies like Q Mobile, Oppo, Changhong Ruba and several others. Findings from this research also reveal a growing inclination towards buying brand new equipment, rather than second-hand products by high-income groups, in contrast to low-income groups that still rely on second-hand equipment.

The paradox of short-term gain – long-term pain

Acquiring cheap new technology represents a paradoxical choice between short-term gain in cost and functionality, but at great longer-term unrealised pain. This is a trap facing Pakistan as increasing volumes of e-waste and resultant increasing volume of e-waste are disposed of using inappropriate recycling and disposal methods. These largely informal, often hazardous, methods lead to heightened risk for recycling workers from exposure to toxic materials that have been shown to pose serious risk to the environment and to human health. Compounding this gain-pain trap is the reality that rewards from recycling have fallen as the content of precious metals that makes recycling attractive has decreased. As a recycling worker voiced:

> "*The increase in waste due to Chinese equipment has negatively impacted our work; earlier if we melted 1kg of gold plated pins, we could extract 3.5-4.5grams of gold and around 30grams of silver; but now silver is just around 18grams and gold is 0.5-2.5grams, so we must extract aluminium to cover the costs and earn money. The efforts in extraction are similar, but the output is less.*"

This anecdotal evidence is supported in the literature. For example, Chen et al. (2016), confirms (see Figure 9 in appendix for the trends in quantities of elements) a sharp decrease in the quantities of precious metals such as gold (107 mg/kg in 1996 to 29 mg/kg in 2010) and copper (235,000 mg/kg in 1996 to 214,000 mg/kg). The decline in the content of precious metal has been reported to be possibly due to resource conservation and cost reduction. In terms of toxicity of waste products, the same study reported a decrease in the use of lead, copper and zinc, but an increase in the contents of other toxic elements such as silver, barium, cobalt, molybdenum, nickel, antimony, vanadium, and specially chromium. The increase has been very drastic in the case of chromium (449 mg/kg in 1996 to 12,800 mg/kg in 2010) and nickel (3290 mg/kg in 1996 to 10,500 mg/kg in 2010). Nickel (Ni) and chromium (Cr) are reported as potentially carcinogenic elements and are regarded as extremely toxic at even small concentrations (Denkhaus & Salnikow 2002; Oliveira 2012; Shen & Zhang 1994; World Health Organization 2000).

In effect, mass production and high uptake of lower-quality, cheaper electrical equipment will likely raise the volume of e-waste creation, while reducing the benefits of recycling and dramatically increase the risk of harm to workers who recycle toxic waste, typically via informal means or indirectly to the environment by e-waste materials going into landfill. This risk is compounded by the preference of consumers who opt for short-term convenience and cost savings (gain), unknowingly incurring often hidden long-term pain for other stakeholders in the ecosystem.

Equipment useful life

Over time, there is evidence of decreased useful life of some electrical and electronic equipment (Akcil et al. 2015; Borthakur & Govind 2017; Tanskanen 2013), while other equipment like CRT televisions and monitors become obsolete. There is also a shift away from desktop computers to now more laptops, notebooks and tablets, particularly by the younger population. These latter equipment have a shorter useful life as compared to desktop computers. The net effect is that this consumer trend also to add to the volume of e-waste generated at the end of their use-by date, some 2-5 years later.

Disposal

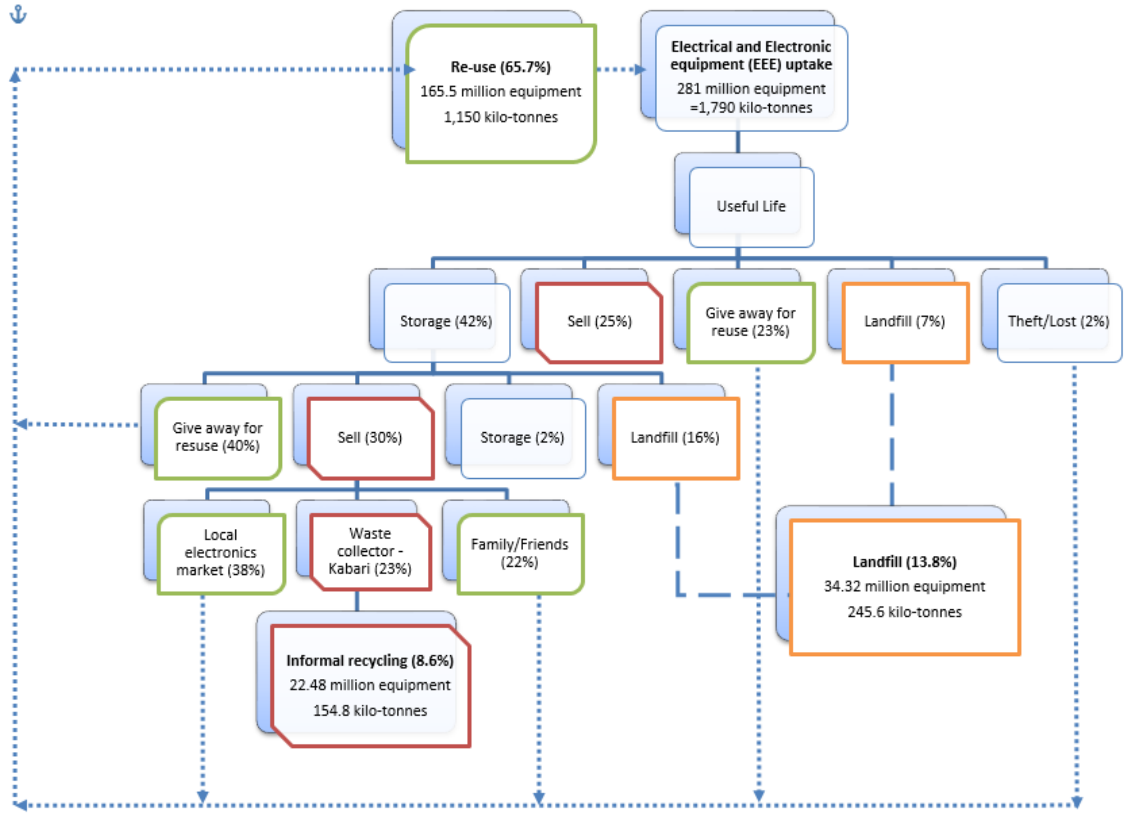
Consumers in Pakistan, like in many other developing countries, see great value in electronic equipment (Liu, X, Tanaka & Matsui 2006). As a result, they prefer to get devices repaired when they break down. However, if electronic equipment cannot be repaired at all or cannot be repaired conveniently, they appear to buy a replacement (new or used) equipment, but with the older devices highly likely to be stored at home. In fact, this study has found that 42% of small goods such as mobiles phones and mouses after being replaced are stored at home. This is the equivalent of 118 million equipment or 751.8 kilo-tonnes of e-waste that collects annually and at some point will need to be disposed of via recycling or some other means. This finding is consistent with other studies that found stockpiling to be the most popular and convenient way of disposal in both developed (Bovea et al. 2018; Nowakowski 2019; Speake & Yangke 2015; Ylä-Mella 2015) and developing countries (Borthakur & Govind 2018; Garlapati 2016; Ongondo, Williams & Cherrett 2011).

