A critical analysis of e-waste management and recycling in Pakistan: a life cycle assessment

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Abstract

Electronic waste or e-waste is a global challenge of increasing significance because of the volume being generated and complexity of this waste. Pakistan, like some other developing economies, generates a significant volume of e-waste and also imports it for processing despite lacking the necessary infrastructure. While e-waste is a business opportunity for the valuable materials that are recovered, at an ecosystem level there is great cause for concern over the use of informal practices. This study is a critical analysis of e-waste management and recycling in Pakistan, using a Life Cycle Assessment (LCA) to examine structures, processes and costs of upstream e-waste generation[1] and downstream disposal and recycling.

Domestic e-waste generated annually in Pakistan is about 1,790 kilo-tons (2018-2019) and is expected to grow at 10.2% annually. Annual imported e-waste is reported to be about 95,145 tons (2011-2014 figures). Of the collective total, about 8.6% (154.8 kilo-tons) is processed using informal practices, while the remaining goes directly into landfill (13.8% or 245.6 kilo-tons), sold/given away for reuse (65.7% or 1,150 kilo-tons), or stored, which is a deferred disposal strategy. Analysis shows that informal recycling is profitable for both dismantling businesses (benefits are 1.19-1.27 times the costs) and extracting/refining businesses (benefits are 1.95-2.22 times the cost). For recycling workers, net economic costs per worker of about Rs.34,069 - 85,478 (USD 203–510) per month, exceed any economic benefit 2.6-4.7-fold.

A methodological contribution is the application of systems thinking and causal loop modelling to strategy formulation at an industry level. A causal map shows overlapping interests and dynamic relationships in e-waste recycling in Pakistan. Four causal loops are identified. They collectively sustain current local practices in e-waste recycling. A systems-level view and pictorial representation of the e-waste situation helps to reveal contentious aspects of informal recycling, and also leverage points to improve e-waste recycling and re-engineer product development. This open-box approach, where the inner workings are exposed and illuminated, can also help policy-makers trace the chain of causality from product design to waste disposal at a fundamental level

[1] Estimates of volumes of upstream e-waste generation only include two out of six categories of e-waste. The two categories included are: category 2 (Screens) and category 5 (small IT and telecommunications equipment). Downstream cost-benefit analysis includes mixed e-waste from all the categories.

and enables consideration of primary prevention strategies at the various levels, including producers, consumers, and recyclers.

Guided by the principle that *what gets measured can be managed*, a practical contribution of this thesis is to present a synthesis of upstream consumer and downstream business considerations. In sum, the informal recycling industry is financially lucrative, but sustained by a lack of regulatory frameworks and limited accountability for known and hidden first-, second- and third-order effects on people and the environment. These externalised costs are not measured. The industry in Pakistan can be conceptualised as being based on local practices contingent on waste value, business opportunity and perceived choice. Leverage points for fundamental, longer-term change in processes associated with waste generation, and for management and disposal of e-waste have been identified. The study develops a consolidated impact factors framework (CIFF) based on financial and non-financial (social) variables to support an analysis of factors that influence upstream generation and downstream processing of e-waste. A multi-level impact assessment framework (MIAF) and related findings can be generalised to other regions in Pakistan and to other countries that similarly generate and import e-waste, and use informal practices to process this material. Crucially, for the necessary focus on the many aspects of e-waste, the starting points are to document, regulate and go beyond return on investment when assessing performance to select multiple criteria and *measure what matters*.

Declaration

I, Salsabil Shaikh, declare that the PhD thesis entitled *"A critical analysis of e-waste management and recycling in Pakistan: a life cycle assessment*" is no more than 80,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

I have conducted my research in alignment with the Australian Code for the Responsible Conduct of Research and Victoria University's Higher Degree by Research Policy and Procedures. All research procedures reported in the thesis were approved by VU Research Ethics Committee with approval number HRE18-053.

I also declare that my thesis was edited by Phillip Thomas (Reading Services), and editorial intervention was restricted to the Australian Standards for Editing Practice.

Signature: [redacted] **Date**: 11 March 2021

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List of Publications

Chapter 4

Shaikh, S, Thomas, K & Zuhair, S 2020, 'An exploratory study of e-waste creation and disposal: upstream considerations', *Resources, Conservation and Recycling*, vol. 155. https://doi.org/10.1016/j.resconrec.2019.104662

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Chapter 6

Shaikh, S, Thomas, K, Zuhair, S & Magalini, F 2020, 'A cost-benefit analysis of the downstream impacts of e-waste recycling in Pakistan', *Waste Management*, vol. 118, pp. 302-312. https://doi.org/10.1016/j.wasman.2020.08.039

Journal metrics - Q1; Impact factor: 5.448

Systematic review protocol

Shaikh, S, Thomas, K & Zuhair, S 2021, 'PROTOCOL: Impact assessment of electronic waste recycling practices: a systematic review', Campbell Systematic Reviews. (Title registered in 2019, protocol under review since 2020); Indexed in the Emerging Sources Citation Index (ESCI). https://onlinelibrary.wiley.com/journal/18911803

Conference paper

Shaikh, S & Thomas, K 2018, 'Electronic waste: challenge and opportunity (a working paper)', *The 5th Annual Symposium on Management and Social Sciences (ASMSS), Tokyo, Japan 10-12 Jul 2018.*

http://accmes.org/data/file/20190502/20190502235951_40617.pdf

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List of Acronyms and Definitions

Benefits	These accrue principally to recycling businesses in terms of financial profits, but also to workers in terms of wages and assurance of employment, as well as limited provision of health and safety actions (masks, chimneys for ventilation) by employers to change clearly unsafe and unhealthy work conditions. Benefits could be financial or social.
CBA	Cost-benefit analysis
Economic impact	A collective term used in the literature to denote financial and non-financial (social) costs and benefits. Environmental costs are evidently absent in this term and this omission is reflected in the lack of substantive discussion on e-waste recycling.
EEE	Electrical and Electronic Equipment are all household or business items that have electrical components or circuits with either battery or power supply, such as TVs, computers, mobile phones, white goods, home entertainment and appliances. See: http://www.step-initiative.org/files/_documents/whitepapers/StEP_WP_One%20Global%20Definition%20of%20E-waste_20140603_amended.pdf
EE-MFA	Economically Extended Materials Flow Analysis - used to evaluate the flow of materials in physical & monetary terms. See: https://www.sciencedirect.com/science/article/pii/S0959652604000691
E-waste (Electronic waste)	Also called waste electrical and electronic equipment (WEEE). All electrical and electronic equipment (EEE) and their parts, which have been discarded by the owner with no intention of reuse. See: http://www.step-initiative.org/files/_documents/whitepapers/StEP_WP_One%20Global%20Definition%20of%20E-waste_20140603_amended.pdf
First-order, second-order and third-order effects	Every action has consequences, called first-order effects, and those consequences have consequences, called second-order effects (Kaufman 2010). First-order effects are the immediate and direct consequences of an action. These might also be the intended consequences of an action or change (Vanclay 2002). The long term and indirect consequences are the second- and third-order effects. Second-order effect is sometimes more important than the first-order effect (initial consequence) (Stuber 2018). Third-order is the consequence of second-order effect and is also the longer term implication (Colley 2020). In the context of this thesis, financial benefit to recycling businesses and workers is the first-order effect (immediate, direct and intended consequence) of e-waste recycling activities. This action has consequences, which are second-order effects that include social and health consequences to the workers. Further in the long-term, there are

	environmental consequences for next generations (pollution of soil used for irrigation, water resources) – these are the third order effects.
ICT	Information and Communications Technology
LCA	Life cycle assessment
MFA	Material Flow Analysis
PAHs	Polycyclic aromatic hydrocarbons - that comprise dioxins and furans produced when coal, oil, gas, wood, waste and tobacco are burnt. Exposure to high levels of PAHs can cause blood and liver abnormalities, and cancer. See: https://www.cdc.gov/biomonitoring/PAHs_FactSheet.html
PBDEs	Polybrominated diphenyl ethers - organobromine compounds that are used as flame retardant and highly toxic. PBDEs have been associated with tumours, neurodevelopment toxicity and thyroid hormone imbalance. See: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1069057/
PCBs	Polychlorinated biphenyls (similar to PAhs and PBDEs – man-made organic chemicals used in industrial and commercial applications such as electrical goods, paint, plastics and carbon paper; banned since 1979 in Australia). See: https://www.epa.gov/pcbs/learn-about-polychlorinated-biphenyls-pcbs
PCDD/Fs	Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans (types of persistent and bioaccumulating organic pollutants with enhanced chronic toxicity and carcinogenic properties). See: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-40422004000600018
PVC	Polyvinyl chloride - the world's third most widely produced synthetic plastic polymer; because of PVC's heavy chlorine content, dioxins are released during the manufacturing, burning, or landfilling of PVC. Exposure to dioxins can cause reproductive, developmental, and other health problems, and at least one dioxin is classified as a carcinogen. See: https://toxtown.nlm.nih.gov/text_version/chemicals.php?id=84
SIA	Social impact assessment - 'the process of identifying the future consequences of a current or proposed action which are related to individuals, organisations and social macro-systems' (Becker 2001)
S-LCA	Social life cycle assessment - a part of SIA methodology with a focus on life cycle activities and their social consequences, both positive and negative on people throughout the life cycle (Liu, S & Qian 2019; Popovic & Kraslawski 2015)
Social costs	A term that is intended to include human health and well-being considerations of workers, their families and local communities. It may include quantifiable matters such as life expectancy and education achievement, as well as attitudes, side effects and reactions that can far outweigh the benefits that accrue principally to recycling workers in terms of wages and assurance of employment.

CHAPTER 1: STUDY OVERVIEW

1.1. Background

Waste or scrap consists of pre-use scrap, which is a by-product or waste originating from the manufacturing sector, and post-use scrap that is waste generated after people or systems have consumed it. Both of these are shown conceptually in Figure 1, but pre-use scrap is not part of this study. In post-use scrap there are multiple streams of waste, including solid municipal waste, industrial waste and electronic waste (or e-waste), among many other categories. The focus of this study is on waste electrical and electronic equipment (WEEE) or e-waste, the overview of which is illustrated in Figure 1, and focus areas shown in grey. The red dotted box highlights the key areas of investigation in this study, consisting of impacts of informal recycling.

E-waste is the fastest growing stream of waste in the world (Cruz-Sotelo et al. 2016; Fu et al. 2018; Oleszek et al. 2018). It is estimated that 53.7 million tons (Mt) were generated globally in 2019 (Figure 1), with an annual increase of 5.1% from 2014 to 2019 and is expected to continue growing at the rate of 3.1% per annum, resulting in the annual generation of around 74.7 million tons by 2030 (Abdelbasir et al. 2018; Alghazo et al. 2019; Forti et al. 2020). Previous estimates by Baldé et al. (2017) forecasted the annual volumes to reach 52.2 million tons by 2021, however, updated estimates by Forti et al. (2020) reveal these estimates have already been surpassed in 2019, highlighting the understated nature of forecasts. Compounding this rising volume of e-waste, is the uncertain fate of much of the discarded electronic devices, whereby global e-waste reported as collected and formally recycled was only 15%-16% of the total e-waste in 2014, 20% in 2016 and only 17.4% in 2019 (Baldé et al. 2017; Forti et al. 2020; Heacock et al. 2016; Kumar, A, Holuszko & Espinosa 2017; Sahajwalla & Gaikwad 2018).

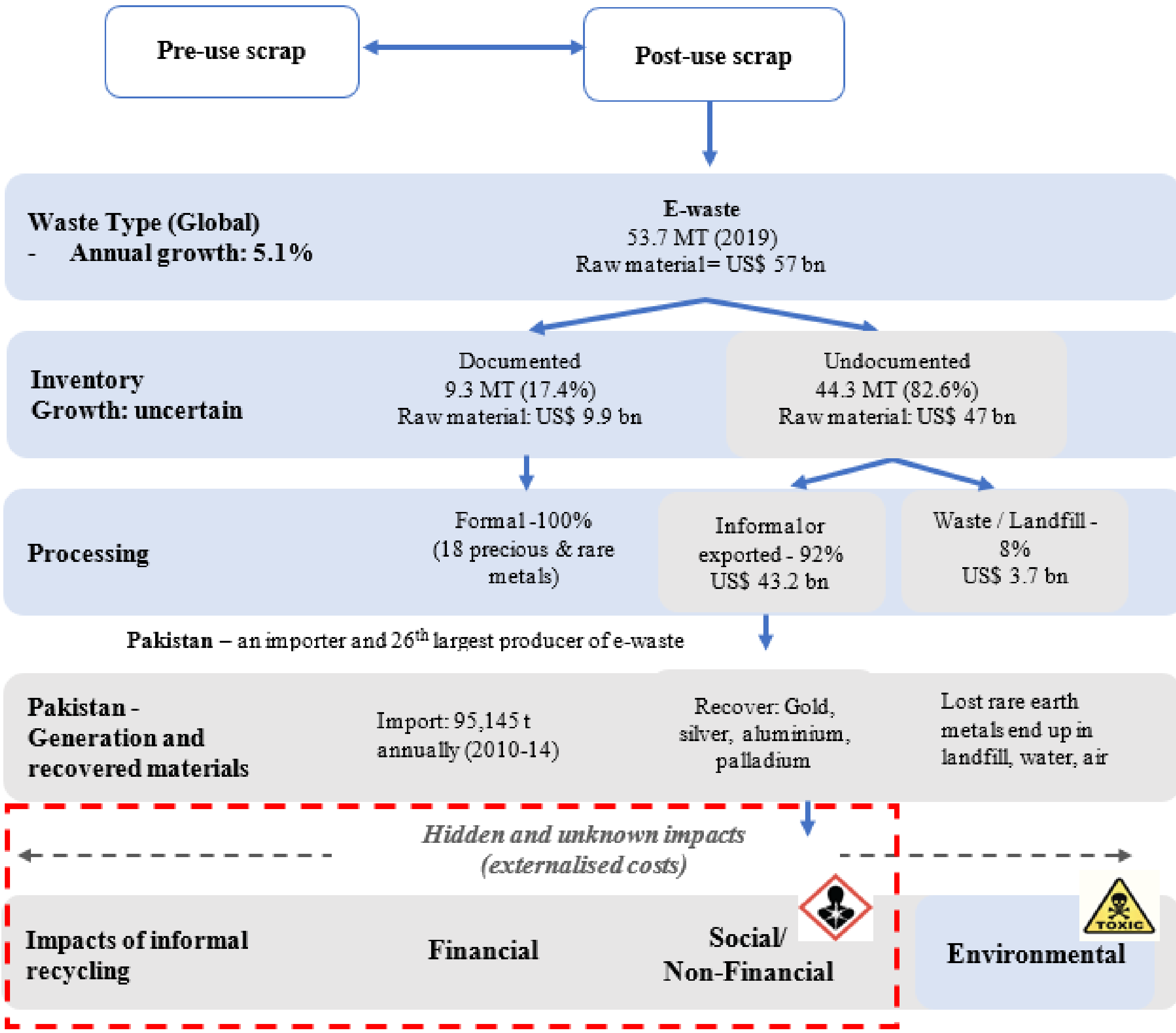


Figure 1: Global E-waste quantities, processing and below the line impacts

The remaining e-waste (about 82.6% in 2019 – see Figure 1) appears to be undocumented and most likely goes directly into landfill as municipal waste (Baxter et al. 2016; Ikhlayel 2018; Speake & Yangke 2015) or is exported to developing countries. There it may be used as second-hand equipment or get recycled directly, typically using informal practices, or stockpiled for later processing or disposal (Bakhiyi et al. 2018; Ongondo, Williams & Cherrett 2011). The lack of documentation and accountability in both developing and developed countries of such large volumes of e-waste is a very serious problem (Christian 2017; Lee, D et al. 2018; Wong 2018). On a positive note, these waste materials contain precious and rare metals such as gold, platinum and palladium (Binnemans et al. 2013; Chancerel et al. 2015; Diaz & Lister 2018), which represent a significant lost economic/business opportunity (Kirby & Lora-Wainwright 2015). Related literature suggests the value of raw material in e-waste equates to approximately USD 57 billion in 2019 (Forti et al. 2020). Described as 'urban mining', the extraction and purification of precious metals from these waste streams captures unrealised potential for resource recycling and environmental improvement (Zeng, Mathews & Li 2018). It is noted that waste processors in China were able to recover pure gold and copper from e-waste streams at costs comparable to virgin mining of ores. In fact the study by Zeng et al. (2018) illustrates a potential for waste disposal and mining globally, particularly as the circular economy comes to displace linear economic pathways.

A second more problematic concern with the informal practices used to dispose or recycle rising volumes of e-waste is the release of considerable amounts of toxic elements such as lead, arsenic and mercury. These materials are known to be hazardous to the environment and also to humans (Rubin et al. 2014; Savvilotidou, Hahladakis & Gidarakos 2014; Yu, J, Williams & Ju 2010). In effect, the current reliance on informal e-waste disposal in developing countries means that not only are rare and valuable resources being depleted and/or wasted (Zeng et al. 2017), but that recycling using improper and hazardous methods, such as open burning and dumping, poses a serious risk to human health (Awasthi, Zeng & Li 2016a; Cesaro et al. 2017; Zhou & Liu 2018). For example, burning metals and plastics is shown to emit dangerous fumes, furans, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyl (PCBs) and polybrominated diphenyl ethers (PBDEs), and dioxins (Anh et al. 2018; Cao, P et al. 2020; Li, T-Y et al. 2019; Premalatha et al. 2014). These anthropogenic or human activity-based sources alter the distribution of metals and transfer the by-products to the soil, water air, sediments and marine life (Ohajinwa, Chimere May et al. 2018), where heavy metals persist (Chakraborty et al. 2018; Song & Li 2015).

Figure 1 also depicts the downstream toxic effects in the environment. This significant concern, while not in the scope of this study, is highlighted here as ultimately toxic by-products and heavy metals enter the food chain via plants (Guala, Vega & Covelo 2010). The downstream impact for both humans and animals has been identified in terms of dietary intake and air inhalation, as well as through dust/soil ingestion and even skin contact (Bruce-Vanderpuije et al. 2019; Li, J, Duan & Shi 2011). This risk, principally to recycling workers and the residents around recycling facilities, is through direct and in-direct exposure to heavy metals and toxins (Esposito et al. 2018; Kumar, Shivam et al. 2018; Li, Juan et al. 2020). The subsequent effects of this exposure is an increase in the risk of cancer, as well as liver, lung and kidney damage among various other health issues (Akortia et al. 2017; Huang, C-L et al. 2016; Isimekhai et al. 2017). There are also less visible and unknown consequences of this exposure – these hidden or below the line costs to the environment, water and air (Figure 1), are described as externalised costs, which are often disregarded.

While there are economic gains from extracting precious metals and valuable materials in e-waste (Cucchiella et al. 2016; Van Eygen et al. 2016), these 'first-order effects' - the immediate and intended consequence of recycling need to be balanced in quantifiable terms to the costs mostly to recycling workers and the less visible second- and third-order effects hazardous effects on the environment (Akortia et al. 2017; Huang, C-L et al. 2016; Jiang, B et al. 2019) and to humans (Heacock et al. 2016; Isimekhai et al. 2017). Second- and third-order effects are the longer-term consequences that flow from first-order effects. These collective negative environmental, social and human health impacts, and real risks to downstream workers, are aided by the absence of regulatory controls (Leung, Anna Oi Wah 2019; Orlins & Guan 2016; Zeng et al. 2017) and seeming complicit behaviours by business owners (Leung, Anna Oi Wah 2019). These effects, unmeasured and largely hidden, make the overall issue of e-waste management and disposal highly problematic. Any move towards a less hazardous and sustainable recycling approach to this category of waste, suggests the need for a rigorous impact assessment of benefits and costs, both known and unknown, and consequent greater accountability throughout the life cycle.

1.1.1. Exploring impact – A life cycle assessment (LCA) approach

A Life Cycle Assessment (LCA) approach has been defined as "*a cradle to grave or cradle to cradle analysis technique to assess environmental impacts associated with all the stages of a product's life, which is from raw material extraction through materials processing, manufacture, distribution and use*" (Muralikrishna & Manickam 2017). A LCA is an environmental management tool that evaluates the impact of a product, an activity or a system on the environment (Khang et al. 2017). However, it is not limited to environmental assessment (Yang et al. 2020) and has evolved to include other complementary approaches with a focus on economic issues and social impact of human activities (Mazzi 2020; Popovic & Kraslawski 2015; Yang et al. 2020). A variation of the LCA, a social life cycle assessment (S-LCA), is a type of LCA aimed at evaluating social impact from a life cycle perspective. It includes both positive and negative impacts on stakeholders (Benoît et al. 2010; Lehmann et al. 2013; UNEP/SETAC 2009; Yang et al. 2020).

There are four generic steps in conducting any LCA: goal and scope definition, inventory analysis, impact assessment and interpretation (Brancoli & Bolton 2019; Muralikrishna & Manickam 2017; Nieuwlaar 2004; You & Wang 2019) – see Figure 2 below. Goal and scope definition describes the purpose of study, methodology and assumptions. Inventory analysis includes data collection and modelling aspects (analysis) and might include quantification and assessment of flows in the systems. Impact is then assessed using results derived from the inventory analysis. Results of all impact indicators are also detailed in this step. The last step of interpretation involves identification of significant results based on the inventory analysis and impact assessment.

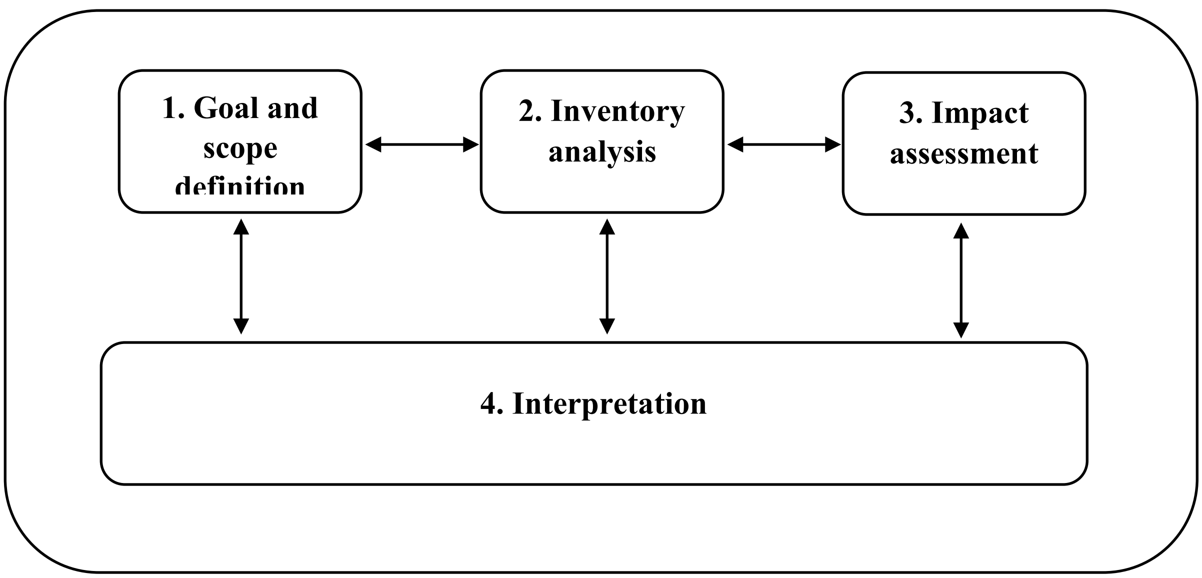


Figure 2: Life Cycle Assessment Steps

Source: Nieuwlaar (2004)

With respect to practical application, LCA is used to analyse the contribution of life cycle stages to the overall environmental load, with an aim to prioritise improvements on products and processes (Muralikrishna & Manickam 2017). In the context of waste management, it is used by policy-makers and in businesses to compare specific waste management technologies in a specific geographical region to support decisions being made in businesses and policy development (Brancoli & Bolton 2019). In recent studies, it has been successfully used to study impact in different contexts, including transition towards bio-based economy, where products wholly or partly are derived from biological materials (Falcone et al. 2019; Martin et al. 2018) and solid waste management strategies (Bisinella et al. 2017; Goulart Coelho & Lange 2018; Khandelwal et al. 2019). A LCA approach has also been employed in the context of e-waste management, to quantitatively investigate the environmental impacts of e-waste treatment (Ghodrat et al. 2017; Iannicelli-Zubiani et al. 2017; Osman et al. 2018; Song et al. 2013).

Reflecting on the principle that has been misattributed to a number of people, including Albert Einstein[2], *not everything that counts can be counted, and not everything that can be counted 'necessarily' counts*, the challenge is - as Ridgway (1956) would suggest - to ensure the validity and significance of what is being measured. This research seeks to assesses and quantify both upstream and downstream (hidden and less visible) impacts using an S-LCA approach based on multiple stakeholders identified using an ecosystem view. Economic impact has been assessed using both financial and non-financial (social) variables using a cost-benefit analysis (CBA). A CBA is a well-known tool to examine economic viability in a variety of contexts (Brent, RJ 2009; Campbell & Brown 2015) – discussed in more detail in section 3.5.3.2.2.

1.1.2. Study aim

Adopting a social life cycle assessment (S-LCA) approach, the aim of this study is to develop a framework for impact assessment of e-waste disposal and recycling, using sector-specific variables. The intention is to develop a macro-level view of recycling, by measuring and quantifying volumes of upstream waste creation based on a material flow analysis (MFA), and a cost-benefit analysis (CBA) of downstream e-waste disposal and recycling practices in Pakistan. This S-LCA methodology is well suited to assess impacts along a value chain, from extraction to production and to end-of-life disposal in terms of social and environmental costs. This impact assessment may also be applied to supporting improved well-being, looking at social benefits and impacts. It can also identify cultural elements and lifestyle issues that affect the way social issues are seen and responded to.

[2] Ridgway (1956) version, *not everything that matters can be measured and not everything that we can measure matters*, is used in this thesis as it complements the utility of measurement by Peter Drucker.

Given the rising volumes of e-waste throughout Pakistan, both imported and generated locally, and the prevalence of informal recycling practice in the country, there is a pressing need to develop capacity to assess environmental, economic and social impacts and benefits. Yet, at present there is no regulation of the industry and only a limited whole system view that can assess the overall business case for the industry based on reliable e-waste inventory volumes, actual dollar costs and relative ratios to quantify downstream impacts. This (system-level) view is arguably crucial and recognising the complexity, this thesis serves as an initial country analysis where not much research has been conducted as a stepping-stone for future analysis of this topic (Schluep 2014).

1.2. What is e-waste?

Electronic waste or e-waste generally refers to all the electrical and electronic equipment that are no longer useful to the owner (Pant 2013; Tanskanen 2013). Globally, a standard definition of e-waste does not yet exist, but it has been defined by the StEP Initiative (2014) as:

***"… all the electrical and electronic equipment (EEE) and their parts, which have been discarded by the owner without the intention of reuse*."**

This definition of EEE includes all personal, household and business items that have electrical components or circuits with either battery or power supply, such as TVs, computers, mobile phones, white goods, home entertainment and appliances (Orlins & Guan 2016; Pathak, Srivastava & Ojasvi 2019). There are some differences and inconsistencies in this classification of e-waste (categories of equipment) from the perspective of legislation and everyday use, and often multiple methods can be used to classify e-waste, such as product type, size or treatment methods and technology. To illustrate the European Union's WEEE Directive (EU Council Directive 2012), the earlier approach to classifying e-waste by product has changed to classification based on treatment according to six categories (see Table 1) that are also accepted by the StEP Initiative (2014). As an aside, currently e-waste systems do not yet include any kind of batteries, accumulators and electric components of vehicles in any classification.

Table 1: Categories of e-waste

Categories	Description
Category 1	**Temperature exchange equipment** Also called heating and cooling equipment and mainly include heaters, air conditioners and refrigerators.
Category 2*	**Screens** Laptops, computers, tablets and televisions.
Category 3	**Small equipment** Fans, microwaves, toasters, vacuum cleaners, small medical and control devices and electronic toys.
Category 4	**Lamps** All types of fluorescent lamps, straight and compact fluorescent lamps, LED lamps and high intensity discharge lamps.
Category 5*	**Small IT and telecommunications equipment** Mobile phones, telephones, pocket calculators, routers, printers and GPS devices.
Category 6	**Large equipment** Bulky equipment like washing machines, dryers, dishwashers, large printing/ photocopier machines and electric stoves.

*Categories 2 and 5 shown in red are the focus of this study. These categories require particular attention because of the toxic elements in screens and small IT equipment compared to the other categories

Source: EU Council Directive (2012)

Figure 3 shows the percentage for each category based on the estimated physical weight of total global e-waste. The scope of this research is limited to two categories – category 2 (Screens) and category 5 (small IT and telecommunications equipment) for practical purposes. These two selected categories require particular attention because of the potentially toxic elements found in abundance in screens, and small IT and telecommunications equipment compared to other categories. For instance: CRTs contain lead in the cone glass and fluorescent coating (Menad 1999; Miskufova et al. 2018; Yu, M, Liu & Li 2016); mobile phones and telecommunications equipment include components containing mercury (Grace Pavithra et al. 2020; Singh et al. 2019); and Printed Circuit Boards (PCBs) commonly comprise very diverse, rare and toxic components including lead and cadmium (Martins et al. 2019; Sannigrahi & Suthindhiran 2019). Furthermore, lead and mercury occur in LCDs (Amato, Rocchetti & Beolchini 2017; D'Adamo, Ferella & Rosa 2019) and plastics contain halogenated flame retardants that produce toxins when incinerated (Cui & Jørgen Roven 2011; Li, TY et al. 2019).

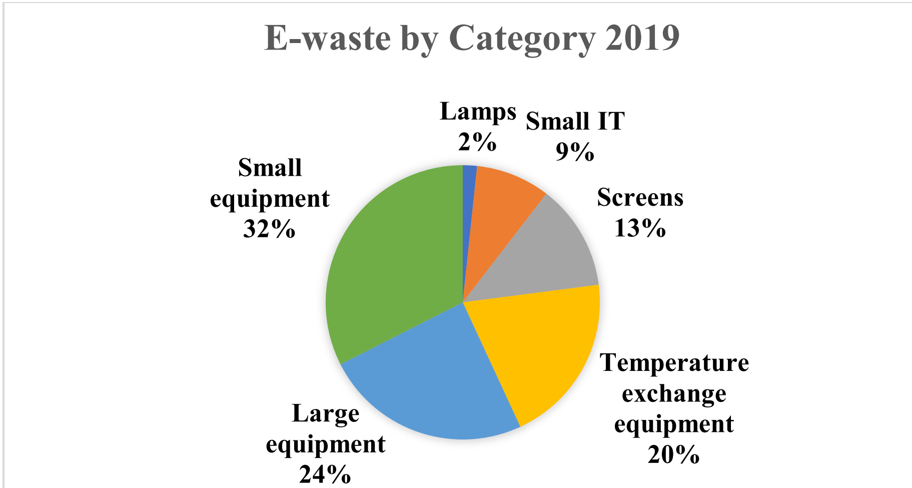
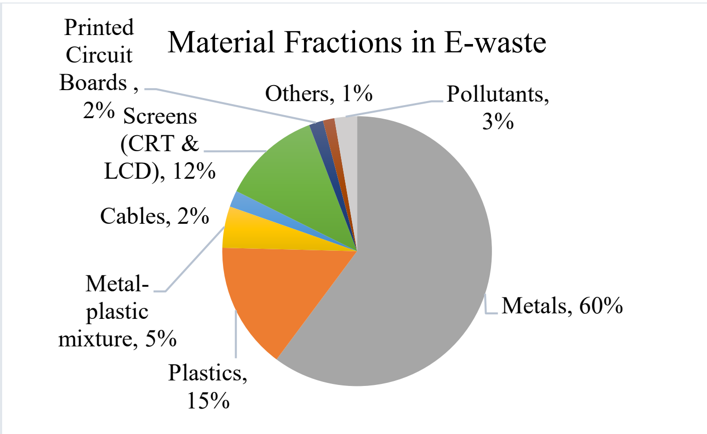


Figure 3: Total e-waste by category (according to the physical weight 2019)

Source: Forti et al. (2020)

1.2.1. Composition of electronic waste

What makes e-waste valuable but also more toxic, relative to other types of waste, is the physical and chemical distinction (Robinson 2009). E-waste contains more than 1000 different substances. Some are valuable like gold and copper, but many are toxic and hazardous like flame retardants, lead, arsenic and mercury (Alam et al. 2019; Puckett et al. 2002; Sepúlveda et al. 2010). E-waste mainly consists of metals (estimated about 60%), plastics (15%) and screens (12%), with additional material fractions of e-waste presented in Figure 4. Importantly, the composition of e-waste varies for different types of equipment; Figure 5, Figure 6 and Figure 7 illustrate the material fractions of three major products: computers, televisions and mobile phones.



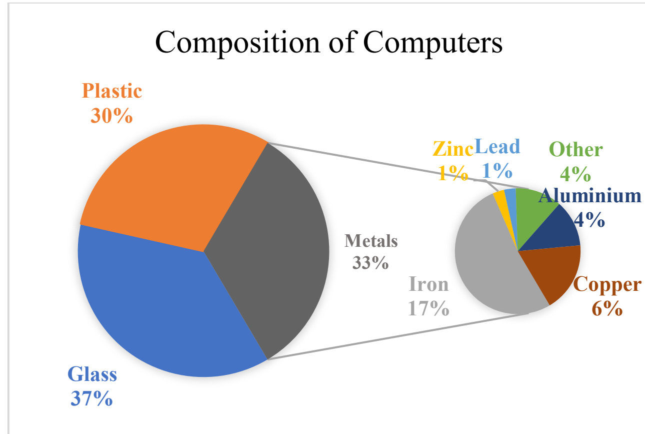
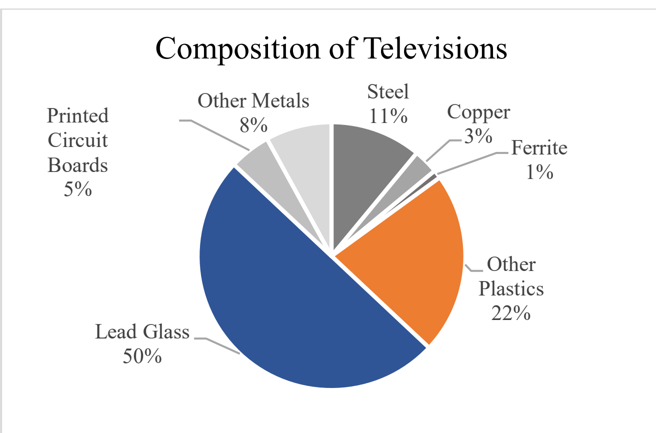


Figure 4: Material Fractions in E-waste

Source: Widmer et al. (2005)

Figure 5: Material Fractions in Computers

Source: Ari (2016)



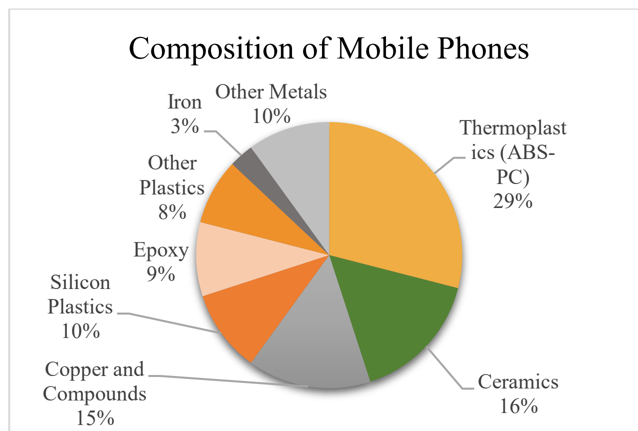


Figure 6: Material Fractions in Televisions

Source: Ari (2016)

Figure 7: Material Fractions in Mobile Phones

Source: Ari (2016)

The respective figures identify product type made up of different materials, in various quantities and processed for disposal in different ways. Understandably, each product offers different benefits and in terms of costs, each product also differs in the relative impact (harm) to human health and the environment. Equipment like mobile phones (Liu, Junli et al. 2020), computers and televisions have: firstly, the most heterogeneous components; and secondly, the highest concentration of precious metals relative to other equipment (Terena et al. 2017). This is despite this equipment falling under the categories of 'small IT and telecommunication' and 'screens', which represent only 9% and 15% of the total e-waste in terms of weight, respectively.

In terms of value, printed circuit boards (PCBs) can contain more than 10 times the concentration of precious metals such as gold, palladium and silver, as compared to respective metal ores (Betts 2008; Lu, Y & Xu 2016; Van Eygen et al. 2016). Conversely, mobile phones contain several valuable metals such as gold, copper, silver, but also have hazardous or toxic metals such as mercury, cadmium, lead, chromium, nickel and arsenic (Jeon et al. 2019; Osibanjo & Nnorom 2008). Gold is one of the metals with the highest economic value (Chancerel et al. 2015; Gu, F, Summers & Hall 2019), which, among other high value metals like palladium and silver, provides the main motivation for metal recovery (Liu, W et al. 2019; Yu, J, Williams & Ju 2010). Other than high value metals such as gold, the principal target metal for recovery are high volume metals like copper (Liu, W et al. 2019; Yu, J, Williams & Ju 2010). Table 2 shows the average metal content and value ratio of typical mobile phones, with gold and palladium having the lowest content percentage but the highest value ratio (Yu, J, Williams & Ju 2010). In contrast, the content of glass, plastics and some other materials in the composition of products is high, yet their economic value is very low.

Table 2: Average metal content and value ratio of typical mobile phones

Element	Copper	Aluminium	Iron	Nickel	Lead	Tin	Silver	Gold	Palladium
Content (%)	13	2	5	0.1	0.3	0.5	0.14	0.035	0.02
Value Ratio (%)	4.3	0.3	0.2	0.1	0.03	0.6	3.9	78.8	11.8

Source: Yu, J, Williams and Ju (2010)

In terms of hazardous impact, parts of equipment such as PCBs contribute up to 59% of the environmental impacts, while liquid crystal displays (LCDs) are responsible for 39% of the impact due to toxicity resulting from improper disposal (Amato, Becci & Beolchini 2020; Boks, Huisman & Stevels 2000; Tan et al. 2017). Therefore, perversely, equipment types that are low in weight are very high in importance due to the toxic effects and potential harm to the environment and to human health, and, to a lesser degree, for the precious metals that are also lost as a result of improper disposal/recycling (Barnwal & Dhawan 2020; Liu, W et al. 2019). Evidently, on one hand, sustainable management of e-waste is required to prevent the loss of precious materials and mitigate their rising shortage (Hagelüken & Meskers 2008; Zhang, L & Xu 2018). Meanwhile on the other hand, these same materials require special handling, treatment and recycling techniques to reduce the damage they do to the environment and people’s health (Xavier et al. 2019).

1.3. E-waste – a growing concern

The growing volumes of EEE are the end result of several long-term trends in the global economic environment. Firstly, rapid advances in technology, growing automation and industrialisation have made EEE essential and ubiquitous in modern societies, where these types of equipment now play a vital role in households to retain and enhance living standards (Grottera et al. 2018; Li, Y et al. 2019). EEE are even more important in retail, manufacturing, healthcare and other industries in order to operate efficiently (Bagheri et al. 2019). Secondly, at the consumer end, higher disposable income, urbanisation and consumer habits, such as more frequent purchases, either to update or access more efficient technology have led to more widespread uptake of technology (Li, C-Z, Wei & Yu 2020; Liu, Jingru et al. 2020). A third factor, at the production level, is increased competition among manufacturers and the decreased lifespan of products – what is known as planned obsolescence (Akcil et al. 2015; Bohlin, Gruber & Koutroumpis 2010; Grace Pavithra et al. 2020), coupled with fewer repair options. This results in a trend to dispose of used equipment sometimes even before the end of their useful lives, which is a serious form of profligacy. These factors in combination add up to an exponential rise in e-waste generation.

1.3.1. Global view of e-waste generation and disposal

The global quantities of e-waste generated annually have risen from 41.8 million tons (Mt) in 2014 to 44.7 million tons (Mt) in 2016 to 53.6 million tons (Mt) in 2019. It is forecast to increase to 74.7 million tons by 2030, doubling in about 16 years (Mt) (Baldé et al. 2017; Forti et al. 2020). Figure 8 shows the trends in global e-waste, per inhabitant from 2014 to 2030.

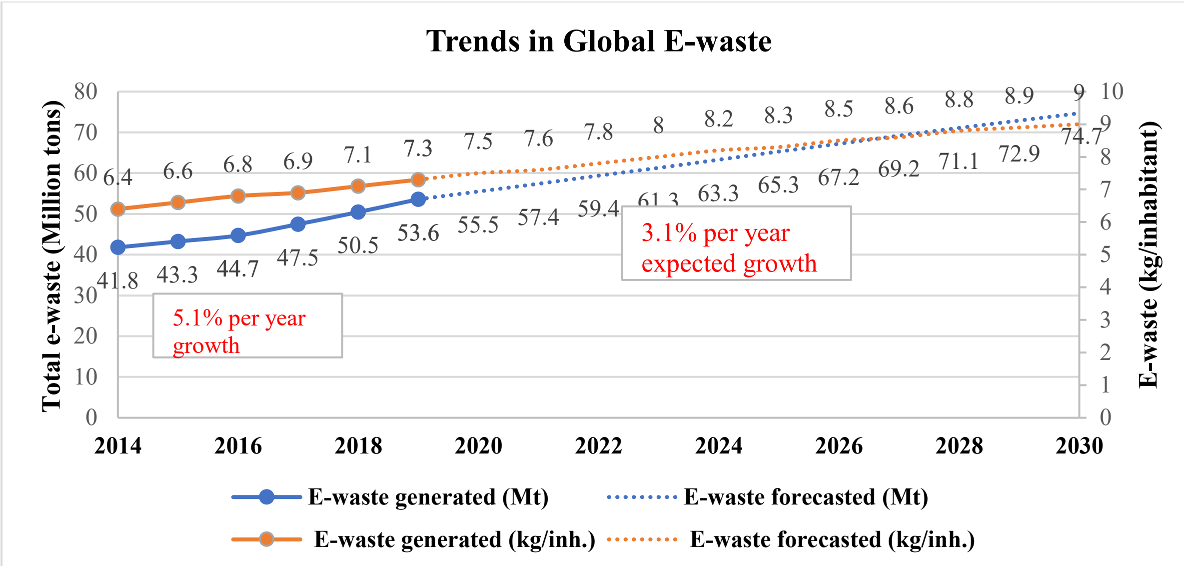


Figure 8: Global e-waste estimates

Source: Baldé et al. (2017); Baldé et al. (2015); Forti et al. (2020)

However, the growth rates in e-waste are not the main problem. Arguably, the greater challenge is the ultimate fate (disposal) of this equipment where recycling rates are not keeping pace with the growth in e-waste quantities. In 2016, globally only 20% (8.9 Mt) of the total e-waste was recycled through proper channels, 4% (1.7 Mt) was thrown in with residual waste that was subsequently sent to landfill or incinerated, while the destination of the remaining 76% (34.1 Mt) was reported as unidentified (Baldé et al. 2017). More recently in 2019, only 17.4% (9.3 Mt) was documented to be collected and recycled through formal channels, and the remaining 82.6% (44.4 Mt) was undocumented (Forti et al. 2020). Out of the total undocumented e-waste, about 8% was discarded with municipal waste in high-income countries, 7-20% was probably exported to developing countries as second-hand equipment or e-waste and the whereabouts of the rest remains unknown, but probably dumped, traded or recycled informally (Ilankoon et al. 2018; Lee, D et al. 2018; Shevchenko, Laitala & Danko 2019). These ‘unknowns’ in the disposal of untracked and improperly treated e-waste are cause for great concern, because e-waste recycling infrastructure is either absent or not well developed in the developing countries that import such waste (Asante, Amoyaw-Osei & Agusa 2019; Nnorom & Odeyingbo 2020). The reality is that e-waste is managed using informal methods that impact negatively on the environment and the health of e-waste recycling workers, their children who live near e-waste recycling facilities, the local community and wider society (Khan, MU, Besis & Malik 2019; Soetrisno & Delgado-Saborit 2020).

1.3.2. Regional view of e-waste generation

Volumes of e-waste generated and collected for recycling at a regional level are presented in Table 3 below. The highest e-waste quantities were generated by Asia, followed by the Americas, as shown in red text in the table. Asia generates 24.9 Mt (annually in 2019) or 46.5% of the global e-waste, making it regionally the largest producer of e-waste (Baldé et al. 2017; Forti et al. 2020). Asia is a complex region, characterised by a range of developing and developed economies, with varying levels of income and therefore very diverse levels of electronics usage, as well as broad range of e-waste management systems. Specifically, as Baldé et al. (2015) pointed out, the rise in consumption of electrical and electronic equipment is more rapid in developing countries than in the developed countries. Moreover, out of the total e-waste produced in Asia, only 11.7% or 2.9 Mt is documented to be officially collected and recycled. This collection and recycling rate naturally varies by country, depending on the national legislation that is in place.

Table 3: E-waste generation and collection per continent

Indicators	Africa	Americas	Asia	Europe	Oceania
Countries in the region (analysed)	49	34	46	39	12
Population in the region (millions)	1,152	984	4,445	740	42
E-waste generated (kg/inhabitant)	2.5	13.3	5.6	16.2	16.1
E-waste generated (Mt)	2.9	13.1	24.9	12.0	0.7
Documented to be recycled (Mt)	0.03	1.2	2.9	5.1	0.06
Formal recycling / collection rate (in the region)	0.9%	9.4%	11.7%	42.5%	8.8%
Informal recycling /Undocumented (est. - Mt)	2.87	11.9	22	6.9	0.64
Informal recycling/Undocumented (est. -.%)	99.1%	90.6%	88.3%	57.5%	91.2%

Source: Forti et al. (2020)

China, with an annual generation of 10.1 Mt (in 2019) is the leading producer of e-waste in Asia and this quantity is expected to increase annually to 27 Mt by 2030 (Baldé et al. 2017; Zeng et al. 2017). This increase is because China is the most populous country leading to a growing local demand, and it is enjoys a relatively high per capita income so that people are now able to afford the latest equipment like laptops, mobile phones and tablets (Ongondo, Williams & Cherrett 2011). Conversely, people who cannot afford new equipment tend to rely on second-hand products

(Ongondo & Williams 2011a). Either way, consumption is rising due to increase in local demand. Fuelling this growth in use of technology, Asia, specifically East and South-East Asia, has also become a hub for manufacturing and assembling of electrical and electronic equipment, which is not just for local consumption, but for global use as well (Baldé et al. 2015; Shen, K et al. 2019).

Other than manufacturing, China and other Asian countries such as India and Pakistan play an important role in the refurbishment, reuse and recycle of e-waste generated locally and imported from developed countries (Baldé et al. 2017; Umair, Anderberg & Potting 2016). India and Pakistan, being the fourth and twenty-sixth largest producers of e-waste worldwide, respectively, are also the recipients of e-waste from OECD countries (Abid, Zulfiqar & Raza 2019; Baldé et al. 2017; Ilyas et al. 2020; Srivastava & Pathak 2020). As a result, the volume of discarded electronics in East and South-East Asia has risen by almost two-thirds, while it more than doubled in China between 2010 and 2015, and this rise in e-waste generation is outpacing the population growth (Honda, Khetriwal & Kuehr 2016). It is estimated that developing countries are likely to discard twice as much e-waste as the developed countries by 2030 (Sthiannopkao & Wong 2013). This expected two-fold rise will be due to high local consumption, but also from hidden and sometimes illegal flow of e-waste from developed countries (Puckett et al. 2002; Wu, Qihang et al. 2015).

After Asia, Europe was the second largest generator until the previous estimates in 2016, now replaced by the Americas, which is recorded as producing 13.1 Mt (annually in 2019). This is about 24.4% of the global e-waste, but with a collection and recycling rate of just 9.4% or 1.2 Mt (Forti et al. 2020). The continent has some general measures to reduce e-waste and has regulations at the federal level (Resource, Conservation and Recovery Act – RCRA) to limit the adverse effects of improper disposal and recycling, which also includes Responsible Recycling (R2) or Stewardship Standards. However, despite the growing number of formal e-waste facilities in the region, including Latin America, Mexico, very large quantities are still processed through informal methods or exported to other developing countries (Guibrunet 2019). In reality, the Americas are still far behind Europe, which has tight legislation that covers the European Union (Baldé et al. 2017), including a (EU) WEEE Directive that has provisions for the design, production, collection, disposal and treatment of e-waste. It is therefore not a surprise that Europe has high collection and recycling rates (42.5% or 5.1 Mt) when compared to other regions.

At the country level, there is an arguably severe dearth in official e-waste statistics. Only 41 countries are reported as having official e-waste statistics (Baldé et al. 2017; Huisman et al. 2019). Reflecting this situation, as Baldé et al. (2017) have suggested, there is a serious need for an e-waste inventory in order to reduce e-waste generation (Kumar, Sashi & Rawat 2018), to prevent illegal dumping and export (Işıldar et al. 2018), to promote recycling, to reduce the impacts of disposal and recycling practices, and to create jobs.

1.3.3. Electronic waste in Pakistan

There is no official inventory management or official statistics on the volumes of both internally generated and imported e-waste in Pakistan (Baldé et al. 2017; Iqbal et al. 2015; Umair, Anderberg & Potting 2016). However, according to a UN report (Forti et al. 2020), Pakistan generated about 433 kilo-tons (kt) of e-waste in 2019, up from 301 kilo-tons (kt) in 2016 and 266 kilo-tons in 2014. Showing an annual growth of 10.2% according to these estimates, Pakistan is the 26th largest producer of e-waste in terms of quantity (Baldé et al. 2017; Baldé et al. 2015). Over time, there have been different estimates of e-waste in Pakistan – of approximately 210 kilo-tons generated in 2005, 300 kilo-tons in 2010 and 317 kilo-tons in 2015 (Breivik et al. 2014; Iqbal et al. 2015; Robinson 2009). However, according to one fairly recent estimate by Imran et al. (2017), Pakistan imported an average of 95,145 tons of e-waste[3] annually from 2011 to 2014, while another study by Sajid et al. (2019) estimated e-waste due to scrap computer equipment to be 50,000 tons annually and total e-waste generated to be annually 114,000-138,000 tons in 2014.

Looking ahead, out of the total e-waste in Pakistan, the waste due to mobile phones is expected to increase at the highest rate (Figure 9). This is indicated by the expected 10.4% annual rise in the sale of handsets, while sales of television/monitors and computers are expected to grow at 5.2% and 3.8% annually (BMI 2017). On reaching the end of useful life of 2 years (mobile phones), 5 years (televisions) and 3 years (computers), e-waste can be expected to increase by the same rate as growth in sales (Betts 2008; Robinson 2009).

[3] Included only the equipment that was a major portion of total e-waste imported to Pakistan: desktop computers, laptops/notebooks, computer monitors, liquid crystal display units, televisions, ink-jet and laser-jet printers, scanners, computer keyboards, computer mice and power cables.

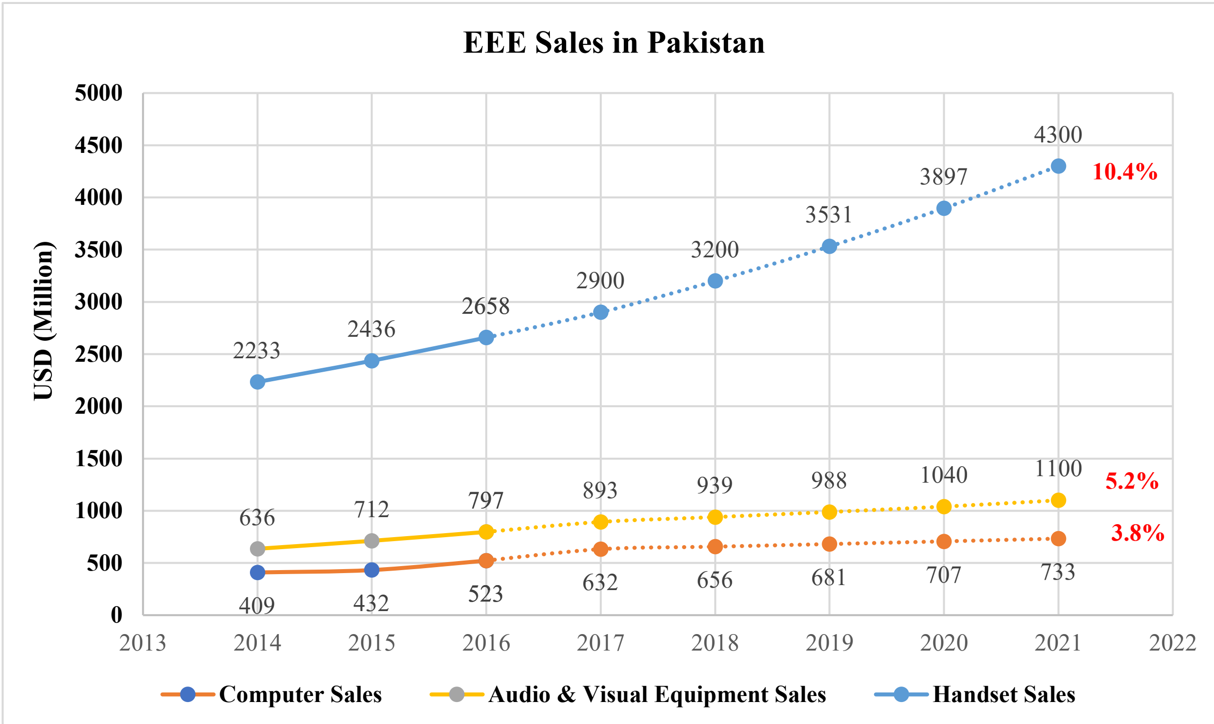


Figure 9: Sales in Pakistan
Source: BMI (2017)

Along with an expected rise in locally generated e-waste, it is worth noting that Pakistan is one of the countries receiving e-waste from the developed economies. In contrast to this trend, the reality for Pakistan and other similar recipient countries is that it/they lack the necessary resources, infrastructure and technology to adequately process e-waste (Ikhlayel 2018; Nnorom & Osibanjo 2008b; Schluep 2014). The outcome is that recycling in Pakistan is based on informal and hazardous methods such as open burning and acid baths (Ackah 2017; Awasthi, Zeng & Li 2016a; Cesaro et al. 2019; Vaccari et al. 2019). These methods are characterised by minimal regulatory oversight by governments and local authorities, making Pakistan a highly vulnerable country.

1.4. E-waste recycling processes

E-waste can either be processed using what are known as formal or informal methods. Informal practices, which characterise the approach used in Paksitan, use crude and unsafe methods of recycling such as burning and acid baths, with waste residue ending in landfills and in local drains and subsequently into waterways. Recycling businesses that undertake this processing are typically unregistered, hidden and operate largely free of regulatory oversight (Ceballos & Dong 2016;

Perkins et al. 2014; Sthiannopkao & Wong 2013). The effects of informal processing have been studied extensively and reported to be hazardous to (and releasing toxic elements into) the environment, humans and animals (Grace Pavithra et al. 2020; Hoa et al. 2020; Kim et al. 2020; Soetrisno & Delgado-Saborit 2020; Thanomsangad et al. 2020; Weber et al. 2018). Exposure to toxic chemicals includes metals such as mercury and lead, while burning e-waste materials is associated with the risk of respiratory and skin diseases, eye infections and cancers for those who work on such waste and also those who live nearby. A considerable amount of pollution from processing this waste also enters the environment. Informal recycling is presented visually in APPENDIX 2 to provide a sense of the activity and general exposure that workers experience.

In stark contrast to informal recycling, formal recycling typically in countries of origin entails purpose-built facilities with proper equipment, facilitating safe extraction processes (Ceballos & Dong 2016; Laha 2015). Mostly, these facilities ensure safe working conditions but they are expensive to build and maintain (Perkins et al. 2014) and so not very common in many developing countries. Importantly, regardless of the relatively safer, regulated processes, formal recycling also has its limitations in terms of eliminating negative impacts on the environment and human health. Workers in these facilities were found to have an overexposure to toxic elements, including dioxins and furans (Li, W & Achal 2020; White & Shine 2016). Both formal and informal processes, including impacts are discussed in more detail in Chapter 2.

1.5. Research problem and objectives

1.5.1. Research problem

As noted in the previous subsections, handling of e-waste in developing countries is mostly characterised by high rates of repair, reuse and recycling based on largely informal practices (Ongondo, Williams & Cherrett 2011; Perkins et al. 2014; Puckett et al. 2002). Stockpiling of unwanted electrical and electronic products is evident in both the developed and less developed economies, and landfilling of e-waste is also a common concern (Liu, X, Tanaka & Matsui 2006; Rahmani et al. 2014; Saphores et al. 2009). Informal practices in handling and recycling e-waste have been shown to have considerable negative environmental and social impacts (Ackah 2017; Anh et al. 2017; Lau et al. 2014; Pradhan & Kumar 2014). In contrast, there is little awareness of these costs and associated implications, a situation that is compounded by the absence of official inventory, statistics, and a lack of e-waste legislation. These are seriously needed to reduce e-waste generation (Kumar, Sashi & Rawat 2018), prevent illegal dumping and export (Işıldar et al. 2018), promote recycling, reduce the impacts of disposal and recycling practices, and create employment.

Reflecting this serious limitation and consequent implications, this research seeks to act as a stepping-stone for further research and policy action by conducting an initial country analysis. This research can be considered as the first step in the three-step approach to developing an e-waste management strategy adopted by the United Nations Environmental Program (UNEP), the United Nations Development Organisation (UNIDO), the Basel Convention, as well as by Solving the e-Waste Problem (StEP). The three stages are illustrated in Figure 10.

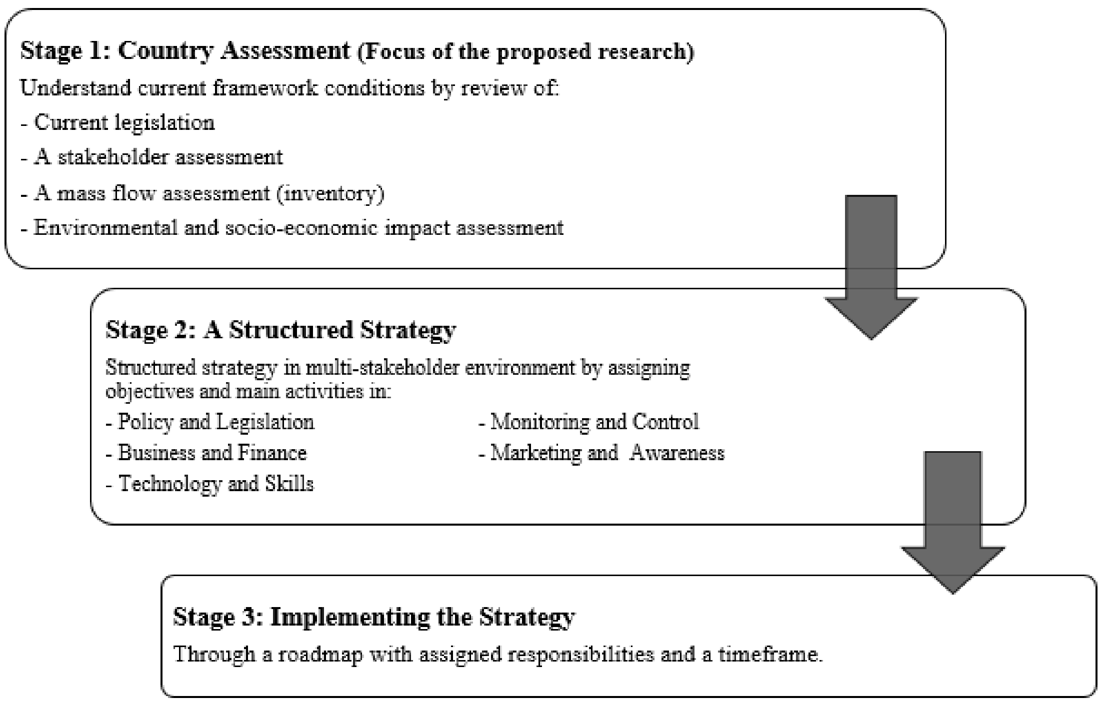


Figure 10: E-waste management strategy
Adapted from Schluep (2014)

Notably, the effective management of e-waste depends not just on the technical implementation of the e-waste management strategy, but also on a structured and comprehensive approach. Crucially, developing countries usually lack the needed infrastructure and the legal and institutional framework. The three-step approach was devised to address these issues and to support the creation of effective e-waste management strategies. As noted earlier, the current research can be regarded as performing a country assessment (the first stage), which will form the basis of a follow-on development of an e-waste management strategy (stages 2 and 3) for the country in focus, Pakistan.

Within the first stage of country assessment (Figure 10), this research uses an ecosystem view and social life cycle assessment (S-LCA) to assess and measure the impacts of e-waste disposal and recycling in Pakistan. The focus is on both upstream waste generation and downstream businesses that are involved in collection and recycling. The LCA steps were illustrated in Figure 2 earlier.

1.5.2. Research question and objectives

The main research question is "***What are the economic impacts of e-waste disposal (and recycling) practices?***"

For this study, the term "impact" in research question includes both positive and negative results/consequences of disposal and recycling practices. Economic impact has been assessed qualitatively and quantitatively using cost-benefit analysis and therefore includes financial and non-financial or social impacts. The financial impacts comprise measurable and tangible costs and benefits for identified stakeholders, while non-financial or social impacts include social and sociological (i.e. interactions and relationships) aspects - both positive and negative. These involve themes of health and safety, human rights, working conditions and socioeconomic repercussions for identified stakeholders. E-waste disposal includes landfill/incineration and recycling, which can be done formally or informally, by storage and export to third-party countries as possible intermediate stages before final disposal.

The two sub-questions (SQ) and their corresponding research objectives (RO) are as follows:

SQ1: What is the current (upstream) situation with e-waste generation and disposal in Pakistan?

- **RO1:** Analyse consumer behaviour concerning the acquisition, usage, disposal, awareness and willingness to pay for e-waste management.
  - **RO1.1.** Assess the buying behaviour for new EEE.
  - **RO1.2.** Estimate the useful life of EEE.
  - **RO1.3.** Assess the factors that influence formal or informal e-waste disposal practices.

RO1.4. Assess the awareness of hazardous/toxic elements and valuable elements.

RO1.5. Assess the willingness to pay for e-waste management.

RO2: Assess the flow (and stock) of electrical and electronic equipment/e-waste through the upstream sector.

SQ2: What are the (downstream) impacts of e-waste recycling practices in Pakistan?

RO3: Estimate the costs and benefits of e-waste recycling for businesses.

RO4: Assess the drivers, social implications and economic cost-benefit of working in the e-waste recycling sector (workers).

RO5: Identify a framework for e-waste impact assessment for developing countries (based on multiple criteria).

As identified earlier, this research uses an S-LCA approach, with the main process of a generic life cycle assessment as illustrated in Figure 2. There is close alignment of the research objectives with the respective steps of an S-LCA. The first stage is goal definition and scoping, which has been described earlier in the current chapter in terms of the application and type of LCA, the product systems (e-waste) under evaluation, and the geographical scope (Pakistan). The second stage is related to sub-question 1 (SQ1) about the generation, quantification (inventory analysis) and disposal practices of e-waste. On the issue of disposal, e-waste enters into the recycling stream, and the impact of these recycling practices is studied in sub-question 2 (SQ2) – the third stage in the LCA assessment. Interpretation of data is carried out at each stage. Therefore, in this study, stages 2 and 3 have been interpreted separately in consecutive chapters, and consolidated findings are presented in Chapter 7, the discussion chapter.

1.6. Anticipated study contribution

Electronic waste is an emerging global waste management and disposal challenge. It is often also described as an economic opportunity because of the many rare and valuable materials used. Aside from the hazardoius nature of waste processing, there is also a significant issue with toxicity in some of the waste such as mercury and lead, that poses a first-order threat to humans and later second- and third-order effect for the environment (Heacock et al. 2016; Herat, Sunil & Agamuthu 2012; Widmer et al. 2005). Many studies have covered different aspects of e-waste, such as estimating the quantities generated in different countries (Araújo et al. 2012; Polák & Drápalová 2012; Rahmani et al. 2014; Tran et al. 2016), the composition of EEE and toxicity of e-waste (Chen, M et al. 2016; Nnorom & Osibanjo 2009; Perkins et al. 2014; Wu, B et al. 2008), and the impacts of formal (Ceballos & Dong 2016; Julander et al. 2014) and informal (Pradhan & Kumar 2014; Streicher-Porte et al. 2005) recycling practices. There is as yet no overarching estimation of economic costs and only limited studies on social impact, albeit typically in the developed world. This research tries to fill this gap in our knowledge, by providing a basis to overcome the limited measurement, compounded by a lack of e-waste statistics and inventory management in Pakistan.

1.6.1. Contribution to knowledge (Academic contribution)

This research contributes to the literature in e-waste management and disposal in several ways. Firstly, as noted earlier, Pakistan does not have any official statistics, nor keeps an inventory of e-waste that is generated nationally or imported. As a result, there is no basis to understand, measure and suitably manage the associated problems with disposal and recycling of e-waste. In addition, no studies have yet been published on consumer behaviour, in terms of their usage patterns and motivations that act as a precursor to the quantities of e-waste generated locally. This research firstly contributes, by understanding the habits of people with respect to technology uptake, usage and disposal practices, then estimating the quantities of e-waste generated by the sample and for the population of Pakistan by extrapolation. This analysis has been used to estimate the fate and destination of e-waste that in turn is used to explore the downstream impact and consequences.

Secondly, studies on the impact of e-waste have mainly highlighted the environmental pollution and intoxication of air, soil and dust (Alcántara-Concepción, Gavilán-García & Gavilán-García 2016; Awasthi, Zeng & Li 2016a; Song et al. 2015), and the social impacts, mainly focused on the health consequences for recycling workers and also the work environment, working hours and social security (Pandey, P & Govind 2014; Song & Li 2015; Umair, Björklund & Petersen 2015). Williams, E et al. (2008) tried to estimate the economic scale of reuse and recycle of computers, but concluded that the sector provided employment. In economic terms, Umair, Anderberg and Potting (2016) also noted that the informal e-waste recycling sector in Pakistan provided employment opportunities and livelihoods. However, there is still a dearth of literature that calculates the economic impacts (financial and non-financial or social) of e-waste recycling. This research contributes by systemic estimation of economic impacts, including estimating the costs and benefits downstream for businesses and recycling workers. To the best of the researcher's knowledge, this type of estimation in the context of e-waste recycling has not been done.

Thirdly, with China (until recently) and India, Pakistan is an attractive destination for e-waste disposal, with each country receiving large volumes from the US, Europe, and Australia, reportedly shipped through Singapore, Taiwan and Hong Kong (Herat, Sunil & Agamuthu 2012; Sthiannopkao & Wong 2013; Zhang, K, Zeng & Schnoor 2012). Most of this obsolete electrical and electronic equipment that includes computers are imported into Pakistan labelled as 'second-hand equipment'. This strategy is described as a contrivance in order to bypass the Basel Convention that prohibits exporting for disposal. However, countries are permitted to export and developing countries can import second-hand materials for reuse and recovery (Basel Action Network 2011; Puckett et al. 2002), with the clause 'reusable' allowing the continued export of e-waste (Abbas 2010; Imran et al. 2017). The evidence also is that only 2% of imported e-waste is reused (in the receiving countries). The rest of the e-waste, along with much of the domestically generated waste, is dismantled and recycled using informal methods in order to recover valuable metals such as gold, silver and palladium contained in the waste, but without examination in terms of the environmental and human health implications (Abbas 2010; Imran et al. 2017; Umair, Anderberg & Potting 2016).

These implications aside, there are other hidden and unknown social costs incurred by workers, their family members and the wider local communities that host processing sites. This research seeks to fill these gaps in literature by developing a consolidated impact factors framework (CIFF) to measure the variables that contribute to upstream and downstream waste considerations, and consequently a multi-level impact assessment framework (MIAF) to identify sector variables and to measure the *hidden* and *invisible* costs. These costs include the opportunity cost, the cost of illiteracy and reduction in productive capacity using cost-benefit analysis, which previously have not been estimated or highlighted in the context of e-waste recycling.

Fourthly, existing research has predominantly explored the area of e-waste for developed countries, in terms of estimates, flow, management, public health implications and occupational exposure (Golev & Corder 2017; Julander et al. 2014; Parajuly, Habib & Liu 2017; Seeberger et al. 2016). There are also a few studies in developing countries, such as India (Annamalai 2015; Joon, Shahrawat & Kapahi 2017; Pradhan & Kumar 2014), China (Deng et al. 2014; Duan et al. 2009; Leung, A et al. 2007; Yan, Xu & Shen 2013; Zheng, G et al. 2013), and a small number of African countries (Ackah 2017; Agyei-Mensah & Oteng-Ababio 2012; Isimekhai et al. 2017; Tetteh & Lengel 2017). However, very little research has been done on Pakistan. For instance, Imran et al. (2017) estimated the amount to e-waste imported in Pakistan, while Umair, Anderberg and Potting (2016); Umair, Björklund and Petersen (2015) explored the social impacts of informal e-waste recycling in Pakistan. Yet as Iqbal et al. (2015) also emphasised, there is a need for reliable and quantitative data on e-waste that is generated locally and imported (illegally), and further, more research is required to help understand the situation of e-waste in Pakistan from a macro view. It should take into account an assessment of environmental, human health and economic impacts of recycling practices. Given the extent and growing volume of e-waste in Pakistan, coupled with a lack of awareness, knowledge and technology for proper recycling, this study adds a country assessment (stage 1 - Figure 10), where official country statistics are absent.

Finally, this research uses the various key stakeholders in the system to illustrate the social dynamic using (a systems view and) causal loops – from upstream waste generation to downstream disposal. Social dynamics is an area that receives little attention and yet is crucial, for example, in the future development of a circular economy. RO5 – identification of a framework for e-waste impact assessment for developing countries - uses the earlier study findings to disentangle what is a convoluted and interconnected problem. In this regard, noting the primacy of informal recycling practices in Pakistan, RO5 presents a multi-level impact assessment framework to enable a systemic estimation of known, as well as some of the many less visible and hidden, primarily non-financial (social) costs in handling and processing e-waste in Pakistan. While shown for conceptual completeness, environmental considerations are largely outside the scope of this study.

1.6.2. Statement of significance (Practical contribution)

This guiding principle, usually attributed to Peter Drucker, forms the start point for this study; *what gets measured can be managed* (Prusak 2010). Regardless of the origin the message is clear: noting a difference between outcome (lag) and performance (lead) metrics, measuring can provide the necessary information to start to manage the necessary changes in the intractable issue of e-waste inventory management. One key element in performance metrics is to devise a framework with variables to measure, manage, promote recycling and ideally inform policy. Reported information, and quantitative measures of performance, arguably play a key role in determining the areas that attract the attention of policy-makers and the availability, measurement and reporting of quality data are regarded as helpful in attracting necessary resources and evaluating effort against desired outcomes (Biggeri 2005; Streatfield & Markless 2009).

This research seeks to design a framework for analysis that can help provide evidence of impact to inform business practice and also guide necessary government intervention/regulation in an, as yet, unregulated sector of the economy in Pakistan. Moreover, and consistent with Ridgway (1956) cautionary remarks on the dysfunctional effects of an emphasis on quantitative measures, this study illustrates the need for a judicious use of data and awareness of the full effects and consequences and responses that can often outweigh the benefits. Rather, introducing a systems perspective, this study encourages a wide view of e-waste recycling that counters the tendency to attempt to state and measure numerically the many variables related to e-waste for management and regulatory attention.

Considering the initial costs of informal recycling, at a surface and instrumental level, it is lucrative and significantly cheaper to recover valuable metals such as gold and silver from electronic products, while disposing of the remaining e-waste product in landfill (Drayton 2007; Sener & Fthenakis 2014). It is lucrative, as informal recycling processes provide: firstly, significant economic benefits for businesses; and secondly, employment and wages for unskilled workers and their families (Asante, Amoyaw-Osei & Agusa 2019; Umair, Anderberg & Potting 2016). Yet, there are also hard-to-quantify costs, some known and many hidden or unknown, associated primarily with social (human health) and environmental factors.

By offering a framework to identify and measure the economic impact (a collective term that encompasses both financial and non-financial or social cost-benefit) of e-waste disposal and recycling in Pakistan, this research will provide the basis for examination and some quantified evidence for policies and related actions to reduce the negative impacts of the industry and maximise the benefits for all stakeholders in the ecosystem. The obvious example is the introducing of formal recycling in order to reduce people’s exposure to the known toxicity in e-waste materials. A more modest example is any effort to negate the social (human health) costs through better workplace conditions and diminished hazards and toxicity (Ceballos & Dong 2016; Julander et al. 2014; Yu, J et al. 2010).

Aside from the non-financial social and environmental benefits, formalising waste recycling will arguably help set in train a positive reinforcement loop that could result, for example, in improved waste processing technology and attendant skills for the presently largely unskilled workforce. Consequent, tangible benefits include: the opportunity to shift from an overreliance on unskilled manual work; creating greater employment opportunities for workers in Pakistan; generating greater profitability for the industry from the recovery of rare earth materials and valuable metals; and intercepting toxic waste that would otherwise end up in landfill with downstream destructive environmental consequences.

1.7. Strategies to guide the study process

At the beginning of this PhD study, e-waste was a new field for the researcher, with the topic selected for innovative opportunity and perceived national significance. E-waste was also an emerging study area, with much of the research in science, engineering and waste management. There was as a result also limited cross-disciplinary studies, and even less management- and finance-specific academic literature on the topic. Consequently, one strategy the researcher adopted was to seek and engage with industry experts who formed an expert advisory group (EAG - discussed in Chapter 3, section 3.6). This strategy proved invaluable over the course of the study.

It is useful to also recall the internal university processes that guide the study progress. The researcher was required to satisfy a thorough monitoring and approval process by the Research Office at Victoria University. The steps included a confirmation of candidature (with a written study proposal), ethics, mid-candidature panel (reporting progress and preliminary findings) and a 'towards submission panel'. All milestones required the researcher to attend and present before a panel of academics with inter-disciplinary subject matter expertise. Guidance received at each of these stages was incorporated into the study. As a result, much of the thesis, including some parts of the results documented in it have been reviewed and broadly endorsed.

A final strategy adopted was to publish results progressively in peer reviewed Q1 journals. So far, two papers have been published, and a further two remain under consideration. The relevant chapters have footnotes that reference the respective publications. This strategy was hugely affirming and enriched the research process despite the challenges encountered.

1.8. Summary and outline of the thesis

Chapter 1 provides an overview of the thesis, describing the subject – a growing concern globally with rising volumes and composition (and toxicity) of e-waste, and the related concern with the use of informal practices in Pakistan. The chapter then defines the research question and objectives and highlights the significance and contribution of this research. This thesis is organised into eight chapters and adopts a recursive method of writing due to the complex nature of the thesis. The intention is to help the attention of the reader to fully comprehend the material presented. Chapters are summarised below.

Chapter 2, presents a detailed exploration of literature in the area of e-waste and pertinent to this study. It starts by reviewing factors that contribute to e-waste, the studies concerning the upstream sector (related to the manufacturing of EEE) including impacts during the production process, followed by a detailed review of the downstream sector (disposal and recycling) and impact assessment in terms of environmental, human health, social and economic impacts. Next, literature regarding the circular economy has been presented, as a transition from a linear to the circular and more sustainable economy. Additionally, the best practices in e-waste management have been identified in the developed and developing economies which can be implemented in Pakistan. The chapter ends with an identification of the gaps in the literature and a conceptual framework to guide the research.

Chapter 3 describes and justifies the methodology used in this study, research paradigm, methods, research process, including data collection and analysis for each research objective that required types of data collected through different methods.

Chapter 4 details the statistical analysis, findings and discussion of RO1 and 2 that study consumers' habits regarding acquisition, usage, disposal, awareness of e-waste and willingness to pay for an e-waste management system, as well as extrapolation to estimate the quantities generated in Pakistan.

Chapter 5 presents the analysis, findings and discussion of RO3 that focuses on material flow analysis, impact assessment (financial cost-benefit analysis) for e-waste recycling businesses and qualitative analysis based on themes. This chapter also highlights a trade-off of competing interests of e-waste recycling businesses.

Chapter 6 provides the analysis, findings and discussion of RO4 that involves cost-benefit analysis using financial and non-financial (social) variables for e-waste recycling workers along with qualitative thematic analysis. This chapter discusses a vicious cycle of poverty that workers are trapped in.

Chapter 7 interprets, consolidates and discusses findings of all the research objectives (RO1, 2, 3 and 4) using systems thinking and the life cycle view in order to untangle and explain the interconnected problem. This chapter also highlights the unknown, unknown, hidden and blind spots in e-waste recycling systems of Pakistan, and identifies a framework for e-waste impact assessment for developing countries.

Finally, Chapter 8 provides summative reflections on the completed thesis and results of research. The chapter also provides recommendations, discusses some limitations of the thesis and makes conclusions on this subject. Possible future research opportunities are also suggested.

CHAPTER 2: REVIEW OF THE LITERATURE

2.1. Introduction

As was noted in Chapter 1, e-waste is a global challenge of increasing significance because of the volumes being generated and associated complexity of this waste (Andersson, Söderman & Sandén 2019; Baldé et al. 2017; Islam, Dias & Huda 2020; Xu, Y et al. 2020). It contains valuable and toxic materials that have demonstrated serious environmental and social impacts, but it is also the business opportunity due to their economic benefits if they recycled intelligently (D'Adamo et al. 2019; Perkins et al. 2014; Robinson 2009; Widmer et al. 2005; Williams, E et al. 2008). Pakistan, like many other developing economies, generates a significant volume of e-waste internally and, like some other developing economies, also imports significant volumes of e-waste for local processing, despite lacking the necessary infrastructure (Abid, Zulfiqar & Raza 2019; Sajid et al. 2019; Umair, Anderberg & Potting 2016).

This chapter reviews the literature on e-waste management and impacts. It starts by exploring the factors that contribute to growing e-waste volumes worldwide before taking a life cycle view with both upstream and downstream sectors. Upstream impacts on the environment and workers during the manufacturing phase have been studied, along with impacts during usage phase. Next, understanding the downstream sector involves studying the disposal behaviour, some common ways of disposing, including transboundary movement from developed to developing countries. Stakeholders in both upstream and downstream sectors are identified, followed by a discussion about the processes used in formal and informal recycling. Subsequently, literature on impact assessment is reviewed, highlighting environmental, human health, social and economic impacts. The best practices in developed countries are discussed, while current practices in developing countries are also highlighted, including Pakistan. A summary is presented and the gaps in the literature on this topic are identified that this thesis tries to fill. This chapter also identifies an adapted ecosystem view as conceptual framework with multiple stakeholders, along with a consolidated impact factors framework.

2.2. The factors contributing to e-waste

In order to assess the impacts associated with disposal and recycling of e-waste, it is important to first review and understand the reasons/factors behind the surge in e-waste, followed by the lifecycle of EEE from the upstream stages (extraction, manufacturing, transport, usage) to the downstream stages (collection, disposal, recycling - whereby EEE becomes e-waste). There are several main factors contributing to the problem of e-waste discussed below, including rapid advancement in technology, consumer demands, attitudes, and strong incentives for consumption drastically reduce the lifespan and encourage faster replacement rates (Borthakur & Govind 2017; Gu, Y et al. 2016). These issues are briefly discussed below.

2.2.1. Rising demand for electrical and electronic equipment (EEE)

A key factor that contributes to rising demand of EEE is better networks with new services and applications are now available at faster speed, providing wider applicability related to entertainment (consumer electronics), communication (mobile technologies), administrative and industrial (education, health, government, commerce) utility (Pothitou, Hanna & Chalvatzis 2017; Røpke & Christensen 2012). These technology centric advances, together with higher levels of disposable income, purchasing power, urbanisation and industrialisation in many developing countries have resulted in surging ownership of electrical and electronic equipment (Baldé et al. 2017). This is evident by the fact that internet users per 100 persons doubled during 2000-2010 in developing countries, while it increased by 153% globally. During 2000-2016, the emerging economies with low purchasing power have shown the highest growth rate in EEE consumption (Baldé et al. 2017). The demand in terms of weight has dominantly been for equipment such as refrigerators, centralised heating units, washing machines and modern LCD/LED televisions (Baldé et al. 2017). Simultaneously, there has been a decline in the sales of certain equipment, such as portable audio and video devices, and cathode ray tube (CRT) televisions (Baldé et al. 2017). The equipment has become obsolete due to rapid technological advances and replacement of many devices with just one (or a few) device(s) that performs multiple functions.

Moreover, according to estimates by Røpke and Christensen (2012), developing countries had internet access in 62% of households as compared to 75% globally. These estimates might be overstated because more recent estimates show global internet penetration of 54% (Baldé et al. 2017). In addition to the internet access, global penetration of mobile subscription stood at 7.7

billion (Baldé et al. 2017) while the world population was estimated to be 7.53 billion in 2017 (The World Bank 2017b). Alongside this the growth in e-commerce as depicted by the global value for both business-to-business and business-to-consumer markets is approximately USD 22 million and USD 3 million, highlighting the shift to online business and consumerism. Consequently, the demand for electrical and electronic equipment has steadfastly risen (United Nations Conference on Trade and Development 2015). In Pakistan, which is the world's sixth most populous country, the increasing population and purchasing power has increased the demand for EEE, including home appliances, telecommunications, computers and IT (Iqbal et al. 2015). Moreover, cheap handsets produced by Chinese manufacturers, offered as affordable entry-level phones have increased mobile/smart phone affordability and usage for low-income groups (International Telecommunication Union 2016).

2.2.2. Rapid obsolescence

Another factor that contributes to rising e-waste is the high technology uptake, partially because of programmed and deliberate obsolescence of EEE by the manufacturers (Cayumil et al. 2016; Echegaray, F 2016; Forge 2007; King et al. 2006; McMahon, Uchendu & Fitzpatrick 2021). The obsolescence is through short innovation cycles in the hardware and software, whereby newer and updated software applications require larger memory and more speed (Berkhout & Hertin 2004). This has translated into higher turnover and shorter lifespan of the equipment, such as the life of personal computer from 5 years to 3 years during 1992-2005, while mobile phones had an estimated life of 2 years (Babbitt, C W et al. 2009; Robinson 2009). Therefore, consumers replace their existing devices even before they break down or complete their useful lives, simply because they become outdated (Robinson 2009). This has been supported by one study (Ala-Kurikka 2015 cited in Kumar, A, Holuszko & Espinosa 2017) contending that 60% of the televisions deemed obsolete in 2012 were in a working condition, probably discarded as a result of technology change from Cathode Ray Tube (CRT) to Liquid Crystal Display (LCD) or Light Emitting Diode (LED) televisions. This suggests the short useful life was a result of rapid advances in technology. This fast uptake of the latest technology can be viewed as symptom of modern materialism and short-term consumerism rather than a sign of dematerialism (Berkhout & Hertin 2004).

2.2.3. Legislation

Unsurprisingly, a key factor influencing demand (and disposal practices too) concerns regulations that govern enforcement and involvement of local government authorities in influencing the generation, importing, handling and recycling of e-waste (Bahers & Kim 2018; Borthakur & Govind 2018; Iqbal et al. 2015; Ni, H-G & Zeng 2009). The absence of laws and low levels of law adherence diminishes the power of subjective norms in affecting the recycling intention and actions (Xu, F et al. 2014). In many developing countries, the lack of regulations, treatment standards, environmental protection measures, recycling infrastructure, enforcement of policies, along with trade of e-waste from developed to developing countries has resulted in the emergence and evolvement of the informal recycling sector that uses crude methods (Baldé et al. 2017; Ismail & Hanafiah 2017). Crude methods of recycling and other informal disposal practices are enabled by limited safeguards, policies, legislation and enforcement and has in turn led to serious environmental and human health problems in these countries (Kiddee, Naidu & Wong 2013).

To illustrate, as of 2017, 66% of the world's population or 76 countries have some form of national e-waste regulation in place, as compared to 61 countries (44% of the world's population) in 2014 that had e-waste regulations, showing growth in the number of countries that are adopting e-waste regulations (Baldé et al. 2017). More countries are now introducing take-back laws where the producer is required to take the used products back at the end of their useful life (Nnorom & Osibanjo 2008b). From a regional perspective, Europe has the most developed e-waste management systems and regulations, and also the highest collection and recycling rates (Baldé et al. 2017). The European Union has devised a wide range of e-waste policies, such as (EU Council Directive 2012) and RoHS, which are mainly aimed at improving the environmental performance of electrical and electronic equipment. Traditionally, legislation targeted at environmental problems essentially addressed the end problem of pollution through a 'command and control' approach (Bailey 2002; Darby & Obara 2005). However, the focus more recently appears to have shifted towards producer responsibility (known as Extended Producer Responsibility or EPR), whereby the manufacturer is responsible for the environmental impact of the entire lifecycle of a given product, starting from extraction and manufacturing to disposal, recycling, and other end-of-life processes (Kiddee, Naidu & Wong 2013; Nnorom & Osibanjo 2008b).

Other regions with somewhat developed e-waste collection and recycling systems are North America, East Asia and South Asia (Honda, Khetriwal & Kuehr 2016; Kahhat et al. 2008; Shinkuma & Nguyen Thi Minh 2009). In Asia, the most populous countries - China and India - have enacted e-waste laws, but only a few countries in Africa have regulations and legislation specific to e-waste (Honda, Khetriwal & Kuehr 2016; Ni, H-G & Zeng 2009; Widmer et al. 2005; Yu, J et al. 2010). Countries with completely absent national e-waste legislation are large parts of Africa, Central and Eastern Asia and the Caribbean (Osibanjo & Nnorom 2007; Oteng-Ababio 2010; Wath, Dutt & Chakrabarti 2011). Even if they do have such laws, many developing countries do not have proper enforcement and implementation systems in place (Chi et al. 2011; Nnorom & Osibanjo 2008b). Therefore, there is an absence or lack of policy effectiveness measures such as collection and recycling targets, and as a result, the legislation might not always translate to concrete actions (Baldé et al. 2017).

At the international level, the Basel Convention is a global agreement and it aims to control the trans-boundary movement of hazardous wastes and their disposal, initially adopted in March 1989 (United Nations Environment Program 2011). The convention came into force as a result of the public outcry after the discovery of imported toxic waste into Africa and other parts of the developing world. The main objective of the convention is to protect human health and the environment from adverse effects of toxic and hazardous waste materials (United Nations Environment Program 2011). However, the Basel Convention was condemned for legitimising hazardous waste rather than prohibiting such material. The Basel Ban decision effectively came into place on 1st Jan 1998, making it illegal for the 29 wealthy OECD countries to export any form of hazardous or toxic waste to non-OECD countries (Basel Action Network 2011). In order to make the ban legally binding, it had to become a part of the Basel Convention through an amendment, which was opposed by many advanced economies like the United States, Canada, Australia and South Korea (Basel Action Network 2011).

2.2.3.1. E-waste legislation in Pakistan

There are no specific regulations on 'electronic waste' management, however, there are some regulations regarding hazardous substances in the Pakistan Environmental Protection Act, 1997. This statute prohibits the discharge of any hazardous material/chemical into the environment, prohibits the import of hazardous waste and it restricts the handling of hazardous substances to licensed entities (PEPA 1997). Import Policy Order 2007-08 and Trade Policy 2006-07 also restrict the import of hazardous waste. Despite these regulations and being a signatory to the Basel Convention (which prohibits the trade of hazardous waste to non-OECD countries), the implementation and enforcement of regulations remains questionable. To date, Pakistan receives large volumes of e-waste from developed countries, which are actively traded, and disposed of and recycled informally (Imran et al. 2017; Iqbal et al. 2015; Umair, Anderberg & Potting 2016).

2.2.4. Consumers

On the consumer side, we now live in a "throw-away" society, one that is characterised by an attitude of discarding and buying new equipment, rather than repairing and reusing the same equipment (Schmidt 2005). This type of behaviour exists because too often it is generally not worth repairing defective equipment, since it involves warranty, data security and functionality issues related to the repaired equipment (Baldé et al. 2017; Schmidt 2005). Another possible reason for this trend in the growing middle class is to purchase new equipment or goods/services as a status symbol and for social recognition (Baldé et al. 2017; Katz & Sugiyama 2006; Sundari 2014).

Other than behavioural attitudes, subjective norms (related to peer pressure to have the latest and best) and perceived behavioural control are key *influencing factors*, some factors that *moderate* consumer behaviour and disposal/recycling intentions include legal advocacy, awareness and consideration of the environment, and recycling experience (Borthakur & Govind 2018; Xu, F et al. 2014). In this context, the (behavioural) attitude of a person towards an action or behaviour (responsible disposal/recycling) depends on the perception of the behaviour as either positive or negative and what the consequences are (Godfrey et al. 2012). Subjective norms are external factors, referring to the perceived social pressure to get (or not to get) involved in certain behaviour, which could originate from the family, peers, neighbours, community or the society (Dongliang et al. 2015; Pakpour et al. 2014). Perceived behavioural control is the perceived ease or difficult in undertaking an action/behaviour, and is driven by the availability of resources, obstacles and opportunities, and an individual's past experience (Borthakur & Govind 2018; Sarkis, AM 2017). Therefore, the disposal channels available to the consumers determine how e-waste is disposed of by them, and failure to provide proper channels might lead to significant disposal in landfills (Bahers & Kim 2018). The implication is that consumers play an integral role in the e-waste management system, so it is not possible to have an effective system without proper consumer awareness and active participation (Borthakur & Govind 2018).

The lack of public awareness about the importance of proper disposal of e-waste results in inadequate collection practices, and therefore low recycling rates. The responsible disposal and recycling attitudes depend on a number of influences (Borthakur & Govind 2017). These are categorised broadly as:

(i) Socio-cultural factors, such as education, age, gender, environmental awareness, ideology,

(ii) Economic factors, for instance income, willingness to pay for recycling processes, and

(iii) Infrastructural factors like familiarity with recycling, available options to disposal including door-to-door collection facility or proximity to the drop-off sites.

Finally, due to the lack of awareness on e-waste management hazards and practices, the public is generally negligent when it comes to e-waste, i.e. usage of EEE and disposal/recycling (Borthakur & Govind 2017; Iqbal et al. 2015). Consumers tend to stockpile the old, used and non-functional electronic devices for some time before they decide to discard them (Babbitt, Callie W, Williams & Kahhat 2011). This stockpiling increases the obsolescence of parts that are still functioning, thereby rendering them completely unsalvageable, and consequently resulting in the loss of material, recovery value and profitability (Guiltinan 2009; Sabbaghi et al. 2015).

2.3. Upstream sector

A review of the upstream sector will help us to understand all the inputs and components that go into the extraction and manufacturing of EEE, reflecting on all the materials that should be recovered from e-waste through recycling in the downstream sector.

2.3.1. Inputs and outputs of the manufacturing process

The lifecycle of EEE starts from the *upstream stages*, which involve extraction and manufacturing phases. These phases involve mining of fossil fuels and other raw materials, processing to make different components and finally assembling the components to produce EEE. The upstream stages of lifecycle typically use land, fossil fuels, and metal resources and release gases like carbon dioxide, sulphur dioxide and nitrogen oxide into the atmosphere, and pollute water by releasing arsenic ion and copper ion (Bekaroo, Bokhoree & Pattinson 2016; Duan et al. 2009).

2.3.1.1. The invisible resource consumption

2.3.1.1.1. Metal resources

Manufacturing of electrical and electronic devices largely demands metals, especially: (i) rare earth elements (REE), (ii) precious metals, and (iii) metals that are very rare on Earth's crust (Tansel 2017). One mobile phone contains 60-64 elements of the periodic table while one computer has over 30 elements (Nuwer 2014 cited in Tansel 2017). One of the most commonly used metals, copper is precious as well as toxic, predominantly embedded in wiring as a conductor of electricity, while gold and silver also play an important role in manufacturing of modern technology (Nassar et al. 2012). Importantly, some of the rare earth elements like neodymium, dysprosium, yttrium and terbium used in very small quantities for features like vibration, and in screens to produce different colours on the display screen (Rim, Koo & Park 2013). Arsenic is also an important element used in high-speed computer chips. Given the importance and potentially high future demand of these metals, Graedel et al. (2015) studied the 'criticality' of 62 metals in terms of supply risk, environmental implications and supply restrictions. Findings revealed that some of the widely used metals like copper, lead, chromium and manganese had no substitute for major uses. Other metals very important for electronic devices that had low substitute potential were rhodium and rare earth elements like dysprosium and yttrium (Graedel et al. 2015; Massari & Ruberti 2013; Nassar et al. 2012).

Analysing and comparing the trends of *precious* and *toxic* elements in mobile phones, smart phones and routers through leaching, Holgersson et al. (2018) found the quantity of lead was significantly small in smart phones compared to mobile phones and routers, confirming the decrease in the content of lead in modern (smart) phones. However, the values of other toxic metals were comparable across all three devices. Internet modems, routers and hubs contain high content of precious metals, specifically due to high weightage of the printed circuit board as compared to total product weight; therefore, they were deemed an equally important category of waste in terms of precious metals as mobile phones and smart phones. However, modems and routers contain less toxic metals with the exception of lead, which was comparable to that in mobile phones and smart phones. Overall, there was no evidence of diminishing the content of precious metals in newer devices over time in any of the electronic devices studied.

2.3.1.1.2. Secondary material resources

According to Williams, E, Ayres and Heller (2002), the production of a single 2-gram 32MB DRAM chip consumes about 1600 grams of secondary fossil fuels, 72 grams of chemical inputs, 32,000 grams of water in fabrication stage and 700 grams of elemental gases (mainly Nitrogen). Therefore, **secondary materials** used in the manufacturing are 630 times the mass of final product, implying that environmental burden of semi-conductors is far more than their size (Kasulaitis et al. 2015; Williams, E, Ayres & Heller 2002). Moreover, according to other estimates, about 1.7 kg of raw materials is required to produce a 2-gram integrated circuit (IC), while approximately 7-gram ICs are installed in one mobile phone (Williams, E, Ayres & Heller 2002; Yu, J, Williams & Ju 2010). The production of a computer with a 17-inch CRT (Cathode Ray Tube) monitor requires about 260 kg of fossil fuels, which is 11 times the weight of the final product, i.e. the computer (Williams, E 2004). This supports the findings that around 98% of the material used in the production of a personal computer goes into the waste while only 2% becomes a part of the final product (Hilty & Ruddy 2000 cited in Berkhout & Hertin 2004).

2.3.1.1.3. Energy consumption

In addition to the depletion of raw materials and fossil fuels, **energy** is significantly consumed in the production of equipment and running of infrastructure like data-centres and server parks (Røpke & Christensen 2012). The production of a computer with a 17-inch CRT (Cathode Ray Tube) monitor requires about 6400 mega joules (MJ) of energy; this high energy intensity in manufacturing computers, coupled with high average turnover in computers results in an annual life cycle energy burden of about 2600 mega joules (MJ), which is 1.3 times larger than that of a refrigerator (Williams, E 2004).

Estimating the energy consumption at different stages of mobile phone life cycle, Yu, J, Williams and Ju (2010) found that 50% of the energy was consumed in the manufacturing phase, 7% in assembly, packaging and transport phases, while usage phase accounted only for 20% of the energy consumption in life cycle. Life cycle energy consumption pattern for desktop computers was found to be similar in another study, whereby 80% of the energy consumption was associated with materials and manufacturing phases, and only 20% with the operation/usage phase (Williams, E 2004). Even the manufacturing phase of screens, such as CRT (cathode ray tube), LCD (liquid crystal display) and LED (Light emitting diode) has been found to cause the maximum damage to the environment in contrast to the usage and end-of-life phases (Bhakar et al. 2015). Currently, ICT is responsible for nearly 15% of global electricity consumption in the residential sector (International Energy Agency 2009). IEA anticipates that electricity consumption from these products will double by 2022 and triple by 2030.

2.3.1.2. The invisible emissions

Besides consumption of resources and energy, the production process and usage of ICT (Information and Communication Technology) equipment result in **carbon emissions (CO_2) and greenhouse gas emissions (GHG)**. Estimated GHG from the ICT sector is about 2% of the total global emissions (Mingay 2007 cited in Añón Higón, Gholami & Shirazi 2017). In terms of carbon footprint, manufacturing of one mobile phone produces about 60 kg of CO_2, whereas using the mobile phone for a year produces approximately 122 kg of CO_2 (United Nations Environment Program, GSMA cited in Velmurugan 2017). These emissions are expected to rise to 55 million metric tons by 2020 because of the increase in mobile communications users (Sonnenschein 2009 cited in Velmurugan 2017).

2.3.2. Impacts of EEE upstream sector

Figure 11 shows the impacts of a PC system on human health, state or quality of the ecosystem and resources during manufacturing, distribution and usage stages.

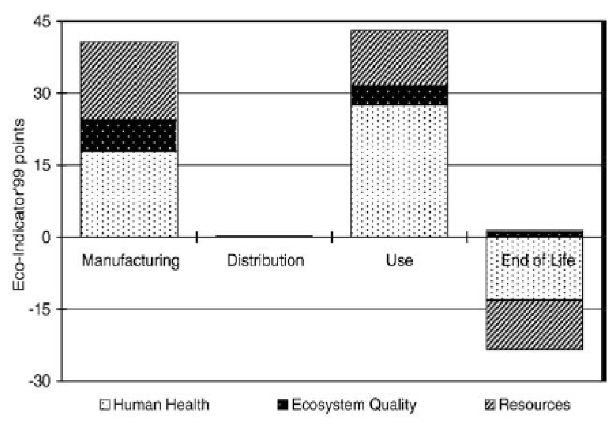


Figure 11: Environmental impacts of a PC system
Source: Duan et al. (2009)

2.3.2.1. The manufacturing stages

As a result of emissions and toxins released during the manufacturing phases, health hazards among workers are high in the electronics manufacturing industry (Koh, David & Quah 2018; Luo, JCJ et al. 2002; Wang, Y et al. 2016). The hazards mainly arise from three sources (Ryu et al. 2017; US Department of Health and Human Services 1985; Yu, W et al. 2013):

(i) *Chemical agents*, such as organic solvents, gases, heavy metals and metallic compounds, particulates and fibres, acids, alkalis and oxidizers, and general manufacturing materials,

(ii) *Physical agents*, such as electromagnetic and particulate radiations, noise, vibration, temperature and pressure, and

(iii) *Ergonomic stresses* from repetitive movements, eyestrain, poor postures, lifting, stress-related health incidents, lower back pain and video display terminals.

The majority of workers (mainly female) in the electronics manufacturing industry had diseases due to chemical, physical and ergonomic hazards, while around 60% of female workers in China were reported to be suffering from such ailments (Inoue et al. 2015; Ryu et al. 2017; Yu, W et al. 2013).

The chemical agents used during the manufacturing of semi-conductors, workers are haematological toxins such as arsenic, glycol ethers and ionising radiation (Luo, JCJ et al. 2002), and toxic metals from the IIIA, IVA, VA families of the periodic table including indium and gallium (Chen, HW 2007; Liao et al. 2006; White & Shine 2016). These metals are toxic and carcinogenic, and long-term exposure potentially results in anaemia, skin cancer, other internal cancers, respiratory problems (asthma, irritation), neuropsychological impairment (Chen, HW 2007; Koh, D, Chan & Yap 2004; White & Shine 2016), and leukopenia (significantly low white blood cell count) among male fabrication workers, photolithography, implantation and maintenance workers (Luo, JCJ et al. 2002). Male fabrication workers could also potentially suffer from restrictive lung abnormality whereas female fabrication workers were susceptible to hepatic (liver) abnormalities, and increased risk of spontaneous abortion (Luo, JCJ et al. 2002).

Among the physical agents, microwave and radio frequency radiations have been suspected of causing cataract formation in humans, pancreatic cancer, and brain cancer, while another principal hazard from radiation is the thermal effect on the tissue of body where thermal sensitivity is poor (that is, the internal organs in the main cavities of the body) (Megha et al. 2015; Thomas, TL et al. 1987; US Department of Health and Human Services 1985). The non-thermal effects involve almost all systems of the human body, especially the central nervous, endocrine and cardiovascular systems (US Department of Health and Human Services 1985). Other radiations like ultraviolet light have been suspected of causing skin cancer (Ahmad 2017). Moreover, ionising and non-ionising radiations are used in the electronics manufacturing industry to test, control the quality and rectify the operations, but these radiations can cause cancer, foetal abnormalities and genetic mutations (Koh, D, Chan & Yap 2004).

The ergonomic stresses potentially lead to cumulative trauma disorders, strains of musculoskeletal system, backache and eyestrain, while headache, dizziness and light headedness might also result from the odour and environmental conditions in the workplace (Koh, D, Chan & Yap 2004). Moreover, repetitive and monotonous work may also cause changes in blood pressure and heart rate (US Department of Health and Human Services 1985).

2.3.2.2. The distribution stage

The second stage of distribution involves transportation, including local distribution and exports. Duan et al. (2009) did not find any significant impacts of transportation related to personal computers manufacturing in China even though 10% of the total products were exported. However, transportation length was found to exert a significant environmental impact through carbon emissions related to mobile phones export in Japan (Sugiyama, Honma & Mishima 2016).

2.3.2.3. The usage stage

The end-of-life stage for any electronic product can also have detrimental effects on environment and human health. Electronic equipment, such as cell phones, cell phone base stations, radio stations, computer screens, and several other electrical and wireless devices used in daily life emit electro-magnetic radio-frequency radiation (EMRFR) (Berg 1992; Kocaman et al. 2018). Specifically, mobile phones use the electro-magnetic radiation in the range of microwave (450-2100 MHz) and penetrate the brain at 835 and 1900 MHz (Velmurugan 2017).

The exposure to electromagnetic fields (EMF) poses serious harm to people and other organisms, while adverse effects depend on the frequency of usage of mobile devices, their proximity to the head, the duration and frequency of mobile phone calls (Aydin & Akar 2011; Bauréus Koch et al. 2003; Kocaman et al. 2018; Velmurugan 2017). Electromagnetic field (EMF) radiations emitted from mobile devices can potentially cause structural damage to neurons, and may harm sperm parameters/concentration and trigger sperm mortality (Haghani, Shabani & Moazzami 2013;

Mehmet Erol et al. 2015). Exposure to radiation can cause a plethora of serious problems such as behavioural changes, insomnia, attention and hearing deficits, tinnitus, Alzheimer's disease, Parkinson's disease and autism (Davis et al. 2013; Sage & Burgio 2018).

Moreover, EMF radiations from mobile devices are not easily detectable, but the resulting health impacts such as DNA damage, sleep disorders, tumour in the eyes, skin problems, risk to children and pregnant women, neuronal damage, ear damage, and increase in cancer causes, have been linked to mobile devices (Behrens et al. 2010; Peñuela-Epalza et al. 2015; Robert et al. 1997; Röösli et al. 2010; Stang et al. 2001; Vastag 2001; Williams, PM & Fletcher 2010). Prolonged use can also result in brain tumours due to EMF radiations in the wireless devices and release of toxic substances (de Vocht 2016; Velmurugan 2017). The users who began using mobile phones or cordless devices regularly before the age of 20 had greater than four-fold increased risk of ipsilateral glioma (a type of tumour), and the highest risk of developing melanoma (a type of cancer) (Hardell et al. 2011; Velmurugan 2017). However, most people appear unaware of the potential health risks from the continuous emission of radiation (Elbetieha, AL-Akhras & Darmani 2002; Hedendahl, Carlberg & Hardell 2015).

Other than mobile or wireless devices, the negative impacts have also been attributed to the use of other devices, where leisure screen time (including watching television) has been associated with increased mortality risk (Wijndaele et al. 2017). Activities, such as watching television, using screens and playing video games are significant risk factors in causing obesity in children and youth (Mark & Janssen 2008; Marshall et al. 2004). In addition, higher daily screen time has been associated with an increased likelihood of developing metabolic syndrome, and suffering from emotional/behavioural issues, such as being more sad or unhappy, bored and having poor relationships with family members (Coon & Tucker 2002; Hancox, Milne & Poulton 2005). Increased exposure to the television can lead to poor short-term memory, cognitive development, language skills and academic achievement (Hancox, Milne & Poulton 2005; Marshall et al. 2004; Salmon et al. 2011). During the usage phase, CRT (Cathode ray tube) and LCD (Liquid crystal display) monitors cause the most damage to the environment in terms of global warming potential, abiotic depletion potential (natural resource) and acidification potential (Bhakar et al. 2015).

2.4. The downstream sector

The downstream sector involves the lifecycle stages of EEE after usage, when it becomes waste (or post-use scrap). Downstream stages include collection, disposal and recycling (that involves dismantling, extracting and refining). In some developing countries, e-waste is disposed of in landfill along with other municipal waste, or simply dumped or even openly burnt (incinerated). These practices are known to release carcinogenic and toxic substances into the environment (Mmereki et al. 2016). Other than direct disposal, informal recycling is used to recover 'valuable' material (such as gold, silver and aluminium) using rudimentary methods in most developing and transitional countries. This is in contrast to formal recycling that takes place in some developed countries with varying degrees of formalisation in processes (Ceballos & Dong 2016; Mmereki et al. 2016). For instance, formal recycling of e-waste (using state of the art technology) is about 40% in the European Union, 24-28% in China/Japan, 12% in US/Canada, while apparently still only 1% in Australia (Baldé et al. 2015). Less formalisation involves the formal collection and dismantling, but then products/parts are exported to developing countries for resale/reuse or informal recycling (Baldé et al. 2015).

Generally, the decisions to recycle or the recycling rates of specific products depend on: (i) the value of recovered material; (ii) the ease of collection, for instance, large number of collection sites that are dispersed make collection costly, thus unattractive; and (iii) convenience/benefits of disposal for customers (Dong et al. 2007; Streatfield & Markless 2009; Zhang, K, Zeng & Schnoor 2012). This section first reviews the factors that shape consumers' disposal behaviour, followed by the possible ways that e-waste is gotten rid of (either formally or informally).

2.4.1. What drives e-waste disposal behaviour?

After the useful life (the creation of e-waste), one factor that hinders its recycling is the low collection rate of ICT equipment (including mobile phones) due to ignorance of how to dispose e-waste, whereby consumers end up stockpiling the equipment rather than returning it (Ongondo, Williams & Cherrett 2011; Welfens, Nordmann & Seibt 2016). A worldwide survey conducted by Nokia revealed that less than 10% of mobile phone users returned their old devices, while around 50% stated that it was because they did not know where to dispose it (Nokia 2008 as cited in Tanskanen 2012; Welfens, Nordmann & Seibt 2016). Other surveys also indicated that around 15-

25% of the respondents are unsure about how to dispose of mobile phones and other e-waste (Ylä-Mella, Jenni, Keiski & Pongrácz 2015).

Public awareness is deemed to be one of the most important factors in the success of takeback and recycling initiatives (Afroz et al. 2013; Borthakur & Govind 2018; Echegaray, Fabian & Hansstein 2017; Ongondo & Williams 2011b). Therefore, low collection and recycling could be a result of lack of knowledge and awareness, because there are no public discussions and debates about sustainability and the issue of electronic waste (Welfens, Nordmann & Seibt 2016). This resulting lack of awareness could be in terms of the: (i) valuable, and hazardous/toxic elements in e-waste (knowledge of the resources); (ii) toxic ways in which e-waste is processed and recycled (awareness of the environmental problem); and (iii) where and how should e-waste be disposed of responsibly, in other words awareness of the relevance of one's own behaviour and abilities (Baxter & Gram-Hanssen 2016; Borthakur & Govind 2018; Islam et al. 2016; Welfens, Nordmann & Seibt 2016).

Using the comprehensive norm activation model by Matthies, E (2005), Welfens, Nordmann and Seibt (2016) attempted to analyse the drivers and barriers to consumers' return and recycle behaviour. They identified some factors influencing the return and recycle behaviour, but those factors could be drivers or barriers depending on the social context and were categorised as (i) internal, or (ii) external (Nixon et al. 2009; Saphores, Ogunseitan & Shapiro 2012; Suckling & Lee 2015; Tanskanen 2012; Welfens et al. 2013). Internal factors are the drivers and barriers, such as personal and social norms, emotions, habits and knowledge, that influenced more at the individual level and developed within and from people's socio-cultural environments (Baxter & Gram-Hanssen 2016; Suckling & Lee 2015).

- **Personal and social norms** act as a driver if recycling is socially desirable and is a common practice or a standard, which results in the social pressure to act in a certain way (Hage, Söderholm & Berglund 2009; Welfens, Nordmann & Seibt 2016). Personal (or moral) standards are set from the feeling of one's own commitment to environmentally responsible action, while social norms are shaped by the social networks that consist of family, friends, local community and the wider society (Gifford & Nilsson 2014; Welfens, Nordmann & Seibt 2016). Personal (moral norms) are activated through social interaction, and therefore social norms can encourage recycling of e-waste if they are considered positive but can be problematic if it is considered negative and if personal/social norms disregard the idea of recycling (Matthies, Ellen, Selge & Klöckner 2012; Tonglet, Phillips & Read 2004).

- **Strong emotional attachment** can act as a barrier to recycling behaviour, because electronic devices such as mobile phones are now becoming more of a personal accessory and an expression of personal style rather than a device for communication or an everyday commodity (Tanskanen 2012; Vincent 2006). This emotional connection to the equipment, along with the issues of data privacy act as a barrier to recycling of e-waste (Pérez-Belis, Bovea & Simó 2015).
- **Habits** emerge from social norms, where habitual practices/actions are the results of already established practices, objectives and understandings (Welfens, Nordmann & Seibt 2016). It can act as a driver is normal recycling that is already a part of routine but can be a barrier if recycling is not a part of routine but requires norms to change (Wang, Z et al. 2011; Welfens, Nordmann & Seibt 2016). Habit such as stockpiling the old equipment as spare equipment in case the new one is lost, damaged or stolen deter return and recycle of e-waste (Pérez-Belis, Bovea & Simó 2015; Saphores et al. 2009).
- **Knowledge** about the problem of e-waste and where and how to dispose can act as a driver of return and recycle behaviour, but if the knowledge is limited, it can act as a barrier (Fielding & Head 2012; Gifford & Nilsson 2014; Levine & Strube 2012). Therefore, sufficient knowledge is important to create awareness and encourage the return and recycle behaviour, but it alone is not a sufficient condition for making informed pro-environmental decisions (Gifford & Nilsson 2014; Welfens, Nordmann & Seibt 2016).

External factors are the drivers and barriers that impact on a person's consumption and recycling decisions due to systematic, structural and institutional factors. They are more determined at the corporate or political level rather than at a personal one.

- **Incentive** (monetary or non-monetary) is an important motivating factor that drives return and recycle behaviour (Baxter & Gram-Hanssen 2016; Ongondo & Williams 2011b). Incentives could be in the form of monetary payments, monetary savings (such as free postage, free envelopes, bags, courier collection, mobile phone bill discount or airtime), monetary gains (such as discount stores, prize draws), environmental incentives or charity donations (Sarath et al. 2015). These forms have different impact and effectiveness, but a system that involves immediate material compensation motivates more people to return and recycle (Ongondo & Williams 2011b; Welfens, Nordmann & Seibt 2016).

- **Infrastructure** for recycling e-waste, such as collection systems with easy and convenient access to recycling bins or other collection points is an integral factor in e-waste return and recycle culture, and recovery rates (DiGiacomo et al. 2018; Ongondo & Williams 2011b; Ylä-Mella, J 2015). If the **perceived effort** (the cost/benefit ratio of an action, the discomfort or the loss of time) for an action is low, or if consumers are rewarded for the action, they are more likely to return and recycle (Welfens, Nordmann & Seibt 2016). On the other hand, if perceived effort (inconvenience) in returning the e-waste is high, consumers are less likely to return it (DiGiacomo et al. 2018). Additionally, if consumers **mistrust the recycling infrastructure** due to the lack of fully understood processes, consumers prefer to keep e-waste with them and be reluctant to return and recycle (Keramitsoglou & Tsagarakis 2013; Tabernero et al. 2015). This might be due to their fear that others might enrich themselves through their devices and their data, or due to uncertainty about where it will end up (Welfens, Nordmann & Seibt 2016).
- **Education and communication** about the resource scarcity, the impact (social, environmental) of production and usage of the electronic devices, and about the recycling process can be effective drivers by creating awareness about sustainable use of ICT equipment (Pérez-Belis, Bovea & Simó 2015). Therefore, education about environment has the potential to encourage more pro-environmental (e.g. return and recycle) behaviour and might help reduce the level of mistrust (Hage, Söderholm & Berglund 2009; Mobley, Vagias & DeWard 2010).

2.4.2. Common ways of e-waste disposal (formal/informal)

According to global estimates (Baldé et al. 2017; Cruz-Sotelo et al. 2016), the fate of e-waste is largely unidentified. Figure 12 shows that out of the total global e-waste produced in 2014, only 16% (6.5Mt) was reported to be formally collected and recycled, while the rest of 84% (35.2Mt) is unaccounted for. Similarly, in 2016, only 20% (8.9Mt) of the total e-waste was collected and treated formally while 4% (1.7Mt) went to the landfill and the fate of remaining 76% (34.1Mt) remains unidentified. The e-waste that went to municipal waste was possibly landfilled and incinerated, while the unidentified e-waste could have possibly been stockpiled, dumped, recycled using informal methods, or exported to the developing countries (Baldé et al. 2017). An important caveat to these findings is that much of the literature is focused on already developed countries, and as related data shows that - based on population - the waste that has been and is forecast to be generated will come from Asia. Pakistan, to illustrate, has an annual growth rate of 10.2%.

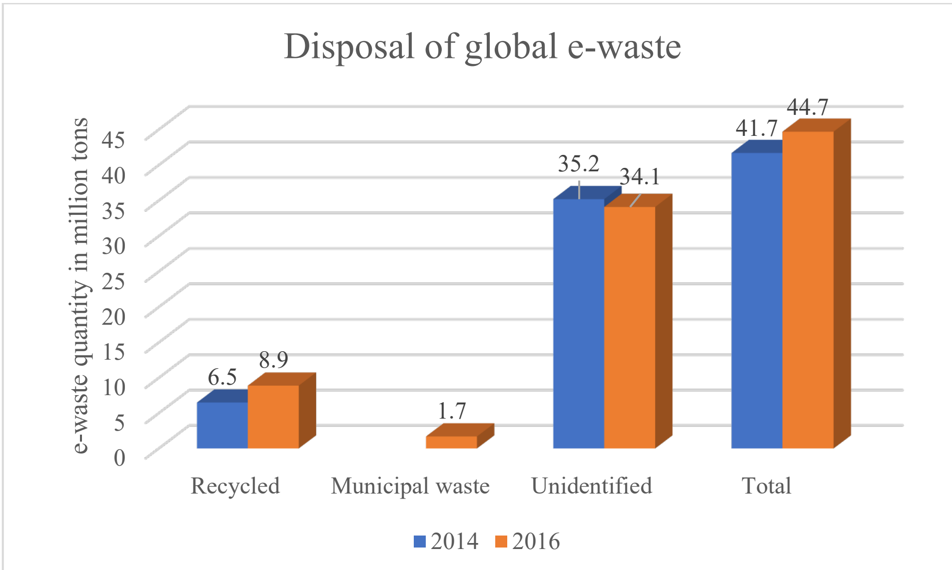


Figure 12: Disposal of global e-waste (2014 & 2016)

Sources: Baldé et al. (2017); Cruz-Sotelo et al. (2016)

So, from the perspective of consumers, there are four possible ways of dealing with the used EEE, that include: (i) storing/stockpiling, (ii) disposing with municipal waste, (iii) informal disposal, and (iv) formal disposal.

2.4.2.1. Stockpiling

Studies have found that stockpiling of e-waste, especially for small equipment like mobile phones is the most prevalent option in both developed and developing economies (Borthakur & Govind 2018; Li, Jinhui et al. 2015; Pérez-Belis, Bovea & Simó 2015; Sarath et al. 2015; Speake & Yangke 2015; Wagner 2009). A study conducted in Liverpool in the UK found that 86% of people stored their used (retired) mobile phones, where half them had at least three to four phones stockpiled, despite being aware of the associated hazards and toxicity, and even knowing that it should be recycled, repaired or reused (Speake & Yangke 2015).

Stockpiling is a complex behaviour which has also been studied in terms of the design features and brand of equipment (Hard Disk Drive), and consumer type (Sabbaghi et al. 2015). It was found that storage time depended on the length of usage of equipment, that is, if consumers used electronic equipment for the normal lifetime, they stored it for a minimum time, and vice versa (Sabbaghi et al. 2015; Thiébaud et al. 2018). If the devices were manufactured more recently, consumers might think they had not been used sufficiently and could be reused in the future, so they were more likely to be stored. Also, if the capacity of equipment (such as hard drive) was high, or the initial price paid by the consumers was high, there were more chances that equipment will end up in storage (Sabbaghi et al. 2015). Moreover, consumers tend to stockpile due to the inconvenience related to e-waste collection/recycling systems, perceived value of the stored equipment, and sufficient space in households for storage (Baxter & Gram-Hanssen 2016; Wagner 2009).

Therefore, similar factors that encouraged storage were relevant to the mobile phones as well, such as short usage time, multi-functionality, high storage capacity and high purchase price (Ylä-Mella, J 2015). The stockpiling of mobiles is higher than other equipment because their size is small, are light-weight, and have more sentimental value because of personal usage and associated memories, i.e. messages, photos, etc. (Speake & Yangke 2015; Ylä-Mella, J 2015). Apart from stockpiling, if the equipment is functioning, consumers also tend to give away the used equipment to other family members, friends and relatives for reuse (Ylä-Mella, J 2015).

2.4.2.2. Disposal into municipal waste

Under this option, consumers dispose their used or damaged equipment in the bins with normal household or municipal waste (Baxter et al. 2016; Macauley, Palmer & Shih 2003; Speake & Yangke 2015). It might then end up in the landfill or waste incinerator, depending on the region, where the chances of separation, sorting and recycling are negligible (Baldé et al. 2017). Mostly small equipment, lamps and small IT equipment are disposed of with the municipal waste and this disposal method exists in both the developed and developing countries and leads to extensive damage being done to the environment (Baldé et al. 2017; Polák & Drápalová 2012).

2.4.2.3. Informal disposal

In developing economies, the e-waste management system and infrastructure are not developed. So, the unofficial or informal disposal process involves collection by local collectors or *kabari walas* who go door-to-door to buy waste from consumers in order to on-sell to local refurbishers or recyclers (Baldé et al. 2015; Umair, Anderberg & Potting 2016; Wath, Dutt & Chakrabarti 2011). It is then recycled using crude methods in the open backyards without proper facilities (Abbas 2010; Iqbal et al. 2015; Sthiannopkao & Wong 2013; Umair, Anderberg & Potting 2016).

In developed economies, collection outside the official take-back system is carried out by individual waste dealers or companies that dispose or sell e-waste through different channels, based on the equipment's condition (Baldé et al. 2017; Golev & Corder 2017). Developed countries have e-waste legislation, and e-waste collected may not be treated formally in a specialised manner, albeit that some e-waste is exported to developing countries (Bisschop 2012; Manomaivibool 2009; Premalatha et al. 2014). The e-waste categories collected under this informal method of disposal include large equipment, IT equipment and temperature exchange equipment (Baldé et al. 2017).