The most commonly stored equipment in order of volume is mobile phones, mouse, CRT televisions and keyboards. Equipment like mobile phones, mouse and keyboard are small in dimension, making them convenient to be stored (Casey, Lichrou & Fitzpatrick 2019; Nowakowski 2019). The most frequent reason for this preference for storage or stockpiling is that these are viewed as possible spare equipment that could be used if needed in the future. This view is particularly true in the case of mobile phones. The second most common reason for storage is unavailability of any convenient disposal option. The high storage rate of CRT televisions might be explained by this reason, as well as the fact that CRT televisions are bulky and not easily carried. However, while deferred disposal is a short-term strategy, the longer term reality is that consumers are often forced into disposing old and dated stockpiled equipment's usually in a forced clean out, often by resorting to the most convenient low cost means, which usually means landfill via municipal collection points.

Other than storage, the common disposal practice, as noted earlier, is by selling e-waste to local markets or to a local waste collector (*kabari wala*) who then sells it to the local recyclers for dismantling and recycling. Out of the total estimated e-waste of 281 million equipment (1,790 kilo-tonnes), only 22.5 million equipment (154.8 kilo-tonnes) are recorded as being collected and recycled via (in)formal practices based on crude and usually unsafe methods. Data suggests that some 35.32 million equipment's (245.6 kilo-tonnes) end up in the landfill annually.

A summary of materials flow in the upstream component of the e-waste lifecycle is provided in Figure 5. As the figure shows, with volumes identified at particular points of the cycle, it is possible to begin to track the respective volumes and measure some of the known benefits and costs incurred in e-waste creation and disposal depending on type and method of disposal, be it formal or informal.

Figure 5: Estimated flows of e-waste from upstream creation to disposal destination



Examining the lifecycle of materials illuminates some hard to measure and less visible 'upstream' considerations, such as volumes being generated and attitudes of consumers that drive buying and disposing decisions. The consequence of these decisions can be quantified to illustrate both tangible and less visible (intangible) costs and related considerations down-stream. These costs are implied but not discussed in any depth in this paper, which is focused on upstream consumers behaviour. As the findings section highlighted, Pakistan is not a trend-driven society when it comes to buying new products, nor is it a throwaway society when it comes to disposal. The unrealised result is that electronic equipment that passes its use-by life is stockpiled for their perceived value, but which is ultimately still disposed of by less than ideal means. Issues that cause consumers to not use formal means of recycling include lack of awareness of and access to convenient disposal methods, and perceived value of the obsolete equipment. The net effect is that storage is a significant pathway for initial disposal of old equipment or e-waste, and which in turn is a deferred pathway to selling at local markets or to waste collectors and so ultimately, albeit unintentionally, to disposal by informal and damaging, though expedient methods, such as dumping and landfill.

A lesser understood by the public reality associated with a lot of electronic equipment is that as they age they also release toxic chemical constituents (Peralta & Fontanos 2006). As such, it is evident that there is an unrealised risk that accrues both during storage and when dumped as landfill. The hidden cost is further compounded by deterring the recovery and re-use of potentially useful equipment and component materials (such as gold, silver and palladium), thereby preventing waste reduction (Ylä-Mella 2015), impeding the operations and sustainability of take-back systems and limiting raw material available for recycling (Borthakur & Govind 2017; Speake & Yangke 2015).

Policy Implications

Public's awareness and participation are essential for the success of electronic waste management initiatives and inadequate awareness and/or convenience in disposal systems has been linked to negligent e-waste disposal behaviour (Borthakur & Govind 2017; Echegaray & Hansstein 2017). Results of this study have found that there is a high levels of public awareness about toxic and hazardous substances, the potential environmental and human health hazards and about the presence of precious metals in electronic equipment in Pakistan. The level of awareness is noted as being significantly related to education level. Therefore, at the policy level, there is a need to increase public awareness by educational campaigns focused on the general public and, secondly by taking specific preventative measures to reduce and even remove the hazards associated with e-waste beyond responsible disposal. Beyond raising awareness levels, efforts are clearly also required to provide better and more convenient formal e-waste management and recycling systems that includes a take-back and recycling system in Pakistan.