2.4.2.4. Formal disposal

Formal disposal in mainly prevalent in some of the developed countries with national legislation for e-waste, and there are designated stakeholders, such as, producers, other organisations or the government for collection and treatment of e-waste (Khetriwal, Kraeuchi & Widmer 2009; Terazono et al. 2006). The collection is via municipal collection points, pick-up services or retailers, which is then treated in state-of-the-art recycling facilities which have minimum environmental and health impacts (Baldé et al. 2017; Terazono et al. 2006). The laws govern control mechanisms related to recycling processes and collection targets.

2.4.3. Transboundary movements

About 50-80% of the e-waste generated in developed countries is exported to developing countries like China, India, Pakistan, Ghana and Nigeria (Gollakota, Gautam & Shu 2020; Illés & Geeraerts 2016; Sthiannopkao & Wong 2013). Moreover, according to the estimates of transboundary movements, about 50-80% of the e-waste generated in the United States is exported every year (Puckett et al. 2002; Roman & Puckett 2002). This export to developing countries is usually in the name of 'bridging the digital divide' but is actually a 'digital dump' as toxic e-waste travels to the vulnerable and poor communities of the world (Nnorom & Osibanjo 2008a). The export of e-waste is preferred over developing own formal recycling systems, using cleaner technologies to develop innovative designs that minimise the use of toxic elements, because developing countries have cheap labour, and lack of government regulations and accountability (Awasthi, Zeng & Li 2016a; Gollakota, Gautam & Shu 2020; Nnorom & Osibanjo 2008a).

2.4.3.1. International regulation: The Basel Convention

In order to control the transboundary movement, an international treaty called the 'Basel Convention' on the Control of the Transboundary Movements of Hazardous Wastes and their Disposal was designed and signed by 179 countries (Salehabadi 2013). It had the objectives to: (i) minimise the production of hazardous waste, (ii) encourage the local handling of hazardous waste, and (iii) reduce the export of hazardous waste from the developed to developing countries (Salehabadi 2013; UNEP Basel Convention 2011). The Basel Convention did not ban the export of hazardous waste completely, rather just prohibited the export for disposal and permitted the export for reuse and recovery (Basel Action Network 2011; Puckett et al. 2002). Despite international regulations and guidelines, e-waste continues to be exported. The clause allowing export of equipment for reuse makes it easier to export the e-waste labelled as 'reusable' (Puckett et al. 2002). Therefore, it is difficult to determine what percentage of equipment traded for reuse is actually reused. According to studies, in the case of West Africa, most imported e-waste is reused and only a small proportion is non-functional, half of which is repaired and reused locally (Salehabadi 2013). However, in the case of Pakistan only 2% of the imported e-waste can be reused (Sthiannopkao & Wong 2013).

The Basel Convention is often criticised for being an instrument that legitimised the export of hazardous waste, rather than eliminating it. Therefore the Basel Ban decision came into effect to completely ban all forms of hazardous waste exported from the wealthiest nations of OECD to all non-OECD countries (Basel Action Network 2011). However, some countries lobbied against the decision, arguing that the ban could not be legally binding until it became a part of the Basel Convention. The decision became part of the convention, despite the opposition from countries like the United States, Australia, Canada and South Korea (Basel Action Network 2011).

2.4.3.2. E-waste export to Pakistan

Figure 13 shows major routes and destinations of e-waste into Asia, mainly from developed countries. The figure identifies Karachi in Pakistan as one of the main ports that receives e-waste and Sher Shah as the known site where it is processed (Puckett et al. 2002; Widmer et al. 2005). Pakistan imports about 8% of the total e-waste generated in the categories of laptops and desktop computers, and most of the trade in South Asian region flows to Pakistan in terms of physical goods (Baldé, Wang & Kuehr 2016). According to estimates by Imran et al. (2017), Pakistan received round 95,415 tons of e-waste annually, and Karachi received the major portion of the imports (89.39% of the total e-waste).

Figure 13: Routes of e-waste in Asia
Source: Widmer et al. (2005)

The main exporters to Pakistan were identified as Taiwan, Japan, China, Europe, the Far East and the US as shown in the Figure 14. E-waste imported from Europe and USA is less in quantity because the waste from these countries is re-routed through Singapore and Taiwan (Imran et al. 2017). For instance, a study that traced the routes of discarded equipment through a tracker found that a Cathode Ray Tube screen tagged in Chicago in November 2014 reached New York by road after two months, then shipped east through the Atlantic Ocean and Mediterranean Sea. It then went through Sharjah in UAE and reached Asia via Port Qasim in Karachi (Pakistan), from where it finally arrived at Faisalabad (Pakistan) after travelling 11,480 km (Lee, D et al. 2018).

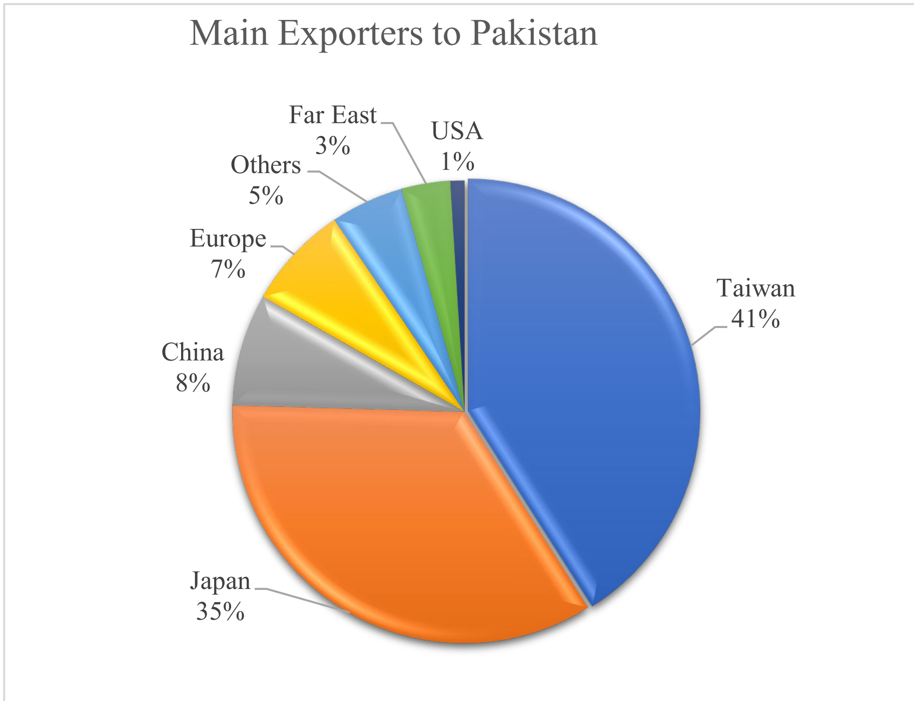


Figure 14: Main exporters to Pakistan
Source: Imran et al. (2017)

2.4.4. Stakeholders in the e-waste disposal and recycling chain

Stakeholder assessment aids in identifying the actors and their roles in the e-waste management along the value chain by categorising according to the groups of stakeholders (Schluep 2014). Stakeholder identification for e-waste management has been done by several studies for various countries (Anwesha & Sinha 2013; Orlins & Guan 2016; Streicher-Porte et al. 2005; Umair, Björklund & Petersen 2015).

2.4.4.1. The upstream sector (stakeholders)

Stakeholders in the upstream sector include manufacturers, importers, distributors and consumers (Schluep 2014).

2.4.4.1.1. Manufacturers, importers and distributors

Manufacturers of equipment include the companies that produce EEE and might not necessarily have physical presence in a specific country, but could rather have commercial and marketing operations (Laissaoui & Rochat 2008). However, these manufacturers, importers and distributors have an important role to play in the creation and efficient recycling of e-waste through the volumes and designing of EEE (Tanskanen 2013). Moreover, producers are now increasingly being held responsible for their products beyond just the point of sale to the end of the lifecycle (EoL), through Extended Producer Responsibility (EPR) (Bahers & Kim 2018; Favot, Veit & Massarutto 2016). EPR is based on the "polluter pays principle", in which the producers at large have the responsibility to organise, finance and operate the e-waste management system (Peng, B, Tu & Wei 2018). However, the overall objective of EPR is to reduce the environmental impact of e-waste, and consequently, the responsibility of tasks such as reduction (prevent), reuse, recycle, and proper treatment of waste also lies with other stakeholders in the product's ecosystem, i.e. consumers, retailers, recyclers, and government (Kalimo et al. 2015).

2.4.4.1.2. Consumers

Consumers, being the main beneficiaries are the main polluters due to their purchase, consumption and disposal behaviour (Afroz et al. 2013; Bovea, Pérez-Belis & Quemades-Beltrán 2017; Islam et al. 2016). The purchase, consumption and repair patterns play an important role in the creation of e-waste (Babbitt, C W et al. 2009; Sabbaghi & Behdad 2018), while the disposal attitudes determine the fate of e-waste (Welfens, Nordmann & Seibt 2016). If disposed of responsibly through formal channels (rather than informal or dumping), the official collection rate would increase and the waste will more likely be treated formally (Baldé et al. 2017).

2.4.4.2. The downstream sector

At the downstream sector, the main stakeholders (mainly workers) are collectors, refurbishers/ repairers, and recyclers (dismantlers, scrappers, metal extractors).

2.4.4.2.1. Collectors

Under the official take-back systems (formal), authorised collectors are the producers, government or other organisations, where e-waste is collected through designated collection points or pick up services. In the informal sector, local individual collectors (street hawkers/kabari wala) collect (buy) the used equipment (mainly non-functioning) or their parts from individual consumers by going door-to-door and from local electronics markets (including repairers).

2.4.4.2.2. Recyclers (dismantlers, metal extractors, metal refiners)

In the formal setting, after collection, recycling companies are usually responsible to erase the data to protect the user's privacy, and then dismantle and recycle further (Baldé et al. 2017). However, in some cases, after the formal collection, recycling companies might export the functioning equipment to the developing countries for reuse, whereby the equipment enters the informal system and is treated and recycled informally (Anwesha & Sinha 2013). In the informal setting, dismantlers buy the e-waste from local collectors, dismantle the parts (scrapping), and sell those parts further for metal extraction and refining, or at times extract and refine themselves (Anwesha & Sinha 2013; Umair, Björklund & Petersen 2015).

2.4.4.2.3. Other stakeholders

If a country imports e-waste from other countries, the stakeholders also include *importers, dealers (agents), customs officials and wholesalers* (Imran et al. 2017; Iqbal et al. 2015). Importers buy bulk quantities of used electronics (e-waste or for reuse) in containers from developed countries (Iqbal et al. 2015). It is then sold to individual e-waste scrappers in different quantities, usually through agents/dealers. Importers also need to deal with the customs officials to get their consignment cleared and have to pay the customs fee. Other crucial stakeholders include *government regulators* whose job is to devise and run e-waste management systems through *municipalities*, to create relevant legislation/policies, for both the upstream and downstream sectors and then regulate the industry (Dou & Sarkis 2013; Orlins & Guan 2016).

2.4.5. E-waste recycling processes

The formal recycling practices ideally take place under permitted and licensed facilities that have indoor processes with some level of pollution controls, industrial hygiene, worker protection, and are guided by regulations (Ceballos & Dong 2016; Laha 2015). On the other hand, informal recycling is decentralised, involves less or no automated procedures and occupational health measures. It is carried out in the open backyards without proper facilities, or property, plant and equipment, relying mainly rely on natural ventilation (Ceballos & Dong 2016; Sthiannopkao &

Wong 2013). Both formal and informal recycling methods can use physical/mechanical techniques in the initial stages, and chemical techniques in upgrading and refining stages (Kaya 2016).

Review of the ecosystem, starting from upstream stages (extraction of material to manufacturing, distribution) to downstream (usage, disposal) gives a fuller understanding of the lifecycle and the potential impacts at the various stages. The main stages of EEE lifecycle, along with formal and informal recycling processes are shown in Figure 15. The focus of this study, however, is on the downstream sector and more specifically on informal processes.

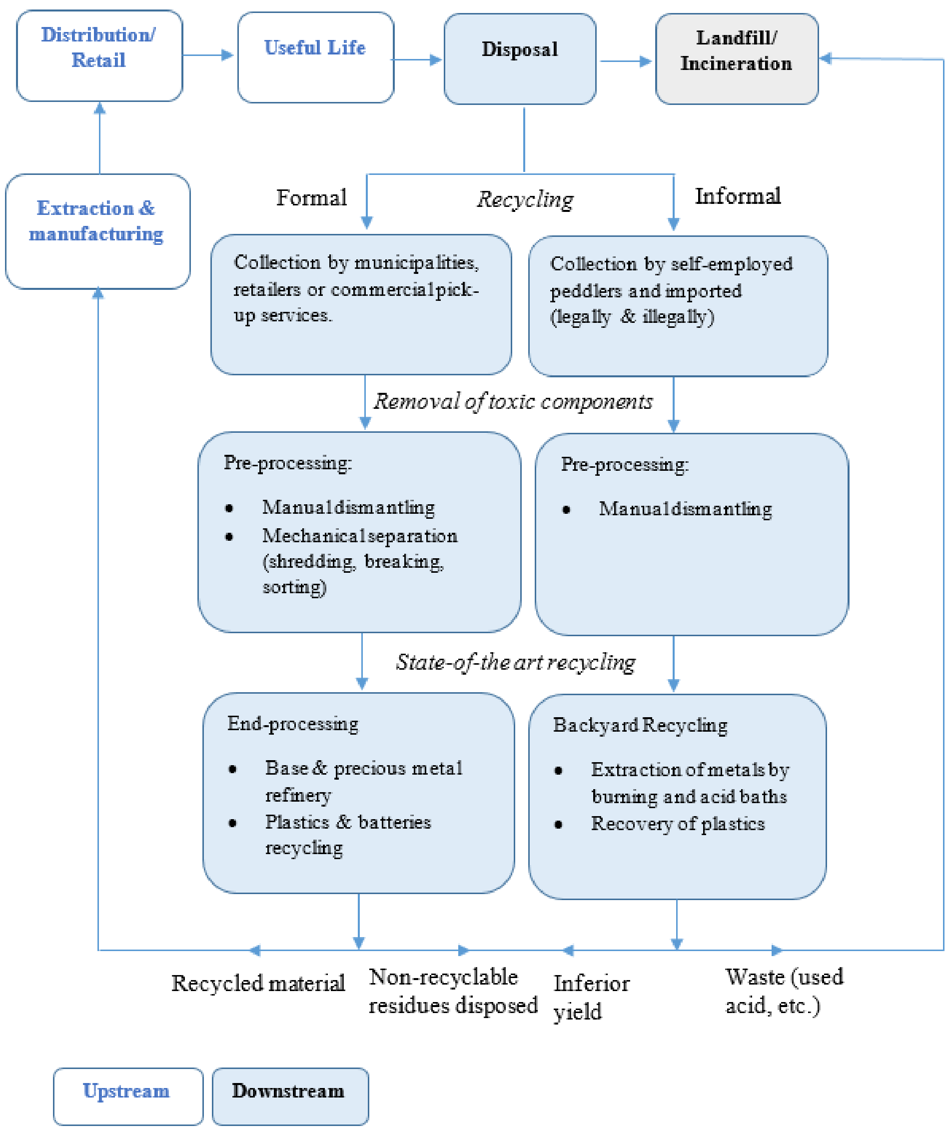


Figure 15: E-waste upstream and downstream stages

Adapted from: Baldé et al. (2015); Duan et al. (2009); Kaya (2016)

2.4.5.1. Formal recycling processes

In the *formal* sector, collection of e-waste is regulated and there is usually an official take-back system where waste is collected by municipalities, retailers, commercial pick up services, while individual collectors or private companies also collect materials under unofficial systems (Baldé et al. 2015; Umair, Anderberg & Potting 2016). After collection, the equipment are sorted, tested, repaired and refurbished, but equipment that need recycling are disassembled through mechanical dismantling, which can be performed by semi-automatic or automatic approach (Kaya 2016). Next, metallic and non-metallic fractions are liberated by shredding and crushing, and sorted using different methods such as gravity separation (glass, plastics, metals), magnetic separation (ferrous metals), electrostatic separation (different electrical conductivity – copper, aluminium, glass, metals and non-metals) (Kaya 2016; Umair, Anderberg & Potting 2016). Then, chemical recycling techniques and metallurgical processes are used to separate organic and metallic materials. Metals can be melted by heat (smelting/pyrometallurgical process) or dissolved by a liquid/chemical (leaching/ hydrometallurgical process) and further sorted based on chemical properties (Kaya 2016). Finally, the metals which are dissolved using leaching method can be recovered by purification techniques (Silvas et al. 2015).

2.4.5.2. Informal recycling processes

In the *informal* sector, collection is carried out by self-employed peddlers, who buy e-waste from consumers because in some developing countries like China, India and Pakistan, consumers expect economic benefits for discarding e-waste (Baldé et al. 2015; Mmereki et al. 2016). Main processes in informal recycling involve manual sorting and dismantling, done by bare hands or simple tools followed by shredding and grinding (Julander et al. 2014). Printed circuit boards are dismantled by open burning, heating or high flame torch, while plastics are also burnt (Sthiannopkao & Wong 2013; Umair, Björklund & Petersen 2015). The precious metals are extracted from printed circuit boards by using acid baths (cyanide salt leaching or nitric acid and mercury), whereby plastics and other components melt, leaving behind the metals (Premalatha et al. 2014). Cables and wires are burnt to melt the plastic and recover copper (Matsukami et al. 2015). The waste from informal processes is disposed of in open dumps, landfills and water (Mmereki et al. 2016). These crude methods help get easily recoverable metals such as copper, aluminium, iron, lead and some gold, with comparatively low yield, but other rare metals like indium, barium, platinum and nickel are not recovered and therefore discarded in the waste (Ari 2016; Chancerel et al. 2009; Sthiannopkao & Wong 2013).

2.5. Impact assessment

This section will review the environmental, social and economic impact of electronic waste recycling practices.

2.5.1. Environmental impact

E-waste lifecycle stages, but in particular, the informal recycling practices pollute the environment, where burning activities cause the most harm to the environment, followed by dismantling and then repairing activities (Akortia et al. 2017; Isimekhai et al. 2017; Ohajinwa, Chimere May et al. 2018). Burning of metals and plastics emit metal fumes, furans, PAHs, PCBs and PBDEs, and dioxins produced are 100 times more than that produced by burning of domestic waste (Gullett et al. 2007; Premalatha et al. 2014). Metal concentrations at e-waste recycling sites were 100-1000 times greater for some metals than at control sites (Ohajinwa, Chimere May et al. 2018). The dismantling phase during informal recycling can lead to accidental leakages and spillage of hazardous substances (Premalatha et al. 2014). Moreover, shredding and grinding generate dust particles of metals, plastics, ceramics, glass and silicon (Jiang, P et al. 2012).

Although metals are naturally occurring elements, the anthropogenic sources such as e-waste can alter the distribution of metals in the environment and transfer them to the soil, water air, sediments, plants, marine life, therefore making it a cause of serious environmental concern (Ohajinwa, Chimere May et al. 2018). After entering into the air, soil and water, these heavy metals persist (Song & Li 2015). As a result, heavy metals enter the food chain by poisoning the plants, and can cause phytotoxicity, leading to weak plant growth, chlorosis, reduced uptake of nutrients, disorder in plant metabolism, and reduced nitrogen fixation in legume plants meant for human consumption (Guala, Vega & Covelo 2010). Subsequently, humans and animals get exposed through dietary intake, air inhalation, dust/soil ingestion and even skin contact (Li, J, Duan & Shi 2011). The consequential accumulation and bio-magnification in human tissues pose serious risks to the human health (Ohajinwa, Chimere May et al. 2018). Moreover, heavy metals are non-biodegradable, and after entering into the environment (air, soil and water), these metals are highly persistent, thereby can harm the aquatic environment and ecological balance (Peng, K et al. 2008;

Song & Li 2015). Metals can dissolve in water and can easily be absorbed by marine life, including aquatic organisms and fish, destroying the water quality, life of aquatic organisms, and human health (Ohajinwa, Chimere May et al. 2018; Peng, K et al. 2008; Xing et al. 2009).

Batteries are also a potential source of hazardous metals in the environment and can adversely deteriorate the environmental quality and human health, especially in regions lacking infrastructure for formal treatment (Awasthi, Zeng & Li 2016a; Brigden et al. 2005; Kang, Chen & Ogunseitan 2013; Yu, Y et al. 2014). Rechargeable lithium-based batteries used in portable electronic devices contain metals such as copper, nickel, lead, cobalt, silver and thallium, that can leach after the battery corrodes and cause toxicity (Kang, Chen & Ogunseitan 2013; Rydh & Svärd 2003). If not handled appropriately, these metals and chemicals can cause severe harm to the environment, for instance, cadmium from the battery of one mobile phone can contaminate around 600,000 litres of water (He et al. 2006; Polák & Drápalová 2012).

The physical/mechanical recycling techniques used both in the informal and formal recycling processes, are simple, convenient and environmentally sound, but also generate significant amounts of dust during shredding, grinding and crushing (Borthakur 2016; Kaya 2016; Lau et al. 2014). According to Jiang, P et al. (2012), the shredding and grinding may cause the formation of dangerous metals fines and dust consisting of dioxins and brominated flame retardants, and lead to around 40% loss of precious metals. This requires a good dust collection system consisting of three-stage equipment (cyclone, bag and air cleaner). Moreover, metallurgical processes such as hydro/pyrometallurgical processes produce large quantities of liquid waste, fumes of heavy metals or may generate mixed halogenated dioxins and furans if PVC or other plastics are included (Bizzo, Figueiredo & de Andrade 2014; Kaya 2016).

The negative environmental impact results not just from informal recycling practices, but also from the formal recycling systems. Literature has confirmed higher concentrations of metals and toxins such as brominated flame-retardants, PCDD/Fs, PAHs, and PCBs in the soil, dust and air samples within and surrounding *formal* e-waste recycling facilities than in reference sites (Deng et al. 2014; Song et al. 2015; Wang, Y et al. 2016).

2.5.2. Human health impact

2.5.2.1. Human body burden of contaminants

In humans and animals, exposure to heavy metals occurs though air inhalation, dietary intake, dust/soil ingestion and even skin contact (Li, J, Duan & Shi 2011). Other than direct occupational exposure to workers, indirect exposure to residents also happens through surrounding air, dust, water, soil and the food chain (Song & Li 2015). Several studies have found evidence of high intakes of heavy metals like lead and cadmium through rice, vegetable, chicken and fish consumption in China (Fu et al. 2008; Luo, C et al. 2011; Xing et al. 2009; Zheng, G et al. 2013).

The absorption and therefore, excess presence of heavy metals in human body has been confirmed by studies examining human body burden of heavy metals. Most of these analyses have explored the human body burden focusing on 5 types of tissues - placenta, umbilical cord blood, serum and blood, hair and urine. The level of cadmium in placentas collected after childbirth had been found to be significantly higher, while the level of lead was about double that in the exposed group compared to the control group (Chan et al. 2007; Li, Y et al. 2011; Zhang, Q et al. 2011). In the umbilical cord blood, the levels of lead, cadmium, chromium and nickel were also significantly higher than the control group (Ni, W et al. 2014). The samples of blood from participants in the exposed sites also revealed higher levels of cadmium and lead especially among children and studies also noticed an increase in the blood lead level with age (Yang, H et al. 2013; Zheng, L et al. 2008). Hair, being identified as an indicator of short-term and long-term exposure to heavy metals, revealed the highest levels of zinc, followed by lead, copper, cadmium and nickel among occupationally exposed workers (Zheng, J et al. 2011). The measure of heavy metals in urine is an important indicator of health risk assessment, which shows human body burden at a specific time (Song & Li 2015). The levels of cadmium in urine emerged as being significantly higher in occupational and non-occupational persons who dismantle equipment (Wang, H et al. 2011).

2.5.2.2. Impact on human health

The impacts of heavy metals exposure on human health have been studied by numerous researchers. In humans, excess copper intake leads to liver damage, lead inhibits learning capabilities and behaviour, and continuing exposure to cadmium results in a high risk of lung cancer and kidney damage (Bhutta, Omar & Yang 2011; Esteban-Vasallo et al. 2012; Yan, Xu &

Shen 2013). Chromium, nickel, lead and cadmium pose lifetime cancer risks to workers and residents, while non-cancer risks of cadmium, lead, copper and zinc are possible (Fang, Yang & Xu 2013; Zheng, J et al. 2013). Lifetime exposure to cadmium has been found to increase the mortality risk dose-dependently in women, and the relative risk of renal diseases, kidney and urinal tract diseases, renal failure and toxic effects of cadmium were significantly higher in women (Nogawa et al. 2018). The cancer and non-cancer risks at informal recycling sites are also higher than formal recycling sites for residents, and especially children (Zhang, Q et al. 2014; Zheng, J et al. 2013).

Detailed studies have been carried out focusing on the health outcomes of neonates, children, adult and changes in cellular expressions specifically in China. The exposure of pregnant women to heavy metals from e-waste leads to several negative effects in neonate's health (Guo, Y et al. 2010; Li, Y et al. 2008; Singh, Ogunseitan & Tang 2020; Song & Li 2015; Xu, X et al. 2012). These negative effectives include a rise in spontaneous abortions, premature births, and stillbirths. Moreover, it also reduces the infants' length, birth weight, neonatal behavioural neurological assessment (NBNA) scores and Agpar scores. Children of 8-9 years of age were also found to have problems with lung functionality due to their exposure to nickel, chromium and manganese (Zheng, G et al. 2013). In children, lead exposure has been found to impact on temperament including activity level, adaptability and approach-withdrawal (Liu, J et al. 2011). Among adults, sex hormone levels were associated with wearing masks (Yang, Y et al. 2013). The evidence of thyroid dysfunction, DNA damage and effects of gene expressions have also been found among exposed groups including neonates and children (Li, Y et al. 2008; Song & Li 2015).

2.5.2.3. Impact of formal vs. informal practices

State-of-the-art or *formal* recycling processes elicited serious health problems. Results of biomonitoring revealed overexposure of workers to toxic elements like cadmium, barium, lead, chromium, indium and mercury, and exposure to dioxins and furans in formal recycling facilities in France and Sweden (Julander et al. 2014; Lecler et al. 2015; White & Shine 2016). Julander et al. (2014) also detected higher exposure of workers involved in dismantling compared to workers in outdoor or indoor tasks, while all these groups had higher exposure than office workers at the same places.

The adverse effect of *informal* recycling on human health include damage to the nervous system, circulatory system, kidney and impact on brain development in children due to lead exposure (Ari 2016). Excess copper intake leads to liver damage, and continuing exposure to cadmium results in high risk of lung cancer and kidney damage (Bhutta, Omar & Yang 2011; Esteban-Vasallo et al. 2012; Yan, Xu & Shen 2013). Chromium, nickel, lead and cadmium pose lifetime cancer risks to workers and residents, while non-cancer risks of cadmium, lead, copper and zinc are also possible (Fang, Yang & Xu 2013; Zheng, G et al. 2013). Mercury has also been found to contribute the largest risk for carcinogens and non-cancer diseases (Singh, Duan & Tang 2020). The cancer and non-cancer risks at informal recycling sites are also higher than formal recycling sites for residents, and especially children (Song & Li 2015; Zheng, G et al. 2013).

2.5.2.4. Potential health risks for different groups

Different groups of people have varying exposures to e-waste. For instance, children are more susceptible and have higher health risks than adults, which is 8 times higher than workers (Leung, Anna O W et al. 2008). The risk for children and neonates is great because of: (i) smaller body size and higher ingestion rate; (ii) added ways of intake such as breastfeeding, placental exposures; (iii) high risk behaviours like hand-to-mouth activities as infants; (iv) changing physiology that involves higher intake of water, air and food and lower rate of toxin removal; and (v) higher permeable blood brain barrier and gastrointestinal uptake (Han et al. 2011; Song & Li 2015; Wang, X et al. 2012; Zhang, Q et al. 2011; Zhang, X et al. 2011). In contrast to residents in recycling areas, workers engaged in recycling activities have higher health risks, through direct inhalation of heavy metals, specifically lead, and through skin contact (Song & Li 2015). Similarly, workers at informal e-waste recycling sites experience higher health risks than workers in formal e-waste recycling sites, especially through lead intake (Fang, Yang & Xu 2013). Moreover, the daily intake of heavy metals and potential risks of chromium, copper, cadmium and lead were higher for workers in mechanical workshops than those in manual dismantling workshops (Fang, Yang & Xu 2013).

2.5.3. Social impact

Socially, *formal* sites potentially have better occupational health and safety standards; they restrict child labour and follow the laws and regulations (Ceballos & Dong 2016). Also, since workers only work for 8 hours a day in formal recycling sites, there would be a low concentration of biomarkers compared to workers in informal sites who are exposed through recycling, contaminated water, air, soil and food items (Julander et al. 2014). Moreover, in terms of yield, formal recycling can help recover about 99.9% of mercury from lamps/switches, and help reuse more than 98% of plastics, metals and wood (Kaya 2016).

The *informal* recycling practices usually have negative social impact, such as working hours were found to be more than 72 hours a week in Pakistan, where the workers were not entitled to any social welfare (Umair, Björklund & Petersen 2015). Much of the recycling is done by underprivileged people such as unskilled labourers, women and children, often members of the same family, working in the same space as they live, eat and sleep (Ari 2016; Premalatha et al. 2014). Other than negative outcomes, the informal recycling sector helps fight poverty by providing employment opportunities and plays an important role in economic development (Lin, CK, Linan & Davis 2002; Streicher-Porte et al. 2005; Umair, Björklund & Petersen 2015).

There have been several studies, establishing that both formal and informal recycling sectors create jobs. For instance, evaluating the job creation potential of compliant (formal) WEEE pre-treatment plant in Ireland, McMahon, Ryan-Fogarty and Fitzpatrick (2021) found that about 400 kg of mixed waste creates 1 full-time equivalent job, while e-waste diverted from scrap yard could create 12-14 jobs in the pre-treatment plant. Similarly, Prakash et al. (2010) estimated that about 20,300-33,600 people were employed by collection, recycling and refurbishing of e-waste in Ghana in 2010. Analysis also suggested indirect employment of an additional 57,600 people who depended on collection and recycling, and 144,000 more people who relied on refurbishment activities in that year.

2.5.4. Economic impact

A few studies have been done on economic impact analysis with very different aims and perspectives. For instance, some researchers highlighted the presence of precious metals to be the main economic driver of e-waste recycling industry, because potentially e-waste contains metals in more abundance than ores (Dong et al. 2007; Zhang, K, Zeng & Schnoor 2012). Exploring the economic aspects of material flow, Streicher-Porte et al. (2005) found these flows from pre-recycling processes, such as from upgrade or repair for reselling to be significantly higher than from post-recycling processes and selling parts. However, this analysis only considered costs and revenues from reselling and excluded other expenses like wages, additional components, and transportation costs among others. More recently, analysis of metal flows and value of e-waste was also conducted by Golev and Corder (2017) based on estimated stock and flows of EEE and their metal contents.

Cucchiella et al. (2015) estimated the economic potential (revenue) of different wastes based on the weights of recovered components from: (i) disposed volumes, and (ii) market prices, and found gold to be the main source of revenue (72% in printed circuit boards, and 56% in smart phones). Similarly, Achillas et al. (2013) determined if the components should be reused, recovered or recycled to maximise profitability or minimise e-waste management costs. Another study concentrated on identifying various techniques for e-waste recycling and then investigating the cost and revenue drivers of each technique (Hai-Yong & Schoenung 2006). Using a similar cost and benefit analysis, a recycling pilot project in China reported higher social benefits of recycling than costs, but the project failed because the producer (recycler) lost money at all stages so there was no incentive to operate (Ma et al. 2009). Importantly, Umair, Anderberg and Potting (2016); Umair, Björklund and Petersen (2015) found economic benefits in terms of employment and livelihood provision by the e-waste recycling sector.

2.6. Best practice in e-waste management

2.6.1. Developed economies

During (and before) the 1990s, e-waste was treated just like municipal solid waste and sent directly to landfill or was incinerated (Nick 2000; Vehlow & Mark 1997; Williams, J, Shu & Murayama 2000). Realising the hazardous and harmful material in e-waste, coupled with the shortage of space in landfills and potential rise in the quantities of e-waste, countries in Europe (and Asia) started to advocate for other take-back systems to deal with the problem of growing e-waste. The EU launched a 'Priority waste stream programme for electrical and electronic equipment' in 1994, which became the basis for the subsequent EU Directive (Cramer & Stevels 1996; Williams, J, Shu & Murayama 2000). Since then, e-waste regulations have gradually emerged at the region and country levels (localised), where the EU has been a global leader in formulating policies on hazardous substances (Selin & VanDeveer 2006), followed by countries like Japan, South Korea, Canada, and now China is tightening its regulations alongside banning the import of e-waste and other forms of waste from developed countries (Herat, Sunil 2009; Lin, S et al. 2020; Pariatamby & Victor 2013). At an international level, the Basel Convention emerged as an overarching set of regulations to restrict the transboundary movement of e-waste from developed to developing countries (United Nations Environment Program 2011). However, there is still a high reliance on landfill and export/trade to deal with the issue of e-waste.

International regulations are not mandatory unless adopted and reinforced at a country level. Of the developed countries, Switzerland was the first to establish and implement the formal e-waste management system (Sinha-Khetriwal, Kraeuchi & Schwaninger 2005). E-waste management in Switzerland and other developed countries in the European Union (EU), Japan, Canada, USA, Australia and New Zealand, is mainly based on the *Extended Producer Responsibility (EPR*), which emerged in EU, also known as the *Stewardship scheme* (Khetriwal, Kraeuchi & Widmer 2009; Kumar, A & Holuszko 2016; Lodhia, Martin & Rice 2017; Mmereki et al. 2016; Sinha-Khetriwal, Kraeuchi & Schwaninger 2005).

EPR places the physical and financial responsibility of the end-of-life processes (handling, disposal and recycling) on the manufacturers and importers (Lifset, Atasu & Tojo 2013; Sinha-Khetriwal, Kraeuchi & Schwaninger 2005). In Switzerland and other advanced economies, the advance recycling fee (ARF) is built into the price of products, which is paid by consumers at the time of purchase (Khetriwal, Kraeuchi & Widmer 2009; Sinha-Khetriwal, Kraeuchi & Schwaninger 2005). The advance fee and provision of common disposal points reduce the incentive of illegal disposal or dumping (Mmereki et al. 2016). Moreover, the strict controls and regulations in Switzerland at multiple levels ensure the proper execution and implementation of the EPR. Similar laws and regulations exist in other developed countries like Japan, US and Australia, but the ambiguous recycling fees, illegal dumping or exports to developing countries remain the great problems of e-waste management system in these countries (Lodhia, Martin & Rice 2017; Mmereki et al. 2016; Nnorom & Osibanjo 2008b).

2.6.2. Developing countries

In developing countries, such as China, India, South Korea, Brazil and Africa, there have been efforts to formulate legislation and schemes like EPR (Bhaskar & Turaga 2018; Garlapati 2016). For instance, China has had laws related to e-waste treatment from 1990 to 2009, which had no effect, until was implemented in 2012 (Cao, J et al. 2016). Under EPR, the taxes from producers and importers are used to subsidise the recycling. Despite the implementation, large volumes of e-waste are still treated informally, mainly which are imported (illegally) since government subsidy cannot be used to treat them formally (Cao, J et al. 2016). However, more recently in 2017, China implemented a strict ban on imports of solid waste from developed countries as a part of "Prohibition of foreign garbage imports: the reform plan on solid waste import management" (Brooks, Wang & Jambeck 2018; Tan, Li & Boljkovac 2018). This has helped China to significantly reduce damage to the environmental in the short-term and save about 2.35 billion Euros of eco-costs annually (Wen et al. 2021). However, other regions such as Hong Kong have witnessed an influx of e-waste import after a ban by China because Hong Kong did not implement the ban as it has different customs policies (Lin, S et al. 2020). This might also indicate a diversion of waste to other developing countries in Africa and Asia that have not implemented any regulation of waste imports as yet.

Similarly, in India, the Ministry of Environment and Forests (MoEF) issued a draft of e-waste management rules for the first time in 2010, which clearly outlined the responsibilities of producers to properly collect and dispose e-waste as in EU EPR directive (MoEF 2008); however, the administrative delays and enforcement of regulations are the main problems (Dwivedy, Suchde & Mittal 2015). Manomaivibool (2009) identified three major elements in the successful implementation of the EPR program. First is the need for controlled and environmentally sound downstream activities. Second, the flow of resources from identifiable producers to downstream markets, whereby the consequences of downstream activities are attributed to the producers and three, reporting and monitoring mechanisms that are vital for the first two elements in making the implementation of EPR successful. Noting these three elements, in India the author identified two main obstacles to ERP implementation, the first being a large grey market for EEE, and the second is the illegal import of e-waste (Manomaivibool 2009). Cultural factors, for instance, not disposing of the used equipment because it is a valuable item, leads to passing on the equipment to second and third buyers, and then selling it off to local collectors for a small amount of money; this hinders the effective implementation of the ERP system (Borthakur & Govind 2017, 2018).

2.6.3. The circular economy

According to the literature on equipment (EEE) manufacturing, e-waste management, recycling practices and impacts, current upstream and downstream practices in most developing and developed countries are based on a traditional linear economy (Figure 16). The cycle begins with extraction for production as much as possible at unsustainable levels and subsequent depletion of natural resources (Maryknoll OGC 2017). These upstream practices of extraction and production might typically be initiated by multinational companies, operating in resource-rich or low wage (production) developing countries so that cheap raw materials can be accessed, and/or facilitate low-cost mass production. The upstream stages of a product life cycle enjoy cheap labour, as well as perhaps less stringent regulatory controls that collectively help keep operating costs down. However, upstream production can also incur considerable costs in terms of human health and environmental degradation, as is well illustrated by e-waste. Again referring to the upstream, the next stage in a product life cycle is distribution, which involves transportation of goods for consumption. After this stage the product cycle conveniently ends with disposal to landfills without any regard to the outcomes. In the value chain of the product life cycle these are downstream 'externalised costs' – aside from potential wage exploitation, primarily incurred in terms of human health and environment (air, water, soil) costs, most acutely borne by recycling workers, their family members and the community.

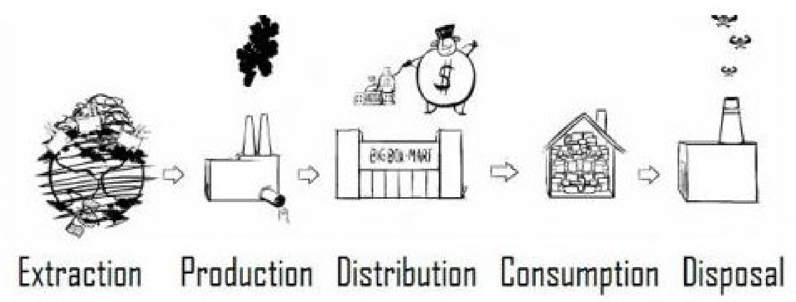


Figure 16: The linear economy - product life cycle

Image source: Maryknoll OGC (2017)

Considering the environmental requirements affecting manufacturing, there is a growing move to embrace green supply chain management (Figure 17). It is very different to the traditional, one-way manufacturing process, where raw materials are converted into products and sold or delivered to consumers (Beamon 1999). Green supply chain management attempts to close the loop between customers and suppliers by including the reverse supply chain (Gholizadeh & Fazlollahtabar 2020; Sarkis, J 2012). In this concept, end-of-life material is consumed back into the system through recycling, remanufacturing, reclamation, and reverse logistics (Sarkis, J 2012).

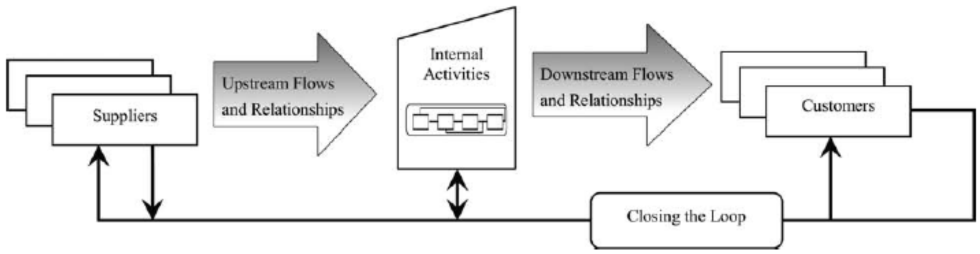


Figure 17: Green supply chain
Source: Sarkis, J (2012)

The concept of a circular economy recognises that the current and traditional linear economy is unsustainable (Frosch & Gallopoulos 1989) and it "*provides an approach to economic growth that is in line with sustainable environmental and economic development*" (Murray, Skene & Haynes 2017). The circular economy refers to *"an industrial economy that is restorative by intention; aims to rely on renewable energy; minimises, tracks, and eliminates the use of toxic chemicals; and eradicates waste through careful design*" (Murray, Skene & Haynes 2017). It is shown in Figure 18 below based on a few principles (MacArthur 2013, 2020). The first principle is 'design out waste' – designing out the negative impacts of economic activity on environment and human health. A second principle is to 'keep products and materials in use' - designing for durability, reuse, remanufacturing, and recycling to keep products, components, and materials circulating in the economy. A, final, third principle is to 'regenerate natural systems' - avoid the use of non-renewable resources and preserve or enhance renewable ones.

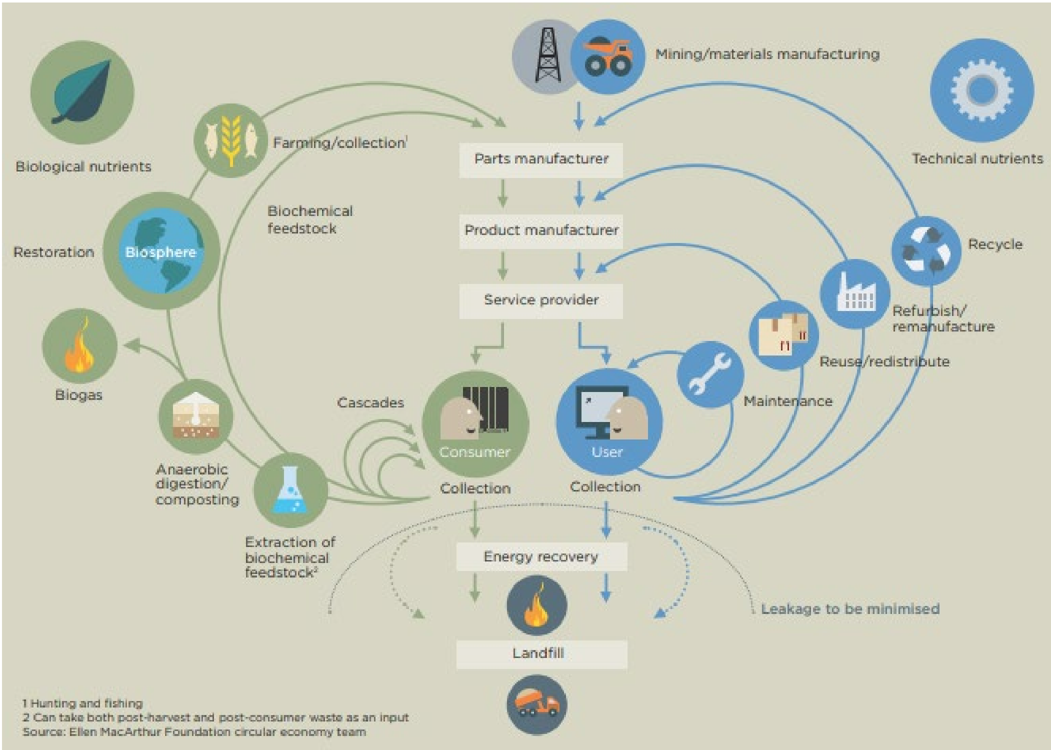


Figure 18: The circular economy
Image source: MacArthur (2013)

Utilising a circular economy approach may reduce the depletion of resources through recycling and reuse. The limitation of the circular economy, however, is that it appears to ignore the social impacts of upstream and downstream economic activity, as there is still toxic residue as well as waste going to the landfill.

2.7. The social-ecology model (framework)

Another way to view e-waste is as a societal problem. This requires the application of concepts from different disciplines. Ideally, a multi-disciplinary approach is needed to solve these complex 'real world' societal problems (Van Dijk 2001). This study applies a social-ecological model, initially developed as a conceptual approach for understanding human development by Bronfenbrenner (1977, 1979), and later formalised as a theory in the 1980s (Bronfenbrenner 1986, 1989). The social-ecological model is illustrated as nested circles, with an individual at the centre, surrounded by various systems (stakeholders – people, organisations, societal norms and rules) that influence the individual and encompass the interactions and relationships of surrounding systems (Golden et al. 2015; Kilanowski 2017). The model takes individuals, their relationship to people, affiliation to organisations and their community to be effective, as shown in Figure 19.

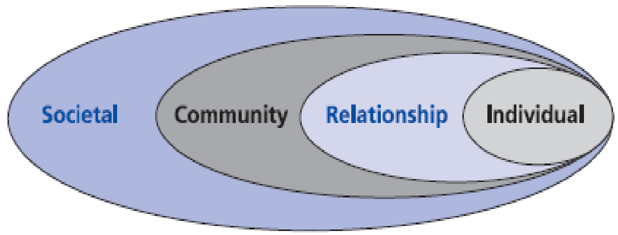


Figure 19: The social-ecology model

Image source: World Health Organization (2002)

The social-ecology model is widely used in health, social and community intervention studies (Baral et al. 2013; Espelage & Swearer 2009; McLeroy et al. 1988; Morris et al. 2020). It has also been used as a tool to improve public health by the World Health Organization (WHO) (Harvey, Garcia-Moreno & Butchart 2007; World Health Organization 2002). Thus, for example, in order to address problems related to public health, the WHO picked violence as one of the leading causes of deaths worldwide for people aged 15-44. It attempted to measure violence and its impacts, and then devise prevention methods. Prevention methods include three stages: *primary prevention*, using health, to promote health via preventative measures such as vaccinations and altering risky behaviour; se*condary intervention* to provide treatment and prevent a worsening of health; and *tertiary intervention*, where the focus is on people already affected, and the effort is to restore function through rehabilitation.

The model is found to be highly relevant to this study because it deals with issues that affects societies in multiple ways, including social and environmental. For instance, Sun and Hilker (2020) analysed the mutual feedback between lake pollution and human behaviour using a social-ecology model. Haraldsson et al. (2020) used the model to analyse the effects of a future offshore wind farm on the local society and ecosystem, including the importance of social compensation. Naja and Hamadeh (2020) presented a framework for action (based on the social-ecology model) to maintain optimal nutrition at the individual, community, national and global levels during the Covid-19 pandemic. The interdisciplinary nature of the approach also makes it suitable for the current study, as the public health approach combines knowledge from medicine, *sociology*, psychology, *economics* and education among others (World Health Organization 2002). The approach calls for collective action to the global issue - with different sectors such as health, *social services*, justice and *policy* helping to solve related problems (World Health Organization 2002).

In the context of the proposed study, the social-ecology model helps to identify the multifaceted nature of e-waste across many kinds of stakeholders (producers, distributors, users, recyclers and disposal workers). Moreover, prevention methods apply to the e-waste problem in this study, whereby policies and government regulations are possible primary prevention methods, requiring the use of less toxic, easy-to-disassemble parts and proper disposal practices. The secondary intervention sets out to reduce EEE and reuse equipment in order to prevent e-waste from rising alarmingly. Finally, the tertiary intervention after e-waste has been generated is to recycle it (recover material while minimising the negative impacts).

2.8. Conceptual framework

Figure 20 depicts the conceptual (ecosystem) framework adapted from the World Health Organization (2002) and Thomas, KT (2019) to include social-ecology model, combined with the levels of prevention. This framework has been modified to solve the identified problem, and it guides research questions and objectives. For this reason, it has been used to devise a suitable methodology for the research. Research objectives (ROs) have been added in red text.

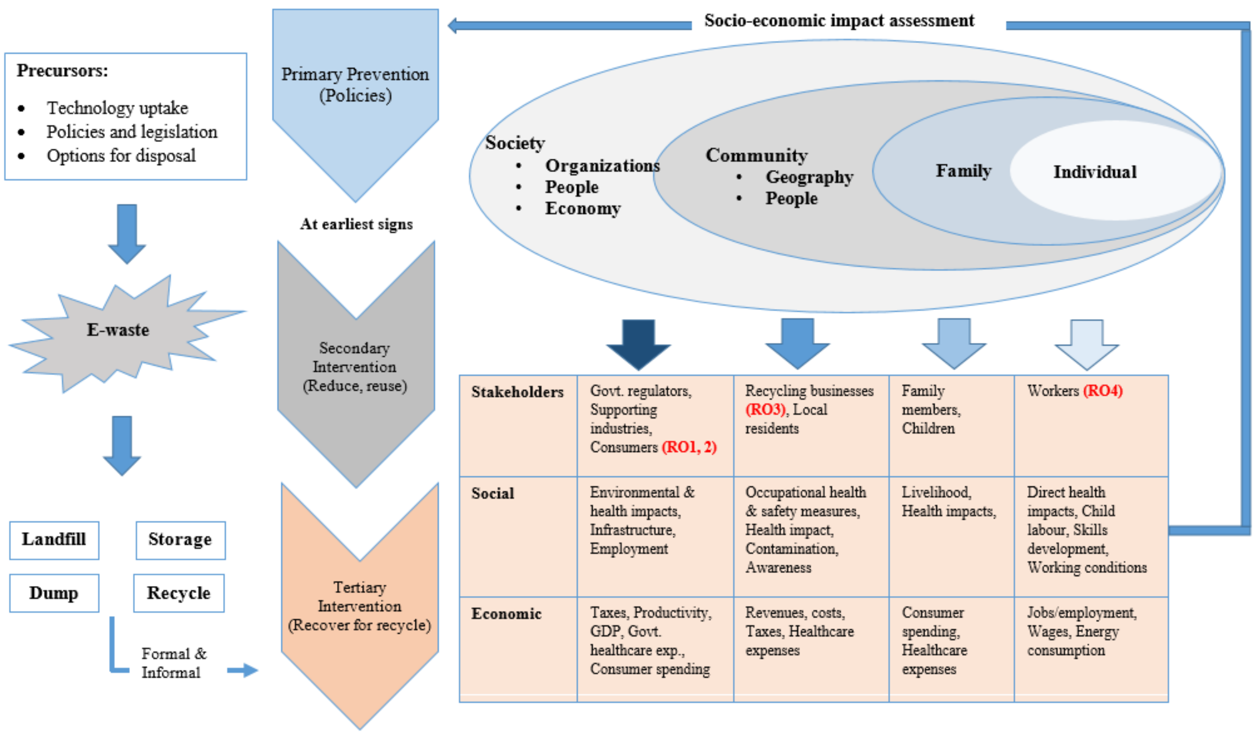


Figure 20: Conceptual Framework

Adapted from World Health Organization (2002)

The rise of EEE and e-waste can be attributed to several factors including high technology uptake and continuous improvement, government legislation and options available for consumers to dispose of goods. The e-waste produced can be disposed of in landfills, be dumped, and be repaired for reuse or recycled (formally and informally). The highest environmental and human health impact is by direct disposal in landfill. Recycling falls under the tertiary intervention, which is the response to a problem (e-waste generation). Informal recycling recovers some material with considerable impact, but adoption of formal recycling reduces the problems. Therefore, despite potential exposure to workers and surroundings, formal recycling is desirable because formal facilities are expected to safeguard occupational and environmental health better than informal sites (Ceballos & Dong 2016). More automation is required in the formal recycling practices to protect workers and the environment (Julander et al. 2014).

The focus, however, only on the downstream sector by tertiary intervention and improving recycling facilities will not provide long-term solutions unless changes are made in upstream stages. This calls for primary prevention measures that help reduce the fallout. One pathway is policy actions that require manufacturing of EEE to be without harmful substances and with easy-to-disassemble components (Ceballos & Dong 2016). The findings of this research will seek to establish the need for further policy actions aimed at primary prevention.

2.9. Consolidated impact factors framework

To assess the impacts, a consolidated impact factors framework has been devised as shown in Figure 21. The framework consists of factors along the dimensions of direct, indirect, financial and non-financial (social). The variables shown in red are not included in this study, as they have already been explored or the data is not available. The framework consists of metrics from a Social Lifecycle Assessment (S-LCA) framework developed by UNEP/SETAC (2009, 2011, 2013) and supported by Benoît et al. (2010); Russo Garrido et al. (2016); Sala et al. (2015). The S-LCA framework provides qualitative and quantitative factors to assess the positive and negative social impacts for various stakeholders like consumers, workers, value chain actors, local community and society. Additional social cost indicators, such as value of statistical life and reduced quality of life measures for health and safety from healthcare have also been adopted.

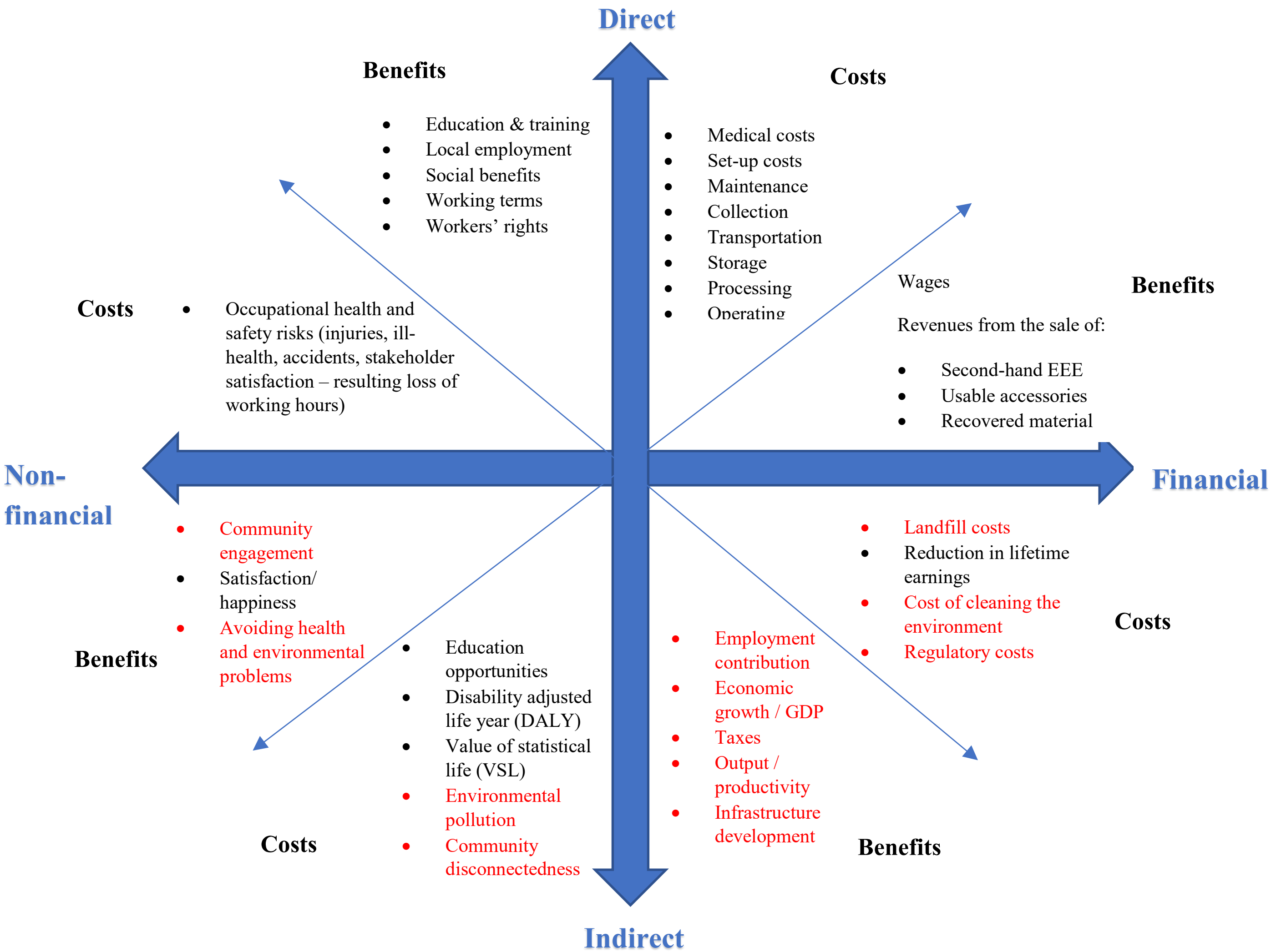


Figure 21: Consolidated Impact Factors Framework

The S-LCA framework is still evolving and has challenges of applicability and appropriateness of indicators in specific situations (Lehmann et al. 2013; Sousa-Zomer & Cauchick Miguel 2015). In a critical review of UNEP 2009 guidelines, Tokede and Traverso (2020) noted these indicators could not be applied across a variety of sectors and disciplines, and there was a clear need to localise and justify the indicators in respective studies. The authors also found that only 47% of subcategories specified by the guidelines were implemented in the examined studies. However, the framework has been appreciated for giving a holistic perspective of the social impacts involved as compared to other tools and decisions based on S-LCA can yield more socially beneficial results (Jørgensen 2013; Mattioda et al. 2015; Sousa-Zomer & Cauchick Miguel 2015). The S-LCA framework has also been employed in different contexts such as for e-waste (Umair, Björklund & Petersen 2015), green building (Fan, L et al. 2016) and clothing production (van der Velden & Vogtländer 2017). More recently, updated guidelines have been drafted by UNEP/SETAC (2020), although not incorporated into this study. These can provide future research studies an opportunity to apply the guidelines extended from products to different levels of assessment including projects, interventions, facilities and organisations.

2.10. Impact indicators

As discussed in the previous subsections, the social ecology framework by Bronfenbrenner (1977) has been adapted to identify different levels of responses to the rising e-waste problem and resulting impacts on human health and the environment. Three levels of intervention are defined: primary, secondary and tertiary. Primary prevention involves interventions before a problem occurs (i.e. policy formation, product design, redesign), secondary (involving reduce, reuse) seeks to prevent further problems after it has been identified, and tertiary interventions (disposal and recycling by formal and informal means) involve actions to reduce the negative impact of an act or problem after it has occurred (DeGue et al. 2014; Eusebi et al. 2020; Harvey, Garcia-Moreno & Butchart 2007). This research seeks to assess the impact of tertiary intervention (disposal & recycling) to inform the basis for primary prevention.

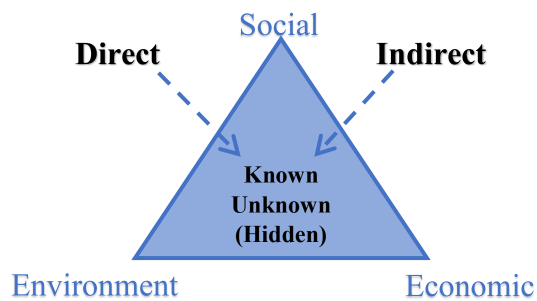


Figure 22: Impact Indicators

Based on Barbier (1987) and more recent scholars, such as Purvis, Mao and Robinson (2019) three key areas of sustainability (and impact) - social, environment and economic - have been identified (Figure 22). The research focuses on identifying and measuring social and economic factors, which include the direct impact (known & unknown) and indirect impact (known & unknown) as shown in Figure 22. The ideas and actions of humans have consequences, some of which are intended and others unintended. It is important to understand the consequences of these actions to understand the overall utility of these actions (Sikdar, Sengupta & Mukherjee 2017). Since human minds often reason linearly, they can overlook or ignore consequences, while other consequences might not be obvious or appear later (Sikdar, Sengupta & Mukherjee 2017). These are the knowns and unknowns, which are also applicable to the consequences or impacts of e-waste recycling.