From the perspective of consumers, this study explores willingness to take responsibility and participate in the e-waste management and recycling systems. Consumer attitudes were positive, with most of the population believing that the government needed to initiate e-waste recycling. Conversely, consumers also indicated that in the majority they were willing to participate and even pay a price for recycling that ideally might be built into the price at the time of purchase. Importantly, this willingness to pay was consistent across low-income and high-income groups. However, in addition to recycling system, high collection rates are also required.

5. Conclusion

This paper illuminates ‘upstream’ considerations in e-waste management using an eco-system framework. The value of this framework is that it also provides a capacity to see issues that are less visible and often, as a consequence, hard to measure. The paper highlights volumes of waste and quantity, as well associated attitudes of consumers that drive buying and disposal decisions. The main methods of disposal in Pakistan are identified as storage, a deferred disposal strategy (42%), informal recycling (8.6%) and disposal via municipal waste into landfills (13.8%). The habit of storage effectively delays final disposal, and unintentionally also ultimately consigns e-waste into informal (and usually unsafe) methods of disposal via local markets and waste collectors, or worse directly into landfills. Disposal decisions appear to depend largely on convenience of available options, although consumers also indicate a willingness to pay for proper recycling of e-waste.

The study reveals a paradoxical trap of ready access in the short-term to cheap electronic product that compounds the lesser visible longer-term downstream negative impact for the country, and particularly voiceless unskilled workers engaged in the recycling process. This issue is arguably being compounded in two ways, again largely unrealised, by a reported recent trend of increased cheaper electronic equipment. First, these equipment offer less return in terms of valuable recycling materials (gold, silver, platinum) and so it makes recycling less attractive for those involved in the business. Second, they also result in more waste that is not recoverable (plastics, lead, mercury, cadmium and even rare earth metals like palladium) and so results in greater volumes of (toxic) e-waste going directly to landfill . This trend is not yet evident in the literature but has been noted by recycling workers interviewed in this study, who are at the coalface. This trend reinforces the need to examine and consider e-waste practices at the ecosystem level as this illuminates and quantifies known and unknown, and even unrealised costs. With the growing trend towards low cost mass production, the effect upstream is to inadvertently shift Pakistan and other emerging countries towards greater consumption, but at great and unrealised downstream cost, as the likelihood is that greater volumes of e-waste product will go directly to landfill. As noted earlier, this interlinked issue presents a paradox, of choosing between short-term gain for ultimately long-term pain felt in the environment and by largely illiterate recycling workers.

This study presents a snapshot of the data focused on the consumer attitudes that generate and contribute to e-waste that is growing at a significant rate. More concerning is the identification of the less visible costs of this waste product and associated consumer behaviour on the environment and on recycling workers. Future studies need to consider a longitudinal approach in order to measure trends in consumer behaviour and the impact of disposal practices. There is also a clear need for effective policy responses focused at both the upstream level to increase consumer awareness and also the downstream level in the form of a responsive e-waste management system that includes improving the convenience on formal disposal, as well as other suitable initiatives. A responsive e-waste management system naturally presupposes investment in e-waste management infrastructure that includes collection and recycling systems, as well as appropriate technology to improve recycling practices.

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Appendix:

Table 3: UNU key and corresponding EEE category under EU-6

UNU Key	**Description**	**EEE CATEGORY UNDER EU-6**
0301	Small IT equipment (e.g. routers, mice, keyboards, external drives & accessories)	Small IT
0302	Desktop PCs (excl. monitors, accessories)	Small IT
0303	Laptops (incl. tablets)	Screens and Monitors
0304	Printers (e.g. scanners, multi-functional, faxes)	Small IT
0305	Telecommunication equipment (e.g. cordless phones, answering machines)	Small IT
0306	Mobile Phones (incl. smartphones, pagers)	Small IT
0308	Cathode Ray Tube Monitors	Screens and Monitors
0309	Flat Display Panel Monitors (LCD, LED)	Screens and Monitors
0407	Cathode Ray Tube TVs	Screens and Monitors
0408	Flat Display Panel TVs (LCD, LED, Plasma	Screens and Monitors
0702	Game Consoles	Small IT

Table 4: Demographics

Demographics	Frequency (N = 175)	Percentage of sample
Gender		
Male	133	76%
Female	42	24%
Age		
18-24 years	63	36.0%
25-34 years	88	50.3%
35-44 years	14	8.0%
45-54 years	5	2.9%
55 years or more	5	2.9%
Education		
No schooling	12	6.9%
Primary (grades 1-8)	10	5.7%
Secondary (grades 9-12)	27	15.4%
Undergraduate	56	32.0%
Postgraduate	57	32.6%
Doctorate	1	0.6%
Professional qualification	12	6.9%
Household Income (Monthly PKR)		
Less than Rs.25,000	21	12.0%
Rs.25,001 to Rs.50,000	32	18.3%
Rs.50,001 to Rs.75,000	23	13.1%
Rs.75,001 to Rs.100,000	29	16.6%
Rs.100,001 to Rs.150,000	16	9.1%
Rs.150,001 to Rs.200,000	14	8.0%
More than Rs.200,000	40	22.9%
City of Residence		
Karachi	97	55.4%
Hyderabad	60	34.3%
Islamabad	5	2.8%
Lahore	3	1.7%
Rawalpindi	2	1.1%
Peshawar	1	0.6%
Quetta	1	0.6%
Sukkur	1	0.6%
Other	5	2.8%

Table 5: Total monthly income according to quintiles

Total monthly income by quintiles					
	1st	**2nd**	**3rd**	**4th**	**5th**
Average monthly income (Rs.)	19,742	23,826	28,020	33,668	60,451
Percent of population	20%	20%	20%	20%	20%
Sample income categories	less than Rs.25,000		Rs.25,001 to Rs.50,000		More than Rs.50,000
Corresponding percent of population	40%		40%		20%

Table 6: The number of equipment (sample)

The number of equipment for each income group (Sample)				
	Income Groups			
Type of Equipment	**less than Rs.25,000**	**Rs.25,001 to Rs.50,000**	**Above Rs.50,000**	**Total**
Televisions (Cathode Ray Tube old fashioned)	18	24	76	**118**
Flat panel televisions (LCD, LED, Plasma)	11	26	189	**226**
Desktop PCs (excluding monitors & accessories)	5	15	78	**98**
Monitors (Cathode Ray Tube)	3	7	72	**82**
Flat panel monitors (LCD, LED, Plasma)	4	14	74	**92**
Routers & modems	1	19	152	**172**
Keyboards	6	17	115	**138**
Mouse	8	18	151	**177**
External drives	9	6	142	**157**
Printers, scanners, faxes, multi-functional	4	5	60	**69**
Laptops, notebooks & tablets	11	24	315	**350**
Telephones, cordless, answering machines	18	10	119	**147**
Mobile phones, smart phones, pagers	53	73	625	**751**
GPS (Global Positioning System)	3	3	43	**49**
Pocket calculator	5	4	102	**111**
Game consoles	4	2	67	**73**
Total	**163**	**267**	**2380**	**2810**

Table 7: Extrapolated total number of equipment (for the population) in million

Extrapolation				
	less than Rs.25,000	**Rs.25,001 to Rs.50,000**	**Above Rs. 50,000**	**Total**
Total family members (of respondents)	129	245	812	1186
Number of respondents	21	32	122	175
Total number of equipment (sample)	163	267	2380	2810
Number of equipment per person (sample)	1.3	1.1	2.9	2.4
Percent of Pakistan population	40%	40%	20%	100%
Adjusted population size (million)	73.6	73.6	36.8	184
Extrapolated quantity (number of equipment per person * adjusted population size) in million	**93**	**80**	**108**	**281**

Table 8: Extrapolated total number of equipment according to the type of equipment (for the population) in million

The number of equipment (in million) for each income group (for the population)				
Type of Equipment	**Income Groups**			
	less than Rs.25,000	**Rs.25,001 to Rs.50,000**	**Above Rs.50,000**	**Total**
Televisions (Cathode Ray Tube)	10	7	3	**21**
Flat panel televisions (LCD, LED, Plasma)	6	8	9	**23**
Desktop PCs (excluding monitors & accessories)	3	5	4	**11**
Monitors (Cathode Ray Tube)	2	2	3	**7**
Flat panel monitors (LCD, LED, Plasma)	2	4	3	**10**
Routers & modems	1	6	7	**13**
Keyboards	3	5	5	**14**
Mouse	5	5	7	**17**
External drives	5	2	6	**13**
Printers, scanners, faxes, multi-functional	2	2	3	**7**
Laptops, notebooks & tablets	6	7	14	**28**
Telephones, cordless, answering machines	10	3	5	**19**
Mobile phones, smart phones, pagers	30	22	28	**80**
GPS (Global Positioning System)	2	1	2	**5**
Pocket calculator	3	1	5	**9**
Game consoles	2	1	3	**6**
Total	**93**	**80**	**108**	**281**

Table 9: Extrapolated weight of the equipment according to the type of equipment (for the population)

Weight of the equipment (for the population)			
	Average weight of equipment (kg)	**Total calculated weight (kg)**	**Total calculated weight (tonnes)**
Televisions (Cathode Ray Tube)	45.50	952,037,374	952,037
Flat panel televisions (LCD, LED, Plasma)	20.81	471,487,250	471,487
Desktop PCs (excluding monitors & accessories)	6.00	65,362,866	65,363
Monitors (Cathode Ray Tube)	16.00	113,240,628	113,241
Flat panel monitors (LCD, LED, Plasma)	5.00	49,207,897	49,208
Routers & modems	0.43	5,661,796	5,662
Keyboards	0.60	8,245,210	8,245
Mouse	0.09	1,513,353	1,513
External drives	0.50	6,686,400	6,686
Printers, scanners, faxes, multi-functional	6.00	39,020,539	39,021
Laptops, notebooks & tablets	1.00	27,761,627	27,762
Telephones, cordless, answering machines	0.60	11,200,172	11,200
Mobile phones, smart phones, pagers	0.35	28,172,788	28,173
GPS (Global Positioning System)	0.26	1,186,021	1,186
Pocket calculator	0.06	520,620	521
Game consoles	2.00	11,838,880	11,839
Total		1,793,143,422	1,793,143

Table 10: The reasons for purchase of new equipment

Rank	Reasons for new purchase decisions	Untransformed		Transformed (0, 1)	
		Mean	**Mode**	**Mean**	**Mode**
1	Damage rendering it non-functional	2.37	1	0.58	1
2	Lost / stolen	2.56	2	0.52	1
3	Upgrade - outdated function	2.46	3	0.47	0
4	Upgrade - outdated style	2.90	4	0.37	0
5	Other (please specify)	4.71	5	0.05	0