In terms of areas of impact, direct disposal by landfill has the worst social and environmental consequences (Cherubini, Bargigli & Ulgiati 2009; Harbottle, Al-Tabbaa & Evans 2007), followed by informal recycling, which recovers some material, but with considerable impact in the immediate and longer-term (Ackah 2017; Alcántara-Concepción, Gavilán-García & Gavilán-García 2016; Añón Higón, Gholami & Shirazi 2017; Awasthi, Zeng & Li 2016a). Adoption of formal methods can help reduce the impact to some extent (Julander et al. 2014). However, the focus only on tertiary intervention and so on downstream effects and formal recycling processes will not provide an adequate long-term solution, since changes are also needed to upstream stages (product design, extraction of resources, manufacture of electrical and electronic equipment (EEE), distribution, sales and to formal recycling supply side deficiencies and safety of remanufactured products) (Chi et al. 2011).

What is needed is an integrated response and a greater focus on primary prevention through economic, environmental and social (health) policy measures, and by product design actions such as requiring EEE to not comprise harmful substances and easy-to-disassemble components (Ceballos & Dong 2016). Findings from this research can help identify local factors that impact on and provide indicators to assess and estimate the (socio-economic) costs and benefits of electronic waste disposal (and recycling) in order to guide policy, ultimately to address all three levels (social, environmental and economic).

2.11. Summary and identified gaps in literature

Reviewing the literature on multiple aspects of e-waste generation, management, recycling processes and impacts has revealed that it is a growing and complex problem due to rising volumes and toxicity. It has been established that due to toxic elements and processes, e-waste does not only have negative (environmental, human health and social) impacts at the downstream stage, but also at the upstream manufacturing and usage stages. Moreover, it has also been discovered that even formal e-waste recycling processes have their own issues, although they are less hazardous than informal recycling. As a result, best practice in developed countries needs to be replicated in developing countries like Pakistan, by interventions in the short-, medium- and long-term.

The literature review has identified the challenges and gaps in studies that need to be further investigated, more specifically in developing countries to facilitate better e-waste management strategies and practices. First, e-waste is inadequately explained by the simple linear process and given its ubiquity needs an integrated and ecosystem approach much like dealing with health and major epidemics. For instance, the notion of green supply chain management (Figure 17) is to close the loop between consumers and suppliers which is left open in a conventional supply chain management system (Sarkis, J 2012). Arguably, a green supply chain is still incomplete as it externalises the upstream impacts during manufacturing, as well as the downstream recycling impacts (added in red dotted box and lines in the modified supply chain – as illustrated in Figure 23) below. The effect of this is to arguably defer the burden (or externalise the costs) that is ultimately borne downstream by humans and the environment. To overcome this gap, this study adopts an ecosystem or systems view that will be key to devising and implementing primary prevention and related intervention strategies.

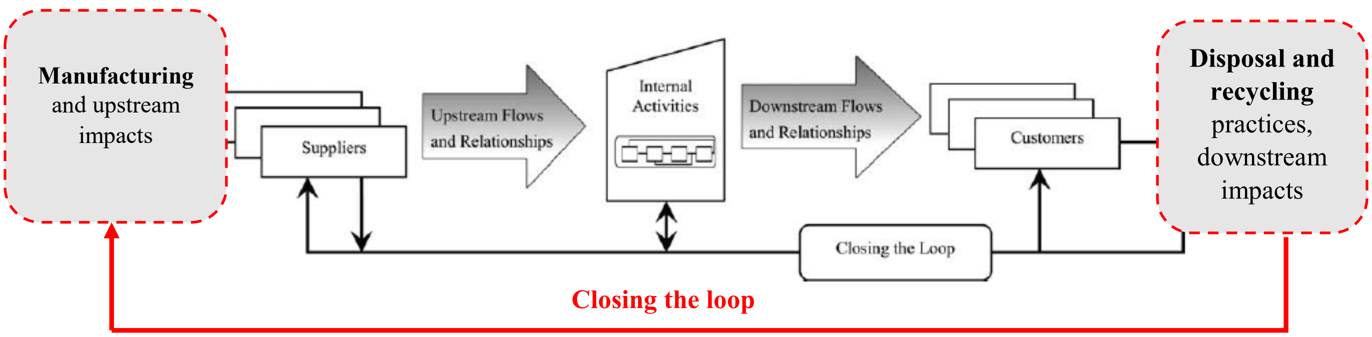


Figure 23: A green supply chain diagram – modified

Source: Sarkis, J (2012)

Second, it is apparent globally that most countries do not have inventory management practices and databases of e-waste or EEE that can help to quantify the scope and scale of this issue (Baldé et al. 2017; Pariatamby & Victor 2013). The issue of quantification and inventory management is crucially important for Pakistan, where large volumes of imported e-waste can go undocumented (Abid, Zulfiqar & Raza 2019; Iqbal et al. 2015). One contributing factor is the e-waste classification systems (HS codes) that classify usable equipment and e-waste with same codes; another issue is lax regulations (Umair, Anderberg & Potting 2016). As evident in the literature, there are seeming numerous studies attempting to quantify the volume and growth of e-waste, both globally and regionally. However, these studies use trade or sales data (Baldé et al. 2017; Forti et al. 2020; Imran et al. 2017; Kumar, A, Holuszko & Espinosa 2017) that might have inherent limitations, due to the classification systems used (imports), and not all of the data might be recorded, as in Pakistan. To close this gap, the present study proposes a comprehensive method based on extrapolation and population estimates for e-waste quantification in Pakistan that can be easily applied to other economies (RO1 and 2).

Third, at the downstream level, there are studies that establish profitability or economic benefits for e-waste recycling businesses (Cucchiella et al. 2015, 2016; D'Adamo et al. 2019; D'Adamo, Ferella & Rosa 2019). However, most studies were done in European nations and so they assess the profitability of formal recycling practices. Noticing the dearth of evidence for informal recycling processes, this study estimates the costs and benefits (through CBA analysis) for informal recycling businesses in Pakistan (RO3). As well, in terms of assessing impact at the worker, community or environment level, there is extensive evidence of damage being done to the environment (Grace Pavithra et al. 2020; Hoa et al. 2020; Li, Juan et al. 2020; Wu, Q. et al. 2019), human health (Cao, P et al. 2020; Fischer et al. 2020; Kim et al. 2020; Zhang, M et al. 2019) and social aspects (Pandey, P & Govind 2014; Rodrigues, Angelo & Marujo 2020; Umair, Björklund & Petersen 2015). However, most studies on social impacts use qualitative indicators to highlight impacts as there are limited ways of measuring them. This study seeks to fill this gap in the literature, by first, conducting a cost-benefit analysis of financial and some non-financial factors, and second, highlighting the hidden and complex dynamics of e-waste recycling through systems thinking, an approach which has not been used in the context of e-waste (RO4).

Finally, limitations are evident in the methodological frameworks. The S-LCA guidelines by UNEP, for example, identify variables for impact assessment but provide limited guidelines on analysis and interpretation. Moreover, since the framework has been developed considering the dynamics of developing countries, many variables do not apply in these places. This study develops a consolidated framework for e-waste impact assessment for developing countries (RO5). Through these analyses, this study can complete the country assessment (the first step of a three-step approach - Figure 10) needed to develop an e-waste management strategy for Pakistan.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Introduction

The previous chapter discussed some gaps in the literature of e-waste management and used an ecosystem framework to devise a consolidated impact factors framework, consisting of factors and variables to assess impacts of e-waste management. This chapter explains the research methodology to answer the overarching research question - "*What are the economic impacts of e-waste disposal (and recycling) practices*?" and subsequent sub-questions and specific research objectives. The chapter begins by explaining the research paradigm appropriate for this thesis, briefly discussing the ontology, epistemology and methodology, followed by the details concerning the mixed methods approach – quantitative and qualitative. Next, the research process, starting from the literature review to the discussion and conclusion is illustrated. This is followed by the methodological details of each sub-question, including data collection tools and data analysis procedures. Finally, the chapter closes with a comment on the ethical considerations, the role of expert advisory group (EAG) and a summary of the key themes covered here.

3.2. Research Paradigm

The nature of knowledge in any research is explored and detailed with respect to the research *paradigm* (Brown & Dueñas 2020). A research paradigm may be defined as a "worldview, complete with assumptions that are associated with that view" (Mertens 2003), or "the set of common beliefs and agreements shared between scientists about how problems should be understood and addressed" (Kuhn 1962). Since a paradigm is a view or assumption on how things work and a shared understanding of reality (Rossman & Rallis 2011), it is important to detail the paradigm as it 'guides how problems are solved' (Schwandt 2014), and influences the choice of methods employed by authors (Brown & Dueñas 2020). According to Guba (1990), a paradigm is characterised by how three basic questions are answered:

1. Ontology – what is the nature of 'reality'? Or what is reality?
2. Epistemology – how can the inquirer know about it? Or what is the nature of the relationship between the inquirer and reality?

3. Methodology – how should the inquirer go about finding the knowledge or reality? It refers to a set of theoretical concepts and methods applied to answering the research questions.

The answers to these questions depend on the basic beliefs, assumptions or paradigms that may be embraced. All researchers make assumptions about the state of the world before undertaking a research study, and these assumptions are essential regardless of the methodology used, as they impact on how the results are interpreted (Brown & Dueñas 2020). However, in fact, these beliefs or assumptions cannot be proven or disproven in any foundational case; if it was possible to prove or disprove, there would be no doubt about how to practice an inquiry or conduct research (Guba 1990). Therefore, since all belief systems or paradigms are human constructs, they are subjective and prone to errors just like any other human activity.

3.2.1. Ontology

There are many ways to answer these questions, the most prominent being the beliefs about positivism, constructivism (interpretivism) and pragmatism, among others like post- positivism and critical theory (summarised in Figure 24 in the next subsection).

Answering the first question (ontology), positivists believe there exists a single truth out there, driven by absolute natural laws, and they aim to uncover the 'true' nature of reality and how it 'truly' works (Guba 1990; Lincoln & Guba 1985). Constructivists, on the other hand, believe in multiple realities and there are always many interpretations that can be made in an inquiry (Lincoln & Guba 1985; Teddlie & Tashakkori 2009). Given there is no specific foundational process to explore the truth or falsity, there is no other option but to take a position in relativism, which is the key to openness and the continuing search for more informed and sophisticated constructs (Guba 1990).

The third belief of pragmatism disregards the idea that truth can be discovered permanently and universally just once; instead, truth is what works and proves itself good for definite reasons (James 2000; Howe 1988 cited in Pansiri 2005; Pratt 2016). It is constantly renegotiated and debated to provide useful solutions to the problems. Similarly, according to Powell (2001), a proposition is true if it helps humans to make useful discoveries, and needs to be applied and improved as long as it gives fruitful results, but if it fails, it should be dropped for better propositions (Pansiri 2005). With an emphasis on choosing explanations that have the best desired results, it subsequently evaluates assertions based only on practical consequences of taking actions and experiencing outcomes (Hall 2013; Morgan 2014; Pansiri 2005). Therefore, in classical pragmatism, a process of enquiry using scientific and empirical investigations serves to understand issues that can be related to a wide range of human issues (Ormerod 2006; Pansiri 2005).

3.2.2. Epistemology

Epistemology is related to the questions concerning the nature, source and scope of knowledge. In terms of epistemology, positivists believe objective knowledge can be obtained through the use of valid and reliable measurement tools, while constructivists take the view that knowledge is subjective and formed at an individual level (Brown & Dueñas 2020; Mertens 2008; Patterson & Williams 1998). Pragmatists challenge this distinct contrast between objectivity and subjectivity of positivism and constructivism (Teddlie & Tashakkori 2009). Rather, they suggest epistemological issues exist on a continuum and not on two opposing poles. At different points of the research process, scholars might use objectivity and subjectivity, or a combination of both depending on the requirement (Teddlie & Tashakkori 2009).

3.2.3. Methodology

Methodologically, positivists mainly use a quantitative methodology that might include statistical analysis, such as descriptive and inferential statistics (Teddlie & Tashakkori 2009). On the other hand, constructivists mainly rely on qualitative methods, like thematic analysis, categorical strategies or contextualising strategies. Pragmatists derive from both the positivist approach support for quantitative methods, while the constructivist approach is based on qualitative methods. As a result, pragmatism has been regarded as the best paradigm for mixed methods research (Glogowska 2011; Shannon-Baker 2016).

Mixed methods research has been referred to as the third methodological movement (Johnson & Onwuegbuzie 2004) or the third research community (Teddlie & Tashakkori 2009), an addition to the qualitative and quantitative methodologies. Mixed methods research design employs both quantitative and qualitative methods in a study to answer questions. It is a rich approach, which combines qualitative data such as "*words, pictures and narrative*" (Johnson & Onwuegbuzie 2004) with quantitative, numerical or statistical data to produce comprehensive results that could be generalised for future studies (Hesse-Biber 2010).

Triangulation of methods and sources for data collection can help integrate the reliability, validity, truthfulness and integrity of the data (Cho & Trent 2006; Pandey, SC & Patnaik 2014). In this study, it has been achieved by collecting data using a mixed methods approach combining qualitative and quantitative methods (survey and interview), and through multiple data sources (discussed in sections 3.3., 3.4.1. and 3.5.2.) comprising of data collected from multiple stakeholders (consumers, businesses and workers).

3.2.4. Justification of paradigm and mixed methods

This research used a pragmatic paradigm and mixed methods approach as shown in the red dotted box in Figure 24, in order to achieve the outlined research objectives, guided by the principle attributed to Peter Drucker: *what gets measured can be managed*. However, as it is not always possible to measure the unmeasurable, a qualitative component was deemed crucial to capture the social complexities, dynamics, hidden and unknown aspects of e-waste recycling in the context of e-waste. Quantitative data and analysis was utilised to estimate the quantities of e-waste in Pakistan and understand upstream consumer considerations on e-waste generation and disposal using surveys. Meanwhile material flow and cost-benefit analysis using quantitative methods helped quantify the first-order and second-order effects to recycling business owners and workers.

Figure 24: Paradigm contrast table

	Positivism	**Constructivism**	**Pragmatism**
Ontology	An objective reality	Multiple, constructed realities	Diverse viewpoints regarding realities; best explanations within personal value systems.
Epistemology	Objective viewpoint	Subjective viewpoint	Both objective and subjective viewpoints; depending on the stage of research
Methodology	Quantitative	Qualitative	Mixed – qualitative and quantitative

Source: Teddlie and Tashakkori (2009)

Mixed methods have emerged as useful for this thesis due to advocating any methodological tools that are appropriate in answering the research questions (Teddlie & Tashakkori 2009). Moreover, the "complementarity" offered by mixed methods was another main reason to use the study design. Complementarity, achieved by the blend of quantitative and quantitative data, and not just the numerical or descriptive data, allowed the researcher to gain comprehensive insights into the research problem which could not be done via single approach designs. Finally, this approach has helped address different research sub-questions and objectives simultaneously with both quantitative and qualitative approaches.

3.3. Research process

The research process utilised in this study is illustrated in Figure 25 below. First, a literature review was conducted to identify the gaps in literature and devise research questions and objectives. Second, a conceptual framework was developed, one that helped determine relevant factors and variables for answering the questions (Appendix 1). Third, questionnaires were developed from identified factors and variables and pilot tested on a small sample. In the next data collection phase, data was collected simultaneously from all three stakeholders, that is, consumers of EEE (RO1 and 2), recycling businesses (RO3) and workers (RO4). So, this study employed a parallel mixed design. Data from consumers was collected via surveys and it was recorded online, while data from recycling businesses and workers was collected through semi-structured interviews and documented as hard copies. Since the survey data was entirely quantitative, it was analysed using quantitative methods and statistical analysis. Interview data had components of quantitative and qualitative data. Quantitative data was analysed using MFA and CBA, while thematic analysis and systems thinking was used for qualitative data. The research process ended with a consolidation all the findings in a final discussion and conclusion.

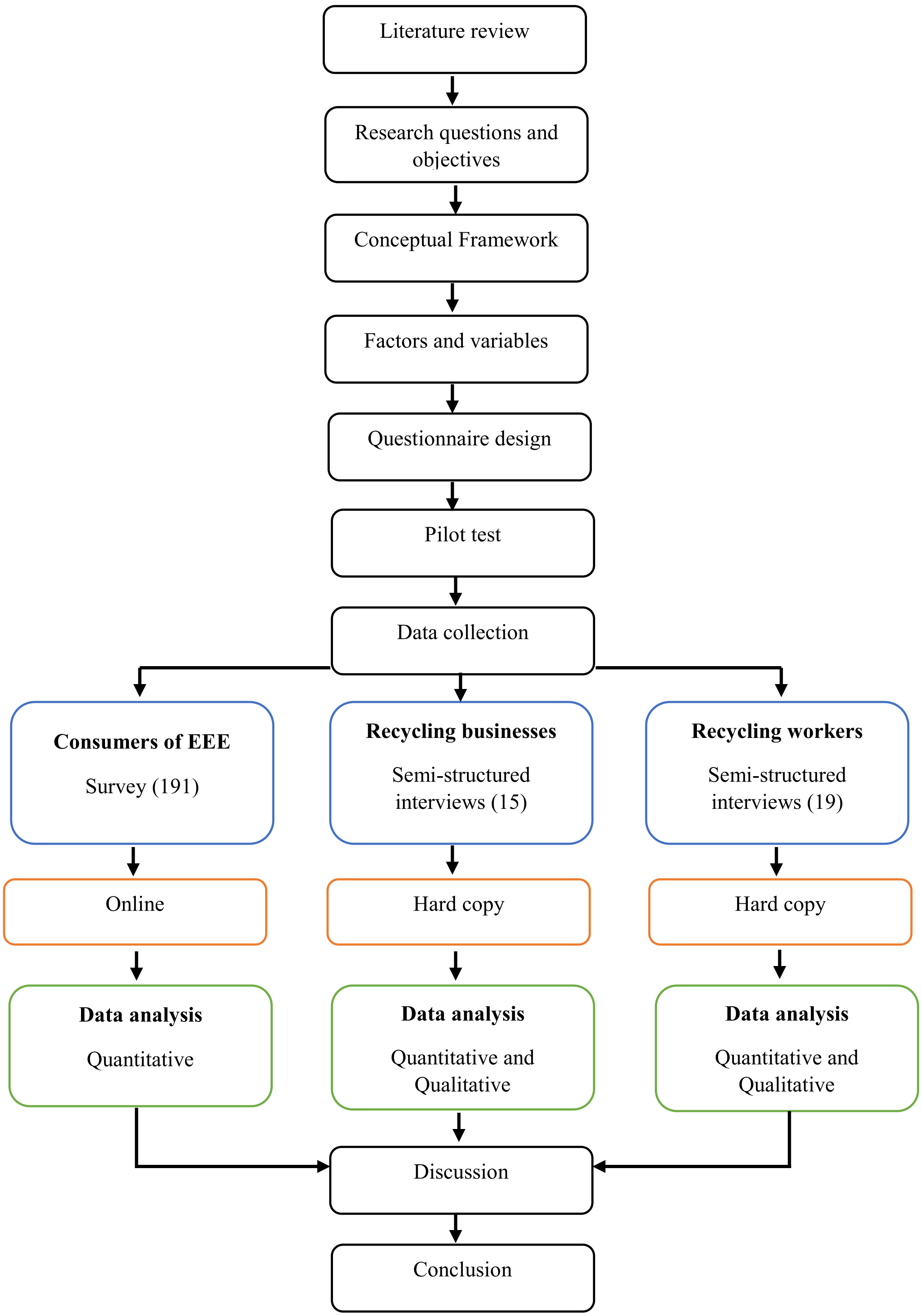


Figure 25: The research process

3.4. Sub-question 1 – What is the current situation with e-waste generation and disposal in Pakistan?

Sub-question (SQ) 1 relates to the current situation with e-waste generation and disposal (personal), and has Research Objective 1 (RO1) and Research Objective 2 (RO2).

> ***RO1:*** *Analyse consumer behaviour concerning the acquisition, usage, disposal, awareness and willingness to pay for e-waste management.*
>
> ***RO2:*** *Assess the flow (and stock) of electrical and electronic equipment/e-waste through the upstream sector.*

The rationale behind this sub-question is that consumers are the main beneficiaries of and contributors to 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, C W 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, responsible disposal and recycling depends on certain factors highlighted by Borthakur and Govind (2017) below and have been used in designing questionnaire for SQ1 of this study:

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

3.4.1. Data collection.

3.4.1.1.Population and sample

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 education backgrounds, located in 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 any bias, questionnaires were distributed using hard copies by the researcher to this category of typically low income and less educated people, 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 from 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% and there are several reasons for this. Firstly, in a developing country like Pakistan, there is little 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, the response rate to strangers can be poor, further impacted by possible concerns related to perceived privacy and security issues of disclosing the number and type of equipment (assets they own). Thirdly, since this is an environmental concern there is a reluctance to disclose and highlight the downsides. Lastly, there was a low response rate and many 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 considered to be adequate, because the thesis adopts an exploratory design to study a highly complex, under-researched area.

This study will set the groundwork for deeper and more extensive studies in the future. The sample size adequacy is supported by Sekaran (2003), who contends that sample sizes larger than 30 and less than 500 are appropriate for most research. Some previous studies have used a similar sample size of 200 in Pakistan and 148 in India to estimate the generation and disposal behaviour of e-waste (Dwivedy & Mittal 2013; Sajid et al. 2019). However, it is worth noting that the present result is an initial estimate, which needs to be refined by future studies. 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.

3.4.1.2.Data and variables

The European Union's 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 4. The type of EEE were extracted based on UNU Key in order to establish consistency with the international research studies on e-waste.

Table 4: UNU Key and Category of EEE

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 -functionals, faxes)	Small IT
0305	Telecommunications 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

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 behaviour, awareness about the toxic and precious elements and the willingness to pay for proper electronic waste recycling. Further details of variables are listed below (Amoyaw-Osei et al. 2011; Borthakur & Govind 2017; Schluep, Müller & Rochat 2012; Shah 2014):

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

3.4.1.3. Questionnaire design and structure

The questionnaire was designed through a systematic approach. First, research questions and corresponding research objectives were determined. Next, the factors which explained and could help achieve the objectives were determined. Factors are not always measurable so for each factor, variables were identified from the literature that could measure or help assess the factors, and ultimately answer the research questions. This macro (research questions) to micro level (variables) process was carried out for each research question, sub-question, research objective and factor as shown in the table in Appendix 1. In the end the questionnaire was developed using the variables identified in the process.

The questionnaire for upstream sector (consumers) started with an introduction and informed consent. The questionnaire was divided into 5 sections:

1. **Demographics:** The first section had some screening questions. For instance, if the respondent was not residing in Pakistan or below 18 years of age, the questionnaire would be terminated. Demographics questions followed the screening questions and were mainly about the age, gender and city.
2. **Access and usage**: The second section had six questions, aiming to ascertain the quantities of each equipment, frequency of buying new equipment, reasons of buying new equipment, where equipment were bought from, the preferred condition of equipment and the first course of action if the equipment stopped functioning.
3. **Disposal**: The third section had five questions about disposal methods used, follow-up question about reasons for storage (if stored), reasons for disposal after storage (if disposed of), disposal method after storage (actual or planned) and if sold, to whom it was sold.
4. **Hazards and opportunity**: The fourth section contained four questions about awareness of hazardous and valuable material. Two questions were answered on a 5-point Likert scale (No idea to very familiar). One question was nominal (agree/disagree) and the fourth was open-ended.
5. **Responsible disposal:** The last section assessed the opinion of respondents about who should take the responsibility for responsible disposal and if they were willing to pay any amount for proper recycling, and what percentage of the product price should it be.

3.4.1.4. Expert advice and feedback

The questionnaire was designed and reviewed several times with the help of an industry expert, Dr Peter Kinrade (please see the subsection on Expert Advisory Group), who has worked on e-waste projects and research for the state governments of Victoria and Queensland. In order to ensure statistical credibility, Dr Christine Millward was consulted several times and the questionnaire was revised and finalised based on her advice.

3.4.1.5. Pilot study

Once the design was completed the questionnaire was piloted on a small sample in Melbourne, Victoria, Australia. Following suitable amendments, the online version of this questionnaire was distributed to Pakistani consumers of electrical and electronic equipment but excluding the corporate sector.

3.4.1.6. Trustworthiness of qualitative data

The data was exploratory in nature (quantification) and the questionnaire was designed with the help of an industry expert and a statistician. Moreover, there were no questions that required factor analysis (and therefore tests of adequacy). However, there were two scaled questions to assess the level of awareness. These questions were firstly derived from the literature, but also tested for validity using Cronbach's alpha, which was 0.7 and is considered to be internally consistent.

3.4.2. Data analysis

The collective data is quantitative and non-normal in nature despite the efforts to include participants from all socio-economic backgrounds. The data has been summarised using descriptive statistics. Extrapolation for the quantities has been done 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 employed 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 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.

3.5. Sub-question 2 – What are the impacts of e-waste recycling practices in Pakistan?

Sub-question 2 (SQ2) relates to the social and economic impact assessment of e-waste recycling in Pakistan, and includes Research Objectives 3 (RO3), 4 (RO4) and 5 (RO5):

> ***RO3:*** *Estimate the costs and benefits of e-waste recycling for businesses.*
>
> ***RO4:*** *Assess the drivers, social implications and economic cost-benefit of working in the e-waste recycling sector (workers).*
>
> ***RO5:*** *Identify an e-waste impact assessment framework for developing countries.*

3.5.1. Pre-data collection phase

The data collection process took several phases to complete. The first visit to Pakistan was made in May 2018 for the purpose of establishing contacts. The first step was to contact a university lecturer in Pakistan to be the advisor for the data collection phase for ethical reasons. The researcher contacted Dr. M. Shahid Qureshi, Assistant Professor at the Institute of Business Administration, in Karachi, who agreed to be the advisor and was willing to provide any support and guidance required by the researcher, and respond to participants' queries.

The next goals of the visit were to establish contacts with business owners/workers, to observe the willingness and openness of potential participants, and to get their approval (consent) to collect data from them. Since there are multiple players in the industry and the value chain, several visits to markets and workplaces were required to understand the roles of these people and their place in the structure. The researcher visited local electronics markets (located in what is called Techno City, in Saddar (CBD), Karachi), where some importers (mostly from Dubai), wholesalers, retailers and repairers/refurbishers were established. Most of the equipment in these markets was for resale/reuse and either brand new or second-hand (not for scrap). The repairers mainly bargained with local consumers and were not involved in the repair of imported equipment. Other than local mobile markets, the researcher visited the SITE area of Shershah, which houses large 'go-downs' or warehouses/storage facilities with scraps of all kind.

According to the researcher's observations, most of the participants approached were helpful, but they did not have enough time to go through the documents and provide detailed responses.

Moreover, they were somewhat hesitant and some were completely unwilling to sign the forms such as an agreement to participate or the consent form, despite agreeing to participate in the research. This is because of privacy and security issues, where signatures can sometimes be copied or forged for different (including illegal) purposes, which can get them into trouble. Another observation regarding e-waste dismantling and recycling businesses was the unwillingness to provide financial information because they usually operate without registration and pay no taxes. Children were also found working in these facilities, but they did not appear to be forced to do so. During the visits, it was also noted that most of the recycling (extraction of metals that include burning) was done inside the houses and in the backyards, so locating the specific houses was challenging and not feasible.

It was at this stage some other possible challenges related to data collection were revealed. First, according to Umair, Anderberg and Potting (2016), e-waste was recycled at one of the warehouses which is known in Karachi as a ‘quality go-down’. Also, locals suggested the same go-down but during field visits, the researcher could not find any e-waste recycling activities at that place. Instead, there was used equipment (looked like scrap) for resale and this made the researcher realise the difficulty of finding e-waste recycling sites. Second, during recycling, equipment were dismantled into parts, so there was a shift from the level of goods to the level of substance. What made it complicated was that all parts were sold to different buyers and could go into different industries, so it might not be classified as e-waste. For instance, white plastics might be sold to the local syringe manufacturing companies, while magnets from hard drives went to door lock manufacturing companies. These dismantled parts might also be treated using different methods, making it nearly impossible to track e-waste down the complete value chain.

3.5.2. Data collection

Primary data was collected by visiting multiple e-waste recycling sites during September and October 2018 in Karachi, while other major cities where e-waste is recycled include Lahore and Rawalpindi. Karachi is the largest city of Pakistan and is the economic hub, which receives most of the EEE through port or air cargo (Widmer et al. 2005), therefore, it can reasonably represent the whole of Pakistan. Sites were located by first approaching local residents in the target areas to enquire about recycling facilities nearby, and subsequently business owners if they knew of other facilities. Recycling sites visited were located in parts of Saddar (CBD) including Sarafa bazaar, and multiple go-downs (warehouses) in Shershah (SITE area), for instance Quality go-down, Faisal go-down, Colonel go-down, Super General go-down and also some residential slum streets, while there is also considerable evidence that hidden and 'below the ground' recycling facilities are commonplace. During field visits, interviews were conducted with two stakeholders – business owners and recycling workers - and were based on several visits to build confidence in the collector, while the research objective of the study helped to defray concerns particularly by participating business owners. Specific recycling activities ranged from collecting e-waste to dismantling, extracting metals and refining.

3.5.2.1. Population and sample

Convenience sampling method had been adopted during field visits to recruit the participants, and the selection and source varied for groups.

3.5.2.1.1. E-waste recycling businesses (RO3)

Informal or backyard recycling in Pakistan is done by businesses of varying sizes, sometimes family-run and mostly unregistered, except for some that import e-waste directly, so they have to maintain relationships with foreign companies and make payments via banks. Smaller businesses are also typically located in local markets as clusters in the suburbs, and difficult to contact or recruit remotely via email or phone. So, in the informal sector, recruitment of participants was done by visiting them as some other studies have done (Umair, Anderberg & Potting 2016; Umair, Björklund & Petersen 2015). Recruitment and semi-structured interviews were conducted using convenience sampling, based on the willingness of respondents. Observations were also used for some data that could not be explicitly gathered. Expected sample size for this group was 30 while the actual sample size was 15 (all male participants). Responses were mainly recorded on hard copies of the questionnaire but also audio- and video-recorded for some who permitted this.

Some challenges were faced during data collection due to secrecy and the hidden nature of some businesses. This was because some businesses were unregistered, so their owners were unwilling to participate due to the fear of being exposed; in some instances, business owners themselves would send the interviewers away telling them the owner was not available. A related challenge was accessing costs with businesses unwilling to share their financial information. Consequently, the cost-benefit analysis was conducted using estimated costs drawn from data collected from a few businesses who were willing to share their stories. Moreover, since the data could not be obtained for all the equipment and components, analysis for selected equipment (desktop PCs and CRT monitors) and respective components was conducted for assessing financial viability of recycling e-waste for businesses. Another challenge faced was determining how far down the value chain and how deep into equipment, component and sub-components should this analysis go, given that after the sub-component level, some components are reused in other industries while some materials (metals and rare earths) are difficult to classify and trace as e-waste.

3.5.2.1.2. E-waste recycling workers (RO4)

Data was collected by field visits to recycling businesses in order to interview workers such as e-waste collectors, dismantlers/scrappers and metal extractors. Workers invited to participate were hesitant initially but trust was built gradually through repeat visits and a reassurance of anonymity. The participant sample size was 19 – all males. Efforts were made to interview as many workers as possible from all the recycling sites visited, the two criteria of selection being at least 18 years of age and had their employers' permission. Responses were mostly transcribed in hard copy format as workers were generally illiterate, but where some allowed, audio recordings were taken. There was an element of 'group-think' noted among participants, in that they tended to provide similar responses and wanted to respond as a group, so some interviews could rather be classified as focus groups. However, in instances when the worker being interviewed was relatively new, there was more independence in the answers as opposed to what could be described as projected loyalty towards colleagues and the business owner to whom they genuinely felt they owed their livelihood.

3.5.2.2. Data and variables

Two interview questionnaires were developed, one for recycling businesses and another for workers. Questionnaires included both quantitative and qualitative variables to capture economic costs and benefits. 'Economic' costs/benefits have been defined as the sum of financial and non-financial (social) costs/benefits. The guidelines for Social Life Cycle Assessment (S-LCA) proposed by UNEP/SETAC (2009) were followed, with modifications based on the academic literature to suit the context of developing countries like Pakistan. These financial and non-financial (social) variables were consolidated in terms of direct and indirect costs/benefits to develop a consolidated impact factors framework (see Figure 21). Costs and benefits in Figure 21 are for multiple stakeholders identified earlier in Figure 20; for instance, direct financial costs and benefits are for recycling businesses, indirect financial costs and benefits are mostly related to the society, direct non-financial costs and benefits correspond to downstream recycling workers, while indirect non-financial costs and benefits are relevant for workers and the general community. Qualitative questions sought to explore the social dynamics of working in the e-waste industry in Pakistan for the two stakeholder groups. The variables highlighted in red are shown for conceptual completeness, but they are not part of the scope of this study or not deemed practical for inclusion.

3.5.2.3. Questionnaire design and structure

A systematic approach described earlier in section 3.5.1.3 and illustrated in APPENDIX 1 was followed to develop the two questionnaires for recycling businesses and the actual workers.

3.5.2.3.1. E-waste recycling businesses (RO3)

Interview questionnaire for businesses comprised 30 quantitative and qualitative questions. Quantitative questions aimed to collect data related to costs and revenues for cost-benefit analysis, while qualitative and open-ended questions were devised to understand the e-waste processes, challenges, risks, working conditions and safety measures. The questionnaire was divided into the following sections:

1. **Information to participants and informed consent**: Information was provided about the research, including objectives, and informed consent was obtained, which was verbal in most cases as participants did not want to sign any documents. Questions to obtain the permission to record and permission to speak to workers (for RO4) were also asked.
2. **Business characteristics**: This section included questions like the type of business (collecting, importing, dismantling, refining), the number of workers and type of facility.
3. **Access to e-waste:** This section included quantitative and qualitative questions to assess the sources (domestic, imports), quantities (kg, tons), frequency (weekly, monthly), cost of buying, type of e-waste and reasons for collecting specific types of waste.

4. **Recycling:** This sections comprises questions related to the processes of recycling, the types of material present in e-waste, the type of material recovered, what happens to the recovered material, how unrecovered material is disposed of, and all the processing costs and revenues from selling the recovered material.
5. **Challenges, risks and safety measures**: The last section focused on questions related to any problems faced by businesses and risks associated with operations. Some questions about workers and occupational health and safety could not be asked of workers for ethical reasons, so these questions were presented to the business owners instead.

3.5.2.3.2. E-waste recycling workers (RO4)

The questionnaire for workers consisted of 40 questions, both qualitative and quantitative. Interview questions put to the recycling workers mainly focused on direct social cost-benefit, direct economic benefits and indirect economic costs. The questionnaire was organised as follows:

1. **Information to participants and informed consent:** Information about the research was provided and consent was sought before conducting the interview.
2. **Demographics:** Demographic questions were related to the age, gender, qualifications, experience of workers and reasons for working in e-waste recycling. Questions about the number of hours per day and number of days a week were also included for analysis.
3. **Social costs and benefits:** Questions in this section were concerned with the reduction in lifetime earnings, indirect social costs like loss of education opportunities, opportunity cost of working in e-waste, value of life, and indirect social benefits such as satisfaction or happiness generally and with respect to work.

3.5.2.4. Pilot study

During the pre-data collection phase, preliminary questionnaires were piloted by conducting interviews with a few local participants. Based on this pilot, questions were revised and refined based on observations from participants and learnings in administering the survey. For instance, when workers were found to be uncomfortable answering questions linked to working conditions, these questions were directed towards business owners instead.

3.5.3. Data analysis

Collected data for RO3 and RO4 was qualitative and quantitative. More importantly, it was ambiguous and complex in nature, warranting the need for multiple methods relevant to research objectives to analyse, interpret or 'make sense' of the data. More broadly, as a part of life cycle assessment (LCA – discussed earlier in Chapter 1 Introduction), social impact assessment (SIA) has been conducted through social life cycle assessment (S-LCA). SIA has been defined as *'the process of identifying the future consequences of a current or proposed action which are related to individuals, organizations and social macro-systems*' (Becker 2001). Developed as an addition to environmental impact assessment (EIA), this methodology helps evaluate components of social sustainability, consisting of health, housing, empowerment, security, human rights and equity among many others, using qualitative and quantitative factors (Brent, A & Labuschagne 2006; Popovic & Kraslawski 2015).

This subsection first discusses the utility of S-LCA in this study, followed by specific approaches for quantitative and qualitative analysis. Quantitative analysis for RO3 and RO4 has been conducted through material flow analysis (MFA) and cost-benefit analysis (CBA). Thematic analysis and systems thinking have been used to analyse qualitative data.

3.5.3.1. Social life cycle assessment (S-LCA)

S-LCA is part of SIA methodology with a focus on life cycle activities and their social consequences, both positive and negative on people throughout life cycle (Liu, S & Qian 2019; Popovic & Kraslawski 2015). The emphasis of S-LCA methodology is on stakeholders, whereby the goal is to support decision-making after assessing the changes in lives of workers, consumers, society and relevant stakeholders of community through any product's life cycle (Cadena et al. 2019; Huertas-Valdivia et al. 2020). S-LCA complements the overarching ecosystem framework used in this study, and because of its focus on the impacts on stakeholders, S-LCA methodology is deemed suitable for this study.

In e-waste management, though LCA has been used to quantitatively investigate the *environmental* impacts of e-waste treatment (Ghodrat et al. 2017; Iannicelli-Zubiani et al. 2017; Song et al. 2013), S-LCA has been used to study the positive and negative *social* impacts. For instance, Pini et al. (2019) employed S-LCA to compare the environmental performance, cost externality and job creation of the life cycle of new and reconditioned EEE in Italian context. More importantly, Umair, Björklund and Petersen (2015) followed UNEP guidelines on S-LCA to assess the social impacts of informal e-waste recycling in Pakistan and found negative impact in terms of working hours, child labour, health and safety (work and living environment), social security, freedom of association, community engagement, public contribution to sustainable issues, social responsibility and fair competition, while positive impact in terms of local employment and contribution to economic development.

Technical steps in conducting S-LCA are the same four (4) steps in LCA (see Figure 2 in Chapter 1), starting from a definition of goal and scope to life cycle inventory analysis, lifecycle impact assessment, and finally life cycle interpretation (UNEP/SETAC 2009, 2020). The first step of goal definition corresponds to the research objectives of this study (see subsection 1.5.2). The second stage of life cycle inventory analysis involves the collection of data for relevant variables from relevant stakeholders, described in detail in subsections 3.4.1 and 3.5.2. The third stage involves categorisation of collected data, examining the data quality and using established methods to analyse data. According to the literature, data could be analysed using a number of methods, such as: firstly, performance reference point method which utilises the scoring method for impact subcategories; secondly, impact pathway method which is based on causal relationships and uses impact pathways as characterisation models consisting of midpoints and endpoints; thirdly, checklist method which employs a tick sign against any impact that is present; fourthly, scoring methods that employ scores; and fifthly, the database method which encapsulates collecting data from databases (UNEP/SETAC 2020; Wu, Y & Su 2020).

Since the aforementioned methods are mostly qualitative and do not facilitate a thorough analysis of costs and impacts, efforts were made to explore other suitable methods discussed in the following subsection. This study builds on the findings of other research that has used S-LCA, such as Umair, Björklund and Petersen (2015), which were based on qualitative data and goes a step further by aiming to quantify the downstream impacts (costs and benefits) of informal recycling in Pakistan through cost-benefit analysis (CBA), for stakeholders associated with e-waste recycling industry. This includes businesses but more importantly workers who are at the forefront of e-waste recycling activity and are affected directly and indirectly.

3.5.3.2. Quantitative analysis

Quantitative analysis for sub-question 2 focused on assessing the flow and quantities of material through the downstream e-waste value chain, and evaluating the economic impact through financial and non-financial (social) costs and benefits. Material flow analysis (MFA) was conducted as a part of RO3, prior to CBA, using STAN (short for subSTance flow ANalysis) software. This software was developed in accordance with Austrian standard ÖNorm S 2096 and has waste management application. Cost-benefit analysis (CBA) was conducted using MS Excel.

3.5.3.2.1. Material flow analysis (MFA)

MFA is a tool to analyse and quantify the flows, stocks, input, transformation, output and losses of a resource (Allesch & Brunner 2015; Graedel & Lifset 2016). The objectives of MFA include: 'assess the relevant flows and stocks in quantitative terms, thereby applying the balance principle and revealing sensitivities and uncertainties'; and 'present results about flows and stocks of a system in a reproducible, understandable and transparent way' to use as a basis for managing resources, the environment and wastes at the policy level (Brunner & Rechberger 2004). MFA in the context of this study is used to assess the flow and stock of EEE through the downstream sector. Flows in MFA are defined in mass per unit of time (e.g. tons/year), and follow the principle of mass balance where the sum of inputs should be equal to the sum of output and changes in stock (Kahhat & Williams 2012; Streicher-Porte et al. 2005). The investigations using MFA can be on the levels/flow of goods (economic entities like computers, etc.), and of substances such as materials composed of units like chemicals (Allesch & Brunner 2015).

Being one of the most widely accepted and utilised tools in the industrial-ecology discipline, the application of MFA has been in the areas of e-waste – generation estimates (Guo, X & Yan 2017; Villalba 2020), material flows and stock estimation (Wang, M et al. 2018), economic impact (Cordova-Pizarro et al. 2019). MFA can also be combined with the input-output (I/O) model to evaluate the physical as well as economic dimension in monetary terms of the industrial systems, which is referred to as economically extended MFA (EE-MFA) (Kytzia, Faist & Baccini 2004; Streicher-Porte et al. 2005). Input-output framework developed by Leontief (1936) measures the flow of commodities in monetary terms for three sectors: (i) primary input, (ii) processing, and (iii) final demand, and also estimates the indirect and induced impacts (Kytzia, Faist & Baccini 2004; Lee, C-K & Taylor 2005). Analysis in this study using STAN software utilises similar methods combining a MFA, I/O model through the law of mass conservation and visual representation made through a Sankey diagram.

3.5.3.2.2. Cost-benefit analysis (CBA)

To assess the economic impacts of e-waste recycling practices (RO3 and RO4), several methodologies were investigated for relevance before opting for CBA. Prior researchers have used the area of reverse logistics, which refers to the backward flow of used products from collection, inspection, recycling, refurbishing to remanufacturing or proper disposal (de Brito 2002). For instance, Alumur et al. (2012) and Alshamsi and Diabat (2015) proposed a profit maximising framework for reverse logistics network design configuration problems such as determining the ideal number of sites, location decisions and capacity. Kuo (2013) used petri net analysis in reverse logistics to evaluate the economic values and environmental impacts based on specific disassembly method. However, the focus of this research is not on the technical or logistics aspects such as collection sites, capacities of collection, inspection and recycling centres, and disassembly methods. For this reason reverse logistics network was not applied.

Some researchers have taken the basic financial approach such as discounted cash flow method, net present value, discounted payback and sensitivity analysis to assess profitability (Cucchiella, D′Adamo & Rosa 2015; Cucchiella et al. 2015). Using the concept of cost-effectiveness, incremental cost-effectiveness ratio (ICER) has been developed, which compares costs with the benefits of an intervention, and has been successfully used in healthcare (Vos et al. 2010). Since ICER is calculated using incremental costs of any intervention, it was not found to be relevant for the proposed research objectives.

Cost-benefit analysis (CBA) has also been used to assess the anticipated costs and benefits resulting from public or private sector projects, programs and policies (Drèze & Stern 1987; Mihaela et al. 2015; Volchko et al. 2017). It is a well-known tool for examining the economic viability in a variety of contexts (Brent, RJ 2009; Campbell & Brown 2015), such as a deposit–refund program for beverage containers in Israel (Lavee 2010), decision-making in environmental studies (Fuster, Schuhmacher & Domingo 2004), estimating economic burden of disease (Birol, Koundouri & Kountouris 2010; Chushi et al. 2007), assessing the cost-effectiveness of recycling agricultural waste in Taiwan (Hsu 2021), evaluating the economic feasibility of photovoltaic modules in a recycling project in China (Liu, C, Zhang & Wang 2020), and in e-waste recycling, such as cost-benefit (social, economic) of e-waste processing (Achillas et al. 2013; Anthony, Jeff & Bruno 2020; Diaz & Lister 2018; Ghodrat et al. 2016; Zadmehr et al. 2018), environmental costs and benefits of disposal options (Macauley, Palmer & Shih 2003; Palmer et al. 2001), and cost-benefit of PC reuse scheme (González, Rodríguez & Pena-Boquete 2017). Therefore the economic impacts in this study, namely financial and non-financial (social) variables have been quantified using cost-benefit analysis (CBA).

3.5.3.3. Qualitative analysis

Qualitative data was transcribed, coded and classified in themes for analysis using NVivo software. NVivo works with different types of qualitative research designs/data analysis methods, and helps in categorisation by coding and finding the related ideas and patterns emerging from data (Elaine 2002; Leech & Onwuegbuzie 2011; Zamawe 2015).

Qualitative findings related to social, economic and environmental aspects were synthesised using the terminology associated with the respective four quadrants – “known”, “unknown”, “hidden” and the “blind spot” – in the Johari Window model, a well-known instrument for self-assessment (Cassidy 2014; Vorce & Fragasso 2016), building awareness (Mahoney 2019; South 2007), facilitating individual self-disclosure (Nofriza 2017), and understanding different perspectives (Beck 1994; Berland 2017). This model is similarly useful in terms of assessing the hard-to-quantify social aspects related to work, such as feelings, attitudes, knowledge and motives of the e-waste recycling workers and to identify areas for improvement. In the context of this study, there was no intention to look at the awareness for one group with respect to the other. Rather, the focus was on awareness and social dynamics of each group of stakeholders separately. So, qualitative findings were consolidated based on systems thinking using Vensim software, a simulation software by Ventana Systems, in order to examine how parts of a system interrelate and how systems work over time and within a larger system.

3.5.3.3.1. Systems theory / thinking

General systems theory was initially introduced by Von Bertalanffy (1956) while exploring a new approach to the study of living things in the field of biology. Systems thinking, as a concept within general systems theory, was introduced by Senge (1990) into management literature. It is a powerful tool that can help devise coherent and sense-making models of the world. These models provide the most effective ways to improve our intelligence and construct our existence (Mella 2012a). However, more than techniques to devise models, systems thinking is described as representing a mental attitude, an approach, a logic, a language (Anderson & Johnson 1997) that facilitates going beyond merely ‘looking at’ to ‘seeing beyond, and more’ (Mella 2012a). According to Senge and Lannon-Kim (1991), “*Systems thinking [is] a way of thinking about, and a language for describing and understanding, the forces and interrelationships that shape the behaviour of Systems. This discipline helps us see how to change systems more effectively, and to act more in tune with the larger processes of the natural and economic world*”. It also offers a way of thinking based on considering the ‘whole’, and recognising patterns and relationships among parts, and deals with hidden complexity and ambiguity by providing tools and techniques to unravel this complexity and to create lasting interventions for chronic problems (Maani & Cavana 2007).

The logic and structure of systems thinking is based on five rules (Maani & Cavana 2007; Mella 2012b, 2015). First, to understand the world, we must be able to see the whole and parts, and develop the capacity to zoom from whole (system) to the parts (components) and vice versa. Second, we must not only observe what appears to be constant, but search for what varies over time. In addition to identifying what varies, we must be able to measure the ‘variation’ over time. Third, to really understand the variation, we must make an effort ‘to understand the cause of variations in variables we observe’, and develop causal relationships. Fourth, causal relationships are not enough; for deeper understanding, we must ‘link together the causal relationships to specify loops among all variations. This means we must move from causal chains to systemic *interconnections*, and from linear variations to systemic *interactions* among the variables. Fifth, we must always specify the boundaries of system we investigate.

Systems thinking facilitates what is described as an open-box approach that highlights the inner working of systems, by explaining how and why outcomes take the form that they do (Ssengooba, McPake & Palmer 2012). This open approach is contrasted to a black-box approach where internal structures and functioning of processes may be unknown (Mella 2015). Systems thinking and dynamic modelling has been used in several contexts to unpack the hidden complexities in the system, and also to identify leverage points for policy development. For example, it has been utilised in the renewable energy sector to investigate the value of R&D investment (Sim 2018), adoption of renewable energy technology (Dhirasasna & Sahin 2021), and to study: the dynamics of political power when changing from a fossil fuel-based electricity system to renewable energy (Gottschamer & Zhang 2020); multiple aspects and impacts of solid waste management and water management (Phonphoton & Pharino 2019; Pluchinotta et al. 2021; Xiao et al. 2021; Zhu et al. 2020); and in the context of e-waste the computer recycling behaviour (Fan, C et al. 2018).

Due to the established utility of systems thinking in understanding complex problems, it has been used in this thesis to explore the social and hidden complexities, and other qualitative aspects of the e-waste recycling industry where multiple groups or stakeholders are important. To capture the social dynamics, causal loops are constructed for the identified variables, which are conceptual models of the problem, within the system boundaries of the e-waste recycling sector in Pakistan.

3.5.3.3.2. Understanding causal loop diagrams

The basic elements of causal loop diagrams consist of variables and arrows. A variable (qualitative or quantitative) is a condition, situation, decision or an action that can influence and be influenced by another variable (Maani & Cavana 2007). Arrows or links indicate the causal association between two variables, or a change in the state of variables. After establishing the links, there is a need to establish the nature (or direction) of relationship between two variables. Two possibilities are the movement of two variables either in the same direction or the opposite direction. For instance, an increase (decrease) in purchase of EEE increases (decrease) quantities of e-waste generated. Movement of two variables in the same direction is denoted by 'S' while movement in the opposite direction is done with 'O'.

Generally, there are two types of causal loops – these are Reinforcing (R) which are positive feedback, or Balancing (B) which are negative feedback loops, also called counteracting of self-regulating loops (Maani & Cavana 2007). Reinforcing loops represent a growing or declining action and can lead to a virtuous or vicious cycle. An example of a reinforcing loop is shown in Figure 26 (an output of Vensim software). A *decrease* in wages leads to an *increase* in poverty (opposite direction – O); an *increase* in poverty leads to an *increase* in illiteracy rate (same direction – S), and subsequently, an *increase* in illiteracy rate leads to a *decrease* in wages (opposite direction – O). This description of the reinforcing loop represents a vicious cycle.

Balancing loops seek stability, return to control or aim to achieve a specified target. An example of a balancing loop is illustrated in Figure 27. An *increase* in free education leads to a *decrease* in illiteracy (O), while a *decrease* in illiteracy leads to a *decrease* in poverty (S). A *decrease* in poverty will *decrease* the need for corrective action (free education). The same convention for understanding causal loop diagrams is utilised later in the thesis (sections 5.7.1, 6.4.1. and 7.3).

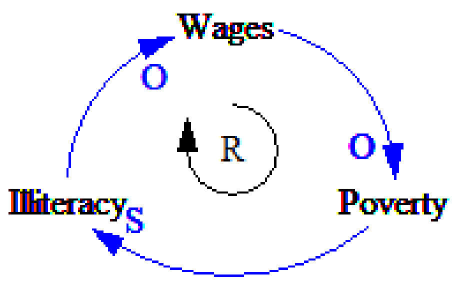


Figure 26: Reinforcing Loop - An Example

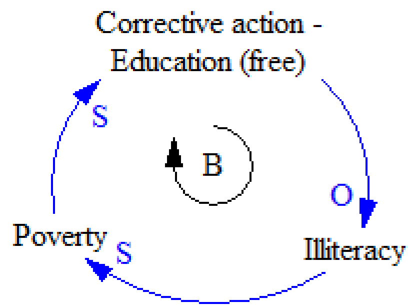


Figure 27: Balancing Loop - An Example

3.6. Research ethics

Ethical considerations for this study were based on the National Statement on Ethical Conduct in Human Research (2007), and an ethics approval was obtained from VU Research Ethics Committee prior to collecting data from participants. Ethics application was assigned number HRE18-053. Due to the risky nature of businesses, the environment in which they operated, and potential presence of mafia-type organisations, this study was classified as high risk. As a result, questionnaires were revised according to the advice provided by the ethics committee in an attempt to reduce any risk to vulnerable workers or to student researchers who collected data through field visits.

Several steps were taken to ensure ethical care in the data collection process. Before interviewing, informed consent was sought from all the participants, mostly verbal as they were unwilling to sign any document. Participation was completely voluntary and participants could opt out at any time. Audio, video recordings and photos were taken only of a few participants who agreed. Most of the unregistered businesses were concerned with government of tax authorities in case they were exposed. Therefore, all the participants (business owners and workers) were assured of anonymity and confidentiality. Recycling workers were not asked any questions about their work or employer that could potentially risk them their jobs, or pose any other threat. Since ethics clearance was not obtained for children, child workers were not interviewed, so all the participants were those who claimed to be aged 18 or above.

3.7. Expert advisory group (EAG)

The researcher formed and engaged with an Expert Advisory Group (EAG) that comprised experts both locally and internationally. These people have been involved throughout the course of this PhD and have proven to be invaluable. The EAG consists of academic and industry experts in the areas of electronic waste, environmental management, sustainability, finance, economics and public policy (details given below). The EAG members were consulted for devising the research objectives, methodology, indicators, conceptual framework, designing questionnaires and methods of analysis. They have also reviewed and provided expert comments on the work.

1. **Peter Allan**
   Speciality: Environmental consultant
   Designation and organisation: CEO, Sustainable Resource Use
   Country: Australia
2. **Peter Kinrade**
   Speciality: Environmental economics, policy, management, material flow, life-cycle analysis
   Designation and organisation: Associate Director, Marsden Jacob Associates
   Country: Australia
3. **Will LeMessurier**
   Speciality: E-waste recycling
   Designation and organisation: Director, MRI E-cycle Solutions
   Country: Australia
4. **Joe Pickin**
   Speciality: Economics of waste, material flow, data modelling
   Designation and organisation: Director Blue Environment Pty Ltd
   Country: Australia
5. **Hoang Anh Cat**
   Speciality: Sustainability, social impact assessment, environmental engineering

Designation and organisation: Global Relationship Manager CSIRO Global

Country: Australia

6. **Federico Magalini**

   Speciality: E-waste management, sustainable development

   Designation and organisation: Managing Director, Sofies Group

   Country: United Kingdom

3.8. Summary

This chapter detailed the methodological approach taken in this study. It first explained the overarching research philosophy or paradigm (pragmatism) that guided the research process and mixed methods approach devised to achieve the research objectives. Next, some justification of the selected paradigm and methods was provided, followed by a visual representation of the research process. Then, data collection and data analysis methods were discussed in detail for the two sub-questions separately. The chapter concluded with a brief discussion of ethical considerations and expert advisory group that facilitated this research. The next three chapters, consecutively, will present the findings and discussion from RO1 to RO4. We begin with Chapter 4 which presents and discusses the findings related to RO1 and RO2, the concerns here being the upstream generation of e-waste and consumer recycling behaviour, respectively.

CHAPTER 4: UPSTREAM GENERATION OF E-WASTE AND CONSUMER RECYCLING BEHAVIOUR[4]

4.1. Introduction

The previous chapter discussed the research methods used in this study to collect and analyse data. This chapter presents findings and discussion of sub-question (SQ) 1, comprising research objectives (RO) 1 and 2 (Figure 28). To recall, SQ1 explores '*the current situation of e-waste generation and disposal in Pakistan*' at the upstream level. More precisely, RO1 analyses '*consumer behaviour concerning the acquisition, usage, disposal, awareness and willingness to pay for e-waste management*', and RO2 assesses '*the flow (and stock) of electrical and electronic equipment/e-waste through the upstream sector*'. This sub-question is answered using survey data collected from consumers of EEE in Pakistan, and analysed using quantitative methods, including extrapolation and statistical analyses using Microsoft Excel and SPSS software.

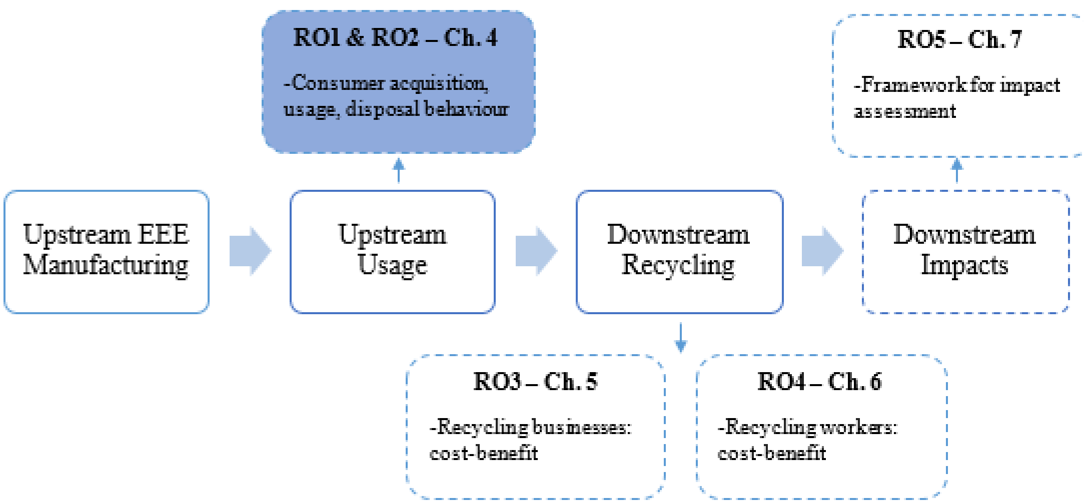


Figure 28: Placing ROs 1 & 2 in the e-waste value chain

This chapter first provides the demographic profile of the survey participants, followed by estimation of equipment quantities for the sample, but also for the population through

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extrapolation. Then, behaviour and practices with regard to buying EEE (acquisition of EEE) are explored based on gender, age groups, income groups and city of residence. Next, usage behaviour is assessed as this helps determine the lifecycle of equipment. This is followed by exploring the possible disposal options and reasons for choosing those options. Consumers' awareness of toxic, hazardous and precious materials used in EEE is explored, as well as willingness to pay for e-waste recycling. These help achieve RO1. This chapter, then presents a discussion of findings and an assessment of the flow (and stock) of EEE/ e-waste through the upstream sector (RO2). Finally, this chapter proposes some policy implications and ends with concluding remarks.

4.2. Demographics

Primary 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 25-34 age group. The respondents were male (76%) and female (24%), respectively. Participants from different socio-economic backgrounds were included based on the education level and income level. The majority of participants had completed an undergraduate or postgraduate degree. Monthly household income for 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 combined into 3 groups based on the population percentage of Pakistan. The first group (less than Rs.24,000) represents 40% of Pakistan's population, the second group (Rs.25,000 to Rs.50,000) represents another 40% of total population, while the third group (more than Rs.50,000) corresponds to 20% of the total population of Pakistan. Table 5 presents demographic information of the participants in detail.

Table 5: 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 Rs.)		
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%

4.3. Equipment quantities

The total quantities of each type of equipment (in use and not in use) were calculated to be 2,810 for the sample as detailed in Table 6. The total family members in the sample include 867 adults (above 18 years) and 332 children (below 18 years), therefore, on average, each adult owns 4 equipment in the sample. Including children, there are 3 equipment per person in Pakistan. Considering the household, there are 17 equipment per household.

Mobile phones (including smart phones and pagers) were found to be the dominant type of equipment in numbers, which amounted to 27% of the total number of equipment. Interestingly, some 15% of the total number of equipment was not in use by the consumers. Since the high-income category was over-represented in the sample, the quantities might be overstated and attitudes might be biased. Therefore, subsequent analysis seeks to distinguish responses based on the income level, rather than considering 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% 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. In contrast, the highest income category (earning above Rs.50,000) was 61.7% of the sample and these people owned around 84.7% of the total equipment.