Table 11: Reasons for purchase based on the city of residence

The reasons for purchase based on the city of residence							
		Important		**Not important**		**Total**	
Damage	Karachi	57	57.00%	38	53.52%	95	55.56%
	Hyderabad	31	31.00%	27	38.03%	58	33.92%
	Other cities	12	12.00%	6	8.45%	18	10.53%
	Total	100	100%	71	100%	171	100%
	Pearson Chi-square 1.192 (0.551)						
Lost/stolen	Karachi	55	61.80%	40	48.78%	95	56%
	Hyderabad	25	28.09%	33	40.24%	58	34%
	Other cities	9	10.11%	9	10.98%	18	11%
	Total	89	100.00%	82	100%	171	100%
	Pearson Chi-square 3.191 (0.203)						
Upgrade – outdated function	Karachi	42	52.50%	53	58.24%	95	55.56%
	Hyderabad	30	37.50%	28	30.77%	58	33.92%
	Other cities	8	10.00%	10	10.99%	18	10.53%
	Total	80	100.00%	91	100.00%	171	100%
	Pearson Chi-square 0.861 (0.650)						
Upgrade – outdated style	Karachi	34	34.00%	61	57.01%	95	55.56%
	Hyderabad	24	24.00%	34	31.78%	58	33.92%
	Other cities	6	6.00%	12	11.21%	18	10.53%
	Total	64	64%	107	100%	171	100.00%
	Pearson Chi-square 1.562 (0.458)						
*Significant at 0.05 level							

Table 12: The preferred condition of equipment

	Used (Functioning)		Brand new		No preference		Total	
Televisions (Cathode Ray Tube)	20	15%	88	68%	22	17%	130	100%
Flat panel televisions (LCD, LED, Plasma)	13	8%	138	86%	9	6%	160	100%
Desktop PCs (excluding monitors & accessories)	34	25%	71	53%	30	22%	135	100%
Monitors (Cathode Ray Tube)	22	19%	63	53%	33	28%	118	100%
Flat panel monitors (LCD, LED, Plasma)	13	9%	110	79%	17	12%	140	100%
Routers & modems	10	7%	115	82%	15	11%	140	100%
Keyboards	24	18%	90	67%	20	15%	134	100%
Mouse	21	15%	104	74%	16	11%	141	100%
External drives	6	5%	106	82%	18	14%	130	100%
Printers, scanners, faxes, multi-functional	16	14%	88	76%	12	10%	116	100%
Laptops, notebooks & tablets	24	15%	124	78%	10	6%	158	100%
Telephones, cordless, answering machines	17	13%	91	72%	19	15%	127	100%
Mobile phones, smart phones, pagers	19	11%	145	84%	8	5%	172	100%
GPS (Global Positioning System)	11	14%	39	49%	30	38%	80	100%
Pocket calculator	9	9%	73	73%	18	18%	100	100%
Game consoles	11	10%	68	65%	26	25%	105	100%
Total	**270**	**13%**	**1513**	**73%**	**303**	**15%**	**2086**	**100%**

Table 13: Gender and preferred condition of equipment

Equipment condition and gender (Phi & Cramer's V)		
	Phi / Cramer's V (value)	**Approximate significance**
Televisions (Cathode Ray Tube)	0.093	0.568
Flat panel televisions (LCD, LED, Plasma)	0.106	0.405
Desktop PCs (excluding monitors & accessories)	0.046	0.864
Monitors (Cathode Ray Tube)	0.131	0.363
Flat panel monitors (LCD, LED, Plasma)	0.071	0.702
Routers & modems	0.130	0.306
Keyboards	0.152	0.214
Mouse	0.113	0.405
External drives	0.122	0.380
Printers, scanners, faxes, multi-functional	0.090	0.625
Laptops, notebooks & tablets	0.064	0.722
Telephones, cordless, answering machines	0.208	0.064
Mobile phones, smart phones, pagers	0.071	0.649
GPS (Global Positioning System)	0.085	0.747
Pocket calculator	0.123	0.468
Game consoles	0.128	0.424
a. Not assuming the null hypothesis.		
b. Using the asymptotic standard error assuming the null hypothesis.		

Table 14: The city of residence and preferred condition of equipment

Equipment condition and the city of residence (Phi & Cramer's V)			
	Phi (value)	**Cramer's V (value)**	**Approximate significance**
Televisions (Cathode Ray Tube)	0.209	0.148	0.223
Flat panel televisions (LCD, LED, Plasma)	0.172	0.122	0.315
Desktop PCs (excluding monitors & accessories)	0.136	0.097	0.642
Monitors (Cathode Ray Tube)	0.321*	0.227	0.016
Flat panel monitors (LCD, LED, Plasma)	0.200	0.142	0.230
Routers & modems	0.192	0.136	0.270
Keyboards	0.280	0.147	0.217
Mouse	0.204	0.144	0.210
External drives	0.153	0.108	0.548
Printers, scanners, faxes, multi-functional	0.120	0.085	0.794
Laptops, notebooks & tablets	0.172	0.121	0.324
Telephones, cordless, answering machines	0.165	0.117	0.485
Mobile phones, smart phones, pagers	0.194	0.137	0.166
GPS (Global Positioning System)	0.208	0.147	0.481
Pocket calculator	0.117	0.082	0.852
Game consoles	0.104	0.074	0.889

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.
*Significant at 0.05 level

Table 15: Where do consumers buy equipment?

Source	**Frequency**	**Total**	**Percentage**
Local electronics market	159	175	91%
Directly from the company	39	175	22%
Online (third party supplier)	34	175	19%
Import (via family/friends)	26	175	15%
Other (please specify)	3	175	2%

Table 16: Expected useful life of each equipment

Expected useful life of the equipment							
	Never	**Within 1 year**	**1-2 years**	**2-5 years**	**5-10 years**	**More than 10 years**	**Total**
Television (Cathode Ray Tube)	**26%**	4%	4%	15%	19%	**31%**	100%
Television Flat panel (LCD, LED, Plasma)	2%	4%	8%	**30%**	**41%**	16%	100%
Desktop PCs (excluding monitors & accessories)	20%	2%	4%	20%	**29%**	**24%**	100%
CRT Monitors	**43%**	3%	7%	17%	7%	**23%**	100%
Flat panel monitors (LCD, LED, Plasma)	13%	4%	18%	**21%**	**34%**	11%	100%
Routers & modems	4%	15%	16%	**43%**	18%	4%	100%
Keyboards	18%	18%	14%	**29%**	11%	11%	100%
Mouse	11%	**34%**	**21%**	19%	6%	8%	100%
External drives	4%	16%	16%	**38%**	**20%**	6%	100%
Printers, scanners, faxes, multi-functional	13%	8%	10%	**26%**	**26%**	18%	100%
Laptops, notebooks & tablets	8%	6%	**20%**	**37%**	**20%**	10%	100%
Telephones, cordless, answering machines	9%	13%	**20%**	**24%**	17%	17%	100%
Mobile phones, smart phones, pagers	4%	**27%**	**32%**	**25%**	10%	2%	100%
GPS (Global Positioning System)	**62%**	8%	15%	0%	15%	0%	100%
Pocket calculators	**24%**	18%	**21%**	**21%**	9%	6%	100%
Game consoles	13%	11%	8%	**37%**	13%	18%	100%

Table 17: First action if an equipment stops functioning

Rank	First action	Frequency	Total	Percentage
1	Try to get it repaired	108	175	62%
2	Discard and buy new (or used)	58	175	33%
3	Try to keep using it	87	175	50%
4	Others	165	175	94%

Table 18: Disposal methods

Count and percent of the number of equipment for each method of disposal		Not applicable	Stored at home	Gave for reuse	Sold	Disposed with municipal waste	Got stolen	Total
		Disposal methods in the last 10 years						
Television (Cathode Ray Tube)	Count	5	55	56	57	1	0	174
	%	2.9%	31.6%	32.2%	32.8%	0.6%	0.0%	100.0%
Television Flat panel display (LCD, LED, Plasma)	Count	17	30	28	28	3	0	106
	%	16.0%	28.3%	26.4%	26.4%	2.8%	0.0%	100.0%
Desktop PCs (excluding monitors & accessories)	Count	5	43	44	36	0	0	128
	%	3.9%	33.6%	34.4%	28.1%	0.0%	0.0%	100.0%
Flat panel monitors (LCD, LED, Plasma)	Count	12	36	20	18	2	0	88
	%	13.6%	40.9%	22.7%	20.5%	2.3%	0.0%	100.0%
Routers & modems	Count	18	33	21	14	16	1	103
	%	17.5%	32.0%	20.4%	13.6%	15.5%	1.0%	100.0%
Keyboards	Count	10	55	27	25	22	1	140
	%	7.1%	39.3%	19.3%	17.9%	15.7%	0.7%	100.0%
Mouse	Count	9	63	22	21	24	1	140
	%	6.4%	45.0%	15.7%	15.0%	17.1%	0.7%	100.0%
External drives	Count	17	34	11	8	10	2	82
	%	20.7%	41.5%	13.4%	9.8%	12.2%	2.4%	100.0%
Printers, scanners, faxes, multi-functional	Count	16	27	11	13	6	0	73
	%	21.9%	37.0%	15.1%	17.8%	8.2%	0.0%	100.0%
Laptops, notebooks & tablets	Count	13	45	40	44	8	4	154
	%	8.4%	29.2%	26.0%	28.6%	5.2%	2.6%	100.0%
Telephones, cordless, answering machines	Count	11	39	15	30	8	1	104
	%	10.6%	37.5%	14.4%	28.8%	7.7%	1.0%	100.0%
Mobile phones, smart phones, pagers	Count	13	165	63	86	4	22	353
	%	3.7%	46.7%	17.8%	24.4%	1.1%	6.2%	100.0%
GPS (Global Positioning System)	Count	28	4	4	5	5	1	47
	%	59.6%	8.5%	8.5%	10.6%	10.6%	2.1%	100.0%
Pocket calculators	Count	18	45	10	11	7	2	93
	%	19.4%	48.4%	10.8%	11.8%	7.5%	2.2%	100.0%
Game consoles	Count	18	22	8	19	3	1	71
	%	25.4%	31.0%	11.3%	26.8%	4.2%	1.4%	100.0%
Total	Count	210	696	380	415	119	36	1856
	%		42%	23%	25%	7%	2%	100.0%

Table 19: Reasons for storage

Reasons for storage	Frequency	Percentage
To keep is as a spare equipment	72	38%
Didn't know where to dispose it	32	17%
Concerned about the security of data	29	15%
Emotional attachment	17	9%
I feel disposal is troublesome	16	8%
It is of intrinsic value to me	13	7%
Other	11	6%

Table 20: Disposal methods after storage

Disposal after storage	Frequency	Total	Percentage
Give it to someone for reuse	71	175	41%
Sell it	53	175	30%
Dispose with municipal waste	28	175	16%
Other	4	175	2%

Table 21: Where do consumers sell their used equipment (or e-waste)

Sell to	Frequency	Total	Percentage
Local electronic equipment shop/market	67	175	38%
Friends / family	38	175	22%
Local electronic waste collector (kabari wala)	40	175	23%
Other (please specify)	4	175	2%

Figure 6: Environmental and human health hazards due to improper disposal of e-waste.