Table 6: The number of equipment (sample)

The number of equipment for each income group (Sample)				
Type of Equipment	**Income Groups**			**Total**
	Less than Rs.25,000	**Rs.25,001 to Rs.50,000**	**Above Rs.50,000**	
Televisions (Cathode Ray Tube)	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**

4.3.1. 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 7). First, population size was estimated to be 184 million, based on the number of mobile phone subscribers and this amounted to 160 million, adjusted for total equipment not in use (15% of 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 8.

Table 7: The number of equipment in million (extrapolated for the population)

The number of equipment (in million) for each income group (for the population)				
	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)	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 8: 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
Percentage of Pakistani 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 percentage of population	40%		40%		20%

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, the corresponding percentage of the population was calculated for each income category. According to the calculations, 40% of Pakistanis earn less than Rs.25,000 per month, while 40% earns between Rs.25,001 to Rs.50,000 per month and only 20% earn more than Rs.50,000 per month. The population size was adjusted and divided according to population percentage 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 9 for calculations). The extrapolated total number of equipment (e-waste) was also calculated by type of equipment (Table 7). Finally, the number of equipment was converted to weights based on the typical weights of each piece of equipment. The typical weight was estimated (see Table 11) from the data on the websites of respective manufacturers and retailers (Dell, HP, Lenovo, Apple, LG, Amazon).

Results of this extrapolation suggest there are presently 281 million equipment (see Table 10) (1,790 kilo-tons - Table 11) in Pakistan, of which 15% (42.15 million equipment or 268 kilo-tons) 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 10.2% based on the growth rates exhibited by the estimates of Baldé et al. (2017); Forti et al. (2020) for Pakistan as opposed to the global growth rate of 3.2%.

Table 9: 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
Percentage of Pakistani 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 10: 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**			**Total**
	Less than Rs.25,000	**Rs.25,001 to Rs.50,000**	**Above Rs.50,000**	
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 11: 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 (tons)**
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

4.4. Acquisition of EEE

This sub-section analyses the motivation and attitudes reported towards technology uptake and acquisition, which determines the rate at which electronic waste is generated.

4.4.1. Why buy new equipment?

According to the results (Table 12), most commonly, people in Pakistan purchase new equipment if and when their current device gets damaged or is 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 Pakistani consumers usually tend to buy new equipment as per their needs and not as a luxury item in order to obtain a new model, whenever this newer item was introduced onto the market.

Table 12: 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

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

4.4.1.1. Gender and the reasons for purchase decisions

Comparing the importance of each reason for both genders, it is found that males and females find the reasons of "lost/stolen" and "upgrade due to outdated function" equally important. However, for the reason regarding "damage", a moderately significant relationship/difference is found between the two genders at the 0.1 level. Mostly, males do not believe damage to be an important reason to purchase (83.1%) compared to females (16.9%). For the reason of "upgrade due to outdated style", a strong significant relationship/difference is detected between the two genders (Table 13). The relationship is significant at the 0.05 level. Males tend to be more 'tech savvy' and are more likely than females to change their electronic devices because of new model and associated features. Around 84% of male respondents ranked the upgrade due to outdated function as an important reason to buy a new equipment, as opposed to 15.6% of females.

Table 13: 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%
	Female	10	15.60%	31	29.00%	41	24%
	Total	64	100.00%	107	100.00%	171	100%
		Pearson Chi-square 3.914** (0.048)					

** Significant at the 0.05 level
* Significant at the 0.1 level
Pearson Chi-square statistics are marked with asterisks and significance (or p-value) is presented in parentheses.

4.4.1.2. 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 the updated version (model) is perceived to be important to them. 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%) in comparison to the low-income groups (15.4%) who tended to regard it as unimportant (Table 14).

Table 14: The reasons for purchase based on income levels

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 the 0.05 level
* Significant at the 0.1 level
Pearson Chi-square statistics are marked with asterisks and significance (or p-value) is presented in parentheses.

4.4.1.3. Age groups and the reasons for purchase decisions

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

4.4.1.4. City of residence and the reasons for purchase decisions

Comparisons of the reasons across the city of residence and income groups did not reveal any significant difference (Table 15). It can be concluded that the reasons for purchase do not depend on the city of residence and are similar.

Table 15: 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 the 0.05 level
* Significant at the 0.1 level
Pearson Chi-square statistics are marked with asterisks and significance (or p-value) is presented in parentheses.

4.4.2. Preferred condition of equipment at the time of buying

In order to determine the preference for buying used equipment, consumers were asked about the condition of products they preferred when buying a new equipment. A substantial majority (73%) preferred to buy brand new equipment, as opposed to second-hand or used equipment (Table 16). These results might depend on demographic factors such as income level, age groups, gender and the city of residence.

Table 16: 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 (excl. 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%**

4.4.2.1. Income level and age groups with preferred condition

The preference for new equipment is seen to significantly depend on the income level for almost all equipment types. High-income groups bought more new equipment, while low-income groups preferred used equipment. However, a Chi-square analysis for income levels cannot be reported since the expected count in some cells was less than 5. Similarly, the preference significantly depended on age groups, wherein young participants (18-34) preferred new equipment, while older participants relied on used equipment. Chi-square results cannot be reported due to insufficient cell count.

4.4.2.2. Gender and preferred condition

Comparing the preference of equipment condition according to gender, there is no significant relationship noted for all of the equipment (except telephones, cordless and answering machines), implying that the majority of people prefer to buy new equipment, irrespective of gender (Table 17). Although both males and females tend to prefer buying new telephones, cordless and answering machines, a moderately significant difference (at the 0.1 level) existed between the two genders, where more males have no preference as compared to females.

Table 17: 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.
** Significant at the 0.05 level
* Significant at the 0.1 level

4.4.2.3. City of residence and preferred condition

A significant difference was found in the preferred condition of Cathode Ray Tube monitors across different cities (Table 18). A large number of respondents in Karachi had no preference about the condition, presumably because it is an obsolete technology and not purchased frequently. In addition, in many cities, new CRT TVs are preferred in Karachi, while already used versions are preferred in Hyderabad.

Table 18: 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 the 0.05 level
* Significant at the 0.1 level

4.4.3. Where do consumers buy equipment?

Most respondents buy their equipment from local electronics markets, where both new and second-hand equipment are easily available – see Table 19. The second most common source is the company, where consumers buy it directly. There is less tendency to buy equipment online possibly because there is little trust in online vendors and the quality delivered.

Table 19: 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%

4.5. Usage stage

This subsection examines the useful life of equipment, and makes comparisons of useful life with demographic factors such as income, age, gender and city of residence.

4.5.1. Equipment useful life

The expected useful life of each type of equipment was determined by how frequently consumers change each product. Results are presented in Table 20 and the expected life of each equipment (read horizontally in the table) has been represented by the numbers in bold according to the highest number of responses. A large proportion of sample reports never buy CRT televisions and CRT monitors or they buy them after more than 10 years. The life of CRT televisions and monitors was long when compared to flat panel televisions and monitors, which is up to 10 years. In contrast, small types of equipment like mobile phones and computer mouse are used for 2 years, while routers, modems, keyboards can be functional for up to 5 years. For impact of demographic factors on useful life, comparisons were made across the levels of income, age, gender and city of residence.

Table 20: 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 (excl. 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%

4.5.1.1. Income and the expected useful life (frequency of purchase)

All income groups are likely to buy all types of equipment with similar frequency except for CRT televisions (Table 21). There is a negative relationship between the frequency of buying CRT TVs and income level. The relationship is significant at the 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 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.

4.5.1.2. Age and the expected useful life

All age groups are likely to buy all types of equipment at a similar frequency except CRT televisions (TVs), laptops, notebooks and tablets (Table 21). Younger respondents (aged 18-34) either never buy CRT TVs, or buy if after 10 years. Older respondents, on the other hand, tend to buy CRT TVs mostly after 10 years of useful life. This association is significant at the 0.1 level. A positive relationship is noted between the age group and useful life of the laptops. The relationship is significant at the 0.05 level. The majority of respondents from the ages of 18-34 years tend to change their laptops within 2-5 years. Conversely, people in the 45-55 age group use their laptops for longer periods and change within 5-10 years.

Table 21: 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 the 0.05 level
* Significant at the 0.1 level

4.5.1.3. Gender and the 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. Females tend to use these types of equipment for longer compared to males. However, the analysis results cannot be reported because the expected count was less than 5. Similarly, the results for comparisons of cities had insufficient data and no significant differences were found.

4.6. Disposal of used EEE or e-waste

After (or even before) the completion of useful life, if equipment stops working for any reason, the first instinct for most people is to try to get it repaired (Table 22). This suggests that Pakistan is arguably not a throwaway society. However, if it cannot be repaired or getting it repaired is inconvenient or too costly, consumers tend to discard old equipment and buy a new one. Continuing to use it even if it is damaged is the least popular action, and continues only in situations where it is possibly difficult to afford a new equipment.

Table 22: 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%

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% equipment were reported as lost or stolen. Table 23 below shows the detailed breakdown and Figure 29 shows the percentages for each disposal method. Extrapolating for the population, out of the total 281 million equipment (1,790 kilo-tons), 42% or 118 million equipment (751.8 kilo-tons) are likely to be stored, while 7% or 19.67 million equipment (125.3 kilo-tons) are likely to end up in the landfill, with consequent downstream hazards for the environment and human health.

Table 23: Disposal methods

Count and percentage 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%

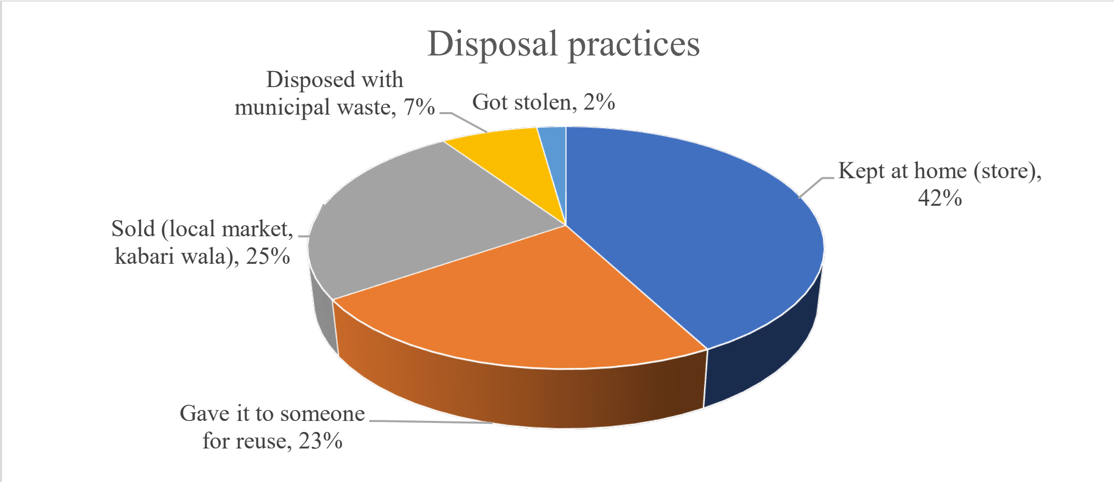

Figure 29: Disposal practices in Pakistan

4.6.1. Reasons for storage of used EEE or e-waste

Investigation of the reasons for storage highlighted that people tend to hoard equipment as a back-up or spare that they might need later. Another main 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, laziness or the feeling of disposal being troublesome, and the intrinsic value of the equipment. The reasons have been detailed in Table 24.

Table 24: 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%

Since storage or stockpiling was the dominant disposal method, we further investigated the categories of equipment stored the most. Figure 30 is a summary of the most stored categories of e-waste. Mobile phones were the single most widely stored category of equipment, followed by computer mouse. The tendency to store small equipment like mobile phones and the mouse is understandable because they do not take up much space in cupboard drawers or storerooms. Storage of mobile phones might also be motivated by protecting data and the monetary value attached to it, which cannot be recovered after is stops functioning and if it cannot be repaired.

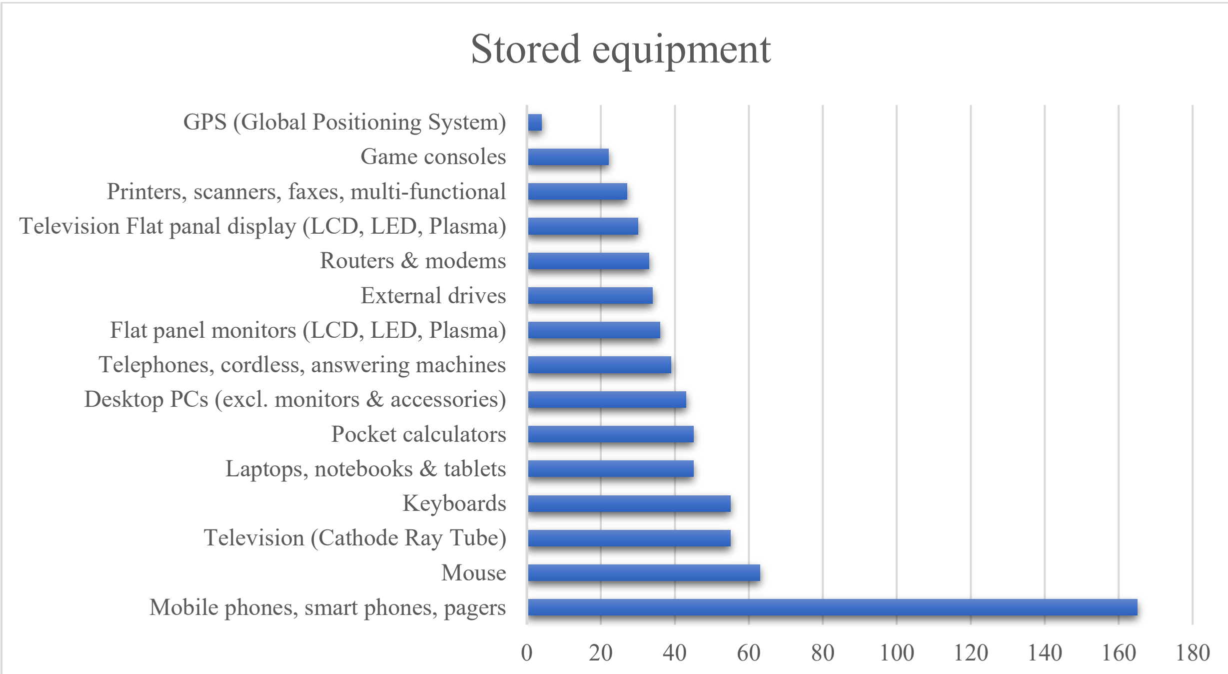

Figure 30: The most stored categories of e-waste

4.6.2. Disposal after storage: Why and how

Stored equipment is sometimes finally disposed of after years when space in the house runs out and nothing more can be stored or when moving house. However, even after years of storage, some participants still wanted to continue storing their e-waste. That said, when some event compels people to dispose the stored equipment, most people give their e-waste to someone for re-use, or sell it at the local market or sell to the local waste collector (*kabari wala* in local language) (details in Table 25 and Table 26). The local waste collector 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 other disposal options, which unfortunately, however, takes e-waste directly to a landfill. The risks and toxic impacts of disposal in landfill and informal recycling practices are hard to see and are unmeasurable, but also certain.

Table 25: 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 26: 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%

4.7. Consumer awareness

Awareness is a key to responsible usage and disposal, as it can make an e-waste management system effective. The awareness of *toxic and hazardous substances* such as lead, mercury and arsenic is high (Figure 31), with 75% of respondents reporting at least some knowledge and the rest 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), but the level of awareness of the presence of precious metals is low when compared to the awareness about toxic and hazardous substances. The majority of people also agree that improper disposal of e-waste can have negative and toxic impacts on the environment, and consequently on human health Figure 32. The current very low level of awareness can be raised through education, which was found to have a significant impact (at the 0.05 level) on awareness. Highly educated (tertiary or professionally qualified) respondents were found to be more aware of toxic substances, precious metals and hazardous impact on the environment and human health in contrast to less educated respondents. Results of the statistical tests are illustrated in Table 27 and Table 28, respectively.

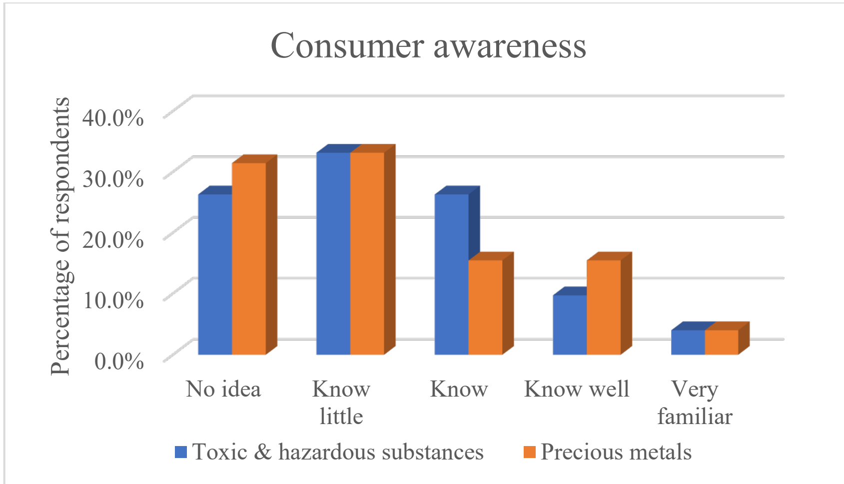

Figure 31: Consumer awareness of toxic, hazardous and precious elements in e-waste

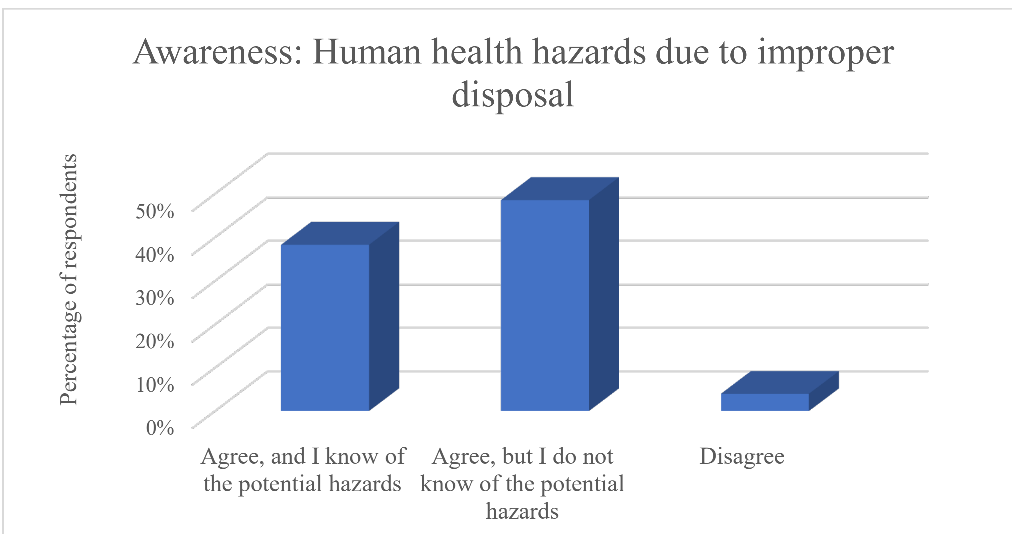

Figure 32: Environmental and human health hazards due to improper disposal of e-waste

Table 27: 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 the 0.05 level
* Significant at the 0.1 level
Test statistics are marked with asterisks and significance (or p-value) is presented in parentheses.

Table 28: 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 the 0.05 level
* Significant at the 0.1 level
Test statistics are marked with asterisks and significance (or p-value) is presented in parentheses.

4.8. Willingness to pay for recycling

In order to introduce an e-waste management policy, it is important to identify the stakeholders who should and who are willing to take the responsibility. Most consumers identified the government as the stakeholder with most responsibility to introduce e-waste management policy and systems (Table 29). 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 30). A significant minority (35%) disagree with taking financial responsibility. However, since the majority of 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.

Table 29: 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 30: 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 of	44	25.1%	98.9%
Other	2	1.1%	100.0%
Total	174	99.4%	

Further analysis (Table 31) on the willingness to pay according to income levels shows that about 60% of people are willing to pay up to about 10% of the product price in order to support proper e-waste recycling and management. It is important to note that the differences across income categories are insignificant, suggesting that people who are in low-income groups are equally willing, as much as the people on high incomes. Therefore, income level does not appear to influence the willingness of people to pay for a proper e-waste management system.

Table 31: 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)								

** Significant at the 0.05 level
* Significant at the 0.1 level
Test statistics are marked with asterisks and significance (or p-value) is presented in parentheses.

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

As discussed earlier, collection rate plays an important role in determining the recycling rates. Therefore, if a take-back system is introduced, that pays some money to the consumers for returning their e-waste, and results indicate that around 87% people are willing to participate and return their e-waste (Figure 33). The rest (13%) are not willing to return it 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 consumers to return their e-waste through the take-back system, while a payback of up to 20% can motivate around 76% of the consumers (Figure 34).

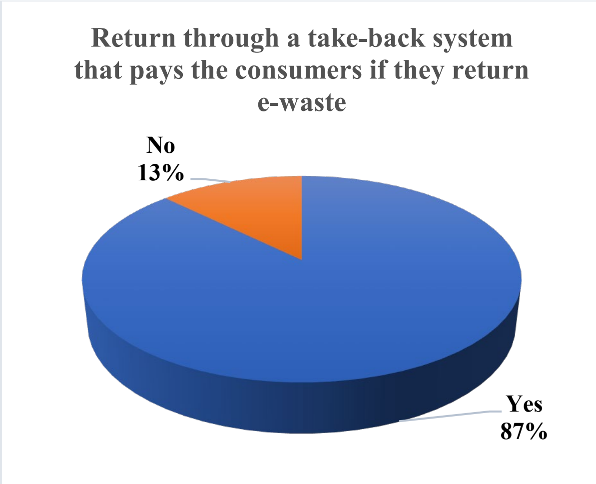

Figure 33: Return through a take-back system

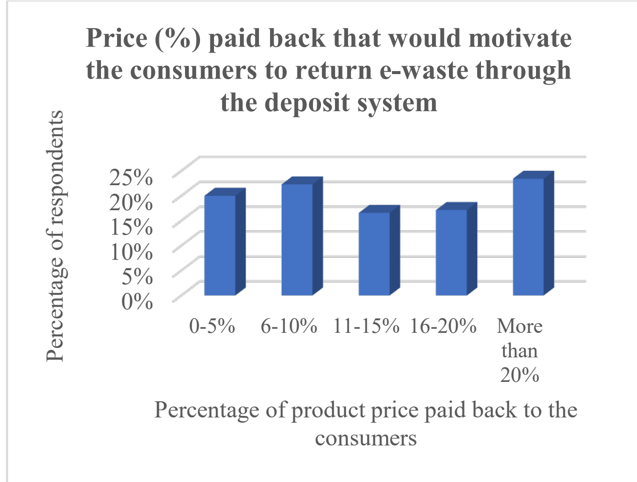

Figure 34: Incentive to return e-waste through the deposit system

4.9. Discussion

This chapter attempts to illuminate 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 inferences suggest that Pakistan generates around 281 million equipment that can be classified as e-waste every year. This is equivalent to 1,790 kilo-tons in the period 2018-2019. These quantities include just two categories of e-waste out of six categories under EU-6.

Noting that the current study employs a comprehensive approach of extrapolation using primary data, based on the income groups and the population, the figures are noticeably larger than previous studies that estimated total e-waste in Pakistan to be 301 kilo-tons in 2016 (Baldé et al. 2017) and 114-138 kilo-tons in 2014 (Sajid et al. 2019). The difference between this study and previous estimates can be explained as being due to several reasons, aside from the fact that the estimates were made at different times. Firstly, 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. A list of the specific equipment in these categories has been provided in Table 4. However, the estimation by Sajid et al. (2019) was solely for desktop computers and laptops that fall in the screens category. Baldé et al. (2017) estimated the quantities for all six categories of e-waste. Secondly, the differences in methodology could lead to varying estimates. Previous studies mostly base their estimates on trade or sales data; however, in many developing countries such as Pakistan, not all imports are registered. For instance, Baldé et al. (2017) based theirs on the sales data, derived from imports and exports data. Imran et al. (2017) estimated the flow of e-waste using imports data. Similarly, in order to estimate 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 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.

4.9.1. Acquisition of EEE

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 obtained directly from international electronic manufacturing companies. Assessing the reasons that drive consumers' purchase behaviour, it was found that most people bought new equipment if their existing devices were damaged, became non-functional, or lost/stolen.

Equipment retention and turnover rates vary, but overall it suggests that Pakistan is not a trend- or consumer-driven society that buys new technology simply to upgrade to a 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 the highest income group although representing just 20% of the population, appears to generate around 40% of the total e-waste volume. It is also noticeable that males are more likely to upgrade for new style than female, in part because the former 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, an also less appreciated reality reported by the recycling workers in the qualitative part of study revealed that electronic goods are made with materials that yield fewer valuable metals but generate the same toxicity and also require the same efforts to extract the metals. The effect, consequently, is to make new equipment more affordable for consumers and so more attractive, but also presenting greater downstream risk to both workers and the environment. For instance, Singh et al. (2019) found that technical innovations in the mobile phone designs had not reduced toxicity for the period 2001 to 2015. Rather, this study by Singh et al. (2019) suggests 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. Study findings 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.

4.9.2. The short-term gain – long-term pain trap

Acquiring cheap new technology represents short-term gain in cost and functionality, but at great long-term unrealised pain. This is the trap facing Pakistan as increasing volumes of e-waste and resultant increasing volumes 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 risks to the environment and to human health. Compounding this gain-pain trap is the reality that reward from recycling have fallen as the content of precious metals has decreased. A recycling worker remarked:

> "*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, M et al. (2016), confirms 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 in 2010). 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 content 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, HM & Zhang 1994; World Health Organization 2000)

In effect, mass production and high uptake of low-quality electrical equipment reduce the benefits of recycling and conversely dramatically increase the risk of harm to workers who recycle toxic waste via informal means or indirectly to the environment by e-waste materials going to 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.

4.9.3. Equipment useful life

Over time, there is evidence of much reduced useful life of some electrical and electronic equipment (Akcil et al. 2015; Borthakur & Govind 2017; Tanskanen 2013), while some equipment like Cathode Ray Tube (CRT) televisions and monitors have become obsolete. There is also a shift away from desktop computers to laptops, notebooks and tablets, particularly by younger people. This equipment has a shorter useful life when compared to desktop computers, but which also stands to add to the volume of e-waste generated at the end of their useful life, some 2-5 years later.

4.9.4. Disposal of used EEE or e-waste

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 done so conveniently, they readily buy another (new or used) equipment but with the old 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 are stored at home. This is the equivalent of 118 million equipment or 751.8

kilo-tons of e-waste that collects annually and will at some point later need to be recycled. This finding is consistent with other studies which 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, J 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 keyboards are small in size, so they can be stored conveniently (Casey, Lichrou & Fitzpatrick 2019; Nowakowski 2019). The most frequent reason for preferring storage or stockpiling is that these as seen as spare equipment that could be used in the future, particular 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 thus not easily carried. However, while deferred disposal is a short-term strategy, the long run reality is that consumers are often forced into disposing old and dated stockpiled equipment, usually in a forced clean up. It means resorting to the most convenient low cost means that usually represent landfill via municipal collection points.

Other than storage, the common disposal practice is to sell 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-tons), only 22.5 million equipment (154.8 kilo-tons) are recorded as being collected and recycled via informal practices based on crude and usually unsafe methods. Data suggests that some 35.32 million equipment (245.6 kilo-tons) ends up in the landfill. A summary of material flow in the upstream component of the e-waste lifecycle is provided in Figure 35, which achieves research objective (RO) 2. As the figure shows, with volumes identified at particular points of the cycle, it is possible to begin tracking 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.

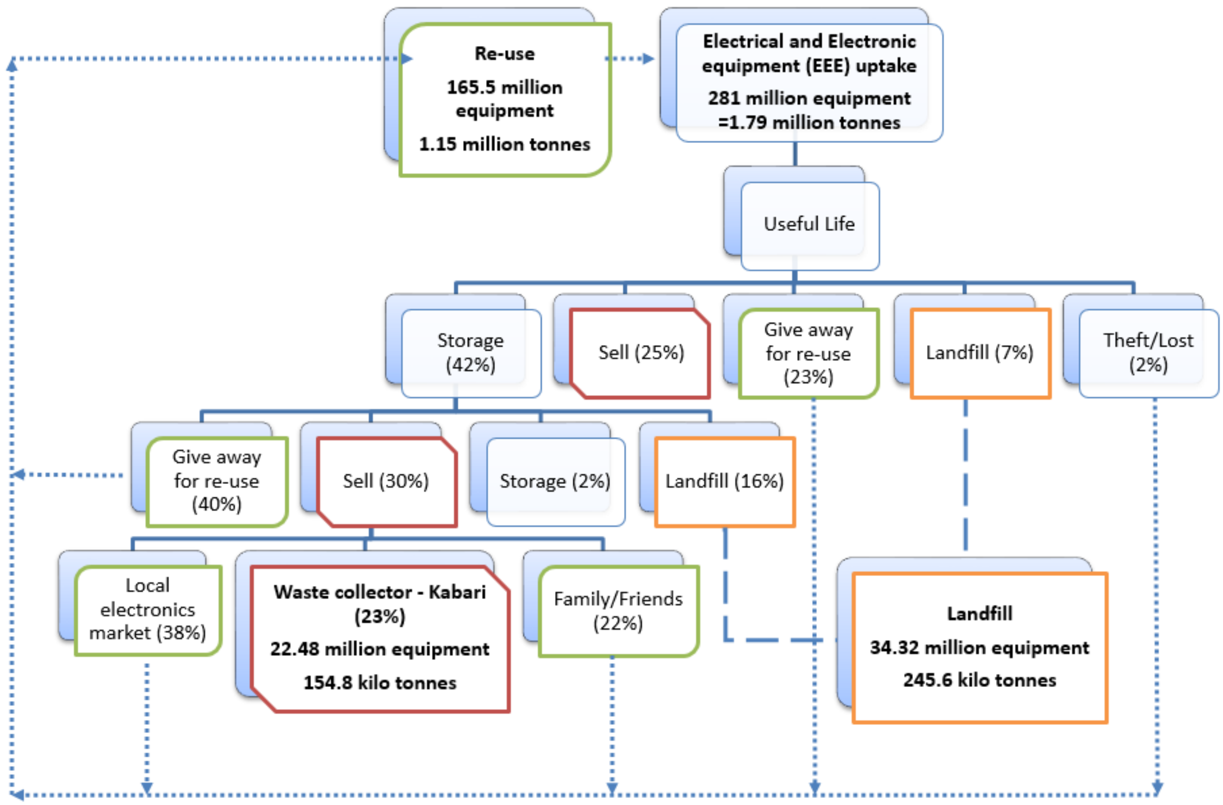

Figure 35: Material flow of electrical and electronic equipment in Pakistan (RO2)

The material flow of EEE illuminates some of the hard-to-measure and less visible 'upstream' considerations, such as volumes and attitudes of consumers that their drive buying and disposing decisions. The outcome of these decisions can be quantified to illustrate less visible costs and related considerations downstream. These costs are implied but not discussed in any depth in this chapter, which focuses consumers, but in subsequent chapters it is discussed. According to the findings, 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 useful 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 pathways to selling at local markets or to waste collectors and ultimately to disposal by informal and less useful methods, such as dumping and landfill. The unfortunate reality for much electronic equipment as they age is that they also release toxic chemical constituents (Peralta & Fontanos 2006). As such, it is evident there is an unrealised and considerably negative effect that accrues from both storage and resort to landfill. The habit of storage also deters the re-use of potentially useful equipment, thereby preventing waste reduction (Ylä-Mella, J 2015), impeding the operations and sustainability of take-back systems and limiting raw materials available for recycling (Borthakur & Govind 2017; Speake & Yangke 2015).

4.10. Policy implications

The public's awareness and participation are essential for the success of electronic waste management initiatives, and inadequate awareness has been linked to negligent e-waste disposal behaviour (Borthakur & Govind 2017; Echegaray, Fabian & Hansstein 2017). Results of this study have found high levels of awareness of toxic and hazardous substances, potential environmental and human health hazards due to improper disposal and about the presence of precious metals in electronic equipment in Pakistani. The level of awareness is significantly related to the education level. Therefore, awareness at the policy level can be increased: firstly, by providing education to the general public; and secondly, by providing specific education about the hazards of e-waste and responsible disposal. However, a simple increase in awareness levels is not useful in the absence of any e-waste management and recycling systems that actually provide an opportunity to return the equipment. So, it is crucial to devise a take-back and recycling system in Pakistan that can recycle the collected e-waste.

For that purpose, willingness to take responsibility and participate in the e-waste management and recycling systems was assessed. Results were positive, where most people believed that the government needed to initiate e-waste recycling, and consumers also indicated that most of them were willing to participate and even pay a price for recycling that might be built into the price paid at the time of purchase. Interestingly, this willingness to pay was consistent across low-income and high-income groups. However, simply paying for the recycling system is not enough; in order to keep the system running, high collection rates are required. Thus, in order to motivate consumers to return their e-waste, a suitable collection system needs also be introduced, which could pay back some amount initially paid for the returned equipment.

4.11. Summary

This analysis illuminated 'upstream' considerations in e-waste management using an eco-system framework. The value of this framework is that it provides a capacity to see issues that are less visible and often, as consequently, hard to measure. The analysis highlighted volumes of waste and quantity, as well as 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.

Analysis further revealed a trade-off between ready access in the short-term to cheap electronic products and the resulting less visible longer-term downstream negative impact for the country, particularly the voiceless unskilled recycling industry workers. This issue is arguably being compounded in two ways, again largely unrealised, by a reported recent trend of increased cheaper electronic equipment. First, these types of 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, since the likelihood is that greater volumes of e-waste product will go directly to landfill. As noted earlier, this interlinked issue presents a trade-off, of choosing between short-term gain for ultimately long-term pain felt in the environment and by largely illiterate recycling workers.

This analysis presented a snapshot of the data focused on consumers' attitudes that generate and contribute to e-waste which is growing at a significant and alarming 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, one that can improve 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.

CHAPTER 5: MATERIAL FLOW ANALYSIS AND COST-BENEFIT ANALYSIS FOR RECYCLING BUSINESSES

5.1. Introduction

The previous chapter presented findings and discussion on the upstream generation and disposal of EEE/ e-waste (SQ1 - RO1 and RO2). This chapter achieves RO3, '*Estimate the costs and benefits of e-waste recycling for businesses*' (Figure 36) as a part of sub-question (SQ) 2 '*What are the impacts of e-waste recycling practices in Pakistan?'* This involves assessing the economic impact (profitability) and associated features of downstream recycling businesses in Pakistan. Primary data, collected by semi-structured interviews is used to conduct material flow analysis (MFA), cost-benefit analysis (CBA), including a net present value (NPV) and a benefit-cost ratio (BCR) that expresses the relative relationship between project benefits (revenue) and costs.

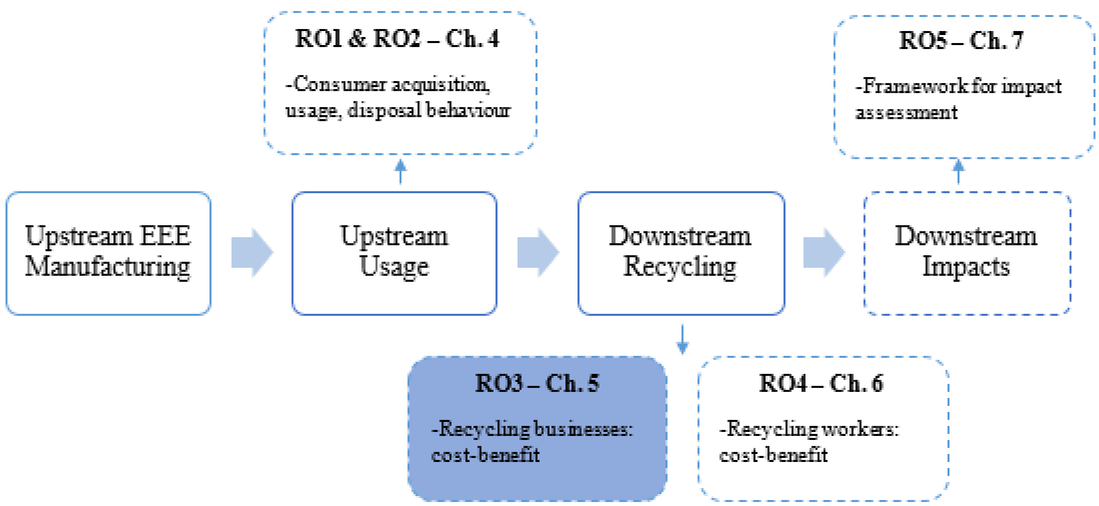

Figure 36: Placing RO3 in the e-waste value chain

Before exploring the impacts, step-by-step informal e-waste recycling process was investigated and documented (video recorded in those cases where participants agreed) to better understand the intensity of impacts. This process is detailed in APPENDIX 2. This chapter first conducts material flow analysis of e-waste, starting from imports and domestic generation as inputs, to reuse or export of substances as outputs. Second, characteristics and details of businesses that participated in interviews are discussed, followed by details of business environment, risks and general practices determined through qualitative analysis. Third, cost-benefit analysis is conducted at the equipment and business levels. This is followed by a discussion that presents social dynamics consisting of competing interests of businesses. Finally, this chapter closes with a summary and the major implications.

5.2. Material flow analysis (MFA) through the downstream sector

A material flow analysis was conducted to assess the flow and stock of e-waste through the downstream recycling sector. As noted earlier, composition of EEE is complex, consisting of numerous components and substances which all have different paths, making it difficult to track everything. As a result, this analysis starts with e-waste in general, but at the recycling level, it is limited to printed circuit boards (PCBs), which is one of the most valuable components in e-waste (Arshadi, Yaghmaei & Mousavi 2018; Pinho, Ferreira & Almeida 2018).

The MFA, illustrated through a Sankey diagram is shown in Figure 37 below. Stocks or quantities are in tons while flows are in tons/annum. There are two sources of e-waste, denoted by 'I' into the system: domestic generation and imports. E-waste quantities for domestic generation have been taken as 154,800 tons per year based on the estimates for collected e-waste in Chapter 4 (Shaikh, Thomas & Zuhair 2020), while imported e-waste has been taken as 95,415 tons as estimated by Imran et al. (2017). Collected e-waste is therefore the sum of imports and domestic e-waste, estimated to be 250,215 tons, which is dismantled manually. As the focus is on printed circuit boards (PCBs), which is about 9% in weight of average equipment (Chancerel et al. 2009), it is estimated to be 22,519.9 tons and is processed further for metal extraction. At manual dismantling stage, weight of residue is about 6% according to the estimates of Ikhlayel (2017), which has been taken as 5% with a deviation of 1%, shown as 'Waste 1' – 12,510.7 tons. Other than PCBs and waste, the remaining 86% of the dismantled equipment have been referred to as 'Other parts' which are resold or recycled further (domestically or exported). However, this is not part of the scope of this MFA.

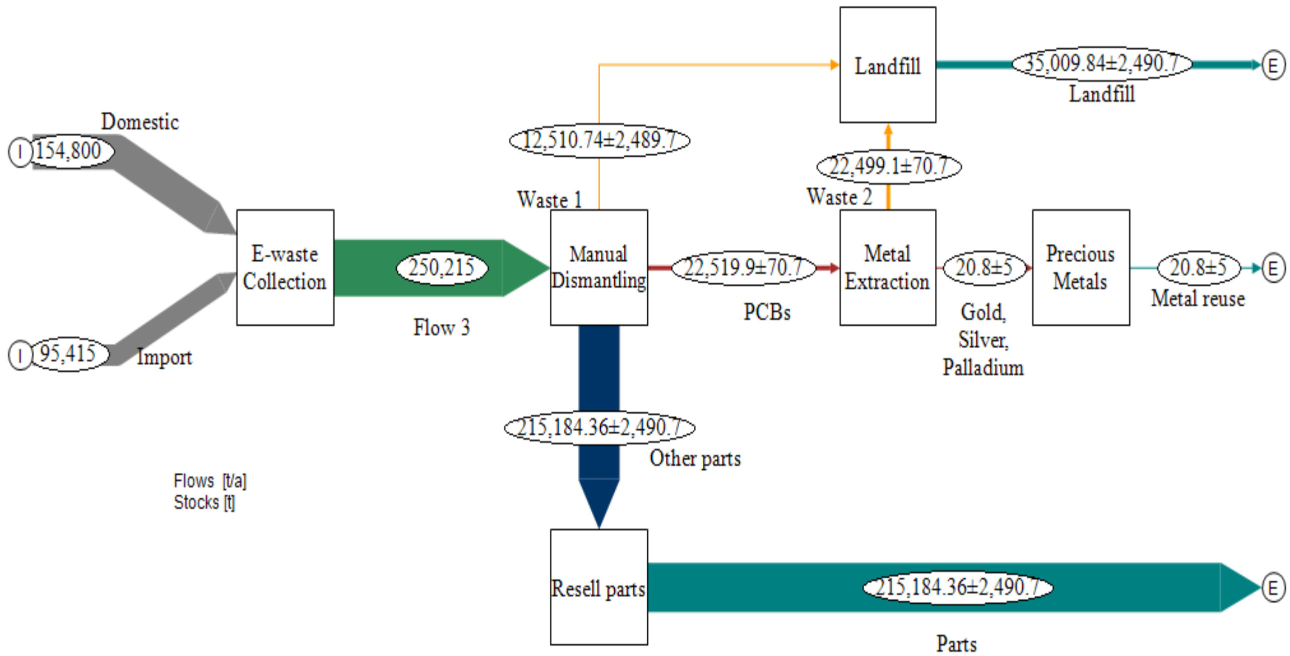

Figure 37: Material flow analysis (MFA) of downstream e-waste flows and quantities

Dismantled PCBs are used for metal extraction and according to Chancerel et al. (2009), respective content of precious metals in grams/ton of input is about 67.6g silver, 11.2g gold and 4.4g palladium. Using these estimates, in total input of 250,215 tons, silver is about 16.9 tons, gold is about 2.8 tons while palladium is about 1.1 tons – altogether about 20.8 tons of precious metals, which can be reused in different industries. The economic value of these precious metals has been estimated using commodity prices as on 31 July 2020 obtained from the Yahoo Finance Australia website[5]. The value of extracted silver is about USD 16.9 million, while gold is about USD 194.3 million and palladium is about USD 11 million. Therefore, annual value of three precious metals extracted from e-waste can be about USD 222.3 million. However, unfortunately large quantities of residue (35,009.84 tons) from dismantling and extraction are disposed of in landfills that represent externalised costs.

[5] https://au.finance.yahoo.com/

5.3. Business characteristics

Characteristics of businesses that participated in semi-structured interviews for this study are discussed in this section. E-waste recycling activities include collection, dismantling, metal extracting and refining where some businesses are involved in one activity while others in multiple or even all – from collection to refining. All businesses use informal methods of recycling, characterised by collection at individual level; manual dismantling using tools such as hammers and pliers, but without any protective or safety equipment; metal extraction and refining through open burning and acid bath, and finally disposing all the hazardous waste in local (mostly open) drains that ultimately feed into the sea. Often, water from these drains seeps into the ground and enter freshwater pipes through leakages, to be consumed by local households.

Businesses are predominantly male-owned and operated so all of the respondents are male. In terms of ownership type, self-employment is the most common type (80%) in research samples, where the owner works on his own and hires one or two other employees. They operate on limited finance available to them, which could be as low as Rs.5000. As a result, they occasionally form partnerships in order to pool the resources or expertise; borrowing money from banks is mostly not considered an option because interest on loans is not permitted in Islam. Almost all of these businesses are small, fragmented across the city, operating in places that were hidden and difficult to locate, such as the streets of slums in Shershah, and the streets in and around Saddar (including Sarafa Bazaar). Because of this hidden nature, they were not asked if their business was registered, however, according to the responses, only a few appear to be registered that import e-waste and therefore have to make payments via banks, or those who source e-waste through bidding/tender notices from local corporations. The other type of ownership is family business (20%), which involves family members including children. Some family businesses have been running for up to two generations. Located in large go-downs in Shershah, such as Quality go-down, Super General go-down, Faisal go-down and Colonel go-down, these businesses have relatively large operations, more power and more finances available than self-employed owners.

Culturally, e-waste recycling businesses rely on social connections and relationships to survive and thrive. Through relationships, it is easier to find not only suppliers and customer, but also workers, mainly because e-waste recycling is labour-intensive and does not require any qualifications or prior skills. Learning takes place on-the-job through experience, and once skilled, some workers start their own business (self-employment) because the financial motive is high and less initial investment is required. Therefore, moderate worker turnover in most cases is evident. However, perceived loyalty of workers increases if owners are considerate in providing basic workplace safety like chimneys and workers can dedicate their lifetime to those businesses.

Most of the businesses visited hire up to 5 employees (93%), while one business had about 15 workers at the time of interview. So, a majority of businesses seem small in size based on the number of employees, yet some large-scale (mostly located in Shershah, Karachi) hire workers on a contract or casual basis, depending on the workload. The month in which interviews took place was "Moharram" which is the first month of the Islamic calendar, during which there is little economic activity and ports and customs services are either closed or operate with a skeleton staff. As a result, imported containers were not cleared at port and there was no work for these businesses. Once Moharram was over, businesses would have an influx of e-waste (up to 3 containers or 60 tons) and some of these businesses hire up to 800 employees to process that waste.

Table 32: Business Characteristics

Business Characteristics	**Frequency (N = 15)**
Type of facility	
Formal	0
Informal	15
Number of workers	
1-5	14
More than 5	1
Type of work	
Import	6
Collect	5
Dismantle	15
Extract metals	5
Refine metals	3

5.3.1. Sources and destinations of e-waste in Pakistan

E-waste is either collected locally or imported. In most cases, even if it is collected locally, it might not be generated domestically, rather just imported by someone else. Table 33 shows the proportions of domestic and imported e-waste according to the primary data collected. Most businesses (53%) collect 100% e-waste from local/domestic sources, and only about 2% import

100% e-waste. Local e-waste is bought from markets such as Regal in Saddar (Karachi), Technocity, Naz plaza, local banks, offices and Shershah (SITE area in Karachi) or even direct collection from residential places by street hawkers called '*kabari walas*'. Referring to imports, e-waste is mostly imported from Dubai, China, UK, USA, Singapore, South Korea, Canada, Germany, Europe, the Middle East, Australia, Taiwan and Malaysia. As suggested by Imran et al. (2017), some of these countries were just used to reroute e-waste to Pakistan from other developed countries. E-waste is imported in containers of different sizes – 20 feet, 30 feet, 35 feet and 40 feet. A 20 feet container can hold up to 15-18 tons of equipment while a 20 feet container has a capacity of 30-32 tons, and one business imported one container (20 or 40 feet) every 25 days.

Processing or recycling takes places at different stages, ranging from just dismantling to extracting and then refining. In Pakistan, recovery of gold, silver, aluminium and sometimes palladium is possible, while other rare and precious metals are unrecovered (lost), often without the knowledge of business owners or workers. A few business owners (13%) are aware of the presence of precious metals (Table 34) and export some components after dismantling to Europe, where companies like and Umicore in Belgium can extract up to 18 metals through formal recycling.

Table 33: Proportion of imported and domestically sourced e-waste

Domestic	Import	Frequency	Percent
100%	0%	8	53%
40%	60%	1	7%
30%	70%	2	13%
2%	98%	1	7%
0%	100%	2	13%

Table 34: Proportion of exported and domestically sold e-waste (or components)

Domestic	Export	Frequency	Percent
100%	0%	12	80%
40%	60%	2	13%
30%	70%	0	0%
2%	98%	0	0%
0%	100%	0	0%

5.4. Business environment and risks

Notwithstanding the evident benefits for business, the evidence also is of known and some hidden risks associated in the workplace and environment. In face of these tensions, there is a form of 'cognitive dissonance' displayed by business owners. Faced with a situation that involved conflicting attitudes, beliefs and behaviours, many business owners appear to adopt the view that recycling tasks were not dangerous and there was no need to improve working conditions, even if it involved affordable minimal costs such as protective clothing. Recycling workers, mirroring this attitude, were similarly unreceptive to the use of protective equipment such as gloves, as these were seen to impact negatively on business productivity. With respect to occupational health and safety, ventilation of the workplace by way of chimneys was seen as a highly considerate gesture by business owners. Minimal workplace-related considerations were noted; the provision of a first-aid kit was noted at just one processing site, which incidentally also included training for workers in first aid and covered the medical expenses for employees injured at work. These facilities and support considerations were, however, the exception and not the norm.

These small businesses were also mostly unregistered and tended to be hidden in nature. The principal reason given for the secrecy in business operations was wanting to avoid municipal oversight and evade taxes. Another important influencing factor that became evident from conversations was the desire for security and avoidance of political risks, including the demand for bribes from local mafia-type organisations or political parties. As one respondent operating a hidden facility noted:

> "*People from the mafia do not want to pay for the products they buy and ask for bhatta (a bribe). I once recovered some money from them and refused to pay Bhatta. As a result they stole my generator worth Rs.150,000 overnight. There are fights with the party gang, so we are safer here, even if we have to pay more rent*."

This subject facility, located in the basement of a parking lot for security reasons, as a consequence also had no ventilation. Recycling workers toiled in suffocating conditions and owners claimed they could ill afford to improve the situation, especially when it was becoming more difficult and costlier to acquire e-waste. Other respondents also complained of less material available for processing than before and associated uncertainty, "*…sometimes we can get equipment from 1-4 offices in a week but sometimes we get nothing for months*." This could possibly be because of the obsolete skills as technology advances but their skills and methods are old. For instance, due to a lack of upgraded skills, businesses that recycled Cathode Ray Tube (CRT) televisions or monitors can no longer find work because consumers have switched to flat panel displays. A declining trend is also noticed in the content of precious metals, such as gold and silver (Chen, M et al. 2016; Golev et al. 2016), most likely due to increasing popularity of Chinese branded equipment that have advanced features, are cheaply priced, and therefore attractive to consumers but have less quantity of precious metals. In addition, Chinese counterfeit equipment (with the name and logo of original company) have become popular, but in fact have proved to be damaging to recycling businesses, mainly because efforts required in extraction and refining are the same but output (reward) has fallen (Shaikh, Thomas & Zuhair 2020). This has diminished the incentive to recycle, resulting in more metals going to waste/landfill because the process of extracting precious metals (other than gold, silver, palladium) is very tedious, so it is not worthwhile in terms of time, effort and money. This subsequently leads to lost opportunities and lost (natural) resources.

Another issue that helped compound the business challenge is uncertainty over the quality of raw product (input) and the rising costs of acquiring e-waste. Business owners reported that they are unable to predict the quality of e-waste materials and component parts with any certainty. In fact, the reality for metal extraction (output) for resale purposes for any given volume of e-waste product (input), had become highly variable. As one business owner commented:

> "*The quantities of metal extracted depends on the quality of material we start with. This variability is because we have all kinds of ICs and chips, which can be from Pentium 1, 2, 3, or more recent models, [and] could be from equipment manufactured by different companies (Apple, Lenovo, Dell) that have different prices and qualities. So, it is a risky business. It is like catching fish: we never know how much output we will get. It depends on luck*."

There is also an element of seasonality in e-waste recycling business as observed from the variability in the number of employees. During certain times of the year, such as Moharram, Ramadan and Eid (religious festivals), there is little economic activity and businesses face backlog risk since their containers are not cleared by the customs at port. It becomes difficult to survive during these times because prices of their output also decline and they have to sell at a loss in order to maintain liquidity and turnover. After the time of low activity, once containers get cleared, huge volumes need to be processed, pressurising businesses logistically.

There are additional risks facing businesses importing e-waste from information asymmetry and lack of governance. This imbalance in information creates opportunities for middlemen who act as agents, dealers, suppliers and customers, and who as a result inject their own profit margins (commissions) for both local and international connections. According to a business owner:

> "*There is high competition in this business. Nobody wants to talk about their business, where do they buy from (middlemen) and who do they sell to. They [the middlemen] are*

directly connected to suppliers and customers, if there is any recycling business that deals directly with their supplier/customer, they are lucky."

While middlemen can demand high commissions, they also serve a valuable function by saving business owners from having to import a (significant) minimum quantity. This quantity was estimated to be about 30 containers or 300 tonnes every month, a quantity that most small businesses can ill afford. The lack of governance in e-waste means businesses must hire agents and lawyers at customs checkpoints to get consignments cleared and ensuring businesses get what they want. Reflecting the lawless reality of the industry, business owners know that if they did not hire these agents and lawyers, they would obstruct their businesses getting the quality product all businesses wanted. Similarly, the lack of governance makes getting through customs at seaports a tedious task. Business owners acknowledge needing to pay bribes at almost every desk in order to get their consignment cleared. These business governance conditions have consequences, with importers and importing business owners forced to find alternative (illegal) means to access (likely illegal) e-waste. According to one importer who was also a business owner:

> "*They [agents] ask for money, which is actually double the amount of legal customs duty. As a result, businesses have to work around and find illegal ways of importing product to avoid that extra (illegal) customs duty*."

There is also considerable risk during customs checks through carelessness by officials and by being unable to check what each consignment carries beforehand. As a business owner commented:

> "*My consignment worth Rs.12,000,000 had one electric converter, which is banned in Pakistan. In order to retrieve that one converter, customs authorities overturned the whole container and damaged everything inside. I could just manage to recover Rs.5,000,000 and lost [approximately] Rs.7,000,000."*

Despite these risks and associated difficulties faced by business owners, on the whole e-waste recycling remains highly profitable. This theme is further explored in the subsection on cost-benefit analysis.

5.5. Recycling stages

Recycling businesses (importers) generally receive what is described as mixed e-waste. This means the initial inventory that arrives in and is sold by sea containers lots, can be variable and a 'lucky dip' as businesses sometimes cannot be sure of quality in terms of recoverable materials. Initial sorting is thus important. Figure 38 depicts the e-waste recycling stages as applicable to Pakistan. Three stages are shown in the informal e-waste value chain, along with details of equipment, components and substances. Dismantling, the first stage in the recycling process, is at equipment level with equipment such as desktop PCs, LCDs and laptops collected and dismantled into subordinate components such as motherboards, hard disk drives and processors. The second stage involves breaking down (extracting) potentially valuable sub-components, such as gold-plated pins, integrated circuits (ICs), whole circuits, resistors and capacitors, as well as gathering general re-useable waste such as glass and plastics.

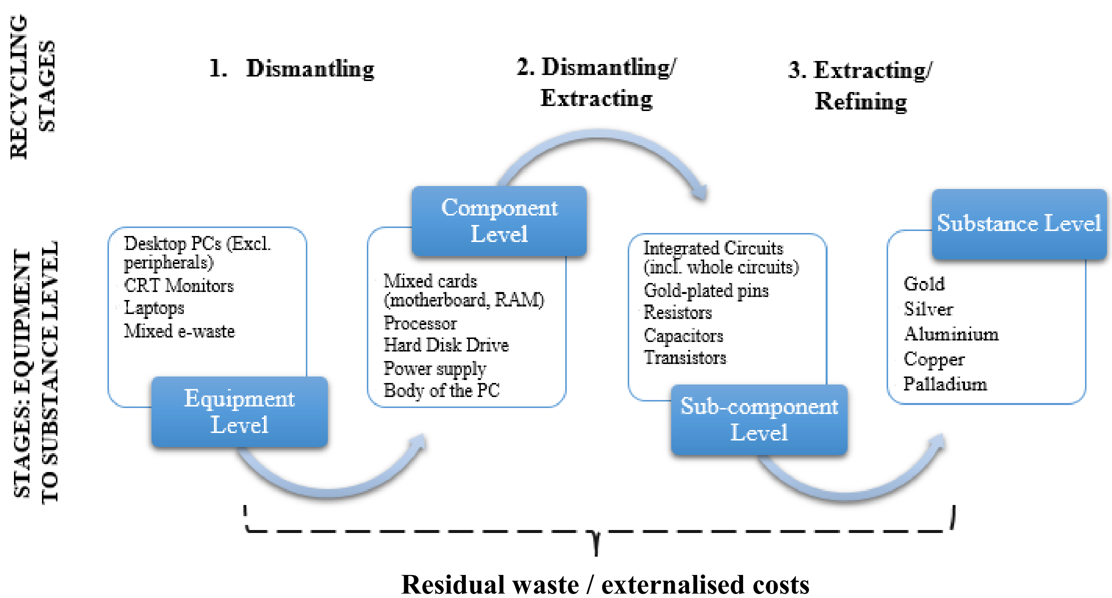

Figure 38: E-waste (informal) recycling stages

The third and last stage in e-waste recycling is extraction and refining. Any capacity to extract valuable metals by informal methods is limited to valuable metals such as gold, silver, copper and palladium contained in sub-component parts. Other valuable and rare metals such as platinum cannot be extracted by informal methods and these metals and associated processing materials go into municipal landfills as residual waste or as lost opportunity. As illustrated in Figure 38, there are also externalised costs involved. Material losses and processing costs aside, there are many by-products of processing and refining that impact as unmeasured (and deferred) costs. These costs are arguably borne directly and indirectly by local stakeholders and the environment. For example, the process of evaporating/dissolving aluminium and lead in acid baths so that gold residue is pure, also results in toxic waste that goes into waterways via open drains. The significant externalised costs conceptually become evident later in terms of second- and third-order effects on the health of recycling workers, families and the general community living in the vicinity of processing sites, as well as the environment (via air, water and soil pollution). These effects are not measured in the CBA and related analysis for recycling businesses.

5.6. Analysis (CBA)

5.6.1. Equipment level analysis (stage 1)

An equipment level cost-benefit analysis during the dismantling (first) stage involves recycling businesses, either buying or collecting whole equipment for manual dismantling (stage 1) into component parts. These components are either processed in the business itself or on-sold to other businesses for further (stages 2 and 3) processing. Estimates were made in two units: Rs. per kg of equipment and Rs. per unit of equipment. Equivalent costs/benefits in USD are calculated using the conversion rate of Rs. 167.686/USD (as of 1 July 2020).

5.6.1.1. Cost-benefit (per kg) calculations

Primary data collected at the dismantling, extracting and refining stages was in Rs./kg in most cases. First, in order to estimate the costs and benefits at dismantling stage, costs and potential revenue for each kilogram of equipment (Rs./kg) were developed based on the selling price in the market - see Table 35. 'Cost' represents the price paid to buy the equipment and excludes any other costs that have been included in Table 37 and Table 38. A full list of components is not included in Table 35 under 'Revenue'. Rather, the list is based on significant components and data available in order to support the subsequent analysis via a benefit-cost ratio (BCR).

Second, the average percentage weight of each component in a desktop PC and a CRT monitor was obtained from the literature (Chancerel et al. 2009), multiplied by the average total weight of a PC (6 kg) or CRT monitor (16 kg) (Shaikh, Thomas & Zuhair 2020) to estimate the total weight of each component in one desktop PC or CRT monitor. Three estimates (minimum, average and maximum) are made for price/kg, to account for possible variations and to conduct a sensitivity analysis. Third, costs and benefits in Rs./kg calculated in Table 35 were used to estimate the costs and benefits of each equipment based on the average weight of each component.

Table 35: Equipment level cost and benefits (revenue) in Rs./kg

Desktop PC (Rs./kg)					
Cost	**Minimum**	**Average**	**Maximum**	**Average weight (kg)**	
Cost (Rs./kg)	159	177	195	6 kg	
Revenue (Rs./kg)				**Relative weight (%) in a PC**	**Weight (kg)**
Motherboards	378	420	462	6.20%	0.37
Processor	173	192	231	1.90%	0.11
Random Access Memory (RAM)	1,421	1,579	1,737	19.70%	1.18
Hard Disk Drive (HDD)	478	580	683	3.50%	0.21
Power supply	90	100	110	8.70%	0.52
CPU body	36	40	45	49.80%	2.99
Floppy drive	18	20	22	3.50%	0.21

CRT Monitor (Rs./kg)					
Cost	**Minimum**	**Average**	**Maximum**	**Average weight (kg)**	
Cost (Rs./kg)	19	60	94	16 kg	
Revenue (Rs./kg)				**Relative weight (%) in a CRT Monitor**	**Weight (kg)**
Plastics	20	30	45	18.50%	2.96
Ferrous metals (iron, steel)	30	35	40	12.60%	2.02
Copper	500	600	680	3.70%	0.59
PCB (Power board)	100	285	500	12.30%	1.97
Aluminium	140	150	160	2.30%	0.37

5.6.1.2. Cost-benefit (per unit) calculations

After establishing costs/benefit per kg, profitability estimates were made for each equipment (Table 36). Profit was estimated as total revenue minus cost, and profit margins were determined by profit divided by total revenue. Next, present value (PV) of benefits was estimated using the discount rate of 16.5%, which is KIBOR+5%, the cost of business loans based on the Karachi Inter

Bank Offer Rate[6]. The number of discounting periods were taken as 10 years for desktop PCs, assuming a business operates for 10 years. Finally, a benefit-cost ratio (BCR) is calculated as total revenue divided by cost, with a BCR of greater than 1 denoting that benefits outweigh costs – in other words, there is expected positive value for business owners. Similarly, cost, revenue, profit, PV and BCR were calculated for each CRT monitor (Table 36). The number of discounting periods were taken as 5, as CRT monitors are now almost obsolete.

Table 36: Cost-benefit of dismantling a Desktop PC and CRT monitor in Rs./unit

Desktop PC (Rs./PC)	**Minimum**	**Average**	**Maximum**
Cost (Rs./PC)	630	700	770
Revenue (Rs./PC)			
Motherboards	141	156	172
Processor	20	22	26
Random Access Memory (RAM)	1,680	1,866	2,053
Hard Disk Drive (HDD)	100	122	143
Power supply	47	52	57
CPU body	108	120	134
Floppy drive	4	4	5
Total Revenue	**2,099**	**2,342**	**2,591**
Profit (Rs./PC)	**1,469**	**1,642**	**1,821**
PV (Present Value)	**8,118**	**9,078**	**10,066**
BCR (Benefit-cost ratio)	**3.3**	**3.3**	**3.4**

CRT Monitor (Rs./CRT Monitor)	**Minimum**	**Average**	**Maximum**
Cost (Rs./CRT Monitor)	300	400	440
Revenue (Rs./CRT Monitor)			
Plastics	59	89	133
Ferrous metals (iron, steel)	60	71	81
Copper	296	355	403
PCB (Power board)	197	561	984
Aluminium	52	55	59
Total Revenue	**664**	**1,131**	**1,659**
Profit (Rs./CRT Monitor)	**364**	**731**	**1219**
PV (Present Value)	**1,372**	**2,755**	**4,597**
BCR (Benefit-cost ratio)	**2.2**	**2.8**	**3.8**

[6] < https://www.sbp.org.pk/ecodata/kibor/2018/Dec/index.asp> State Bank of Pakistan (access date 20 June 2020) – KIBOR taken corresponding to the months data was collected in 2018.

Results of an equipment level analysis for desktop PCs and CRT monitors are shown in Table 36. This level of analysis is by its nature limited to dismantling (stage 1) businesses. As the table shows, one desktop PC can be bought for Rs.630-770 (USD 3.8-4.6) and components of each PC after dismantling can be sold for a total revenue of Rs.2,099-2,591 (USD 12.5-15.5). This represents a profit of Rs.1,469-1,821 (USD 8.8-10.9), and a profit margin of about 70% on each desktop PC. The PV of profits from dismantling a desktop PCs is estimated to be about Rs. 8,118-10,066 (USD 48.4-60), while the BCR is about 3.3-3.4, which implies that benefits of dismantling a desktop PC are about 3.3-3.4 times higher than the costs incurred.

Similarly, costs and revenue was calculated for each CRT monitor (Table 36). Based on the results, a CRT monitor can be bought for Rs.300-440 (USD 1.8-2.6). After dismantling, the components of one monitor can be sold for about Rs.664-1,659 (USD 4-10), which represents a profit of Rs.364-1,219 (USD 2.2-7.3) and a profit margin of 55%-73%. Moreover, if measured by benefit-cost ratio (BCR), the benefit of dismantling one CRT monitor is about 2.2-3.8 times higher than the cost, while PV of profits is estimated to be around Rs.1,372-4,597 (USD 8.2-27.4).

Given a BCR of greater than 1 for both equipment, it is clearly financially beneficial for e-waste recycling businesses to buy whole equipment, dismantle and on-sell these components. High profitability for both equipment is most probably explained by the informal process used that are inherently low cost and can externalise many costs. Put in perspective, recycling of CRT monitors and televisions via formal means is unprofitable, because it largely consists of leaded glass that has few options for reuse and it is also highly toxic (Ciftci & Cicek 2017). Conversely, it is evident that ‘recycling’ the same product is profitable using informal methods.

5.6.2. Business-level analysis (Stages 1 and 3)

The following business level cost-benefit analysis is provided in two components: first, it concerns recycling businesses that either buy or collect whole equipment for manual dismantling (stage 1) into component parts only; and second, it concerns a cost-analysis for businesses that process – extract and refine e-waste materials (stage 3). Cost components are estimated and respective revenue and profitability including BCR are shown for businesses operating as dismantling businesses first, and next those operating as more substantial extracting and refining businesses.

5.6.2.1. *Cost components (Stage 1 - Dismantling)*

Business-level costs for dismantling businesses (stage 1) include set-up, transportation, storage and processing costs, as well as operational costs. Respondents described e-waste disposal businesses as being like an ocean, in that no matter how much one had invested, it was never quite enough. Three estimates for costs are made, based on size or scale of business – small, medium-sized and large. Due to the informal nature of e-waste processing, businesses are highly labour-intensive and without much technology.

Set-up costs involve the cost of starting a business. This included buying inventory, storage facilities and basic tools. Interviews with business owners established that set-up costs could vary, based on finance available and the scale at which one intended to start the business. As tasks are performed manually using basic tools such as hammers and pliers, set-up costs could be as low as Rs.30,000 or USD 179 (for small businesses). Large businesses could start at around Rs.15,000,000 or USD 894,523, with larger warehouses and more equipment required. The majority of recycling businesses operated at a very small scale, even inside homes and backyards. As a result they could start and run at very low cost, mainly based on buying inventory. The range of inventory costs is large as shown in Table 37. This is because every business owner indicated they bought inventory in the quantities they could afford. The upper limit and only constraints were budget and capacity for scale.

Transportation cost were estimated using data provided by the participants: Rs.74,000 (USD 441) worth of inventory incurred transportation cost of around Rs.600 (USD 3.6). Using these estimates, costs can be calculated for the three scales of businesses. *Storage cost* is the rent of a facility where inventory could be stored. Typically, this was the same facility where recycling activity took place, with rent depending on the type of area and size of facility. *Processing costs* include wages for recycling workers. The number of workers was taken as 3, 5 and 10 (based on the average number of workers found on-site) and monthly wage estimates adopted from Shaikh, Thomas and Zuhair (2020) are Rs.8,000, Rs.30,000 and Rs.50,000 (USD 48; 179; 298), respectively. *Operating cost* comprises daily expenses, including meals for workers provided by business owners and petty cash for operations. Three estimates are made using daily expenses of Rs.1,000, Rs.2,000 and Rs.3,000 (USD 6; 12; 18 based on primary data). These are multiplied by 25 to estimate the monthly operating cost.

Table 37: Cost-benefit for dismantling businesses

Consolidated Cost-Benefit (Rs. per month)			
	Small	**Medium**	**Large**
Revenue	**85,395**	**690,541**	**13,982,905**
Costs			
Set-up cost	30,000	500,000	15,000,000
Inventory	20,000	300,000	10,000,000
Transportation	162	2,432	81,081
Storage (rent)	2,000	50,000	100,000
Processing	24,000	150,000	500,000
Operating	25,000	50,000	75,000
Total Costs (excl. set-up cost)	**71,162**	**552,432**	**10,756,081**
Profit	**14,232**	**138,108**	**3,226,824**
NPV (Net Present Value)	**780,327**	**7,363,218**	**168,720,016**
BCR (Benefit-cost ratio)	**1.19**	**1.23**	**1.27**

5.6.2.2. Revenue and profitability (Stage 1 – Dismantling)

According to respondents, the profit margin of their businesses was about 20%. Revenue was calculated as 120% of the total costs (excluding set-up cost) and profit was subsequently calculated by deducting total costs (excl. set-up costs) from revenue. To calculate the NPV, first, monthly profit was converted to yearly profit, by multiplying by 12. Next, using a discount rate of 16.5% and 10 years as the number of periods, PV was estimated. NPV was subsequently calculated by subtracting set-up cost from the PV. BCR indicates the relationship between benefits and costs, calculated as PV of yearly revenue (benefits) divided by the PV of costs (including set-up cost).

5.6.2.3. Results (Stage 1 – Dismantling)

This discussion concerns cost-benefit details in Table 37 that is related to dismantling businesses that resell components or subcomponents. Positive NPV ranging from Rs.780,327 to 168,720,016 (USD 4,654-1,006,166) for all three scales of businesses shows high profitability and financial feasibility of dismantling businesses. All three estimates of BCR are greater than 1, meaning benefits are greater than costs. It is also evident that BCR increases with the size of business, most likely due to economies of scale.

5.6.2.4. Cost components (Stage 3 - Extracting/refining)

The cost components for businesses operating as stage 3 extracting and refining businesses are as follows (and are shown in Table 38). *Set-up cost* is estimated as the same as for dismantling (stage 1) businesses. The *cost of inventory* was calculated as a product of two variables – cost/kg of buying the inventory and quantity (kg). Cost/kg was the average price of gold pated pins and ICs, while quantity for small businesses was used as 46 kg per month based on the primary data. Weight of medium-sized and large businesses was then calculated according to the size difference in comparison to small businesses. For instance, in dismantling businesses, medium-sized businesses were estimated to be 15 times larger than small businesses based on inventory, and large businesses were estimated to be about 500 times bigger. These factors were used similarly to calculate the quantity in kg, which resulted in 690 kg and 23,000 kg of inventory for medium-sized and large extracting and refining businesses, respectively.

Transportation cost was estimated using the data provided by participants. Cost of Rs.600 was incurred to transport 740 kg of inventory (worth Rs.740,000); both of these were used to calculate the cost for each kg of inventory. Per kg cost was then multiplied by the quantity of inventory (kg) for each size of business. *Storage cost* is the rent expense as described earlier, while *processing cost* has multiple components. Workers' wages are the same estimates as for dismantling business costs – section 5.6.2.1. Wages of refiner, fuel for the burner and extraction costs are variable costs and have been calculated based on the quantity of inventory. Extraction cost includes buying of materials such as acids and something called 'khar' in local language to aid the process of extraction. *Other variable costs* include the cost of a process of liquefying and the solidifying the burnt and powdered e-waste, called 'palta' in local language, while *operating cost* is assumed to be the same as for dismantling businesses.

Table 38: Cost-benefit for extracting/refining businesses

Consolidated Cost-Benefit (Rs. per Month)			
	Small	**Medium**	**Large**
Revenue	777,602	1,1664,036	388,801,200
Costs			
Set-up cost	30,000	500,000	15,000,000
Inventory - (IC and gold-plated pins)	318,734	4,781,010	159,367,000
Transportation	37	559	18,649
Storage	2,000	50,000	100,000
Processing costs			
Wages of workers	24,000	150,000	500,000
Wages of refiner	4,000	60,000	2,000,000
Fuel for burner	14,000	210,000	7,000,000
Extraction	2,450	36,750	1,225,000
Other variable costs (palta, potassium)	8,800	132,000	4,400,000
Operating	25,000	50,000	75,000
Total Costs (excl. set-up cost)	**399,021**	**5,470,319**	**174,685,649**
Profit	**378,581**	**6,193,717**	**214,115,551**
NPV (Net Present Value)	**21,524,606**	**352,140,735**	**12,175,720,204**
BCR (Benefit-cost ratio)	**1.95**	**2.13**	**2.22**

5.6.2.5. Revenue and profitability (Stage 3 - Extracting/refining)

Revenue estimates are based on the sale of recovered precious metals. However, since the quantity of valuable metals in output varies and commodity prices are internationally determined, there are some fluctuations and uncertainty in revenue. As shown in Figure 38, gold, silver, copper, aluminium and palladium can be recovered at substance level. For the purpose of this analysis, however, only revenue for gold and silver are incorporated as the exact ratio of the other metals recovered (that are also in very low quantities) is hard to establish. The most prized metals in e-waste are gold and silver, and the normal practice in Pakistan is that businesses only expend effort to extract and refine other valuable metals in e-waste if quantities of recovered gold and silver are not enough to generate profits.

According to the primary data, 1kg of IC can yield, on average, about 4 grams of gold, which is sold at Rs.5,000 or USD 30 per gram[7]. Similarly, 1kg of gold-plated pins can yield, on average,

[7] As per the market rates of gold at the time of data collection in November 2018.

about 2.5 grams of gold and about 20 grams of silver (estimated value of Rs.65.44 or USD 0.4 per gram). Revenue can then be calculated: for an inventory (input) of 46 kg, 690 kg and 23,000 kg. Profit, NPV and BCR are calculated using the same methods described earlier in section 5.6.2.2.

5.6.2.6. *Results (Stage 3 - Extracting/refining)*

This discussion concerns businesses engaged in extraction/refining e-waste, and with processing involving extraction of substances from components and sub-components. Given the informal recycling methods used, the focus is on extracting and refining valuable metals (substance), such as gold and silver, from sub-components like gold-plated pins and ICs. The CBA shown in Table 38 is only based on gold-plated pins and ICs (integrated circuit boards) due to the availability of relevant data. These items are also the most valuable components for precious metals such as gold and silver that are the focus of extraction and refining.

E-waste recycling businesses are evidently very profitable, with a positive NPV of about Rs.21,524,606-12,175,720,204 (USD 128,363-72,610,237), and a BCR greater than 1. It is also clear that the BCR for businesses that extract and refine e-waste (stage 3) is greater than that for dismantling business. Similar to dismantling, the extraction and refining process is arguably more profitable in Pakistan relative to other similarly engaged countries, because informal processing is low cost and there is no need to invest in modern technology.

5.7. Discussion

E-waste recycling businesses operate at different scales, from very small to large, with a motive to earn some financial benefits are restrained by skills or lifelong experience in just e-waste recycling. According to the results, monthly profits for small, medium-sized and large dismantling businesses are, respectively, Rs.14,232; Rs.138,108; and Rs.3,226,824 (USD 84.9; 823.6; and 19,243.3), while these financial benefits are 1.19-1.27 times greater than financial costs incurred. Monthly profits for extracting/refining businesses are comparatively higher, estimated to be Rs.399,021; Rs.6,193,717; and Rs.214,115,551 (USD 2,379.6; 36,936.4; and 1,276,884) for small, medium-sized and large businesses, respectively, raising the benefits up to 1.95-2.22 times the costs due to precious metals.

These findings support the literature on business profitability and economic feasibility of e-waste recycling, that, for instance, showed recycling of disused LCD was profitable in the baseline scenario (€134,000), but was not economically feasible without a disposal fee (D'Adamo, Ferella & Rosa 2019). Elsewhere, Cucchiella et al. (2015) found the overall potential revenues from e-waste recycling in European market were about €2.15 billion in 'as is' scenario. Similarly, Cucchiella et al. (2016) and D'Adamo et al. (2019) assessed the profitability of European recycling processes for PCBs, and both studies verified the economic feasibility of the processes used. In contrast, Qiu and Suh (2019) in a study on the economic benefits of processing rare earth oxides from e-waste, concluded that it was not economically feasible at any scale. However, as evident, these studies focus on profitability of formal e-waste recycling, mostly in Europe. This study extends the literature by exploring profitability and conducting cost-benefit analysis for informal recycling. With visible financial benefits (first-order effect) come hidden social costs (second-order effect) to the workers and environmental costs (third-order effects), but also some dilemmas to the businesses that can best be explained by the 'competing interests of busineses' as shown in Figure 39 and discussed in the subsequent subsection.

5.7.1. Competing interests facing businesses

The preceding analysis has focused on financial benefits as a first-order effect, without regard for other (externalised) costs on human health and the environment. These, often hidden social and health costs, emerge as second- (and potentially third-) order effects affecting downstream workers, their families and the communities living close to the recycling sites. These second- and third-order effects appear to be sustained by the social dynamic termed as 'competing interests of businesses', which is made possible in large part by social attitudes, lax governance and absent regulatory frameworks, and is a contribution of this study.

As noted in the analysis above, e-waste recycling businesses in Pakistan rely on low-value (informal) e-waste recovery processes. The principal driver is profitability. The industry is faced with dilemmas that present challenges to their livelihood and to existing profit margins. Described as competing interests, businesses face choices in terms of continuing informal methods in Pakistan, on-selling product to Chinese recycling companies (that also use informal methods) or shifting to more responsible practices, by exporting dismantled waste to European recycling companies for formal recycling, but at less profitability. According to a business owner:

> *"Chinese companies offer to buy e-waste at (let's say) $1300. If it is just about me, I will still sell to Umicore or Sims (European companies) at $1200, forgoing $100 profit to make*

things legal. However, if I refuse to sell the product to the Chinese, they will still go out and collect e-waste at $1300 from other sellers in Pakistan (through their network). This will make me worse off and make it difficult for me to survive. They actually want to sign a contract with me to get the supply for the whole of Pakistan. If I refuse their offer, they will still buy at $1300 from someone else in Pakistan and my business will shut down."

These social dynamics and dilemmas have been illustrated through causal loop diagrams based on systems thinking in Figure 39. The first scenario is represented as reinforcing loop 1 (R1), where profitability is the lead variable, and higher profitability motive leads to higher local (informal) processing or selling to Chinese companies who also recycle informally. These companies are new (large) entrants in the e-waste market and make lucrative offers to buy e-waste in Pakistan. Informal (methods of) recycling in these cases incur lower costs of processing, thereby increasing profitability.

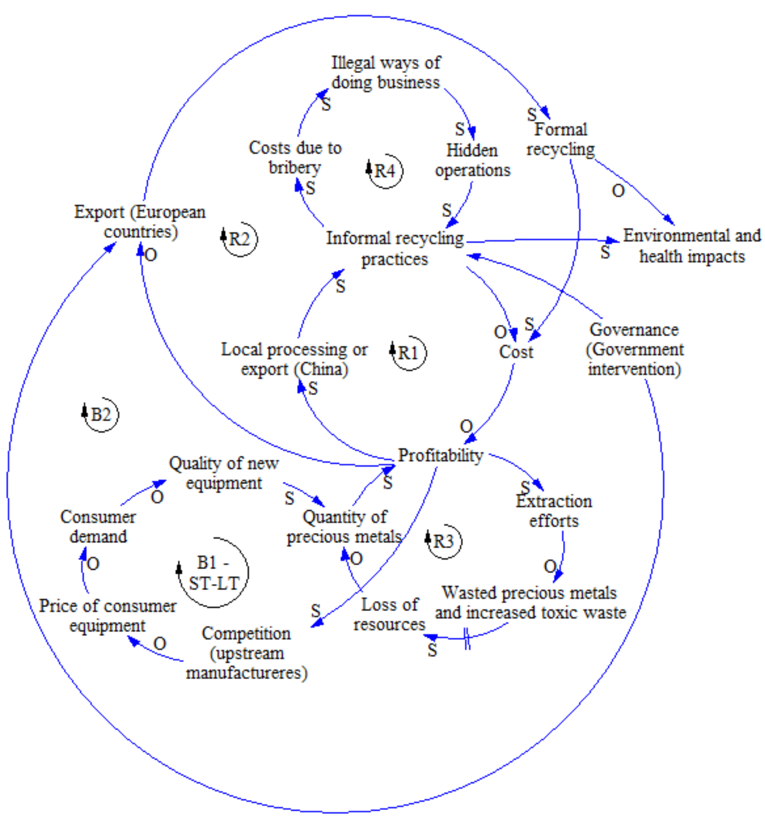

Figure 39: Competing interests facing businesses

Reinforcing loop 2 (R2) presents and alternative scenario whereby a businesses chooses to export to European countries for formal recycling, but on the downside, formal recycling has higher costs and therefore lower profitability. Profitability is also low in this alternative because in Europe, consumers pay for recycling but in Pakistan, on the contrary, consumers sell their waste (expecting money in return); therefore, these companies cannot pay high sums for waste. Reinforcing loop 4 (R4) is an associated loop of R1, where informal recycling practices attract more costs due to demands of bribes from mafia, political parties and even authorities in addition to legal fees. In order to avoid these additional costs, businesses try to find illegal ways of operating and try to stay hidden. This cycle (R4), along with R1 and R2 reinforces the informal and hidden ways of running businesses and this remains a vicious cycle without any intervention.

Reinforcing loop 3 (R3) highlights the effects of declining trends of precious metals which in turn lowers the expectations of profitability, thereby reducing the incentive to make efforts in extracting as many precious metals as possible. Reduced efforts lead to more precious metals going to waste and landfill, causing a loss of (natural) resources in the long-term. This consequently will lead to a decline in available metals and quantity that can be used in manufacturing of new equipment. Reduced quantity then results in lower profitability, closing another vicious reinforcing loop. Another loop associated with profitability at the upstream level is B1 - ST-LT that shows a trade-off between long-term loss and short-term benefit. Higher profitability of manufacturing electronic equipment encourages more companies (mainly Chinese) to enter the market, causing competition and setting the prices of equipment very low. Lower prices attract higher demand, but this compromises the quality of equipment by using lower quality of input (metals), in turn meaning less profitability to recycling businesses and then discouraging them to extract (continues R3).

These practical dilemmas aside, business survival and profitability is enabled by discrepancies or loopholes in regulations and a lack of accountability, as well as being able to externalise costs to workers who have no voice and no perceived choice, and to the environment (Shaikh et al. 2020). The social costs to workers, in terms of lower value of life and lower life expectancy relative to the general population, as well as lower quality of life and the opportunity cost of working in e-waste, and resulting illiteracy for their children who need to work in the industry for family income is discussed in Chapter 6. There are equally compelling reasons for e-waste recycling business owners to retain the status quo. Their businesses provide much-needed employment and a lucrative livelihood for business owners and their families. While some are willing to forgo immediate financial advantage, shifting the industry to formal recycling methods is prohibitive for most owners. This reality and the related social dynamics highlight the need for upstream policy and technology investments, as well downstream process change levers. This broader intervention challenge is implicit in the ecosystem model (see Figure 20). Simply, upstream ‘primary prevention’ actions before e-waste is generated will reduce the negative consequences that are conceptually flagged as first-, second- and third-order effects of e-waste.

5.8. Summary and implications

Based on a cost-benefit analysis at equipment and business levels, informal e-waste recycling is highly profitable at both equipment-level and business-level. Total benefits for equipment are 2.2-3.8 (CRT monitors) and 3.3-3.4 (desktop PCs) times cost, while benefits for dismantling businesses are 1.19-1.27 times and for extracting/refining businesses are 1.95-2.22 times total costs. This profitability can be achieved via easy metal recovery, as long as the industry can be sustained by the ability to externalise costs, such as the health and well-being of workers, families, communities and the environment. Aside from profitability, it is tertiary intervention in recycling that characterises informal recycling e-waste. A greater focus on primary prevention will involve business strategies upstream, including the redesign of products and implementation of an Extended Producer Responsibility (EPR), which ultimately places responsibility for disposal on manufacturers. For recycling businesses, the issues are largely greater policy clarity and guidance frameworks. Businesses presently accrue great profits for little effort, but owners, trapped by a lack of necessary funds are unable to change. The realities of significant financial benefits without regulatory frameworks and accountability is sustained by apathy towards known and unknown second- and third-order effects on the environment and workers. The business-level tensions are best described as competing interests.

CHAPTER 6: DOWNSTREAM IMPACT ASSESSMENT - RECYCLING WORKERS[8]

6.1. Introduction

The preceding chapter presented findings and discussion on costs and benefits for e-waste recycling businesses (RO3), and included material flow analysis, cost-benefit analysis, also highlighting social dynamics of competing interests of businesses. This chapter seeks to achieve RO4 '*Assess the drivers, social implications and economic cost-benefit of working in the e-waste recycling sector (workers)*' (Figure 40), which is also a part of sub-question (SQ) 2, '*What are the impacts of e-waste recycling practices in Pakistan?'* To achieve this objective, qualitative and quantitative data, collected through semi-structured interviews was analysed using thematic analysis, cost-benefit analysis (CBA) and systems thinking approach.

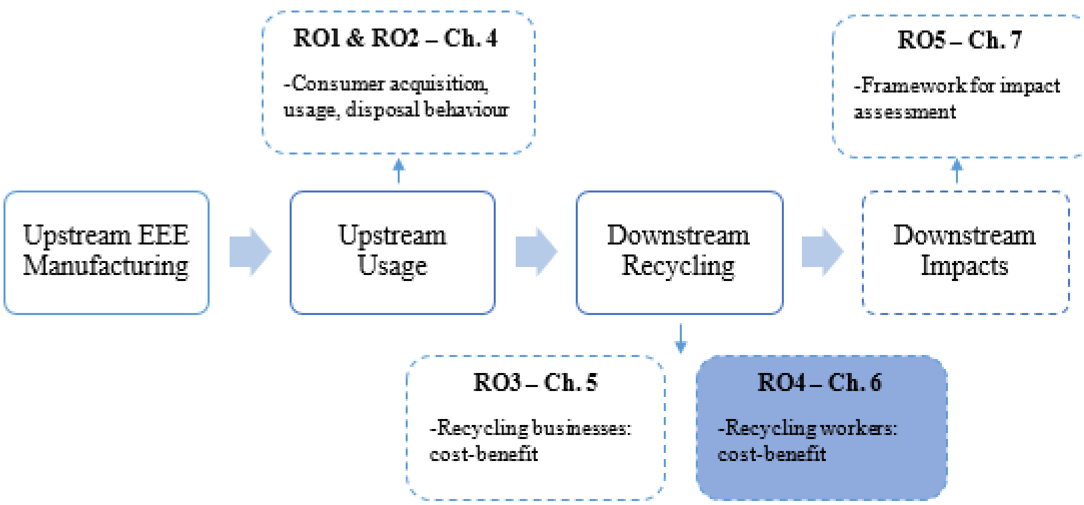

Figure 40: Placing RO4 in the e-waste value chain

This chapter first presents a qualitative analysis of the interview findings about what drives the interests of working in e-waste recycling and social implications. Next, a cost-benefit analysis (CBA) of economic (consisting of financial and non-financial (social)) costs and benefits is presented. This is followed by a brief discussion, highlighting social dynamics (using systems

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thinking and causal loop diagrams) that trap workers and their families in poverty. These hidden and unknown aspects have been discovered with the aid of qualitative analysis. This chapter concludes with a summary and some implications.

6.2. Qualitative analysis – drivers and social implications

This sub-section analyses qualitative data, collected via semi-structured interviews conducted with e-waste recycling workers. Data was analysed using NVivo software by dividing the information into four themes or nodes (Figure 41). The first theme was workplace environment, consisting of two sub-nodes on occupational health and safety precautions and work hazards. The second theme was driving interests for working in e-waste recycling, and further included two sub-nodes reflecting wages (financial benefits) as a driver, and a trade-off between money and health that workers make. The third theme is on worker attitude with three sub-nodes, highlighting the uncomplaining behaviour of workers, cognitive dissonance and some common unethical practices, such as stealing. The last theme reveals social implications, comprising four sub-nodes including workers' voice, value of life, opportunity cost and quality of life. Added to these themes, demographic details of workers were collected and they are presented later in section 6.3.

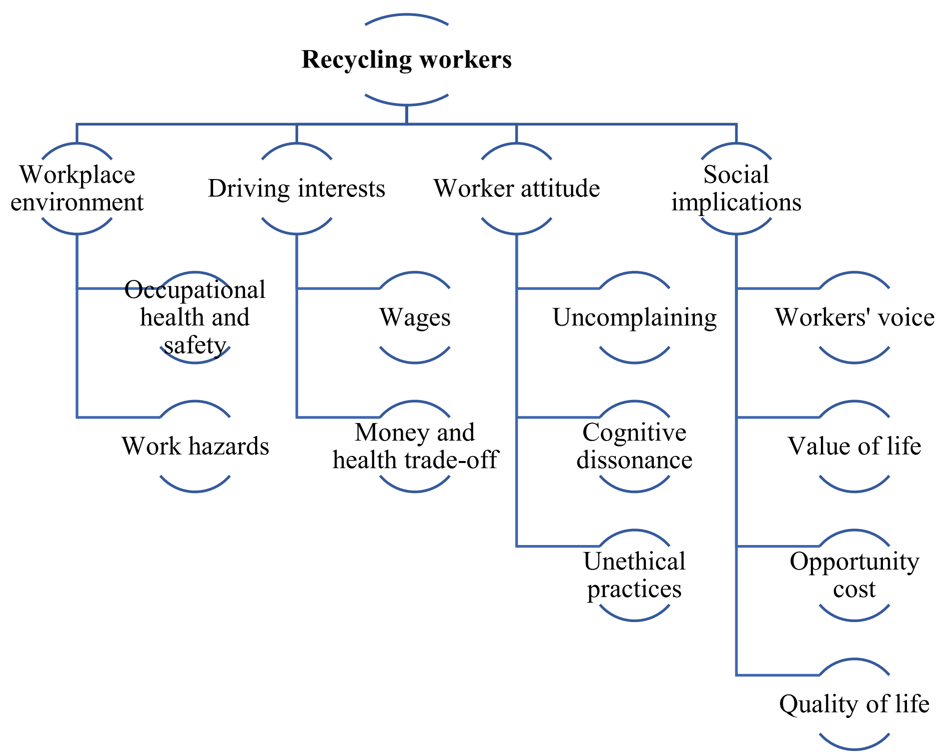

Figure 41: Themes from qualitative analysis

6.2.1. Workplace environment

The work environment and relationships among workers or between bosses and employees appeared to be friendly. Through the interviews, it emerged that workers who had more experience of working in e-waste, had been with the same boss ever since they started work. They had also spent many years working with their colleagues and so had a close bond with each other, and were seemingly content with their work. During a group interview, child labour was observed, with around six (6) children seen to be working with four (4) young adults (estimated ages 19-20). The children were lively and happy. No forced employment was apparent and these children would go around the streets playing during their work breaks. The business owner provided all workers, including children, the same food he had for himself. However, in some cases, if their bosses were around, workers were either reluctant to answer or their answers seemed to be, understandably, positively biased.

There was an element also of what appeared to be 'group-think' among workers, in that they tended to provide similar responses and wanted to respond as a group (safety in numbers). However, in some instances, such as when the worker being interviewed was relatively new, there was more independence in the answers (greater disclosure) and not biased through perceived loyalty towards colleagues and the business owner. New workers faced problems in integrating and getting along with other colleagues, and faced criticism at certain instances. For example, one young worker relatively new to the workplace was more open in his answers, including disclosing his wages, something that two relatively experienced work colleagues did not. Upon disclosure, an experienced worker laughed and commented, *"…he earns Rs.18,500 in a month, so now how much of his earnings should be paid in taxes?*", implying he was naïve to answer and should not have disclosed his earnings. This depicts a fear of tax authorities, but workers also appear not to know that they are being paid well below taxable rates.

6.2.1.1. Occupational health and safety

All recycling sites, from dismantling to extracting and refining were engaged in informal recycling practice using crude and primitive methods (see Figure 42 and Figure 43) and were scattered inside the city of Karachi. Most of the dismantling/scrapping work was being undertaken in small shops on a very small scale in Saddar (the main market in Karachi), but Shershah (an industrial area also in Karachi) was a central location for all kinds of scrap, not just e-waste.

Figure 42: Burning of motherboard

Figure 43: Process after burning

Photos taken by the researcher during field visits between September-November 2018 (Location: Shershah)

The dismantling sites in Saddar were open shops on the streets, operating with just natural source of light and air and sometimes a fan. There was no equipment other than hammers, pliers and other basic tools for dismantling. The workers sat and did their jobs around piles of e-waste or parts such as printed circuit boards (PCBs). Everything was done using bare hands, with no protective gloves, masks or any other safety equipment evident. In Saddar, some workers were also involved in the burning of motherboards and other boards that had gold-plated components. However, many of these locations were not easily accessible, and are located underground or at different levels of the premises for security and safety (from extortion). There was one dismantling site in the basement (parking) of a shopping plaza, which had fans but was suffocating. No toilets were found in any of the recycling facilities.

Shershah is a home of large go-downs (or warehouses), where businesses are large-scale (importers employing up to 200+ in the peak season) compared to smaller sites in Saddar (sole owners engaged in dismantling and then they on-sell to Shershah businesses, which in turn recycle and extract valuable metals, using informal methods). The e-waste recycling sites in the go-downs were open spaces, sometimes without any shelter or ceiling. The only source of air and light was the natural source. Informal methods were used to dismantle and extract the metals without any protective equipment. However, one recycling site had a first-aid kit and the owner/workers were trained to provide the first aid in case of any accident. They also took the workers to hospitals and paid the medical bills in case a worker was injured at work. Despite some minimum safety measures such as first-aid kit, the workers and owner were not fond of using protective equipment, especially gloves. This is because gloves made their work difficult and took longer to complete if they wore gloves. There were no toilet facilities seen at any of the recycling sites in Shershah.

Other than commercial go-downs in Shershah, many small e-waste recycling sites were located in the slum streets. One such facility was visited, which had separate 3 warehouses in the area. The warehouses were large and it was dark inside, the visibility was poor because they were located in very narrow streets where the sunlight could barely reach. There was a power failure due to load shedding at the time of the visit and the weather was very hot. Many children and a few adults worked in these facilities. The location was supposed to be hidden because the owner seemed concerned that if the researcher was successful in finding the site, the tax authorities might find them too. There were no measures and arrangements with respect to occupational health and safety; no protective equipment were provided; and the workers, including children were expected to unload the vehicles that brought e-waste for processing with bare hands. Workers admitted to being injured in the processes of unloading.

The last type of sites were metal extracting and refining sites. These were also located in the narrow slum streets of Shershah, and many gold refiners were located in Sarafa Bazaar (Saddar) where the gold extracted from e-waste was sold. In Sarafa Bazaar, gold was also extracted and refined directly from e-waste. These sites mostly had the ovens to melt the metals and then acids were used to purify. Therefore, the temperature was extremely high and workers melted the metals sitting right in front of burning ovens without any protective equipment. After melting, the process of purification produced toxic smoke from melting metals in the acids. Most of the purification sites had chimneys to remove the toxic air from the facility. The workers used informal methods, without any protective equipment such as gloves or masks, and relied just on chimneys for protection. There were consequently high occupational health and safety risks for this group because of the inherent toxicity. As one old worker explained:

> "*Recently my eye got damaged while extracting silver when a small piece of burning lead flew into my eye. I had to get it treated and now I get my eyes checked every three months*."

An insignificant moment of carelessness while recycling or refining can result in a significant, life-time loss in terms of health.

6.2.1.2. Work hazards

As already stated, informal processes are used to dismantle and recycle e-waste and their parts without any occupational health and safety measures at the workplace. Absence of such measures leads to the exacerbation of toxicity in the informal processes. At one recycling site, workers were dismantling printers and cleaning the cartridges on the pavement of a street of a residential area. These workers were all covered in multi-coloured powdered cartridges of laser and other printers, and breathing the same polluted air filled with ink particles. In the same facility, upstairs in the house, other workers were extracting metals by burning the boards. The researcher could just see the smoke coming out from the window. The owner of this site was rude and avoided speaking to the researcher. Workers across the street highlighted this hidden burning of e-waste, and also complained about the smoke and pollution due to ink cartridges. The workers dismantling and cleaning the printers did not mention any potential health hazards associated with their work.

At another recycling site, workers were dismantling the parts of e-waste, including motors that had copper coils. The facility was full of plastic and dust particles, and the researcher was covered in these particles after spending around 20 minutes in that facility. Just one worker, who was dismantling was wearing a protective mask, while other workers and the owner sitting next to him did not wear any mask and were inhaling the particles. One other dismantling site was located in the basement parking of a shopping plaza in Saddar. There were lights and fans but the heat, pressure and suffocation were unbearable, while workers spent around 8-10 hours in that facility every day.

Hazardous conditions of a higher intensity were observed in the recycling sites involved in metal extraction and refinery. Starting with the process of burning, several components are burnt for metals. Wires are burnt to extract copper (see Figure 44), while boards such as motherboards and cards were burnt inside facilities, sometimes in the open spaces. It results in direct inhalation of toxic smoke as wiring, paint, plastics and metals burn and fall off. Other than direct inhalation, the smoke is simply released into the environment. In the next processes of extraction, the burnt boards and metals are ground manually to form the powder, which is then mixed with acids. The temperature was extremely high and the workers have to sit near the oven. The heat, smoke and acid caused foul smell and bitter taste in the mouth after staying for about 30 minutes. After solidified metal is formed, it is boiled in nitric acid, which produces brown smoke as the acid boils and some of the copper evaporates, which is very hazardous. Chimneys and ventilation help a bit, but inhaling the toxins is still very dangerous. After extracting the desired types of metals, the liquid containing the acid, remaining metals and toxins are disposed of on the street or in open sewerage drains at the roadside. These processes are described in detail in APPENDIX 2.

Figure 44: Burning of wires

Photo taken by the researcher during field visits between September-November 2018 (Location: Shershah)

6.2.2. Why work in e-waste? (Driving interests)

Recycling workers were asked about the main reasons for their involvement in e-waste recycling. Results are presented in Table 39. Over 63% identified the lack of skills required for other work as the main reason for being in e-waste recycling. In effect, they were trapped in the industry because of their lack of skills and education, compounded by their poverty and overall sense of helplessness. This cycle was reinforced by some 37% of the workers indicating they had been in this work since childhood, had to meet the pressing financial needs of their family, and were not being physically fit for other labouring work. A worker said:

"... we cannot do any labour work after working in e-waste (metal extraction and refining) because we are not physically strong anymore for the work requiring physical exertion."

In addition, a worker mentioned that some critical events in his life lead to the situations in which he had to work in e-waste:

"*I learnt typing and shorthand writing, but I am working in e-waste because of some crisis that came up and I was helpless (majboor)*".

Illiteracy along with unfavourable circumstances such as personal circumstances led to some 26% respondents saying they had no option but to work in e-waste. Some employees (around 21%) worked in e-waste because it paid better than othe jobs they once had. As one said:

"*It is not my passion or something I like, but I have to do it because I have to earn money*".

Table 39: Why work in e-waste?

	Frequency	Total	Percentage
Not skilled for other work	12	19	63%
Other reasons	7	19	37%
No other option	5	19	26%
Family business	5	19	26%
Pays better than other work	4	19	21%

6.2.2.1. Wages (Financial incentive)

The main motive or benefit for working in the e-waste recycling was found to be financial, that is, providing them with the livelihood so they could feed and support their families, including wives, children, parents and families of their siblings. Most of the workers were reluctant to disclose their wages. However, it was found that workers earn somewhere between Rs.8,000 and Rs.30,000 per month, usually based on the level of experience. More specifically, out of those who disclosed their wages, around 50% earned Rs.20,000 per month or less, while the remaining 50% earned Rs.20,000-Rs.30,000 per month. Sometimes, workers are hired on a contract by recyclers (and importers) operating at a large scale in Shershah. Workers are also hired on contract, depending on the work and imports (containers) received. In that case, a new worker without any experience is paid Rs.500 per day, worker with some experience is paid Rs.800 per day, while an expert worker is paid somewhere between Rs.1200 and Rs.2000 per day.

The range of Rs.8,000 and Rs.30,000 is equivalent to AUD 75 – AUD 282 per month, or AUD 2.5 – AUD 9.4 per day. In Pakistan, this wage level is insufficient to cover the cost of living, especially for joint families. However, in most cases, other family members worked and contributed financially in order to make ends meet. For instance, 31.5% of the workers mentioned that their family members worked, while the rest 68.5% workers had no other source of personal income.

6.2.2.2. Income-health trade-off

Because of low earnings and the financial responsibility of the whole family, these workers just work in order to make the ends meet without considering their health. To explore the value these workers place on their lives, they were asked if they would be willing to accept lower income if working conditions were improved (and therefore, made less hazardous). A majority of workers (68%) did not want to accept any lower income for better working conditions while the remaining 32% agreed. Their wages were already too low that they could not accept any lower, or it would be difficult for them to survive, and as one work stated:

> *"I cannot accept lower income because I need to support myself and my family – kuch majboorian hoti hain insaan ki (*in local language*)*". Similarly, another worker voiced, "*I have to support my family, so I cannot afford to work for less money.*"

Some workers wanted better conditions but without reducing their wages, as one worker commented, "*Yes, we want better conditions, but no reduction in wages. If better conditions come at the cost of reduced wages, we are happy with whatever conditions we are currently working in*". A few workers were uncomplaining about the conditions, as one worker said, "*I am happy with whatever work I do and whatever money I get*". Similarly, another worker expressed, "*I am satisfied with the working conditions, and I need money for my family*". There were workers who worked for the money irrespective of their need, as one worker remarked, *"…more money is better; why would someone ever want to work for less money by choice?"*. Another worker with a similar mindset believed there should be a balance between health considerations and income, however, he emphasised the importance of having a high income. Contrary to the common belief, a few workers disregarded the importance of money. For instance, one worker said, *"…money is not the only important thing, learning the key skills is more important*."

One refining facility had strong chimneys that removed toxic air from the site. The workers at that site were very satisfied and were not concerned about the money they earned despite being paid Rs.8,000 per month. In order to determine the value of life and willingness to pay from these workers, the question was reversed, and they were asked if they were willing to accept higher wages if these facilities (like chimneys) were removed. These workers valued their health, and replied:

> "*…we have had several work offers that pay higher wages but working conditions were not safe. We always refuse and no amount of money can encourage us to work at such places*".

6.2.2.3. Value of life (Willingness to pay)

In order to determine the value of life of the recycling workers, when asked about how much lower wages could they accept in lieu of better working conditions (less hazardous), turned out only two workers (10.5% of the total workers) could seriously give up on financial benefit for their life or better health condition. One worker, who earned Rs.22,000 per month could accept Rs.18,000 per month and give up Rs.4,000 per month. Another worker, who was a gold refiner earned Rs.20,000 per month and could accept Rs.15,000 per month (giving up Rs.5,000 per month) for a workplace providing better working conditions. These results indicate that workers value financial benefits more than their health because their responsibility is to support their families financially. They are even willing to continue risking their lives by working in the same hazardous conditions when faced with no options to further decrease their income or livelihood. Therefore, the value of life for recycling workers is very low.

6.2.3. Recycling worker attitudes

Despite the informal work environment, low wages and negative health implications, the majority of workers interviewed were ***uncomplaining*** and acknowledged they were happy and satisfied with the work they did, the working conditions, and their wages. This attitude was likely influenced by the presence of the owners, but also reflective of a cultural habit of uncomplaining acceptance of fate and stoicism that leaves them happy with the bare minimum. For instance, a worker expressed the view, "*I am happy because I don't sleep hungry*". Similarly, another worker said, "*I am happy because I can run my household; I do not need to ask anyone for money for survival*". With respect to the working conditions, they have always worked in the same environment, so they are content. For example, a worker mentioned: "*everything (working condition) is good and we are happy with just the fans*", and another said, "*I am satisfied with the working conditions*".

The uncomplaining behaviour could be the result of *low agency*, coupled with a *sense of helplessness*. Low ambition or apathy are reflected in their continuing to work in a similar way without changing the methods while knowing fully well the negative outcomes of their workplace conditions. This, is partly explained by a sense of helplessness, as the workers have limited choices due to illiteracy and poverty. Therefore, anything sufficient to meet their needs is enough and the short-term is prioritised at the expense of health and environment in the long-term. Apathy likewise is evident in the belief by workers that nothing can be changed to improve the circumstances. For instance, while discussing the nature of work, one metal refining worker said:

> "*It is our fate ("taqdeer" in local language) to work here and we cannot do anything about it, so we should accept this fate*".

For some, this work environment could be better than their previous workplace, as a respondent mentioned, while working at a suffocating workshop located in the basement of a plaza:

> "*Earlier, I worked at a welding workshop and my eyes were swollen all the time, so now I am happy with my current work*".

A small proportion of the workers (11%) was genuinely ***happy*** with their work. These were the workers who had basic chimneys in their workplace, as a worker said, "*Our health is very good, the colleagues are friendly and our boss takes care of us." There have been visits from doctors and government authorities to check health and safety precautions, and they are always happy to see our facility and approve it"*. Happy workers are generally loyal and stay with their bosses for extended periods – more than 10 years or even their entire lifetime. These workers have developed a form of expertise by working at the same workplace over a long time, while their loyalty was seemingly earned by simple actions that conveyed a feeling of being cared for by the boss and through basic safety precautions such as chimneys "*…the seth (boss) is really good and is an expert. He understands the health risks that workers might face and he takes precautions for safety…so he has installed these huge chimneys which leave toxic smoke into the air*". The satisfaction with very little facilities to the workers shows that marginal improvements to the work environment can earn lifetime loyalty. According to one worker, *"I am happy at my current workplace. I am loyal and do not want to leave. I have grown up at this place"*.

However, some workers appeared and reported to be "happy" because their bosses were nearby and they were being observed. A worker reported cautiously while glancing at his boss, "*I am happy and my heart is satisfied; I like the boss because he is helpful and very easy-going*"; he was working in a basement while the boss sat nearby. In the face of being satisfied with the current work, working and health conditions, some appeared to be **open for any opportunity**, and seemed to be willing to switch their jobs if offered. One worker remarked, "*I can do every type of work, including laborious tasks*".

However, some workers were reported to be involved in **unethical practices**, such as stealing. An owner explained that in e-waste, gold plated components, including the pins and integrated circuits are the most crucial parts because they are the most valuable. Some workers, who extract these parts steal from the owners and carry out further processing separately in their homes:

> "*Some workers are dishonest, who steal half of the integrated circuits and return the other half after dismantling to their bosses*".

The motivation for this theft, with significant downstream health implications for the family, is personal financial benefit, masked by an excuse of not being paid enough.

6.2.4. Social implications

Social aspects have been divided into the following themes: health considerations, opportunity cost of working in e-waste recycling, the quality of life and disability adjusted life years.

6.2.4.1. The e-waste workers' voice (health considerations)

The voices of e-waste recycling workers in terms of health considerations are best captured by the word cloud in Figure 45 below. Interviews reveal social implications in terms of a lack of awareness of hazards, injuries and illnesses resulting from recycling practices, cognitive dissonance, non-availability of paid leaves and no choice or perceived agency, as discussed below.

Figure 45: Health / Agency considerations

6.2.4.1.1. A lack of awareness

Health considerations depend on the awareness or knowledge of possible risks associated with working in the e-waste recycling. The knowledge or awareness of potential risks in turn drives actionable response towards minimising the impacts. During the interviews, a lack of awareness was observed as most recycling workers believed their work was safe and did not cause any injury or illness. A common attitude among the workers was observed, especially those involved in dismantling, according to which the work was always safe, while it might be "others" who were involved in hazardous practices. For instance, one dismantling worker reported, "*…the dismantling and extraction business across the street causes cancerous pollution in the area we operate in. We get at least 10% of the total poisoning*". When asked if he believed his work was hazardous, he confidently replied, *"…our work is safe because we just dismantle. The stages after dismantling such as burning of PCBs are dangerous and carcinogenic but we do not engage in such work.*" However, heavy metal pollution has been found in the proximity of e-waste dismantling sites by several research studies (Lu, S-y et al. 2017; Shi et al. 2019; Xu, P et al. 2015).

Notably, extraction workers who were involved in burning and acid baths also failed to accept the hazardous nature of their work and their poor health despite being sick and subconsciously aware of the associated toxicity. A refining worker (X), who also happened to listen to the interview with another refining worker (Y) pointed out, "…*he* (the other worker - Y) *was not open to you, but he has actually been really sick recently and suffers from breathing problems like asthma*." Interestingly, this worker (X) did not mention any potential health-related problems for himself.

6.2.4.1.2. Injuries and illnesses

In terms of illness or injury due to hazardous working conditions, most of the workers asserted, "*…there is nothing we do that causes any injury or illness*" and "*everything is fine*". Some agreed to mild illnesses or injuries, for instance, "*…we just have work related stress but no other illnesses*". Two workers even joked, "*there is just one problem – when I started working in my childhood, I was cute, but now my skin colour has turned black*". Upon further probing, other workers added fever, wounds, injuries due to heavy lifting, breathing problems such as asthma as normal problems among e-waste recycling workers. Young workers were expected to load and unload heavy supplies from vehicles, resulting in wounds, sprains and injuries.

Moreover, sitting for long hours in awkward postures on low wooden stools leads to later ergonomic problems including back-ache and spine-related conditions. Out of the total workers interviewed, those working in metal extraction and refining openly admitted to the health hazards. This admission might easily be extended to include the hidden elements of the materials flow, particularly the proportion of raw materials that are stolen for the precious metals content and processed at home, almost certainly without protective equipment and ventilation. For instance, as a younger recycling worker (30+ years old) observed:

> "*People involved in this work have lives that are half the normal life. If normal life expectancy is 50 years, we just live for 25 years. We suffer from breathing problems, stomach problems and Hepatitis C. Our body eventually becomes hollow from the inside and organs stop working because we breathe in cancerous smoke. We feel so lethargic and physically weak that we can no longer walk or run or do any laborious tasks. It is all because of chemicals.*"

Another worker identified the source of toxicity, "*Toxic smoke is released when lead is added in the acid and integrated circuits, and we directly inhale it. The furnace oil we use to melt the metals also results in hazardous smoke that causes stomach, heart, lung diseases and worst of all, even cancer*". Direct skin contact with nitric acid creates a layer on hands, which turns yellow in colour over time and vanishes by itself after some time. Workplaces for metal extraction usually had chimneys and workers believed these chimneys made their work completely harmless, "…*acid is harmful and damages the lungs, but we do not know much about it because we have chimneys, so we operate in a safe environment*" (Figure 46). These workers were happy that chimneys removed toxic smoke from their workplace and that was deemed enough, "…*we have systems (chimneys) installed that release toxic smoke into the air outside our workplace*". What workers turned a blind eye on is that toxic smoke is as harmful when released into the environment through chimneys as it was when inhaled directly. One worker acknowledged that chimneys are not enough to protect the workers, *"…during the process, acid and copper evaporate and we inhale that smoke. Moreover, the heat is so high that not everyone can work in e-waste recycling; one must be very strong physically. Chimneys and ventilation help a bit, but it is still extremely dangerous.*" Yet, when asked, most workers responded that working conditions did not need any improvement, and in fact "*there is no need to improve the working conditions; we are happy here*".

Figure 46: Metal refining using acids

Photos taken by the researcher during field visits between September-November 2018 (Location: Sarafa Bazar, Saddar)

6.2.4.1.3. Coping behaviour - cognitive dissonance

An emphasis on "*we do not get sick and there is no need of improving the workplace conditions*" stems from what might be a simple coping mechanism prompted by "cognitive dissonance". Despite being consciously aware, these workers are seemingly unable to accept that using informal methods of recycling are hazardous for their health, the negative consequences of which could take just a few years to manifest. Most interviewed workers suffer from health problems but do not care much. One reason is that they do not understand the severity of health problems because local doctors are not able to diagnose the disease until it is too late and becomes fatal. Meanwhile, workers/patients maintain the idea they are suffering from normal stomach-ache or cough (symptoms).

It was also observed that although workers visited doctors when sick, most of them believed in taking "precautions". For instance, it was very common among workers to eat around 20 grams of jaggery (unrefined sugar, called "gur" in the local language) in the morning each day. Alternatively, they added jaggery to the morning tea in order to prevent any problems from smoke or acid. According to one employee:

> "*I eat gur (jaggery) whenever I have breathing issues due to work. It cleanses all the smoke from my throat and windpipe and takes it to my stomach.*"

Another remedy was to consume more food to gain more energy for work and when sick, and to have chimneys at the workplace to control the heat and smoke. However, when consistently sick, they did consult a doctor for treatment in most cases.

6.2.4.1.4. Non-availability of paid (sick) leave

Regardless of poor health, most of the workers continued work without taking any day off because paid sick leave is not available. Workers lost wages if they took any day off even when sick. Occasionally, if they felt unwell they sent their siblings or a family member to cover their shift for them. It was easier to take leave if workers were the relatives of owners, knew the owner well or if they owned/had some stake in the recycling business. Around 74% of employees usually take 2-8 days of unpaid sick leave in a month (amounting to 25%+ unavailability as the hidden cost of health related conditions). "*Sometimes if the condition is worse, I am unable to work for weeks or even months. I just have to stay on bed-rest. The condition of health is unpredictable*". Moreover, they spend somewhere between Rs.300 to Rs.3000 per month in medical costs every month, which could range from 4% to 10% of their monthly income. Medical costs actually have no upper bound. According to a worker:

> "*…Health and medical treatment - it is like a sinking ship where you are stuck. You just have to keep spending money on treatments, and you know you will die in the end anyways (the ship will sink)*."

6.2.4.1.5. No choice or perceived agency

High risk of life-long illness and early death are realities compounded by a lack of agency. The effect is this apathy and inability to think beyond what is immediately required - to stop caring about health – because they will die in the end anyway so other options are not considered. As an older worker highlighted, "*My age fellows who worked in e-waste recycling with me have all passed away; only a few are alive including myself. I take care of my health and have a blower/ chimney that removes heat and smoke. The average age [expected lifespan] of people who are in e-waste recycling is around 50-55 years*." The same worker/owner had chimneys at the workplace but suggested that other businesses should have fire extinguishers, masks, gloves, blowers and chimneys installed for the workers.

The risk of mortality due to accidents at the workplace is high, resulting primarily from a lack of technical and work-related knowledge. Imported e-waste sometimes contains other types of scrap equipment that e-waste workers are unfamiliar with and not skilled enough to identify. A worker narrated an incident:

> "*There have been instances of bomb blasts in several go-downs nearby, where workers dismantle the equipment which turn out to be actual bombs (some are usually found in the scrap/waste) and the bomb explodes. This has happened in 2-3 go-downs. The most recent accident took place about 6 months ago. A worker was breaking/dismantling the scrap without knowing what that equipment really was (a bomb), and he hit it with channi-hathora (hammer). There was a huge blast and that worker died*!".

Even after being affected by such accidents, workers have no choice or perceived agency but to continue to recycle e-waste in these harsh working conditions. As discussed earlier, most of the workers do not have skills for any other job, so they are trapped because of unfavourable circumstances. According to two employees:

> "*Earlier, I was a mechanic, but now I am working in e-waste recycling because of some problems and I have no other option*".

> "*I work in this industry because I have to earn for my children. I was the eldest son in my family, so financial responsibility of the whole family rests on my shoulders*."

6.2.4.2. Opportunity cost

The decision to work in e-waste recycling comes at a cost, not just financial or health-related costs but also the opportunity costs. Firstly, there is an opportunity cost in terms of time. If a worker spends 8-12 hours at work for 6-7 days a week, he does not have enough time left for any other part-time job if his financial conditions are pressing. Also, he might not have quality time to spend with his family given the physical exertion required at work. In the case of children (child labour - not interviewed), not being able to attend or afford the school consequently means a significant loss in the human capital and in life-time earnings. Secondly, financial opportunity cost could be assessed through other employment opportunities/ jobs given up for the sake of e-waste recycling.

Around 42% of the respondents believed they could get any other job if they searched, while 42% responded positively about finding a job if they tried. Possible work could be laborious tasks in factories (more exhausting physically), working in some general/convenience store, bike mechanics, but also some risky jobs, such as welding. One of the young workers aspired to join the police but was not successful in the recruitment process. The remaining 16% of respondents had never even tried to look for any other work. This group did not know if any suitable opportunities existed for them. Out of the total people who responded they could have job opportunities, 37% believed it would pay less than their current jobs (e-waste recycling), 10% responded it might pay higher, while 53% had no idea about what other opportunities might bring.

6.2.4.3. Quality of life

Despite hazardous working conditions, poor health and poverty among the workers, they regarded their lifestyle and quality as better than those not working in e-waste recycling. About 57% of the worker respondents were of the view that their lifestyle was better, 21% believed it was the same, and remaining 21% responded it was worse than others. Mainly refining workers reported their lifestyle to be worse than other people and did not recommend others to get involved in this work due to the toxic nature and health risks. The workers who responded positively about their lifestyle were happy because they could feed their families without asking anyone for money and were satisfied after accepting it as their fate, they could do nothing about. A few also responded positively because they could not be ungrateful to God for whatever they were blessed with:

> "*…thanks to Allah that every person is spending their lives well in their own ways. Everyone can happily spend their lives according to their willingness and happiness. Nobody would want to call their own lives worse than the lives of others*."

The majority of workers did not have hobbies or any recreational activities. Culturally, in Pakistan, most people go on tours or excursions annually during summer or long vacations. Recreational activities are even less popular among less privileged people such as e-waste recycling workers. Most workers had no time for such things and would just prefer to go home (Punjab – another province) and spend time with their families instead. Based on the studied factors, the quality of life of e-waste workers appeared to be poor. However, since the majority of the workers believed their lifestyle and health was better compared to others when they were asked explicitly, it was difficult to measure or assess the quality of life (QoL). Instead, another measure, called Disability Adjusted Life Years (DALYs) was used to assess the quality of life.

6.2.4.4. Disability adjusted life years (DALYs)

Disability adjusted life year (DALY) is a measure that summarises overall burden of disease. It combines "mortality" – the years of life lost due to premature death with "morbidity" – a measure on all non-fatal illnesses. One DALY signifies an equivalent loss of one healthy year from life. Total DALY attributable to the environment represents burden of disease that could be avoided by altering the environment. Environment that could be modified includes air, water (polluted), soil, built environment, noise, electromagnetic fields, occupational risks, ecosystem degradation, individual behaviours related to the environment such as cleanliness, food contamination and unsafe drinking water.

Estimates have been made by the World Health Organization based on a combination of comparative risk assessments; calculations based on some limited epidemiological data; entire attribution of certain diseases to the environment based on their transmission pathways; and surveys of expert opinions on the attributable fractions for some environmental risks. Attributable fractions were estimated for 92 out of the 133 major diseases and injuries quantified by WHO.

According to the data in Table 40, total DALYs for Pakistan are 19,468,399, which means 19,468,399 years of healthy lives are lost due to environmental factors. This is equivalent to the total healthy lives of 19,468,399/66 = 294,976 people, given the normal life expectancy in Pakistan is 66 years. The major implication is that every year, an equivalent of 294,976 people die because of some sort of disability. Over and above this there is a loss of production. Considering the fact that this is simply the normal environment in Pakistan, the DALY loss to e-waste recycling workers will be much higher. In e-waste recycling, the normal life expectancy in Pakistan is nearly half of the normal population. If we calculate the number of equivalent lives, it appears 589,951 people (19,468,399/33) lose their lives annually from the effects of their work environment.

Table 40: Disability Adjusted Life Years for Pakistan

	Disability-adjusted life years (DALYs) attributable to the environment	Disability-adjusted life years (DALYs) attributable to the environment (%)
Infectious, parasitic, neonatal and nutritional	9 569 515	
Non-communicable diseases	5 744 589	
Injuries	4 154 295	
Total	19 468 399	23%

Source: World Health Organization (2016)

6.3. Cost-benefit analysis

This subsection presents a cost-benefit analysis (CBA) using financial and non-financial (social) costs and benefits to e-waste recycling workers.

6.3.1. Demographics

The sample workforce comprised largely illiterate males, aged 18 to 60 years (see Table 41). Most workers indicated that they had worked in e-waste recycling since childhood – estimated from age 7 years onwards, and site visits visually confirmed the presence of young children at some workplaces.