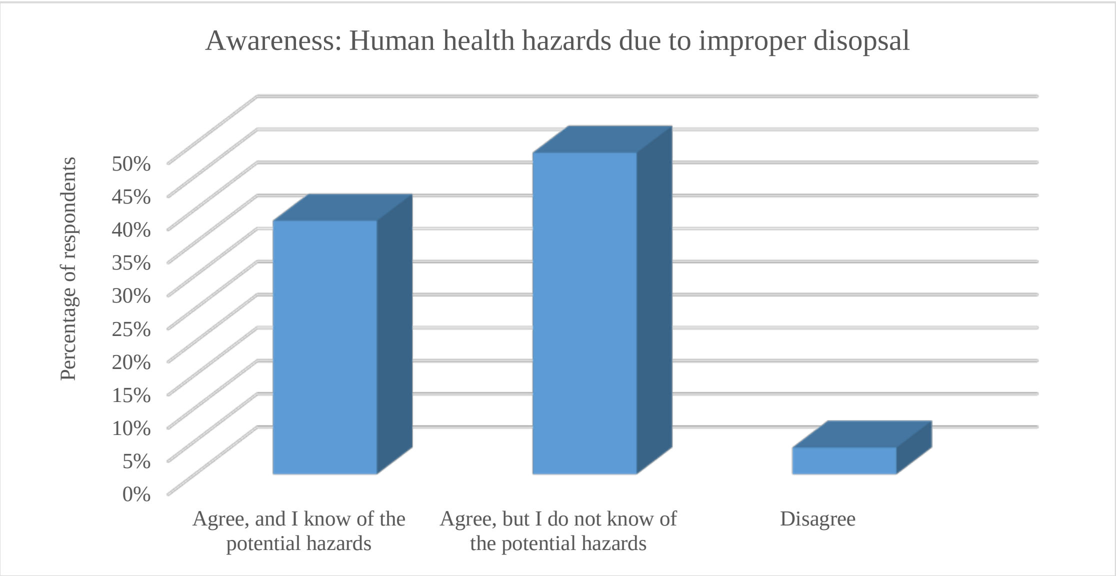

Table 22: Awareness and education level

Awareness and Education Level										
		No idea		Know little		Know well		Total		
Awareness: Toxic and hazardous substances	No schooling completed	11	23.9%	1	1.0%	0	0.0%	12	6.9%	
	Secondary (Grade 12)	16	34.8%	19	18.3%	2	8.3%	37	21.3%	
	Tertiary or Professional Qualification	19	41.3%	84	80.8%	22	91.7%	125	71.8%	
	Total	46	100%	104	100%	24	100%	174	100%	
	Goodman and Kruskal's Gamma 0.709 (0.000*)									
Awareness: Precious metals and substances	No schooling completed	8	14.5%	4	4.7%	0	0.0%	12	6.9%	
	Secondary (Grade 12)	11	20.0%	20	23.5%	6	17.6%	37	21.3%	
	Tertiary or Professional Qualification	36	65.5%	61	71.8%	28	82.4%	125	71.8%	
	Total	55	100%	85	100%	34	100%	174	100%	
	Goodman and Kruskal's Gamma 0.271 (0.042*)									
a. Not assuming the null hypothesis. b. Using the asymptotic standard error assuming the null hypothesis. *Significant at 0.05 level										

Table 23: Awareness on environmental and human health hazards

Environmental and human health hazards due to improper disposal of e-waste								
	Agree; know of the potential hazards		Agree; don't know of the potential hazards		Disagree		Total	
No schooling completed	1	1.5%	4	4.7%	1	14.3%	6	3.8%
Secondary (Grade 12)	11	16.4%	15	17.6%	6	85.7%	32	20.1%
Tertiary or Professional Qualification	55	82.1%	66	77.6%	0	0.0%	121	76.1%
Total	67	100%	85	100%	7	100%	159	100%
Goodman and Kruskal's Gamma -0.402 (0.016*)								
a. Not assuming the null hypothesis. b. Using the asymptotic standard error assuming the null hypothesis. *Significant at 0.05 level								

Table 24: Responsibility of e-waste recycling

Responsible falls on	Frequency	Total	Percentage
Government	111	175	63%
Consumer	60	175	34%
Common responsibility	59	175	34%
Manufacturer	44	175	25%
Seller	16	175	9%
Other	4	175	2%

Table 25: Willingness to pay for recycling

Consumers are the ultimate beneficiaries of product and services, and should pay a part of charge for the recycling of their e-waste.			
	Frequency	**Percent**	**Cumulative Percent**
Disagree	61	34.9%	35.1%
Agree; Payment pattern: prepaid deposit system	31	17.7%	52.9%
Agree; Payment pattern: paying when purchasing the products (embedded)	36	20.6%	73.6%
Agree; Payment pattern: paying when disposed	44	25.1%	98.9%
Other	2	1.1%	100.0%
Total	174	99.4%	

Table 26: Willingness to pay across income categories

Percentage (of the product price) that consumers are willing to pay for recycling (based on income levels)								
	less than Rs.25,000		**Rs.25,001 to Rs.50,000**		**More than Rs.50,000**		**Total**	
None	9	42.9%	6	19.4%	24	19.7%	39	22.4%
0-5%	4	19.0%	15	48.4%	51	41.8%	70	40.2%
6-10%	1	4.8%	3	9.7%	32	26.2%	36	20.7%
11-15%	2	9.5%	1	3.2%	8	6.6%	11	6.3%
16-20%	1	4.8%	2	6.5%	4	3.3%	7	4.0%
More than 20%	4	19.0%	4	12.9%	3	2.5%	11	6.3%
Total	21	100%	31	100%	122	100%	174	100%
Goodman and Kruskal's Gamma 0.026 (0.837)								

Figure 7: Return through a take-back system

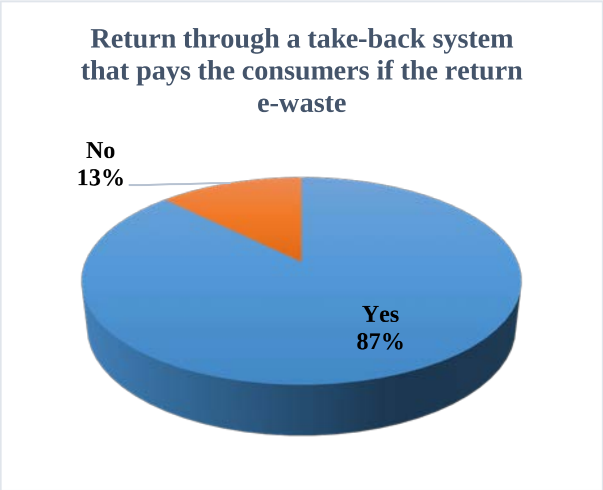

Figure 8: Incentive to return e-waste through the deposit system

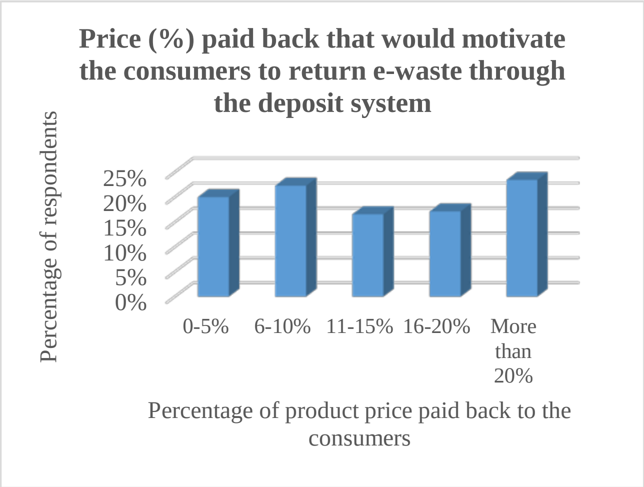

Figure 9: Trends in the quantities of precious and toxic elements (source: Chen et al. (2016))

Leachates from Waste Printed Circuit Board Assemblies according to the "Total Threshold Limit Concentration" (TTLC) procedure.

Year of manufacture	1996	1997	1998	1999	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	TTLC limit	Detection limit
Ag	337	102	164	**619**	**592**	375	92	118	503	**756**	416	**642**	482	483	**500**	**7.58**
Al	34,500	29,500	33,700	56,100	57,200	43,900	62,700	51,700	49,100	33,600	81,600	69,100	45,100	59,200	**N/A**	**189**
As	18	N.D.	18	N.D.	N.D.	N.D.	17	13	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	**500**	**7.58**
Au	107	75	55	50	43	85	31	54	47	36	12	12	14	29	**N/A**	**2**
Ba	964	346	626	2420	1600	2040	2510	4090	3040	1030	2060	2520	2460	3680	**10,000**	**37.9**
Be	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	**75**	**7.58**
Cd	N.D.	N.D.	11.6	60.6	N.D.	N.D.	11	N.D.	8	N.D.	N.D.	N.D.	15	9.94	**100**	**7.58**
Co	23.9	12.3	12	27.3	22.5	14.1	19.1	28.6	56.2	20.9	36.4	72	28.2	173	**8000**	**7.58**
Cr	449	259	156	760	194	184	158	1760	6080	808	2150	5530	1690	**12,800**	**2500**	**7.58**
Cu	**235,000**	**268,000**	**217,000**	**229,000**	**263,000**	**231,000**	**240,000**	**211,000**	**179,000**	**177,000**	**243,000**	**239,000**	**189,000**	**214,000**	**2500**	**189**
Fe	27,400	34,600	31,200	51,800	49,700	30,600	24,900	46,400	14,200	64,400	78,000	87,000	149,000	96,200	**N/A**	**189**
Hg	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	**20**	**7.58**
Li	33.8	N.D.	91.8	10.7	N.D.	9.34	18.2	13.1	12.5	9.58	21.2	17.2	13.3	19.2	**N/A**	**7.58**
Mg	69.2	75.3	856	207	1730	101	221	217	425	235	490	555	227	5090	**N/A**	**37.9**
Mo	N.D.	N.D.	2.77	N.D.	N.D.	9.84	N.D.	13.1	45.7	16.5	N.D.	67.4	11.8	21.8	**3500**	**7.58**
Ni	**3290**	1460	1650	**4720**	**3700**	**4220**	**3030**	**4170**	**5280**	**3250**	**3480**	**5270**	**3230**	**10,500**	**2000**	**7.58**
Pb	**29,100**	**21,300**	**30,100**	**43,200**	**17,700**	**23,000**	**23,400**	**26,000**	483	386	185	525	313	**15,200**	**1000**	**7.58**
Pd	12	8	N.D.	24	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	**N/A**	**2**
Sb	**1280**	**4500**	**4080**	**4360**	**4240**	**4720**	**3300**	**4900**	**8450**	**6650**	**2570**	**4700**	**2830**	**1360**	**500**	**7.58**
Se	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	**100**	**7.58**
Sn	50,500	44,600	43,900	64,800	39,300	40,200	44,100	51,400	32,300	45,000	33,400	61,500	35,700	35,800	**N/A**	**10**
Tl	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	**700**	**7.58**
V	9.86	N.D.	11.3	15.2	18.5	14.5	N.D.	13.8	35.1	N.D.	15.4	29.2	76.6	71.6	**2400**	**7.58**
Zn	**31,900**	**32,700**	**55,200**	**50,800**	**35,300**	**54,500**	**29,800**	**21,900**	**19,000**	**30,200**	**33,900**	**48,700**	**18,600**	**33,100**	**5000**	**189**

Note: N.D.: not detected; N/A: not applicable; concentrations in bold and red are above the regulatory limit; the unit of measurement is mg/kg.