Table 41: Demographics and socio-economic factors of e-wase recycling workers

Demographics	**Frequency (N = 19)**
Gender	
Male	19
Female	0
Tasks (Multiple response)	9
Collector	14
Dismantler	8
*Metal extractor**	9
*Metal refiner**	
Age	
18-24 years	7
25-34 years	7
35-44 years	1
45 and older	4
Education	
No schooling	8
Primary (grades 1-8)	6
Secondary (grades 9-12)	5
Contract	
Permanent	0
Temporary	0
Local residence	
Yes	6
No	5
Punjab (another province)	8
Experience	
Less than 1 year	2
1-10 years	7
11-20 years	5
21-30 years	2
31-40 years	3
Wages (Rs.)	
Rs.8, 000-10,000	2
Rs.11, 000-20,000	3
Rs.21, 000-30,000	5
Did not disclose	9
Income from other sources	
No	6
Yes, family income	13

While the government has established regulations for child labour consistent with the ILO Worst Forms of Child Labour Convention (C182) and Minimum Age Convention (138) that define the minimum age for employment, including hazardous work, as 14 years (International Labour Organization 2014), there is a general lack of enforcement of these regulations. As this study did not have ethics clearance to collect data from children, only workers who claimed to be aged 18 and above were interviewed. The e-waste recycling sector largely employs people locally, but the majority of workers appear to have moved to Karachi from other provinces (typically Punjab) in search of employment. None of the workers interviewed had any sort of employment contract, not any kind of employment benefits or protective clothing. Due to lack of access, the workforce composition of the hidden and below the ground recycling sites is unknown.

Workers could be termed as 'skilled' in informal recycling methods that involved dismantling, burning, melting and otherwise extracting (using acid baths) precious metals from e-waste components. These skills are acquired on-the-job, learned by observation and practice, with the boss (teacher or *ustaad*) usually training new workers. Skills were reported also as having been passed on from family members. Due to the laborious nature of the job, long working hours were reported as required. A large number of workers (58%) reported working for 6 days in a week, with some (37%) indicating they worked all 7 days in a week. Normal working hours were 10-12 hours, but some workers (36.8%) reported they worked for 8 hours a day. These general work practices appear to contravene the Factories Act, 1934 passed by the International Labour Organization and ratified by Pakistan. According to this statute, no adult employee (those above the age of 18) can be required or permitted to work in excess of 8-9 hours including breaks per day and beyond the maximum of 48 hours a week (International Labour Organization 1934). Further, the legislation entitles workers to over-time pay that is twice the ordinary rate if they work for more than 9 hours a day.

In reality, however, the wages of e-waste recycling workers ranges from Rs.8,000 to Rs.50,000 per month (USD 48 – 298) without any allowance or compensation for over-time work. This appears to be normal practice in the industry. With minimal wages, these workers struggle to financially support their extended families that typically consist of 1-6 members (47%) or even larger groups of 7-10 members (53%). As a result of long working hours, there is no option to supplement their income from other sources and in order to make the ends meet, the priority is for all or as many family members as possible to seek work to sustain the family financially. The priority is income generation and not worry about one's health or its implications for the family.

Table 41 shows the detailed demographics and socio-economic factors of the sample e-waste recycling workers. The items in italics and with an asterisk identify tasks that involve the use of oxyacetylene torches and acid baths, and known to be toxic (Sovacool 2019; Sthiannopkao & Wong 2013). These tasks typically result in significant exposure of workers to toxic fumes and to lead inhalation (Nie et al. 2015).

6.3.2. Estimation of costs

Economic costs have been divided into two components - financial and non-financial (social). Three estimates for each cost/benefit are identified: minimum, average and maximum, in order to account for variation in responses. Equivalent costs/benefits in USD are calculated using the conversion rate of Rs. 167.686/USD (correct as of 1 July 2020).

6.3.2.1. Financial costs

Financial costs are tangible, directly measurable and have been measured in terms of reduction in productive capacity, lost wages and medical expenses.

6.3.2.1.1. Reduction in productive capacity

Reduction in productive capacity depicts the wages lost due to inability to work after a certain age (illness) or premature death. As highlighted by interview participants[9], the lifespan of e-waste recycling workers is almost half that of the normal population. Assuming an average lifespan of 66 years (The World Bank 2017a) and workers being unable to work due to illness or death for the last 15 years of their lives, it is estimated they work to the age of 50. Thus, the total number of productive years is around 35. To account for variability, estimates are also made for 20 and 25 lost years. Reduction in productive capacity was calculated as the yearly wage multiplied by the number of years lost (15, 20 and 25 years). Accordingly, monthly reduction in productive capacity was calculated as Rs.8,000-Rs.50,000[10] (USD 48 – 298).

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[9] The average lifespan of e-waste recycling workers is self-reported and needs further research.

[10] Wages (monthly): Calculated as the wage rate multiplied by 25 (days in a month).

6.3.2.1.2. Lost wages

Lost wages depend on the number of unpaid leaves taken by the workers, which is 1-14 days a month. Lost wages have been calculated as a product of the number of unpaid leaves and average wages. Therefore, lost wages could range somewhere between Rs.320 and Rs.28,000 (USD 2 – 167) per month. However, as an example, if workers were bedridden for weeks, no upper boundary to lost wages was calculated.

6.3.2.1.3. Medical expenses

Medical expenses as a result of work-related illness vary from Rs.300 to Rs.10, 000 (USD 2 – 60) per month, depending on severity of the illness. The worker pays these expenses.

6.3.2.2. Non-financial (social) costs

Non-financial or social costs in terms of 'negative benefits' for the workers have been assessed through opportunity cost, illiteracy cost (absenteeism from school) and the value of life.

6.3.2.2.1. Opportunity cost

Opportunity costs represent the wages, as well as education, training and even health, foregone as a result of working in e-waste recycling. The issues of regional geography, poverty, illiteracy and lack of skills are interlinked. There are few employment opportunities for these workers and most report that they have not even searched for other jobs, although a few workers admitted they could find alternative work as a labourer for daily wages, which pays Rs.800-1,200 (USD 5 – 7) per day. Multiplying this daily wage rate by 25 days in a month, the likely monthly wage as a labourer is around Rs.20,000-Rs.30,000 (USD 119 – 179). It is clearly a potential opportunity cost for e-waste recycling workers.

6.3.2.2.2. Cost of illiteracy

Most people in the e-waste recycling industry started working as children and as a result tend to forego education. The resultant illiteracy has its own socio-economic costs in terms of health, crime, lost earnings, welfare, lost future business opportunity and other societal problems. In this study, the personal cost of illiteracy is measured only in terms of lost earnings. According to a report by the World Literacy Foundation, illiterate people earn about 30-42% less than their literate counterparts (World Literacy Foundation 2018). To estimate the lost earnings (personal cost), average monthly income in Pakistan was used from Pakistan Bureau of Statistics (2017b) as Rs.35,662 (USD 213). The minimum and maximum illiteracy cost was calculated as 30% and 42% of the average monthly income, estimated to be Rs.10,699 and Rs.14,978 (USD 64 – 89), which is lost each month throughout their lives. Moreover, as they have limited opportunities for promotion and personal or professional growth, workers' incomes remain static throughout their lives. In contrast, the income of educated workers can double or triple from their initial salary (Lal 2015). This growth has not been considered due to the lack of data. Another aspect that has been excluded from calculations (in Table 42 presented later with restults) is the cost of illiteracy to society, which was estimated for Pakistan by Cree, Kay and Steward (2012) as USD 5.86 billion per annum. Equivalent (Rs.) illiteracy cost to the society in can be estimated as Rs. 982.64 billion each year or Rs. 81.887 billion each month.

6.3.2.2.3. Value of life

The value of life or value of statistical life (VSL) is the cost of life in economic terms, which can be estimated by how much a person or society is willing to pay for reduced risk of death or to avoid a fatality. Workers were asked how much they would accept in lower wages in lieu of better working conditions (less hazardous). It turned out only two workers could give up immediate financial benefit for a better life or better health condition. One worker, who earned Rs.22,000 per month could accept Rs.18,000 per month and give up Rs.4,000 (USD 24) per month. Another worker, who was a gold refiner earning Rs.20,000 per month, said he could accept Rs.15,000 per month (giving up Rs.5,000 or USD 30 per month). Interestingly, the value of life is the lowest of all non-financial (social) costs in Table 42, meaning the life of these workers is the least costly. These workers seek financial benefits over health considerations. What drives this behaviour is a sense of responsibility to support their families financially. Evidently, the value of life, as an economic value for avoiding a fatality for recycling workers, is very low. Similarly, the implied societal cost of averting a fatality is also very low.

6.3.2.2.4. Other non-financial (social) costs

Other non-financial or social costs include firstly, the cost of not being able to interact or socialise due to long working hours. This cost is particularly applicable to Pakistan, a collectivist society that places a high value on interaction and loyalty to the wider community. Because of the difficulties in measuring this cost and with no estimates found from comparable countries in the literature, this cost has not been included in this study. A second and more tangible non-financial cost is working over-time or on weekends as identified in section 6.3.1. The official over-time rate is double the normal wage rate. However, the reality is that the wages for recycling industry workers are calculated either on a daily, weekly or monthly rate, without over-time allowances being paid. This appears to be normal practice throughout much of Pakistan, so it has again not been included as a social cost.

6.3.3. Estimation of benefits

Similar to economic costs, economic benefits also consist of financial and non-financial (social) benefits.

6.3.3.1. Financial benefits

6.3.3.1.1. Wages and meals

Financial benefits include wages and meals provided for workers by business owners. Monthly wages of e-waste recycling workers vary between Rs.8,000-Rs.50,000 (USD 48 – 298) while business owners provide meals worth Rs.1,250-Rs.2,500 per month (USD 7-15). The total monthly financial benefit ranges from Rs.9,250 to Rs.52,500 (USD 55 – 313). This benefit is lower than total financial cost (Rs.8,620 to Rs.88,000 or USD 51 - 525) owing to the greatly reduced productive capacity due to ill-health or early demise.

6.3.3.2. Non-financial (social) benefits

Non-financial (social) benefits are those additional benefits accrued by participating in an industry. Potential social benefits of e-waste recycling identified include employment opportunities, already incorporated as wages in financial benefits. Other benefits include learning new and relevant skills on the job. The direct benefits of skills and employment opportunities, along with items as relief and protection for vulnerable migrants, community identity and dignity, efficient scrap collection and a cleaner city have been identified as ‘ostensible benefits’ by other researchers (Rodrigues, Angelo & Marujo 2020; Sovacool 2019; Zhang, K, Zeng & Schnoor 2012). Any comprehensive analysis should include social benefits but results from the interviews and literature suggested limited social benefits to the workers. Therefore, this study does not include quantitative social benefits. Society-wide costs and benefits in terms of environmental pollution and provision of recycling services, are respectively recognised but also seen as not part of the scope of this study.

6.3.4. Present values of costs and benefits

Present value of all costs and benefits has been calculated as total cost or benefit for a person's lifetime. Firstly, yearly costs/benefits were estimated from monthly costs/benefits. Secondly, the expected remaining life or life expectancy was determined based on interview findings. Using an average male lifespan of 66 years in Pakistan (The World Bank 2017a) and a minimum productive age of 15 (International Labour Organization 1973), the number of productive years were taken to be 25, 30 and 35 years in order to incorporate variations. Thirdly, for discounting, the interest rate at which the public can borrow money from the banks was used as 29% per annum, taken from the websites of different banks (HBL 2019; UBL 2019). The other two discount rates used in calculations were 20% and 38%.

Present values were calculated for the total costs/benefits using discussed parameters, and it was found that net economic cost or a reduction in lifetime earning to each worker is between Rs.1,073,587 and Rs.5,093,629 (USD 6,402-30,376), with an average of Rs.2,075,958 (USD 12,380). This relative imbalance in cost/benefits for recycling workers has not been previously quantified and was unknown. It is a lose-win arrangement for workers, arguably trading their health and ultimately their lives for immediate financial need.

6.3.5. Results of the cost-benefit analysis

Table 42 presents a summary of costs and benefits where total economic cost and benefits are calculated as a sum of financial and non-financial (social) costs and benefits. Based on estimates, the average monthly economic cost of working in e-waste recycling is about Rs.82,238 (USD 490) and average economic benefits amount to Rs.31,875 (USD 190) per month. Overall, economic costs are assessed as being higher than economic benefits. There is average net economic cost to a worker, estimated as Rs.50,363 (USD 300) per month and Rs.2,075,958 (USD 12,380) over a lifetime per worker. It can be seen that economic costs are about 2.6 to 4.7 times higher than economic benefits. Implication being that although informal e-waste might provide financial benefits for survival but is socially disadvantageous for the workers.

Table 42: Economic (financial and social) costs and benefits

ECONOMIC COSTS AND BENEFITS						
	Rs. per Month			Present Value (Rs.)		
COSTS	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**
Financial Costs						
Reduction in productive capacity	8,000	30,000	50,000	250,616	1,233,757	2,968,552
Lost wages (unpaid leaves)	320	8,400	28,000	10,102	347,419	1,677,156
Medical costs	300	1,500	10,000	9,471	62,039	598,984
Total financial cost	**8,620**	**39,900**	**88,000**	**270,189**	**1,643,215**	**5,244,692**
Non-financial (Social) Costs						
Opportunity cost	20,000	25,000	30,000	631,378	1,033,985	1,796,953
Illiteracy	10,699	12,838	14,978	337,756	530,972	897,159
Value of life (WTP)	4,000	4,500	5,000	126,276	186,117	299,492
Total Social Cost	**34,699**	**42,338**	**49,978**	**1,095,410**	**1,751,074**	**2,993,604**
Economic costs (Financial + Non-financial)	**43,319**	**82,238**	**137,978**	**1,365,599**	**3,394,289**	**8,238,296**
BENEFITS						
Financial Benefits						
Wages	8,000	30,000	50,000	252,551	1,240,782	2,994,921
Food, tea	1,250	1,875	2,500	39,461	77,549	149,746
Total financial benefit	**9,250**	**31,875**	**52,500**	**292,012**	**1,318,331**	**3,144,667**
Non-financial (Social) Benefits						
Employment	-	-	-	-	-	-
Skills	-	-	-	-	-	-
Economic benefits (Financial + Non-financial)	**9,250**	**31,875**	**52,500**	**292,012**	**1,318,331**	**3,144,667**
NET ECONOMIC BENEFITS (COSTS)	**(34,069)**	**(50,363)**	**(85,478)**	**(1,073,587)**	**(2,075,958)**	**(5,093,629)**

6.4. Discussion

Analysis of downstream cost-benefit for e-waste recycling workers suggests the e-waste recycling industry provides employment and a livelihood for a significant number of people. These workers accrue economic benefits of around Rs.9,250 – Rs.52,500 (USD 55 – 313) per month. In comparison to average wages, it appears that workers incur economic costs (financial and social) of around Rs.43,319 - Rs.137,978 (USD 258 - 823) per month. After netting the costs and benefits, the effect is economic cost of Rs.34,069 – Rs.85,487 (USD 203 - 510) per month. Besides these quantitative estimates, interviews reveal social dynamics of a '*Poverty trap*' for recycling workers that are not easy to quantify and sustain current e-waste recycling practices.

6.4.1. A poverty trap

Figure 47 below illustrates the downstream social dynamics involved for the recycling workers.

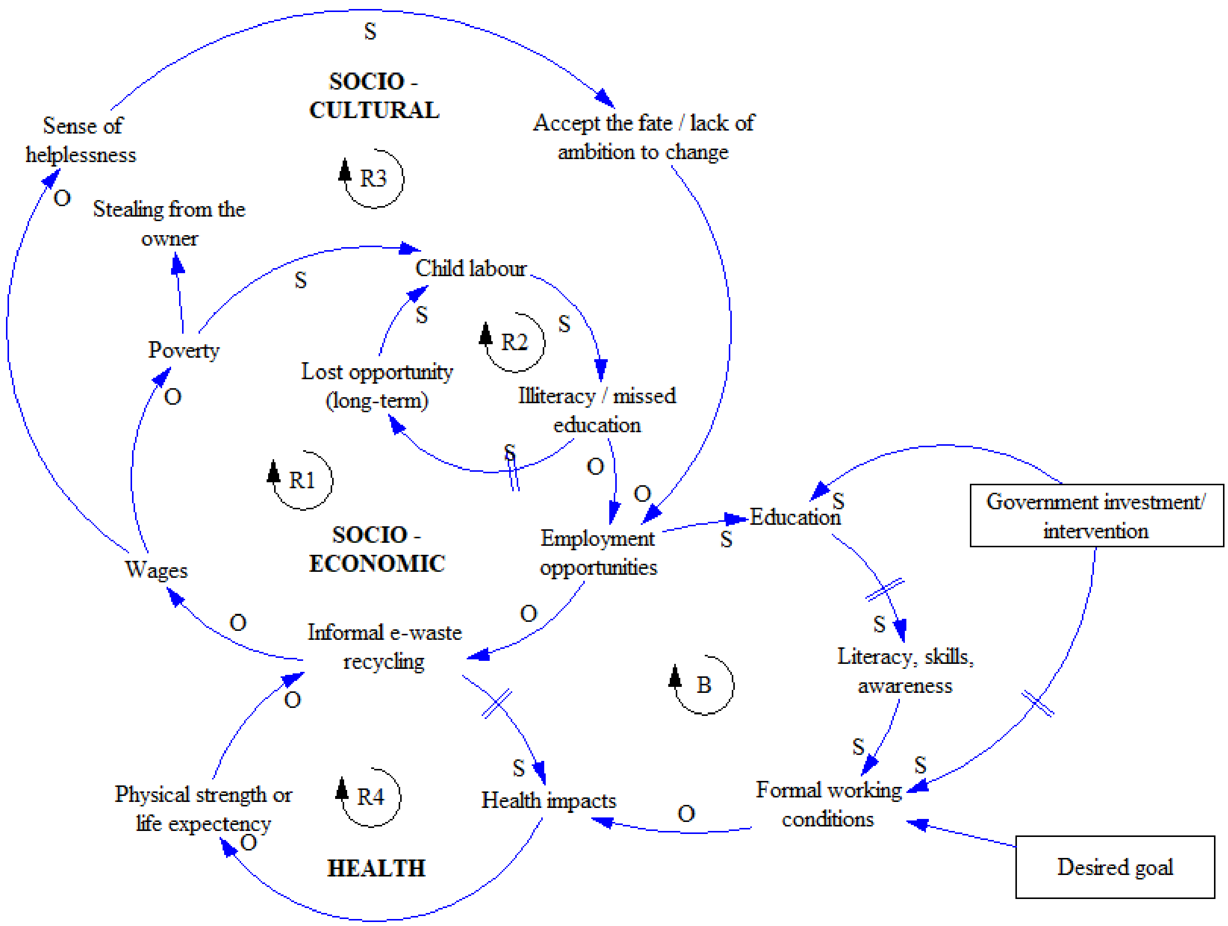


Figure 47: Downstream Social Dynamics (Poverty trap)

Externally, the industry is sustained by low wages and loose regulatory oversight that crosses international borders. Within the industry it can be argued that these workers are driven by the need to generate income for survival (socio-economic reasons). The consequences of the prevailing conditions, however, can be described as workers are caught in a poverty trap reinforced by socio-economic factors, but one that is also supported and sustained by socio-cultural and health considerations. Reinforcing loop 1 (R1) starts with working in informal e-waste recycling, which pays workers the wages and meals needed to meet their basic needs. Typically, although not the focus of this study, children work (as young as 7) to supplement the family income and they are employed in recycling-based work. This employment comes at a cost to their education, as these children are not able to attend school. The downstream effect for these children is to be trapped in a hazardous workplace and missed opportunity for better work options over a lifetime. Deprived of opportunities that come with education the costs are systemic illiteracy, as the next generation too abandons their basic right to an education for family income. In the short-term, illiteracy and lost opportunity (R2) in terms of education reinforces the need to keep working in the informal e-waste recycling industry.

In the long run (R4), it can be seen that recycling workers also face serious health conditions that are shown by a delay in the reinforcing health loop. Often, poorer health in turn makes these workers weak and unable to toil in other labour-intensive unskilled jobs, which forces them to continue working in e-waste. These factors along with lower wages create a sense of helplessness and a lack of agency, where recycling workers become fatalistic about their lives and believe they have no choice and power to change circumstances (R3). Thus, workers tended to accept everything as fate – and this general external locus of control results in the idea that they cannot change the situation. Rather, workers are uncomplaining, grateful to God and happy with whatever they have, and for instance, something as basic as the provision of a chimney in the workplace earns the business owner lifetime loyalty.

The reinforcing loops (R1-R4) collectively depict a vicious cycle – that together make up the poverty trap for workers. There is no easy way out, and at business level breaking the cycle requires an external intervention by the government and business investors – to turn the balancing loop (B) arguably into a virtuous reinforcing cycle (R5), based on skills, regulatory interventions and formal recycling technology. Supported by training/skills of workers, direct investments and ideally subsidies by government, the desired goal is to formalise recycling using technology. Beyond a sustainable industry, R5 would also reduce the negative second-order health and environmental effects, and open the doors for better first-order employment opportunities.

6.5. Summary and implications

The chapter highlighted and estimated the known and also less visible, financial and non-financial costs of informal recycling, which so far has no visibility because of a lack of data. Estimating economic costs and benefits (financial and non-financial or social), the focus was on downstream effects on recycling workers. Using estimates that are modest as it only relies on known and quantifiable costs, the study contends that these costs (monthly and lifetime) are 2.6 – 4.7 times higher than the financial benefits received. Average monthly net economic cost to each e-waste recycling worker is estimated to be about Rs.50,363 (USD 300), while for a lifetime, it accumulates to about Rs.2,075,958 (USD 12,380).

Behind the façade of financial benefits are unknown first-order (immediate) social costs, while second- and third-order societal and environmental effects are as yet unknown or in a blind spot. Poverty leaves workers and their children – who, as is normal social practice, are incorporated into supplementing the family income – no seeming choice, but to work in an industry that is injurious to their health and that robs children of opportunities that come with education. Compounding this harsh reality, workers suffer from serious work-related illnesses that are as yet not quantified but which weaken their capacity to earn a living, and for many ensures an early demise. As qualitative data also suggests, owners of recycling businesses may be unaware or apathetic towards the less visible negative social and environmental impacts, while recycling workers and their families appear trapped in a cycle of poverty.

Noting that what can be measured can in the future be better managed, a systematic assessment of informal recycling, based on identified impact factors at the latter end of the electronic equipment supply chain, is crucial to mitigate and even avoid the consequential negative impacts, both visible and hidden. In order to break the vicious cycle of poverty and curtail the negative net economic (financial and social) costs, this study strongly recommends the need for government intervention at many levels. Firstly, government intervention is required in education to open the doors for better first-order employment opportunities for e-waste recycling workers, but also to support skills and knowledge to move towards the formalisation of this industry. Secondly, to facilitate the process of formalisation, investment from the government and business owners is required with an emphasis on technology.

CHAPTER 7: DISCUSSION – A CRITICAL REVIEW OF E-WASTE MANAGEMENT AND RECYCLING

7.1. Introduction

The focus of this study was Pakistan, a country that generates a significant volume of e-waste and imports e-waste for recycling, despite lacking the necessary infrastructure. As the preceding chapters in this study revealed, e-waste is a highly profitable business opportunity for the valuable materials that can be recovered. At an ecosystem level, however, there is great cause for concern. The principal issue is that of informal recycling practices that are not limited to Pakistan but replicated in many other developing economies. Aside from the inadequacies of informal recycling in terms of the hazardous conditions for workers and ineffective recovery and reuse, a significant quantity of waste product that includes toxic materials goes into landfill or into waterways. As the study reveals, these limitations and externalised costs are counter-balanced by the short-term gains at a business level. Recycling is still highly profitable for businesses and it provides much needed employment for the families of business owners and unskilled workers. Shifting our attention upstream, the challenge of e-waste recycling is compounded by systemic weaknesses in policy and in governance systems for waste management, specifically the e-waste recycling industry.

This study is a critical analysis of e-waste management and recycling in Pakistan. It used a Life Cycle Assessment (LCA) approach based on mixed methods to examine the structures, processes and costs of upstream generation[11] and downstream recycling and disposal in the country. As noted during the research, problems and challenges related to e-waste, like other complex social problems in (businesses and) wider societies, are interwoven and interdependent. The study draws attention to the complex processes from waste generation to disposal, while also highlighting the motives and dynamics that sustain the prevailing informal approaches to e-waste recycling in Pakistan. This chapter presents a synthesis of study findings with respect to the research question (RQ): "*What are the economic impacts of e-waste disposal (and recycling) practices?*" The economic impact includes both financial and non-financial or social costs and benefits measures.

[11] Estimates of volumes of upstream e-waste generation only include two out of six categories of e-waste. The two categories are: category 2 (Screens) and category 5 (small IT and telecommunications equipment). Downstream cost-benefit analysis includes mixed e-waste from all categories.

Conceptualising the e-waste lifecycle into four stages, manufacturing and usage (upstream), and recycling and impacts (downstream), two sub-questions (SQ) and subordinate research objectives (RO) were identified to examine the RQ. To recall, these were:

SQ1: What is the current (upstream) situation with e-waste generation and disposal in Pakistan?

> **RO1:** Analyse consumer behaviour concerning the acquisition, usage, disposal, awareness and willingness to pay for e-waste management.
>
> **RO2:** Assess the flow (and stock) of electrical and electronic equipment/e-waste through the upstream sector.

SQ2: What are the (downstream) impacts of e-waste recycling practices in Pakistan?

> **RO3:** Estimate the costs and benefits of e-waste recycling for businesses.
>
> **RO4:** Assess the drivers, social implications and economic cost-benefit of working in the e-waste recycling sector (workers).
>
> **RO5:** Identify a framework for e-waste impact assessment for developing countries (based on multiple criteria).

The broad approach to quantifying upstream waste creation and assessing the cost-benefit of downstream disposal in Pakistan was based on an ecosystem model. Three analyses were conducted: a Life Cycle Assessment or LCA, which is a 'cradle to grave' technique to assess impacts through all stages of a product's life, as well as a material flow analysis (MFA) and a cost-benefit analysis (CBA). We first review upstream generation and disposal practices of e-waste, followed by an impact assessment of downstream costs (financial and non-financial) for the two stakeholders involved – recycling businesses and workers. Based on a structured approach this research sets out to quantify the known costs, both financial and non-financial, of a convoluted and interconnected (wicked) problem. In the process, the study identified less known, unknown and even some hidden downstream costs, and attempted to quantify these costs, in the spirit of Drucker's logic that *what gets measured can be managed*. Figure 48 illustrates the research objectives of this study at the corresponding stages of e-waste life cycle and the chapters where these objectives were answered in this thesis.

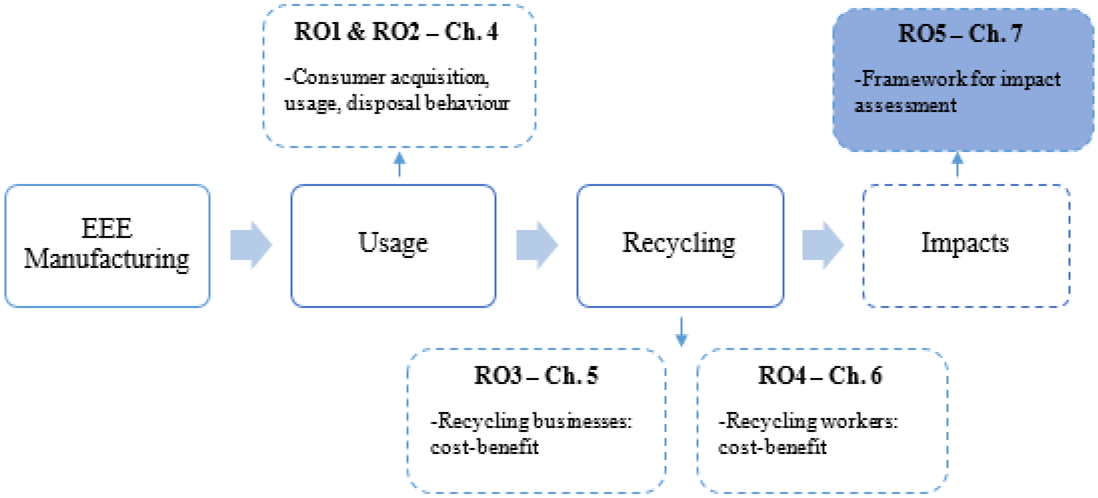


Figure 48: Placing RO5 in the e-waste value chain

7.2. Discussion: a multi-stakeholder view of intervention

E-waste is an international phenomenon that involves and impacts on multiple stakeholders and the environment, both directly and indirectly. Figure 20, the ecosystem model, helped guide a multi-stakeholder view based on a LCA, to examine both upstream and downstream events. The LCA-based consideration of the various stages of e-waste extended to the conventional supply-chain frameworks that typically end at the consumer (see Figure 23). In contrast to these supposed green and closed-loop supply chains, an LCA-based approach commenced from sale to consumers and upstream waste generation (when equipment reach their end-of-life) to subsequent downstream recycling and disposal, including an impact analysis of workers.

Upstream generation was considered in Chapter 4 and downstream impacts in Chapters 5 and 6. Most notably, reverting to the three intervention stages identified in the ecosystem model, e-waste disposal (formal or informal) can be categorised as largely equating with tertiary and secondary interventions. That is, recycling actions taken to reuse and recover materials at the end of their lifecycle, either formal and informal, can be categorised, using a public health analogy, as efforts principally to reduce the symptoms of the disease (e-waste) that is already in society (tertiary) or to detect (early) and prevent it from getting worse (secondary), such as by classifying waste and improving collection systems. While these efforts are significant in public health and so also in waste management and recycling, the challenge is to greatly increase efforts at the primary prevention level – particularly in developing economies.

From a multi-stakeholder viewpoint, there are system-wide implications arising from the findings reported in the general literature. Arguably, the primary outcome is to identify and raise awareness of the dysfunctional consequences of relying on a single measure of effectiveness, profitability, and to highlight the underpinning social dynamics that sustain a flawed recycling system in terms of first, as well as second- and third-order downstream effects that are presently hidden or unknown. These findings, in the context of managing and recycling waste in Pakistan and other emerging economies, must surely also be seen globally in the context of rising volumes of e-waste every year and what Ceballos and Dong (2016) have suggested is the inability to adequately process current volumes of waste. A number of priority actions can be advocated. Arguably, the indicated leverage points are seen as ideal focus areas for action, particularly primary prevention, supplemented by a necessary precursor of attempting to quantify materials flow across the many stages in the e-waste process and measure effectiveness.

Drawing from public health experience, considerable interventions can be made before worrying health conditions emerge, either through preventative measures such as vaccinations and altering risky behaviour or by banning the sale of specific products. In an e-waste context, primary prevention strategy might focus, like public health, on various determinants in the whole society – for illustrative purposes, on product design and consumer habits or on target risk groups such as manufacturers, recycling businesses and workers in order to reduce the incidence and prevalence of the disease measured in damaging human or environmental outcomes. Using a topical example, washing hands, and wearing masks and protective clothing are examples of primary prevention to reduce immediate risks to recycling workers. These are useful in conjunction with other preventative actions. Analogous with vaccine development and downstream medical distribution and injection networks for COVID-19, upstream primary prevention in regard to e-waste includes the notion of extended producer responsibility (EPR), product redesign to reduce or remove toxicity in waste and enable easier dismantling, and changes in consumption and related user disposal behaviour. These should be supported by suitable policy interventions. A summary of possible interventions across the various stakeholder groups is presented in Table 45 in the next chapter. Implicit in the table is the basis to raise funds upstream that can serve to fund immediate downstream interventions beginning with education and improved technology.

7.2.1. Upstream disposal

To analyse downstream e-waste's impact, it was necessary to first understand and quantify upstream behaviour in terms of how this waste is generated. This issue was explored in RO1 – assess upstream acquisition behaviour with respect to EEE usage patterns and disposal norms in Pakistan, and RO2 – estimate the quantities of e-waste flows through the upstream sector. Based on an extrapolation of the number of equipment from primary data, e-waste volumes for Pakistan have been estimated as 1,790 kilo-tons per annum. The processing of this waste in terms of material flow is illustrated in Figure 35 (section 4.9), noting that e-waste generated locally is estimated to be increasing by 10.2% annually.

At this upstream level, consumers typically acquire technology (EEE) for personal use and with a preference for low cost equipment. This preference gives rise to a tension that can be described as short-term gain that comes at a greater downstream pain (cost) – as this 'cheaper' equipment also results in reduced levels of recovered valuable material and greater waste going to landfill. While these matters are not of direct concern to consumers, from a whole systems perspective there is a direct impact on recycling businesses and workers in terms of profit and the effort taken to recover valuable materials. This trade-off incurs known, as well as unknown and hidden downstream costs that were discussed in Chapters 5 (recycling businesses) and 6 (workers), respectively.

Disposal behaviour by consumers after equipment reach their respective useful lives can be immediate disposal, which is rare or, more frequently, stored or resold to second-hand dealers. Both latter options are described as deferred disposal. Discarded e-waste, typically direct to local collectors or indirectly via intermediary rubbish collectors known locally as '*kabari walas'*, becomes the responsibility of recycling businesses and workers in the downstream sector. These recycling businesses typically separate e-waste into component materials for further processing, typically by informal practices. Waste classification for disposal is noted in this study as somewhat informal and based primarily on perceived value that itself is based on capacity to recover and the perceived effort needed to recover materials. Categories of materials types include those designated for re-use, re-purpose or resale and products that give inferior yield and plastics that are separated for on-selling. Materials are also categorised by composition, such as rare (earths) and/or valuable (gold, silver). What is not given much attention are materials that are, for example, toxic or hazardous, and non-renewable or able to be reconstituted. This formative classification of materials type and composition is a synthesis of literature and is partially confirmed in this study. Waste classification is a clear issue that matters, but one that is currently not measured and it is an necessary extension to the current literature on waste management. A summary of the research objectives, and the respective key findings and the associated outcomes and study contributions are summarised in Table 43 below.

Table 43: Sub-question 1 - summary of key findings

Research question/ ROs	Key Findings	Outcomes/ Contribution
SQ1: What is the current situation with e-waste generation and disposal in Pakistan?		
RO1: Consumer acquisition, usage, disposal, awareness and willingness to pay for e-waste management. **Research Gap** - No study on the upstream generation of e-waste in Pakistan. - No study on the consumer perspective of e-waste in Pakistan.	- Buy new equipment when the old one stops functioning. - Tending towards a consumer driven society. - Declining useful life of equipment and Repair culture - High tendency to store or stockpile used equipment - High levels of public awareness - Strong willingness to pay for e-waste management	There is a trade-off of short-term gain (buying cheaper new products – high growth in e-waste generation) for long-term unquantified pain (in terms of second- and third-order effects in environment and human health)
RO2: The quantities and flow of e-waste through the upstream sector. **Research Gap** - No estimate of internally generated e-waste in Pakistan. - No documentation on flow of e-waste along the downstream sector.	- Annual generation of 281 million equipment or 1,790 kilo-tons - Landfill: 34.32 million equipment or 245.6 kilo-tons (13.8%) - Informally recycled: 22.48 million equipment or 154.8 kilo-tons (8.6%) - Reuse: 165.5 million equipment or 1,150 kilo-tons (65.7%)	Estimated volumes of e-waste internally generated in Pakistan. Mapping the flow and quantities of e-waste from usage to disposal.

7.2.2. Downstream impact

Downstream, at the recycling businesses and worker level, is where the visible and the less visible, negative impact of informal recycling becomes evident. Respective profits and wages aside, the overwhelming impact is in deferred costs and long-term pain incurred by recycling workers, their families and the local communities, and the environment. Downstream costs were categorised as financial and non-financial (social and environmental) and by two broad types, direct and indirect. Besides tangible financial measures, there are hard-to-measure costs that are either known but ignored, or unknown, hidden / or in a blind spot. While outside the scope of this study, for conceptual completeness, the effect of these costs were categorised as first-, second- and third-order effects that reflect consequences of actions that in a rational system might influence the system's functionality and longer term viability.

As noted earlier in the discussion of upstream impact, there is evidence, both from primary data and general literature, of reduced recoverable content in terms of valuable metals and the same or even increased level of toxic elements (Chen, M et al. 2016; Singh et al. 2019). Currently, financial profitability and wages are the driving incentive for recycling businesses and workers, respectively (Achillas et al. 2013; Cucchiella et al. 2016; Khan, SA 2018). This measure of business performance is problematic at two levels. First, the use of return on investment or profitability as a sole measure of performance for businesses is limited and at risk of fostering many dysfunctional consequences (Ridgway 1956). Second, this first-order effect (profitability) has its own first-, second- and third-order consequences that are in small part known and larger part not known in relation to workers, their families and local community, and the environment. These effects in turn arguably give rise to known and unknown long-term pain. First-order benefits and costs (effects) of e-waste were measured, where possible, using financial cost-benefit analysis for e-waste recycling businesses. The results were presented in Chapter 5 (RO3) for businesses, and in Chapter 6 (RO4) for workers. Briefly, it was evident that:

- A cost-benefit analysis (CBA) based on financial costs and benefits was conducted for e-waste recycling businesses. Financial benefits for businesses were estimated to be 1.19-1.27 times the financial cost, making the operations of such businesses financially very attractive. This result is consistent with literature for developed regions like the EU and also for some developing countries (Cucchiella et al. 2015, 2016; D'Adamo, Ferella & Rosa 2019; Sajid et al. 2019). In parallel, these businesses face what we called 'a trade-off between competing interests' (see section 5.7.1), i.e. should business owners be more ethical by exporting e-waste to Europe for formal recycling for less return? Or should they sell to China for greater return or earn better profits processing waste locally by informal methods and no accountability for known and unknown / hidden consequences? This easy trade-off, which is sustained broadly by a lack of governance structures upstream, and owner apathy and worker poverty, lack of agency and associated social dynamics downstream, is an extension to the current literature.

- A cost-benefit analysis (CBA) based on economic (including both financial and non-financial/social) costs and benefits was conducted for businesses. Benefits, as a first-order effect, for recycling workers in terms of regular employment and adequate wages, were discussed in Chapter 6. Some second-order effects were quantified using a cost-benefit analysis in order to explore social consequences. Results show that net economic (financial and social) costs to workers were about Rs.34,069 - 85,478 (USD 203–510) per month, per worker, which exceeds by 2.6-4.7 times the calculated economic benefit (broadly, wages and meals). Despite the relative imbalance in long-term social costs, workers, however, prefer to remain in this sector due to the effect of what is termed in this study a 'poverty trap' – discussed in section 6.4.1. The identification and initial quantification of a poverty trap extends the existing literature, which so far explores outcomes in terms of biological human health burden or qualitatively identifies some social implications (Cao, P et al. 2020; Gangwar et al. 2019; Grace Pavithra et al. 2020; Kim et al. 2020).
- First and second-order effects are conspicuous in literature for what happens to the environment (Cao, P et al. 2020; Grace Pavithra et al. 2020). The effects become apparent in the long-term and the practices that contribute to them are identified in this study. These practices include the use of open burning and acid baths to recover some valuable materials, and the tendency to operate hidden businesses often in underground sites without any suitable ventilation. As well, there is a tendency to dispose of significant quantities of materials deemed non-renewable, unrecoverable or of inferior yield into landfill. These downstream effects and recycling specific decisions reported in this study are a formative contribution to literature for developing economies. Detailed analyis is, however, out of the scope of this study.

A summary of key findings for sub-question 2 is presented in Table 44. On examining the social dynamics of e-waste recycling, what stands out is the interconnected nature of the issue, which is untangled and explored using systems thinking in the following subsection.

Table 44: Sub-question 2 - summary of key findings

Research question/ ROs	Key Findings	Outcomes/ Contribution
SQ2: What are the impacts of e-waste recycling practices in Pakistan?		
RO3: Cost-benefit analysis for e-waste recycling businesses. **Research Gap** No identification of quantifiable or non-quantifiable costs in prior studies.	- Financial benefits for dismantling businesses are 1.19-1.27 times the financial costs incurred. Financial benefits for extracting and refining businesses are 1.95-2.22 times the financial costs due to the presence of precious metals.	A trade-off of competing interests for e-waste recycling businesses – dilemma of whether to be responsible and opt for formal recycling but giving up on profitability, or ensure survival (and profitability) at a cost to environment and health.
RO4: Impact assessment and cost benefit analysis for e-waste recycling workers. **Research Gap** - Prior studies have identified social costs for e-waste recycling workers in Pakistan, but this study has attempted to quantify and conduct a cost-benefit analysis of financial and non-financial costs.	- E-waste recycling workers incur 2.6-4.7 times the costs than benefits. - The estimated net economic cost on average is about Rs.50,363 per month. - This cost in lifetime earnings is a reduction on average of about Rs.2,075,958.	A poverty trap – systems dynamics reinforcing the vicious cycle of poverty the workers are trapped in, coupled with illiteracy, a sense of helplessness, deteriorated health conditions and no other skills and options of employment. -
RO5: Framework for impact assessment. This is presented later, and so details are not included here.		

7.3. Social dynamics

Social dynamics discussed in Chapters 5 and 6 have been brought together to form a pictorial representation of the system, with causal loops based on the discipline of systems thinking – see Figure 49. The causal loops illustrate the dynamics observed in the e-waste recycling industry in Pakistan. Four 'reinforcing' loops were identified in this diagram. Reinforcing types of loops generate growth (or collapse) at an ever-increasing rate. Illustrating a possible control mechanism, a regulatory system in the form of governmental actions can help generate stability in the system. This type of loop, a balancing loop, is notably absent. As a result, the reinforcing loops in the image are able to dominate. Importantly, the causal loop model illustrates an interconnected problem, with trade-off at both upstream and downstream stages. It also shows leverage points for change. Conceptually, small changes at these leverage points can reverse the current system at ever increasing rates or can generate resistance (balance) to prevailing forces in current practice. The methodological technique of causal loop mapping and the pictorial representation are valuable formative contributions to the literature on e-waste management and recycling, and for developing economies, respectively. As noted elsewhere, the image is an open-box approach and this facilitates transparency or full disclosure and targeted policy interventions.

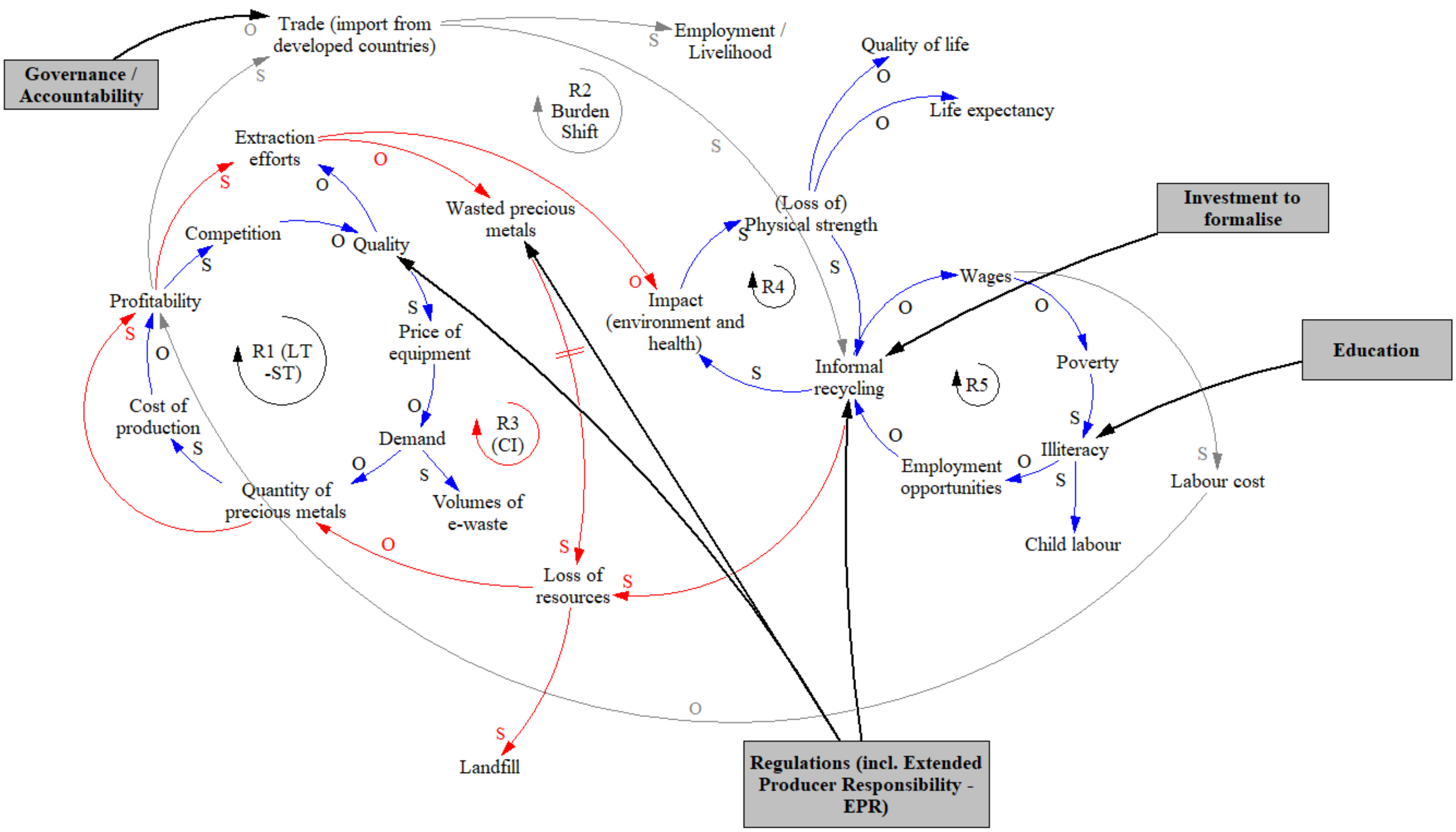


Figure 49: Social dynamics - an open-box view (with leverage points)

7.3.1. Upstream dynamics and impact

At the upstream level, as reported earlier, the quantities of valuable or precious metals as an input in electronic equipment have been declining over time (Chen, M et al. 2016). The assessed quantity of these recoverable precious metals has been used as a starting variable for Reinforcing loop 1 (R1). A decline in the quantity of precious metals in e-waste helps increase the profitability of electronics manufacturing companies by decreasing the costs of production. Conversely, it will serve also to reduce the profit for downstream informal recycling businesses. High profitability in turn attracts new businesses, notably Chinese. This has increased competition in the electronic equipment market and has helped drive prices down of electronic equipment, but the side effect of this price-based competition is compromised quality of product and downstream reduced profitability, but also increasing waste to landfill.

As a result of competition and lower prices, consumers benefit as they have greater choice. Rising demand also provides incentive to manufacturers to reduce costs by using less quantities of precious metals in processes. In effect, an increase in demand for cheaper electronic product leads to a rise in e-waste as pieces of equipment are discarded at the end of a short product life or given up earlier in favour of a newer model with improved functionality. These loops are a reinforcing effect in terms of cost of production and price, and in terms of company profitability, competition, and consumer demand of equipment. Potentially, it also means a growth in e-waste generation with inferior yield or materials that may not be readily reconstituted and so deemed non-renewable.

Another upstream condition noted is the trend for e-waste generated in developed countries being diverted for re-use and recycling in developing countries such as Pakistan. This trade is reported as often through informal channels and is discussed variously in literature as 'transboundary movement' (Gollakota, Gautam & Shu 2020; Nnorom & Odeyingbo 2020; Salehabadi 2013). This causal loop dynamic is illustrated in reinforcing loop 2 (R2) in Figure 49. It is sustained by absent governance and limited accountability in developing countries (Gollakota, Gautam & Shu 2020). These gaps are reportedly exploited by developed countries to export and trade second-hand electronic goods and e-waste to willing developing countries. The subsequent trade (import) provides employment opportunities for recycling businesses and workers, but the industry is sustained largely by informal recycling, which requires limited technology and skills. The resultant low cost-wage structure for workers, ensures suitable profitability for businesses (Ilyas et al. 2020; Sajid et al. 2019). Both these dynamics provide an incentive to exporting and importing countries, respectively, to trade more e-waste. This loop is also reinforcing in nature because it signifies a growing action.

7.3.2. Downstream dynamics and impact

Downstream, recycling businesses face a trade-off of competing interests represented by reinforcing loop 3 (R3). As discussed earlier, informal methods of recycling are only able to recover a few of the many precious metals in e-waste, like gold, silver, aluminium and palladium while many unrecoverable rare earth and precious metals are lost. This loss of resources and depletion of rare metals is both a short- and long-term consideration. Loss of rare earths reduces the quantity of scarce materials available for manufacturing of electronic equipment, and downstream, impacts the profitability of recycling businesses that generate income by selling recovered metals. As a result of reduced profitability, the motivation to extract can decline as the effort required is the same (or more) for a smaller reward. The effect also is for unquantified amounts of precious metals going to landfill because extraction from low volume and/or difficult to extract rare metals may be deemed not worth the effort. Potentially, aside from an uptake on urban mining (for e-waste that has been sent earlier to landfill), the rising demand for electronic equipment each year means a greater reliance on virgin mining, perhaps to unsustainable levels – a vicious cycle and a negative reinforcing loop.

The social dynamics and poverty trap for recycling workers were illustrated in reinforcing loops R4 and R5. To illustrate these loops' effect, the hazardous and unsafe methods used in informal recycling practices will exert a more pronounced threat to the environment and human health (Awasthi et al. 2018; Cesaro et al. 2019). Direct and indirect exposure to waste materials and hazardous work conditions cause many illnesses and a reported loss of physical strength made workers unable to take on labour intensive tasks. As a result, while they continue working in informal e-waste recycling their earning capacity is diminished. In the longer-term, illness tends to impact their quality of life, the number of healthy life years and general life expectancy (Ohajinwa, Chimere M et al. 2017). R4 explains the trap from a health perspective, while R5 has a social focus. Low-cost, informal recycling offers lower wages to workers that is sometimes described as the bare minimum to survive on (Moletsane & Venter 2018; Popoola, Popoola & Purchase 2019). Lower wages and general poverty among workers also means they are not able to afford to educate their children – firstly, in terms of paying a minimal school fee, but secondly in terms of a perceived opportunity cost – if children study, they are unable to work and supplement the family income. This study finding is anecdotal, as any focus on child labour was disallowed by the university's ethics process. However, many of the workers interviewed indicated that they had worked in the industry since childhood (estimated as 7+ years), and there was evidence of children working at some of factory sites visited. This study observation is consistent also with literature that also records illiteracy and poverty reduce employment opportunities for children

(Okpukpara & Odurukwe 2006; Sabates 2008). The effect is that generations remain trapped in poverty.

7.3.3. Leverage points for future intervention

At a meta-level, the contribution of this study is to build a heightened awareness of a seemingly dysfunctional waste management and recycling system. At a system level, deep-rooted, hidden processes and social dynamics were identified in the e-waste management and disposal processes in Pakistan. Described as vicious cycles, the causal loops illustrate several trends discussed in the previous subsections. Notably, these loops are reinforcing in nature and reflect vicious cycles in each case – the dynamics show an increasing (growth) or decreasing (collapsing) effect. Balancing loops or actions are required in order to provide stability and control, and so change these vicious cycles into more virtuous ones, that is, are reinforcing, but with a positive impact. For this purpose, leverage points have been identified for government intervention that could either create balancing loops or virtuous reinforcing loops. These interventions or leverage points, boxed and highlighted in grey (see Figure 49), are discussed below. Loops shown in red lines represent competing interests; grey lines represent burden shift; blue lines denote the poverty trap and trade-off between long-term pain and short-term gain; and the black lines highlight leverage points for intervention.

7.3.3.1. Leverage point: Trade (imports from developed countries)

- Based on 2001 and 2006 figures reported by Lepawsky and McNabb (2010) there is a largely internal trade for e-waste in Asia. Other studies suggest that developing countries, such as Pakistan, India, China and Nigeria, import about 50-80% of the e-waste generated in developed countries (Gollakota, Gautam & Shu 2020; Illés & Geeraerts 2016; Sthiannopkao & Wong 2013). While Pakistan is identified as receiving 8% of the global e-waste in the categories of laptops and desktop PCs, it also generates large volumes of general e-waste domestically (Baldé, Wang & Kuehr 2016). This trade is under the circumstances of a deficient internal recycling capacity of the country and can be categoriesed as a tendency towards burden shift by some developing countries, enabled by the loopholes in the existing international agreements (Basel Convention) and a lack of internal country governance procedures. There is a clear need to improve upstream governance that includes regulations, in time a self regulatory environment and accountability at both national and international levels.

- Governance and transparency of processes is needed at the national level to moderate the practice of bribes, typically at retail level, but often also by government officials, for example customs. This externality is compounded by the presence and facilitative role played by political parties and by other middlemen. The aim of governance must be to build confidence in the industry and encourage companies to import via official channels instead of illegal means aimed at avoiding bribes and other roadblocks.

7.3.3.2. Leverage point: Regulating equipment/ material composition

- The introduction of regulations (including implementation of extended producer responsibility – EPR) at the production stage to stipulate the quality of equipment and material composition with an eye to downstream recycling processing is important. Similarly, regulatory controls to require the non-use of non-toxic elements, while supporting easy dismantling can incentivise and reward recycling. Another intervention and necessary leverage point involves controlling for the production and sale of counterfeit electronic equipment that bypasses production processes, as the evidence is that the widespread uptake of cheaply manufactured goods causes downstream harm to the environment and to multiple stakeholders in the recycling process.
- There is an obvious need to improve the effectiveness of recycling technology. The wider use of formal recycling, albeit with identifiable limitations, is still a must for all recycling processes. The funds for this distributed capacity is arguably possible through EPR and through international agencies, as well as by a premium paid for by consumer. As this study has shown, users and upstream consumers indicated a willingness to pay some costs towards the proper disposal of waste.

7.3.3.3. Leverage point: Wasted precious metals

- Currently, informal e-waste recycling practices only recover some precious metals such as gold, silver, palladium and aluminum. Because informal practices are unable to recover some metals, rare earths are effectively lost to landfill. Regulations are required to introduce formal methods of recycling, specified minimum standards and safety precautions to ensure environmental sustainability and occupational health and safety. This might, in part, be achieved by making the producers responsible for end-of-life through EPR. As producers are well aware of the content of metals initially used in manufacturing, they might possibly invest in better ways of efficient extraction. While it will provide them precious metals for reuse in manufacturing on one hand, it will also result in a reduction in wasted precious metals on the other hand.

7.3.3.4. Leverage point: Informal recycling

- Regulations are needed on the disposal of waste residue after recycling. Unrecovered precious and rare earth metals represent a significant loss of resources, but some materials and principally waste residue (in acid baths that go directly into water ways) also contain highly toxic elements. This study found that acid used in the extraction and refining phases, was often disposed in open drains, onto streets or even used to wash the floor of toilets and bathrooms.
- Private investment is needed to help introduce technology that is needed to shift from informal recycling to formal methods. Internally, there needs also to be an incentive or a legal requirement to shift away from a low-cost method that does not require large sums of initial investments. Conversely, legal requirements without incentive, might simply mean more illegal and hidden operations will occur in hard-to-reach areas. This might be overcome by implementing EPR, which can lead to lower volumes of e-waste going through the informal channels and recycling, but also might encourage producers to support and collaborate with local businesses and workers for recycling of e-waste using formal methods.

7.3.3.5. Leverage point: Illiteracy

- Increased formalisation of recycling processes cannot be successful without providing relevant technical skills to local workers or engineers. Therefore, it is crucial to first train the workers to operate recycling plants based on a formal diploma or vocational program, and gradually provide an environment and incentive for local engineers to import and maintain (or to manufacture) the necessary recycling capability internally.

- Formal education of the workforce, but most importantly of children is needed in order to increase their employability in the future and so break the vicious cycle of poverty.

7.4. Identifying and reducing the blind spots[12]

Aside from quantitative-based estimates, semi-structured interviews with business owners and recycling workers helped reveal a range of other outcomes that are not easy to quantify. Social dynamics and causal loops have been discussed in the previous subsection. In addition, hard-to-quantify and sometimes less visible costs/ benefits have been consolidated for both business owner and worker level in four categories: "known", "unknown", "hidden" and the "blind spot" (Figure 50). These categories are based on the Johari Window model, a well-known instrument for self-assessment and especially self-awareness (Cassidy 2014; Vorce & Fragasso 2016), build self-awareness (Mahoney 2019; South 2007), facilitate individual self-disclosure (Nofriza 2017) and understand different perspectives (Beck 1994; Berland 2017). Applied to this study, these four categories are similarly useful to raise awareness of less visible issues such as the attitudes, knowledge and motives of e-waste recycling workers. In this study, the four categories are used as convenient descriptors for social dynamics that range from known to not visible, and no attempt is made to study the awareness for one group with respect to the other. The aim to increase the known and decrease the unknown, hidden and the blind spots of the e-waste recycling industry. This awareness of social factors is seen as a necessary first step to better management of the industry.

7.4.1. What is "known"

Profitability is the driving force in the e-waste market and all parties involved from importers to recyclers make large profits, according to Umair, Anderberg and Potting (2016). While this study also suggests recycling industry workers benefit with wages that are the equivalent or slightly

[12] This subsection has been published in *Waste Management* (a Q1 journal, Impact factor: 5.448) - https://doi.org/10.1016/j.wasman.2020.08.039

above the minimum wage and poverty line, this study contests that estimation. A wages disparity notwithstanding, what is known is that workers are at the forefront of the informal e-waste recycling activity and the most vulnerable. Driven primarily by the need to earn income for the family, they work in hazardous working conditions (Khan, SA 2018). Being illiterate and living largely at or below the poverty line, these workers see few alternatives and are glad to simply have regular employment.

Another "known" in e-waste recycling is the use of informal methods to process materials. The lack of suitable technology and the consequent informal processes adopted are known by both business owners and workers. Both groups, however, appear blind or are apathetic to health and environmental implications. Some workers, specifically those involved in metal extraction know the risks from open burning and related extracting processes, but appear satisfied by simple precautions such as good air circulation and ventilation via chimneys. The health consequences of informal processes are also known in general terms. For example, most workers report having experienced symptoms such as stomach pains and breathing difficulties, as well as not much energy. Some workers also reported major illnesses like cancer that they know caused the premature deaths of a number of their peers. If unwell, their usual recourse is to treat any health-related problems with simplistic home remedies like eating jaggery (raw sugar).

Business owners are complicit in the informal recycling practices used to process e-waste material. While not openly acknowledged, owners are aware of the health issues for the workers they employ. Reflecting this awareness, some provide ventilation and chimneys at extracting and refining worksites, yet these are the only known strategies to mitigate direct risk. Equally, these businesses and the wider community are aware of the absence of regulations to govern e-waste and this allows them to operate as they do. Local councils appear to limit their oversight to ensuring unsafe burning is not done in populated public spaces. There is clear need for regulatory actions locally, but in a full LCA the stakeholders in this system include international agencies and so the necessary restorative actions must logically also be much wider and systemic.

7.4.2. What is "unknown"

The primary "unknown" in informal e-waste recycling in Pakistan concerns the numbers of workers engaged in recycling. Given the labour-intensive nature of work and the seasonal volume, it is likely that this industry employs a significantly larger number of workers than were observed during the site visits. What is also unknown are the number of actual businesses and the intention by business owners to, for example, access suitable technology in order to adopt more efficient, even formal recycling processes in the future. The primary cause for inertia is cost (of technology), and the absence of regulatory incentive. Because of this, any prospective remedial action by business owners remains latent, and the unquantified downstream costs of informal recycling are borne by workers, their families, community and the environment.

The community-wide and environmental impacts incurred from the use of acid baths and chemicals are unknown. Reflecting gaps in worker awareness and in governance, for example, residual acid is treated like any normal liquid and allowed to flow into open sewerage drains that flow on either side of slum streets. Similarly, the downstream community-wide impacts of using contaminated and hazardous wastewater to wash the floors of bathrooms and toilets is unknown. In effect, toxic materials pass unchecked into normal drinking water via sewerage lines or freshwater pipes that are broken, or through seepage. In sum, while the costs are unknown, there are externalities for humans working directly in the industry, and humans and animals living in the vicinity of e-waste processing plants are likely to ingest toxins directly by drinking water and /or from breathing polluted air, and indirectly by toxic waste that enter the food chain through contaminated water used for cultivation or from eating fish taken from polluted streams.

A final unknown is linked to work opportunities forgone by workers who enter and remain in the e-waste recycling industry for the whole life. Many of these workers start in e-waste recycling from an early age (estimated as 7 years old) and appear not to have considered other less hazardous jobs. The related unknown is missed economic opportunity with the inability to extract certain precious metals by the informal methods being used. While businesses may be aware of the presence of rare earth metals such as platinum, palladium and neodymium, the informal processes being used means they are unable to recover these materials that end up going into landfill or wastewater. This is a significant but as yet unknown missed business opportunity.

7.4.3. What appears "hidden"

There is a degree of secrecy in recycling prompted by businesses being unregistered and/or by the desire to avoid the unwanted attention of middlemen or government authorities. It is also likely that some workers steal e-waste material that they process at home, in order to supplement their meagre incomes. Consequently, it is hard to penetrate the veil that shrouds businesses and their practices. There are other hidden elements that, for example, keep workers in e-waste recycling. The attitude of helplessness ("majboori") that leads some workers to believe they have no choice or that it is their fate. This social or religious belief contributes to a lack of agency or urgency in terms of looking for other work or seeking improved conditions. Another feature that is hidden is the sense of fear – businesses are in fear of being exposed to government authorities, and workers are afraid of being fired, particularly if they speak out against their employers and workers also express a deep fear of not being able to feed and care for their families. The cumulative effect for workers is described as being caught in a "poverty trap".

7.4.4. "Blind spot"

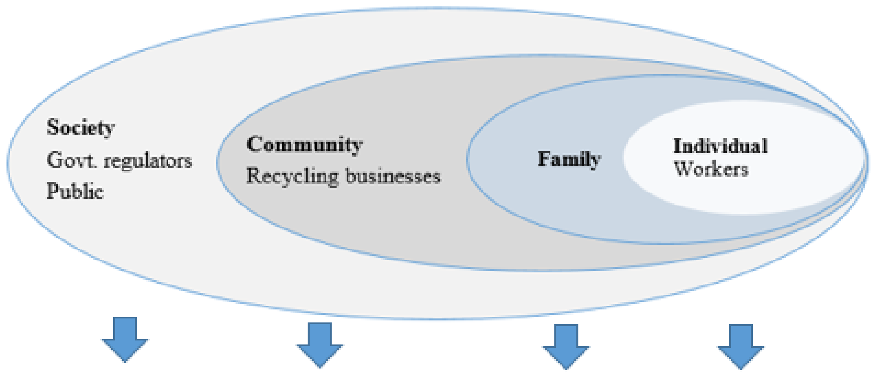
A blind spot suggests not seeing or understanding how important something may be. It can also include factors that might be in the subconscious of workers. Workers confronted by work-related hazards (heat, smoke) and resultant (respiratory) illnesses explain things away or get defensive in face of this question, saying "*…we do not get sick and there is no need to improve the working conditions*". This denial may be out of fear and (misplaced) loyalty to owners or plain inability to see all the cultural conditioning that supports this apparent blindness. Another blind spot concerns occupational health and safety considerations; many workers believe good ventilation is adequate for safety and health, and appear blind to the pervasive health effects on their peers, family members and on the community. There is a further blind spot in terms of the quality of the number of healthy years in a lifetime, which are greatly reduced. While as yet unquantified, it is also very likely that older workers spend a number of their later years suffering from work-related illness and being unable to meet basic life necessities. The wider downstream environmental implications of the business and of waste residue do not register as a concern. In sum, environmental considerations are a complete blind spot.

Similarly, business owners appear blind to their wider responsibilities, being demonstrably unable to act in terms of the best health interests of their workers and environment. There is similarly a blind spot in terms of the quality of life for their workers and of the basic health and safety measures that can be taken to protect workers, via ventilation and protective clothing. Similarly, business owners are blind to healthcare benefits, job security, paid leave or other forms of social benefits. Governments echo this apathy towards the rights and plight of workers.

7.4.5. Mapping downstream impacts

Figure 50 summarises the downstream impacts in terms of known, unknown, hidden and blind spot discussed for stakeholders across three dimensions: financial, non-financial (social) and to a lesser degree environmental costs, noting issues with the environment were not the focus of this study. Key stakeholders are added to illustrate the cross-industry impacts, particularly "social" costs. The table shows stakeholders in the community, including businesses, and general society are largely "blind" or apathetic to downstream impacts, while workers are caught in a poverty trap driven by economic need and their circumstances are compounded by a lack of agency.

Applying the logic of the Johari window technique to improve awareness, the challenge in the recycling industry is to increase the "known", and decrease the "unknown", "hidden" and "blind" through greater transparency and accountability. In the immediate future this would suggest a focus on the systemic externalisation of costs, on recycling industry workers and the local community, and the environment that would naturally include governance and regulatory guidelines.



Stakeholders / Costs		Government, regulators, public	Recycling businesses & society	Family and children	Recycling workers
Financial					
	Known	Use of Informal method in recycling industry	Profitability Employs family members	Employment	Wages and meals
	Unknown		Precious/ rare earth elements (urban mines)		Precious/rare earth elements
	Hidden		Over-time wages avoided	Processing of sourced materials	Unpaid over-time wages
	Blind spot	Need for regulation of industry	Informal method effects Protective equipment		
Social					
	Known	No regulations No governance	No accountability No regulations or industry oversight	Family members involved	Informal working conditions Poverty
	Unknown	Toxicity in e-waste Toxic impact of recycling process	Proper (formal) methods of recycling		Illnesses Unexplored work opportunities Toxicity
	Hidden		Hidden / illegal operations Middlemen (business/political)	Fear (income loss)	Work-related hazards Social norms Helplessness / no choice
	Blind spot		Health impacts Minimal social welfare: No employee benefits Job insecurity No health and safety	Illiteracy Low value of life	Long-term health costs Low quality of life External locus of control (fate)
Environmental					
	Known	Air pollution (metal extraction)	Air pollution (metal extraction)		
	Unknown	Food contamination	Second-order environmental effects	Food contamination	
	Hidden		Water pollution		
	Blind spot	Impact of informal recycling – first and second order effects	Impact of informal recycling Toxic waste residue		Air pollution Second-order environmental effects

Figure 50: Summary of (some) stakeholder specific downstream impacts

7.5. Policy considerations

Arguably, the focus must shift to upstream primary prevention, where there are at least two broad areas identified for necessary change. First, there is a need to lift the veil that enables systemic blindness in industry and consumer behaviour, problems that are driving the rising volumes of electronic products, arguably out-of-control waste management and recycling processes. Second, there is a need to change the downstream informal processing of electronic waste in developing economies such as Pakistan. The use of one criterion, profit, has altered the landscape of waste management and disposal throughout the world. In Pakistan, allowing that the majority of e-waste is undocumented and likely ends up in landfill, the informal processing that treats a small quantity of e-waste is grossly ineffective and releases unaccounted for volumes of hazardous and toxic materials into the environment. Both areas, industry and consumer behaviour, and the unregulated process using informal processes raise multiple subsidiary considerations. Most of these considerations are issues that matter but are not currently being measured.

The downstream costs are evident in terms of first-order effect on human health, but the costs and wider concerns to the environment appear generally to be tolerated by stakeholders in the industry and government, and ignored by businesses. The lesson from the Bamako Convention is that African countries that have not signed the agreement are at risk of becoming dumping grounds for hazardous waste (The Conversation 2020). This convention, like the Basel Convention, seeks to control the transboundary movement of hazardous waste as illegal without the consent of the receiving states. Yet, as this study also noted, like in Pakistan, e-waste represents a much needed source of revenue, and the informal sector for recycling offers a source of employment for poor and vulnerable people in African nations such as Ghana, Cote d'Ivoire and Nigeria.

The general issue of hazardous waste disposal and its effects is perhaps out of the public eye and community consciousness, but it is not an unknown. For example, a recent study in China (Huang, Y 2020) points to clear genetic effects of toxic materials on humans evident in falling birth rates. Nor is the issue of proper waste disposal limited to the developing world. Closer to home, as a recent report in an Australian newspaper (Vedelago, Ilanbey & Houston 2019) revealed, a paper-based tracking system and lax inspection regime contributed to the illegal dumping of millions of litres of contaminated and untreated toxic waste in farmland in Victoria, the second largest state in Australia. Further, the failure to intercept this illegal operation had a second-order effect, as it apparently contributed to Melbourne's worst-ever industrial fire in 2018. The pitch that allowed the syndicate to win the business was simple – *they could do it cheaper*, and as industry sources noted the waste industry operates on thin margins.

Echoing the competing interests in Pakistan, but in a developed economy, the report by Vedelago, Ilanbey and Houston (2019) also noted some Australian businesses may not have been aware of the syndicate they were dealing with, some had their suspicions but were happy to take the lower costs, while more than a few did not give any thought to where their waste materials were going to end up. Bookending this dismal state of affairs in a progressive jurisdiction such as Victoria, toxic waste is required by regulations to be remediated and is meant to be traceable from cradle to grave by the Environmental Protection Authority (EPA). Human factors upstream such as lax governance and downstream greed and self-interest intruded.

The enormity of the challenge for e-waste specifically, but also for general industrial processes is daunting. Moreover, the evidence is that manipulation by rogue operators is as much a reality in the developed economies as it is in the developing economies that are further constrained by lack of regulations and basic infrastructure. The matter of second- and third-order effects from these hazardous disposal practices is a more complex issue that is out of this study's scope, but nevertheless this study provides a basis to frame, and ideally subsequently measure, these downstream effects. This framework for identifying downstream first-, second- and third-order effects make a formative contribution to literature and not just limited to developing economies.

7.6. A framework for e-waste impact assessment for developing countries (RO5)

This study has presented research results over the life cycle of e-waste, from generation to recycling and impacts. A consolidated impact factor framework illustrated in Figure 21 helped identify direct/indirect, financial/non-financial costs and benefits associated with e-waste recycling. This framework, which consolidated the many variables in waste management literature, was used to identify and examine objective measures (expressed in terms of costs and benefits) for subsequent quantitative data collection. At the same time, qualitative responses in interviews with business owners and workers helped identify deep-rooted social considerations (issues, cultural norms, beliefs, practices and impacts) not identified in the variables of the consolidated impact factor framework. Although these social dynamics may not help measure the impacts or costs/benefits themselves, they nonetheless matter considerably since they contribute to and sustain the overall system.

Turning out attention to a summative assessment that answers RO5, Figure 51 represents a multi-level impact assessment framework that is arguably suitable for developing countries like Pakistan. This framework incorporates the key variables in the consolidated impact factor framework (Figure 21) that were used in this study in order to quantify costs and benefits. Key features of this summative framework include:

- Variables that are identified in this assessment framework range from visible to less visible;
- Financial variables are most tangible or 'visible' in nature, while non-financial (social) variables are 'less visible' and less obvious;
- Measurable variables in the multi-level impact assessment framework that represent costs and benefits analysis are similar to the tip of an iceberg – and fail to capture the deeper dynamics of the system;
- There are harder-to-measure factors existing underneath at a deeper, systemic level – these social dynamics, which were been discussed earlier with the aid of systems loops (Figure 49), identify grouped under four broad trade-offs or systemic tensions:
    - o a poverty trap to workers and their families;
    - o competing interests for business owners who are attracted by the profits that can be made in the industry and are willing to trade off welfare and environmental considerations;
    - o short-term gain for consumers and long-term systemic pain, as the availability of cheaper electronic equipment comes at an immediate cost of less profitability for recycling businesses and greater downstream, unknown first-, second- and third-order effects (costs) for humans and the environment; and
    - o a tendency towards 'burden shift', wherein upstream e-waste disposal and associated pollution costs by developed countries are transferred to developing

countries. This tension is arguably being mitigated by local conditions such as the need for revenue at a national level and a source of employment at a local level.

Social dynamics underpin the more tangible financial and non-financial (social) costs and benefits in the framework. Considered as a sustaining factor across multiple stakeholders and associated general practices, these dynamics need to be included in any impact assessment. They are particularly useful at a policy level, in terms of identifying focus areas for primary, secondary and tertiary prevention based on the leverage points noted in the respective causal loops.

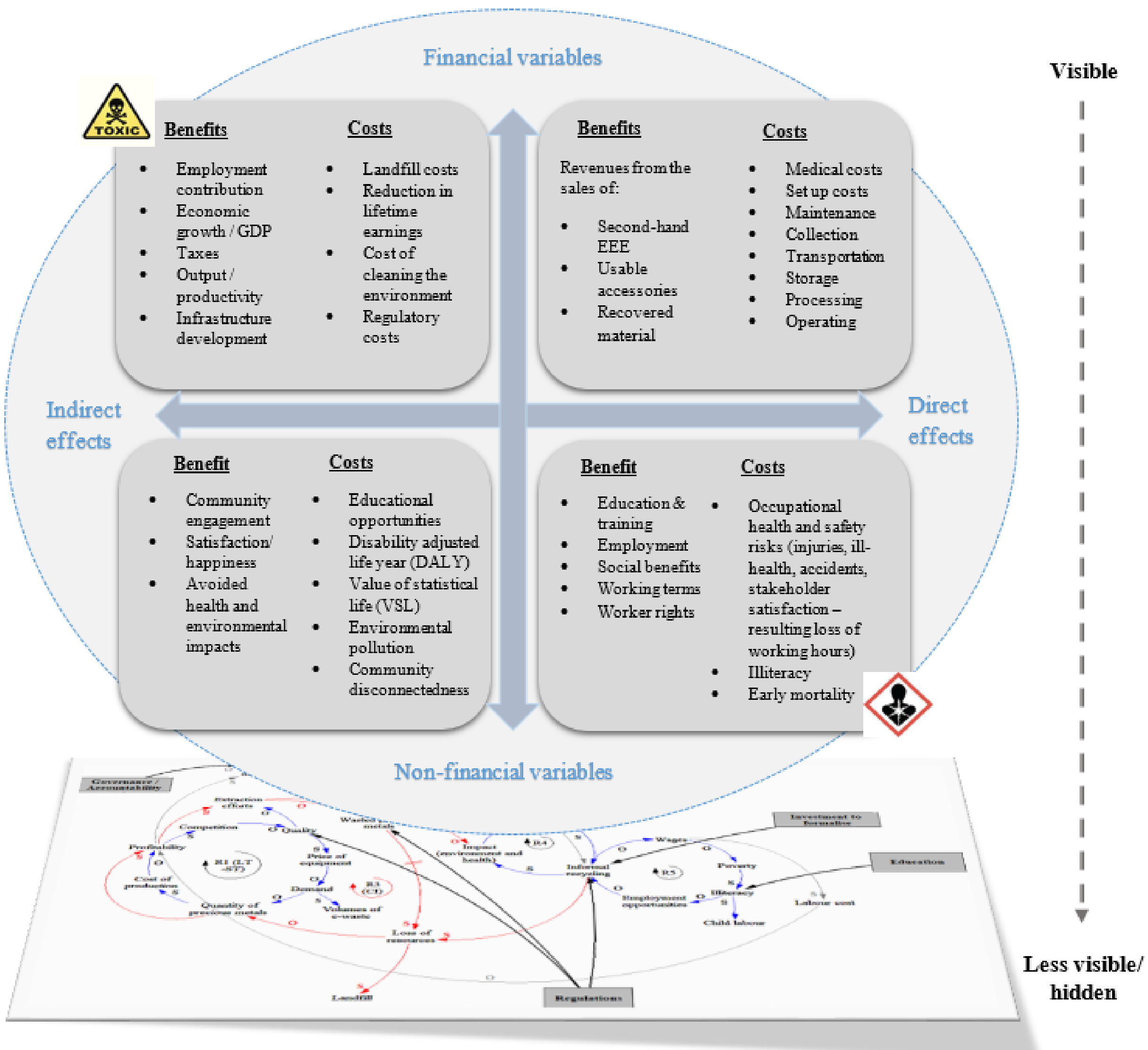


Figure 51: Multi-level impact assessment framework (for developing economies)

7.7. Summary

The findings and related discussions for the respective research objectives need to be seen in the context of a significant social issue. As recent research suggests, e-waste is growing at a rate faster than it can be recycled (Ceballos & Dong 2016). This finding is very troubling because it firstly, suggests an inability to cope with current volumes and yet we know that global rates are increasing at 5.1% and in Pakistan at 10.2%. Arguably these rates are comparable for uptake in technology in other developing economies. Secondly, the reality is that current processing is largely informal – and this is despite efforts to control the trans-boundary movements of hazardous waste by the Basel Convention. Further, as this study has shown the dysfunctional consequences of a single criterion, profit or return on investment, in conjunction with an absent upstream governance process, have simply encouraged an inefficient industry to grow unchecked with grave human and environmental consequences.

This study used an ecosystem view and life cycle assessment (LCA) approach to assess the impacts of e-waste recycling. Notable insights in the upstream stage (RO1 & RO2) relate to consumer behaviour with respect to acquisition of EEE, usage, disposal, awareness and willingness to pay for a proper e-waste management system. The annual generation of e-waste was estimated for Pakistan by extrapolating data. At the downstream level, impacts, defined as economic (financial and non-financial (social)) costs and benefits were calculated for e-waste recycling businesses and workers (RO3 & RO4). For both downstream stakeholders (businesses and workers), profitability and survival are the respective motives. Informal e-waste recycling businesses are highly profitable. Workers in the e-waste recycling industry receive a basic wage that this study suggests could be slightly or markedly below the minimum wage. However, these workers, their families and the local communities incur considerable, as yet unquantified, social costs. This is the current price of business – wages for immediate survival in lieu of longer, healthy lives and opportunity for education forgone for children. Arguably, at a system level, the uncritical reliance by recycling businesses on a single criterion of profitability as a measure of business success has resulted in significant upstream and downstream dysfunctional consequences for the country. This latter insight applies perhaps to many other emerging economies that recycle e-waste for short-term benefits.

Also at a system level, it is evident that business profitability is sustained by deep-rooted, hidden social dynamics. These causal loops help capture various trade-offs and tensions in the industry. These trade-offs highlight the opportunity for revenue by importing e-waste and businesses that are heavily enmeshed in the industry that employs many generations of family members). In parallel, poverty traps workers in e-waste recycling despite the great costs. A multi-level impact assessment framework for developing countries (RO5) combines the hidden social dynamics and relatively more visible financial/non-financial cost and benefits considerations to identify multiple criteria for future evaluations. This framework can guide necessary industry rationalisation and future research to quantify material flows and impacts of developing countries. More widely for system level change, key leverage points for government intervention are identified. Making a distinction between types of interventions and drawing on lessons from public health, there is a pressing need for primary prevention and systemic change to shift from what is a very linear approach to a circular economy. The necessary changes should include product redesign at the upstream level, government regulation both at upstream and downstream levels, investment in formal e-waste management systems, education and other low-cost interventions downstream.

CHAPTER 8: SUMMATIVE REFLECTION

8.1. Introduction

To sum up, this study was a critical analysis of e-waste management and recycling in Pakistan. The use of an ecosystem framework and a life cycle assessment helped illustrate the complexities and many interdependencies in e-waste recycling given there are multiple stakeholders with overlapping relationships. This chapter provides some summative reflections to draw the study to a close. First, this chapter presents a review of the research approach and guiding principles involved, followed by a review of the primary findings and associated contribution to the topic. Next, the chapter outlines an agenda for change that includes a review of indicative primary prevention strategies at upstream and downstream levels of e-waste management. This discussion serves to highlight policy considerations, as well as immediate actions that can be enacted at the lower level to mitigate and prevent damage being done to humans and the environment. Finally, the chapter discusses some challenges faced and limitations of this study, with recommendations for future study before closing with some brief reflective remarks inspired by Schön (1987).

8.2. Study approach (Reflections)

The study, based on a Life Cycle Assessment (LCA), used mixed methods to examine the structures, processes and cost-benefit of upstream waste generation and downstream processing of e-waste. Conceptually, the study was conceived of as a country assessment – the first step of a three-step approach (Figure 10 in introduction) based on the StEP initiative that emerged in 2004 to address the many dimensions of a digitised world.[13] The three-step approach has been accepted by international organisations such as UNEP and by the Basel Convention.

The study was guided by two complementary principles. These were:

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[13] In this respect, StEP addresses UN Sustainable Development Goal 12 "Responsible Consumption and Production".

- First, "*what gets measured gets managed*". This truism attributed to Peter Drucker, identifies the utility of measurement in order to understand a phenomenon and thus inform strategy or shape response and mitigation actions, such as in the case of e-waste. A practical benefit of this initial principle was to encourage an analysis of upstream consumer and downstream business / worker considerations with reference to e-waste. Selected performance measures were in terms of financial and non-financial (social) variables as identified in the consolidated impact factor framework. Illustrating the embedded risk in the uncritical use of inappropriate measures of performance (Ridgway 1956) and the limitation of a single measure of success (profit), this study demonstrated that (informal) e-waste businesses are highly profitable and hence very attractive in developing economies such as Pakistan. Yet, the inclusion of multiple criteria and some qualitative considerations to the e-waste recycling equation helped to identify significant externalised downstream costs (impacts) that far outweigh the profits from recovered waste materials and benefits in terms of employment.
- Second, *"not everything that matters can be measured. Not everything that we can measure, matters*". This principle attributed to Ridgway (1956), a contemporary of Drucker, highlights the need to measure the 'right' things. It suggests less focus on measuring as a quantitative exercise and greater exercise in risk-taking judgement, incorporating as Ridgway (1956) suggests, inclusion of motivational and behavioural consequences of performance measures that can give incentive to dysfunctional and undesirable consequences for overall industry performance. An open-ended analysis of e-waste recycling, using the consolidated impact factor framework as a start point, helped uncover the hidden social dynamics that sustain informal recycling in Pakistan. A systems-level view and pictorial representation (Figure 51) of e-waste recycling, shifts attention from a discussion over 'burden shift' and 'pollution havens' to understanding that recycling is situated 'in local practices contingent on waste value, business opportunity and perceived choice' (Agyei-Mensah & Oteng-Ababio 2012; D'Adamo et al. 2019; Khan, SA 2018).

Through the process of applying these principles, the study helped reveal some contentious aspects in informal recycling and some leverage points for interventions to improve recycling. Two fundamental realities provide the context: first, e-waste volumes are growing rapidly worldwide and as Ceballos and Dong (2016) suggest, faster than it can be recycled; and second, the primary focus in current recycling approaches, formal or informal, appear to be tertiary interventions – in effect, treating the disease and providing rehabilitation. As such, particularly given the contextual realities, this study asserts an unarguable need to fundamentally reconsider e-waste management and recycling activity across the value chain, from product design to disposal, in order to shift towards culturally sensitive, primary prevention initiatives. Moreover, in an exercise in risk-taking judgement given limited time and resources, this researcher also suggests two areas of focus: upstream design and downstream disposal with a particularly emphasis on the poor and under-served workers at the bottom of the value chain. These two focus areas are identified in Figure 23. Upstream, the need is for re-engineering in product development; this challenge is recognised in the literature (Jaiswal et al. 2015; Mundada, Kumar & Shekdar 2004; Nnorom & Osibanjo 2008b), but downstream considerations are limited. This study thus adds several crucial ideas for waste management and recycling. One is to establish the conceptual distinction and substantive difference between tertiary and secondary interventions, and primary prevention. Another idea relates to leverage points that can arguably form the basis for policy-led changes to change current practice. Moreover, noting often 'what matters is not measured', the study adds the need to consider first-, second- and third-order effects when measuring costs that can currently be externalised downstream in terms of significant human and environmental impacts.

8.3. Research objectives and summative reflections

The research question for this study was, "*What are the economic impacts of e-waste disposal (and recycling) practices?*" The term 'impact' included both positive and negative consequences of e-waste recycling practices. 'Economic' impacts, by definition, included both financial and non-financial (social) impacts that were assessed using quantitative and qualitative methods. Based on an ecosystem model that supported a social life cycle assessment (S-LCA), this study offers a macro-level view of recycling, initially measuring and quantifying volumes of upstream e-waste generated using material flow analysis and subsequently assessing the downstream cost-benefit of (informal) recycling in Pakistan. The main research question was explored using two subsequent sub-questions (SQ). These SQs, the corresponding ROS and findings were presented in Table 43 and Table 44 in the preceding chapter.

The broad answer to the initial RQ is a complex one that ranges from volume of generated waste, to governance gaps and to competing tensions and deeply embedded social dynamics. As was noted in Chapter 1, e-waste is a global challenge of increasing significance because of the volumes being generated and the associated complexity of this waste. Furthermore, as Ceballos and Dong (2016) suggest, this waste is growing faster than it can be recycled. Turning to Pakistan, this country like many other developing economies, generates a significant volume of e-waste internally and imports significant volumes of e-waste for local processing despite lacking the necessary infrastructure. The consequent problems associated with informal processing are magnified by a lack of formal inventory and general record-keeping in relation to the movement and composition of this e-waste.

Compounding a lack of formalisation in terms of material flow and inventory is the absence of transparency in a largely hidden industry, which is based on many small and micro businesses, some operating from backyards in family homes. Enabling conditions include a lack of upstream governance and profit-seeking by middlemen, sustained downstream by a lucrative opportunity for businesses and low skilled workers need to be employed. At the wider ecosystem level though, there is cause for great concern over an industry largely sustained by the ability to externalise costs identified in this study as first-, second- and third-order effects. An initial intervention, that is implicit in answering the economic impacts fully, is the need for data collection to document both waste volumes and composition, in order to monitor trends. A further intervention is to measure impact, including efforts to identify the motivational and behavioural consequences of performance measures in the industry. As Ridgway (1956) warned a long while ago, the consequences of measurement are not well understood, and multiple criteria are needed at different levels of the system to focus attention on the many facets of the task. Summative conclusions with respect to the SQ1 and SQ2, and the associated sub-objectives are addressed next. These are grouped into upstream and downstream, and associated methodological, considerations.

8.3.1. The current state of (upstream) e-waste generation in Pakistan (SQ1)

Detailed analysis of SQ1, the current state of e-waste in Pakistan in terms of consumer behaviour (RO1) and equipment/ e-waste flows (RO2), respectively was presented in Chapter 4 and summarised in Table 43 (see Chapter 7). Findings related to upstream e-waste generation and consumer attitudes show that about 281 million equipment or 1,790 kilo-tons (2018–2019) of e-waste are being generated locally. The annual rate of increase is expected to be 10.2% based on the estimates of Baldé et al. (2017); Forti et al. (2020). The main methods of disposal in Pakistan are identified as storage or what can be seen as a deferred disposal strategy (42%). Informal recycling comprised 8.6%, and disposal via municipal waste into landfills was estimated as 13.8%. The remainder is disposed for reuse or is on-sold.

The habit of storing old, unused equipment at homes by consumers, effectively delays final disposal and noting the estimated volume of undocumented waste, it is likely that storage also unintentionally consigns e-waste into more convenient, but ultimately more unsafe methods of disposal, such as via local markets and waste collectors or worse, going directly into municipal landfill. Disposal decisions by consumers depend largely on convenience of available options, while positively, consumers also indicated a willingness to pay for recycling of e-waste. These findings related to consumer habits are generally consistent with literature (Ananno et al. 2021; Parajuly et al. 2020; Speake & Yangke 2015), whereby the habit of storing disused equipment at homes or offices is common in both developing and developed countries.

Another trend that is cause for concern in the near future is shifting consumer habits in Pakistan. The country is arguably not a consumer driven society and the majority of the participants in this study indicated they bought new equipment based on their needs. There is however a seeming shift to a throw-away society facilitated by the growing availability of cheaper, mass produced equipment from China, and counterfeit equipment. These equipment have high functionality, but lower useful life and lower content in terms of valuable material for recyclers. The combined effect of greater uptake of (lower quality) equipment is to increase the volume of e-waste produced locally and reduce recoverable materials from processing. The likely significantly changed ratios also means reduced financial incentives to extract metals for the same effort and anecdotal evidence from workers confirms a trend towards less productive processing and rising volumes of waste going to landfill. In turn, hazardous (and toxic) waste risk to workers and the environment is heightened. These tensions are captured in the '*short-term gain and long-term pain'* trap facing businesses and the wider society.

8.3.2. (Downstream) impact of e-waste recycling in Pakistan (SQ2)

This sub-question included ROs 3, 4 and 5. A summative discussion follows.

8.3.2.1. Cost and Benefits of e-waste recycling businesses (RO3)

The CBA of e-waste recycling businesses (RO 3) was examined in Chapter 5. Analysis was conducted at two levels – equipment level and business level. Findings indicated high levels of profitability at both equipment and business levels. Monthly profits for dismantling (Stage 1 recycling) businesses vary by size, ranging from Rs. 14,232 to 3,226,824 (approximately USD 85-19,243). Businesses that extract and refine e-waste (Stage 3 recycling) are even more profitable, with estimated earnings based on size ranging from Rs. 378,581 to 214,115,551 (USD 2,258-1,276,884) per month. These findings are consistent with similar studies that explored profitability and the economic feasibility of e-waste recycling. For example, a study in Europe of recycling disused LCDs determined it was profitable in the baseline scenario (€134,000), but was not seen as economically feasible without a disposal fee (D'Adamo, Ferella & Rosa 2019). Similarly, Cucchiella et al. (2016) and D'Adamo et al. (2019), assessing the profitability of recycling of PCBs in Europe, both verified the economic feasibility of the processes being used. In contrast, however, Qiu and Suh (2019) in a study of the economic benefits of processing rare earth oxides from e-waste, found it was not economically feasible at any scale. This finding has considerable meaning given the notion of urban mines in related literature that is itself reinforced by the practice in Pakistan of sending rare earths to landfill simply as these materials are unable to be recovered by the informal methods used.

Another business specific consideration is that the focus in literature appears mostly on 'formal' recycling processes, typically in plants in European countries. This study contributes to the literature on profitability and economic feasibility for businesses using informal recycling processes. Realistically, notwithstanding the significant downstream costs (effects), these businesses are likely continuing in the short- and medium-term in these countries. The priority thus is to try and reduce volume and mitigate the externalised costs via greater focus on primary prevention. One opportunity relates to the current fragmented and hidden nature of the industry and the presence of many micro businesses that offer employment and income, but are less profitable than larger ones. Restructuring and even consolidating e-waste recycling businesses seems a practical primary prevention strategy to increase profitability, control processing practices and mitigate undocumented and uncontrolled volumes of e-waste materials and hazardous and toxic by-product going into landfill and into waterways waste. Suitably managed, these more profitable businesses, should have more funds to smooth the supply chain and provide regular employment, and better wages and conditions for workers.

Greater formalisation of recycling businesses would also reduce the current need for businesses to operate in hidden and consequently unsafe work environments, as they are unregistered and/or wanting to avoid the attention of local middlemen or political gangs. The overall tensions of operating in a low-structure, competitive business environment creates what this study suggests is a '*trade-off of (multiple) competing interests.'* Business profitability has priority over concerns over the hazardous nature of work and any effects on the environment. It prevails even in the re-export of materials for further processing, where China (which operates a hybrid informal system) is preferred for the higher profit margins over export of the same materials to European countries for formal (safer) recycling, but at lower profit.

8.3.2.2. Impact assessment for workers (RO4)

The impact analysis of economic (financial and social/non-financial) for e-waste recycling workers (RO4) was examined in Chapter 6. Financial cost-benefit elements included reduced productive capacity, lost wages, medical expenses, wages (and meals). Non-financial cost-benefit elements included opportunity costs, cost of illiteracy and value of life ratio that have been quantified nationally. Further, unknown and hidden costs, and associated social dynamics were uncovered with the help of qualitative analysis.

According to results, the main finding suggests that the net economic cost incurred by each worker is about Rs.34,069 - 85,478 (USD 203–510) per month, which exceeds by 2.6-4.7 times the economic benefits derived. A similar comparison of results was not found in the literature to the best of the researcher's knowledge. Previous studies focused on biological susceptibilities like human health impact in terms of injuries, body burden and exposure to high levels of toxic elements, such as lead, PCBs, PBDEs among others (Amankwaa, Adovor Tsikudo & Bowman 2017; Awasthi, Zeng & Li 2016a, 2016b; Fischer et al. 2020; Wang, Y et al. 2016). There is a qualitative study by Umair, Björklund and Petersen (2015) that assesses some social impacts of informal e-waste recycling in Pakistan according to UNEP guidelines on S-LCA. This study, going a step further, quantified the downstream impacts (costs and benefits) of informal recycling for e-waste recycling workers using a CBA. In contrast to the profitability reported for businesses, workers are caught in '*a poverty trap*' driven by economic needs to support their families and compounded by illiteracy and a sense of helplessness. This harsh reality is compounded by workers evidently suffering from work-related illnesses that reduces their capacity to earn a living and, anecdotally, the evidence is leads to shorter than average life span.

8.3.2.3.A framework for impact assessment for developing countries (RO5)

The design of a framework for e-waste impact assessment for developing economies (RO5) was presented and discussed in chapter 7. This framework reveals the need to factor in a complex picture of interdependencies. While the focus is informal recycling in Pakistan, it is noteworthy that formal recycling itself is not without its problems. As such, a broader takeaway is to understand that e-waste generation and recycling needs reconsideration. In the interim, and while far from ideal, informal recycling will remain a material consideration in dealing with e-waste in the developing economies of the world – as a source of revenue and for local employment.

Reflecting this complexity, the multi-level impact assessment framework for developing countries proposed is in two parts: first, the consolidated impact factor framework that can be used to measure the visible and known, direct and indirect cost-benefit for multiple stakeholders; and second, the social dynamics that exist underneath and reflect complexities that are primarily hidden and unknown. These dynamics have been explored using a system thinking approach in an open-box manner (Ssengooba, McPake & Palmer 2012; Wood 2018, 2019). The open-box approach, in contrast to a black-box approach where the internal working are not evidenced, helps expose (visualise) and illuminate the inner working of the system and can subsequently enable policy-makers to trace the chain of causality from input to output at a fundamental level. The approach has helped to identify significant unknowns and some contentious aspects in the e-waste industry.

8.4. Study contribution

The research questions discussed in the previous subsection were formulated to '*measure what matters.'* Equally, as Ridgway (1956) might have added, not everything that matters can be measured. Answering the research questions and going through the research process has helped this study make some significant academic, methodological and practical contributions to the literature on e-waste management. These three categories overlap and could be visualised conceptually as a Venn diagram, with systems thinking a discipline and causal loops a methodological technique, respectively. These methodological contributions influence and complement the academic and practical contributions noted below.

8.4.1. Academic contribution

As e-waste in an emerging area of interest, there are few frameworks available to explore the complexity of the industry, hence there was a need to either create a new framework or adopt something compatible from a known discipline. This study combined a process-oriented life cycle assessment (LCA) to conduct a CBA, with a holistic ecosystem framework to capture the multiple stakeholders and overlapping interests. The ecosystem, incorporating three levels of interventions (tertiary, secondary and primary), is a well-established framework in the health sector and serves to emphasise environmental and policy contexts for behaviour. It helped explore the impacts and overlapping interests of multiple stakeholders, and later it helped to conceptualise possible primary prevention strategies at both upstream and downstream levels.

Beneath the seeming focus on measuring quantities of waste streams in the multi-level impact assessment framework (Figure 51), there are also social and psychological influences that are harder to measure. The social dynamics sustain e-waste recycling practices in Pakistan and are as yet unexplored. Academically, this study added systems thinking as a discipline and causal loops as an approach to explore these hard-to-measure variables in the e-waste industry. The causal loops help to highlight leverage points for necessary policy intervention if change is to come to the e-waste informal recycling industry. Another academic contribution in the use of a life cycle view (from upstream consumer considerations to downstream disposal and recycling) is to close the loop not captured by other methodologies, such as supply chain management (Sarkis, J 2012), that does not consider upstream manufacturing and downstream disposal impacts (Figure 23).

Moreover, by attempting to identify variables in e-waste management in four broad categories, known, unknown, hidden and blind spots (Figure 50), and adding immediate, second- and third-order effects, this study provides a necessary rigorous approach to classifying and assessing impact. This more expansive approach contributes both academically and practically to the field of waste management and recycling, increasing the ‘known’ areas of waste management, and providing a basis to further reduce the unknowns, the hidden and the blind-spots in the field. A final conceptual contribution is a system-level representation of e-waste processes from post-use scrap to downstream impact (Figure 52). This is a revision of Figure 1 from Chapter 1, adapted to include summative findings from this thesis and related literature. The focus of this study in the areas shown in grey, while the specific contribution of this thesis are highlighted by the red dotted box. Financial and non-financial (social) first- and second-order effects have been estimated and marked with a single red asterisk. Material composition is largely unknown and not measured, and is a significant blind spot, while second-order and third-order effects (particularly environment) are important but outside the scope of this study, and so marked in double red asterisks.

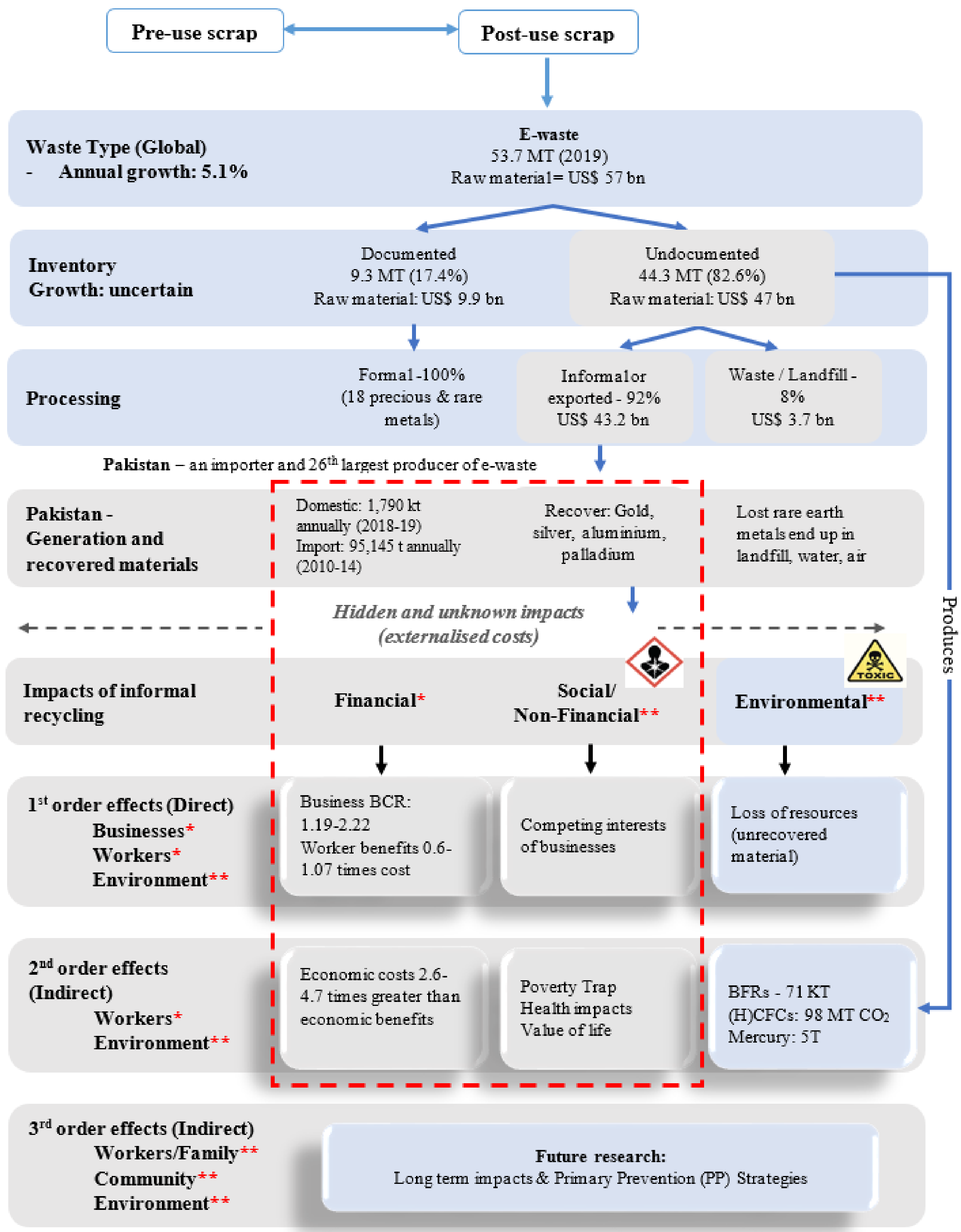

Figure 52: A system level view of e-waste processes and downstream impacts (2019 data)

Data sources: Forti et al. (2020); Imran et al. (2017)

*measured

**matters, but not measured

8.4.2. Methodological contribution

Over the research process, some weaknesses were noted in UNEP guidelines for social life cycle assessment (S-LCA). Although comprehensive, the S-LCA appears more suited to use in developed countries, as many of the variables were irrelevant to a developing country like Pakistan. As well, S-LCA guidelines only provided a list of possible relevant variables, but no further guidelines on analysing and interpreting the data. Therefore, methodologically, the consolidated impact factors framework was useful to assess the impact of e-waste recycling for workers and businesses in an emerging country context. Similarly, identifying variables in terms of direct, indirect, financial and non-financial costs, was arguably well suited for a developing country context.

Methodologically, a cost-benefit analysis (CBA) has been used in many contexts to assess anticipated costs and benefits resulting from projects, programs or policies (Drèze & Stern 1987; Mihaela et al. 2015; Volchko et al. 2017). This is, however, arguably the first time that a CBA has been applied in e-waste management. A final methodological contribution is the approach taken to extrapolate quantities of internally generated e-waste in Pakistan using primary data, based on income groups and population. Previous studies have typically based their estimations on trade or sales data (Baldé et al. 2017; Forti et al. 2020; Sajid et al. 2019). This approach is flawed when applied to Pakistan, which like in many other developing does not have rigorous record-keeping and not all imports are registered. As such, the use of another approach was warranted. These methodological contributions overlap with and therefore act as a bridge between the academic and practical contributions made by this study.

8.4.3. Practical contribution

Practically, this study investigated the growing and largely underexplored problem of e-waste management and disposal. Focused on an emerging economy, the study used a product life cycle assessment (LCA) to examine and map the processes in informal recycling practice from post-use scrap to upstream waste generation and downstream benefits and hidden, externalised, costs associated with recycling. As well as estimating upstream volumes, another practical contribution of this study is to reveal the positive consumer attitudes, demonstrated by their willingness to carry some of the burden in helping improve the effectiveness of e-waste management. The heightened level of awareness appears to be related to attaining a sound education. At a policy level, there encouraging public readiness is evident for educational campaigns and desire for better and more convenient disposal methods to consumers, including formal e-waste management that includes a take-back and recycling system in Pakistan. A final important practical contribution for policy is the identification of key leverage points in the various causal loops that suit government intervention in the form of regulations, investment and/or education. With respect to policy, reported information, and quantitative measures of performance, arguably play a key role in determining the areas that attract the attention of policy-makers and therefore, are helpful in attracting necessary resources and evaluating effort against desired outcomes.

8.5. Agenda for change – intervention strategies

Focusing on e-waste recycling at an ecosystem or meta-level, it is clear recycling approaches, both formal or informal, are inherently at a tertiary level (after the problem has occurred - Figure 20). While 'informal' recycling is clearly of limited use in terms of recovering valuable metals and incurs as yet unquantified costs for humans and the environment, as several studies also highlight, formal recycling is itself also not a completely satisfactory solution. Besides the high cost of associated technology that is not affordable by developing countries, formal waste approaches appear to not be free of negative impacts of waste residue (Deng et al. 2014; Song et al. 2015; Wang, Y et al. 2016). Given these facts, it is clear the industry needs to shift towards primary prevention in order to stop pollution happening in the first place, with possible later secondary and tertiary efforts to reconstitute waste materials and restore the environment.

An awareness of interdependence invites an understanding of wider system dynamics and the major processes, drivers and responses in any agenda for change in regard to this social and environmental problem. A whole of system view that informed other strategic assessments in the context of health, marine and social, is thus equally applicable to e-waste management and Table 45 is a summary of suggested stakeholder focused interventions. Speculative items that need to be (measured) and actions to mitigate potential second- and third-order effects are also included. Core principles include the need for: data to measure, formal process to reduce and ultimately stop externalisation, use of measures that matter, but as yet not measured, and finally, audit programs for greater accountability and continuous improvement.

Table 45: Intervention strategies

	Upstream				**Downstream**
	International/ Local Governance	**Manufacturing businesses**	**Consumers of EEE**	**Recycling businesses**	**Recycling workers**
Tertiary level	Intervene in waste flows / collection points	Components classification codes	Recycle responsibly [s] Pay for recycling	Oversight/ audit[1] Waste mitigation[2,3]	Medical treatment[2,3]
Secondary level	Site visit and monitoring	EPR[s] Circular economy Fund downstream waste material reconstitution	Reuse Pay for waste management services	Ventilation [2,3] OH&S conditions[2,3]	Check protective clothing[2,3] OH&S conditions[2,3] *Training and skills development1*[1]
Primary level	*Trade data*** *Governance to control bribery* Waste classification *Investment for better education and formalisation* Transparency of processes	Redesign [s] *Material composition* Reduce forced obsolescence	Reduce consumption Recovery waste points Education/awareness (reduce, reuse, recycle)	*Measure/ Data*[1] *Fund better technology*[2,3] Formalise processes[1] [s] *Responsible disposal of waste residue*[2,3] Change incentives of practice[1]	Train for better practices[2,3] Fund protective clothing[2,3] *Educate children*[2,3] Health / cultural impact strategies** Build awareness and long-term impact assessment **[2,3]

Points in *italics* refer to key leverage points

[s] strategies based on literature - (Bocken et al. 2016; Kiddee, Naidu & Wong 2013; Patil & Ramakrishna 2020)

[1]Mitigate for first-order effects [2,3] Mitigate for second- and third-order effects

As Table 45 suggests, there are several interventions possible across all levels of stakeholders. To illustrate, at a governmental level what is required is trade data to document e-waste volumes and flows. National regulations and greater formalisation of the recycling industry are needed in the shape of approved treatment and disposal methods, minimum standards and safety precautions to discourage harmful practices. Other systemic changes include improved governance to control shortcuts to avoid the many middlemen and need to bribe agents, which encourages many businesses owners to import from illegal channels. There are apparent loopholes with respect to waste classification (Basel Convention) that need to be addressed at an international level, and the need to implement agreements including Basel Convention and Bamako Convention.

Manufacturers should seek to redesign equipment to slow down or close the resource loop – as proposed by Bocken et al. (2016). Slowing the resource loop refers to the strategies that reduce the use of resources. Designing life-long products by creating emotional attachment, trust, reliability and physical durability, and designing for product life extension by making repair or upgrade of existing equipment can further contribute in slowing down the demand for resources. Another strategy is to make elements biodegradable and/or completely recyclable, and where this might not be absolutely possible for e-waste, efforts must be made to design and manufacture equipment that is easy to disassemble, easy to recycle and compatible with natural ecosystems.

At a consumer level, education and awareness regarding 3Rs (reduce, reuse and recycle) can help instil behavioural change and reduce waste going directly to landfill. Crucially, downstream at the recycling business level, direct funds raised at the secondary level to encourage investment in better technology is required, as are efforts to support formalisation, and change the incentives for business from purely financial to a social and environmentally conscious one. For workers, training and upskilling are needed to build internal capacity and raise profitability. A hidden factor is the harsh reality of children needing to work order to supplement the family income. The transition to formalisation of the industry might include a living wage for workers and completion of formal education by children, as education is an imperative to break the cycle of poverty. In the long-term, longitudinal studies can be undertaken to measure impact for further policy purposes.

Naturally, implementation of these changes is a challenge and will need to be phased in using a stages approach: the immediate term, medium-term and long-term. Arguably, the immediate focus is and must be multipronged: at the tertiary level, upstream on government regulations to provide the structural basis for changed practice and downstream within businesses to mitigate the worst in waste disposal. This activity can be supported by low-cost awareness programs to shift consumer and business behaviour, enabled by non-government and local community-based organisations to secure national and local government support. In the medium-term, attention must shift to upstream tertiary level intervention by businesses, and greater primary prevention efforts at the business and worker level.

8.6. Challenges and limitations of the study

Completing a PhD thesis is a long journey, full of challenges but also with many moments of excitement (getting a paper published). Challenges encountered and study limitations that impacted the conduct of this research are summarised below:

1. E-waste is classified into six (6) categories, with further classification at equipment level. This micro level classification made it impractical to include all the categories of e-waste in upstream analysis as data collection for each category was not feasible (Sub-question 1). Data availability was also an issue; data collection was based on individual consumers representing households and excluded companies or organisations.
2. Primary interview data of e-waste recycling workers and business owners was limited to Karachi, which is the largest city of Pakistan in terms of population and economic activity. All other cities were excluded due to time and resource constraints.
3. Most businesses were unregistered and pay no taxes. For these are other reasons, recycling businesses are hidden and informal nature, and recycling sites are difficult to locate and access. As a result, the sample size of workers and businesses was low. Understandably, most businesses were also unwilling to provide financial data.
4. Child labour is a significant (hidden) part of e-waste recycling, much like it is in other systems in Pakistan. The reason children work is to supplement the family income and most workers indicated they started working in childhood in any case to support their families. Child labour considerations were not included in this study, as no ethics clearance was obtained for the collecting of data from children.
5. This thesis presents a static snapshot of a dynamic phenomenon, which is underexplored and still evolving. The volume of e-waste, legislation, recycling practices, and most importantly the technology is constantly changing, which makes it difficult to incorporate all the dynamic elements.
6. Conducting a material flow analysis was a further challenge. Conceptually, material flow starts at the level of goods (assembled equipment), then component level after dismantling, and then to micro-component level and finally substance level. By the time materials reach substance level, it is no longer e-waste but rather substances, elements or metals. Setting the boundaries and levels to include in the analysis was consequently difficult. The research

adopted a rule of thumb strategy to track just a few valuable materials such as gold, silver and aluminium to substance level (refining), and the remainder to components and subcomponents level; this is the practical limitation of this study.

8.7. Recommendations for future study

Notwithstanding e-waste is an emerging global problem, certain areas are still under-explored in the academic literature. This study contributed by assessing the impacts of informal e-waste recycling practices. Future analyses could extend the current research, address some of the noted limitations and explore the following under-researched areas:

1. This study estimated the quantities of e-waste generated in Pakistan. As there is lack of inventory management and data on the estimates of e-waste worldwide, future studies can try to develop a standardised mechanism or tool for systemic estimation of e-waste able to be used at a country and global level. This tool might help incorporate multiple categories of e-waste and capture the dynamic nature of e-waste, rather than providing a snapshot like most existing studies do.
2. The present study estimates the financial and non-financial (social) costs and benefits for e-waste recycling workers in Pakistan. A future study could possibly develop a single tool for systemic estimation of impact in various contexts through modelling for standardisation. This is a post-doc intention of the researcher.
3. Future longitudinal studies are suggested to monitor changes in consumer purchasing behaviour and preferences with reference to electrical equipment, average useful life and disposal behaviours depending on the options available. These behaviours will ultimately determine the growth rate of e-waste and the ways it is recycled – and which in turn then will need to be managed.
4. Current research has studied the first-order (direct) effects and some second-order (indirect) effects, using financial and social variables. Future studies can focus on a fuller exploration of second- and third-order effects over the long-term, which are still completely unknown. This impact could be typically social and environmental and might extend from one generation to the next.
5. A study of practical, innovative and environmentally sound (and also affordable) interventions to reduce toxicity in e-waste and improve recycling practices could be the

basis of future research. The study could focus on scientific experimentations across countries actively involved in e-waste recycling.

6. Finally, as noted earlier in study limitations, e-waste contains multiple complex components, elements and metals in varying quantities, even in the same type of equipment. There is limited research on yields (output) of precious and toxic metals recovered through different recycling techniques. Future research might explore the quantities of recoverable precious metals, as well as of toxic elements.

8.8. Personal reflections

My research journey has been challenging yet rewarding. As I moved from Masters to PhD, I realised I had to go through a mental transition – from reading for understanding, learning and taking exams (a reader or student perspective) to reading, thinking, reflecting and writing something valuable for others to read (a researcher perspective). This was a significant change to begin with. With an academic background in business and finance, I opted to do my PhD in the area of e-waste naïvely after realising I was not content with further study in finance, and wanted something challenging and of great personal interest. It, first, took courage to decide to specialise in a new field, but also needed extensive guidance from my supervisors and technical advice from a small expert advisory group who helped me narrow the research area and devise achievable research questions and sub-set objectives. As I progressed, I had concerns about my direction at every stage. While designing questionnaires, though I consulted with industry experts as well as a statistician in addition to my supervisors, yet I was uncertain, and some questions constantly bothered me: am I asking the right questions?; am I collecting the right data to answer my research questions?; and will participants be willing to provide responses? There were many more questions until I collected the data.

Data collection was also a challenge and a learning experience in itself. Despite being brought up in that culture (Pakistani), I got to learn and uncover aspects of the society and the informal economy that otherwise was hidden or not relatable. During data collection, I also realised that things do not always go as planned – evident by the unwillingness of many respondents to provide financial data. However, they provided interesting qualitative data that was rich and beyond the planned semi-structured interview questionnaire. Somewhat limited and ambiguous data raised my next concerns – how will I make sense and analyse the collected data? Collected quantitative data had turned out to be a bit different from expected data – due to the complexity of e-waste (many different categories, processes for each components), and due to unwillingness by participants.

Similarly, qualitative data revealed social complexities that were difficult to untangle. It was then I discovered what emerged as a very useful, novel approach based on systems thinking to analyse the data I had and answer my research objectives. This is consistent with the pragmatic paradigm, which advocates choosing explanations that have the best desired results (what works).

Throughout my journey, I developed interesting and valuable insights in the area of e-waste, which broadened my knowledge. At the same time, I also underwent a whole process of change, characterised by personal growth, and changes to the way I think and ways I perceive and relate to the world. I was then able to respond to my own criticism of doing a PhD degree – I earlier believed spending 3-4 years on a PhD focused on a very specific topic made the researcher stale in other earlier areas of knowledge. However, as I approached the completion phase of this PhD thesis, I realised the process provides transferrable skills that can be applied to other problems and areas of study interest. I discovered I now have a larger view and look at the wold in a different way – holistically and in parts, just like in systems thinking. In the end, I realise that what matters the most is how I have transformed through the journey; the thesis is just an outcome.

8.9. Concluding remarks

Guided by the formative principle that *what gets measured can be managed*, this thesis presents a critical analysis of upstream consumer and downstream business considerations. The informal recycling industry is financially lucrative but is sustained by the ability to externalise most costs because of an absent regulatory framework and hence limited accountability for known and hidden first-, second- and third-order effects on people and the environment. These externalised costs are not currently measured. Thus, a substantive contribution is the development of a multi-level impact assessment framework for developing countries (RO5) comprising financial and non-financial (social) variables to support an open-ended analysis of e-waste recycling shaped by the logic of the second guiding principle: to *measure what matters but not often measured*. The recycling industry in Pakistan can be conceptualised as being shaped by local practices, local culture, contingent on waste value, business opportunity and perceived choice. Leverage points for fundamental, longer-term change in processes associated with waste generation, and for management and disposal of e-waste have been identified. Arguably, the multi-level impact assessment framework and related study findings can be generalised to other regions in Pakistan and other countries that similarly generate and also import e-waste and use informal practices to process this material. Crucially, for the necessary focus on the many aspects of e-waste, a starting point has to be to document, regulate and measure performance that goes beyond a singular focus on return on investment for a single stakeholder – businesses, to select multiple criteria and to *measure what matters*.

==== End of thesis ====

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APPENDIX 1

The following table has is based on the literature and with extensive guidance provided by the supervisors. The main research question is ***What are the economic impacts of e-waste disposal (and recycling) practices?*** Shown below are the sub-questions and corresponding research objectives. For each research objective, the important factors were identified and variables to measure were derived, all based on the literature. Next, the variables for the proposed study were chosen based on the importance and feasibility. Finally, questionnaires were drafted from selected variables and the literature.

The variables mentioned in green have been included in the study, those in blue will be taken from the literature, red shows variables not too relevant for this study, while those in purple are not feasible.

Table 46: Research objectives, factors and variables

Sub-questions (SQ) and Research Objectives (RO)	Factors	Variables	Methods
SQ1. What is the current situation with e-waste generation and disposal in Pakistan?	• Policies and legislation about e-waste (implementation and enforcement) • Technology uptake • Population growth • Cultural norms?	Important, included in the study Important, literature Important, not too relevant Important, not feasible	Qualitative and quantitative assessment from primary and secondary sources.
RO1. Analyse the consumer behaviour concerning the acquisition, usage, disposal, awareness and willingness to pay for e-waste management. **RO 2.1.** Assess the buying behaviour for new EEE. **RO 2.2**. Estimate the useful life of EEE. **RO 2.3**. Assess the factors that influence formal or informal e-waste disposal practices **RO 2.4**. Assess the awareness about hazardous/toxic elements and valuable elements **RO 2.5**. Assess the willingness to pay for e-waste management.	**RO1** **1.1: Acquisition** • Estimate the total quantity of equipment, the quantity of equipment in use and the quantity of equipment not in use. • Extrapolate the quantity to estimate the e-waste quantities for the population. • Identify the sources and preferences of buying equipment. **1.2: Usage** • Estimate the useful life of equipment **1.3: Disposal (reasons for informal disposal as opposed to formal)** • The actions (attitude/cultural norms) towards non-functioning equipment • Available (and accessible) **disposal options** (are necessary for formal disposal and recycling) • The attitude towards disposal **1.4: Awareness** • Awareness about hazardous substances • Awareness about valuable and precious metals	**RO1** **1.1.** • The number of equipment in use and not in use • The number of people in Pakistan subscribing to a telecommunications network • The income levels of Pakistan's population • The source of buying electrical and electronic equipment • The main reasons for buying or changing equipment (attitudes – frequent buying for luxury) – contribution to e-waste. (Steady or sharp increase based on the preferences/attitudes/behaviour). • The preferred condition of equipment (re-use culture or throwaway and buy society). **1.2.** • The frequency of buying new equipment (the useful life, expected increase) **1.3.** • Cultural norms: first course of action if the equipment stops functioning (a throwaway society?) • The number of prevalent ways of disposing of e-waste • Why is e-waste disposed of in a particular way – reasons **1.4.** • Consumer awareness about hazardous substances in equipment • Consumer awareness about valuable and precious elements in equipment • Consumer awareness about environmental and human health hazards due to improper disposal and recycling of e-waste.	

RO2. Assess the flow (and stock) of electrical and electronic equipment/e-waste through the upstream sector.	**1.5:** • Willingness to take responsibility • Willingness to pay a charge for disposal and recycling • Willingness/motivation to return the used/old equipment **RO2** • Collection: • Recycling: • Final disposal:	**1.5.** • Willingness to accept the responsibility for creating e-waste • Willingness to pay a charge for recycling e-waste • The acceptable charges (percentage of price) • Willingness to return old equipment • Financial benefit (percentage of price) that would motivate the consumers to return the old/used equipment **RO2:** • Generation/quantities of e-waste (domestic) - (in-use rate, population, household size, income groups - extrapolate) • Storage rate, landfill rate, collection rate and direct reuse rate • Active stock age composition, disposal-after-usage age composition • Transfer coefficients representing storage rate, landfill rate, collection rate and direct reuse rate • Transfer coefficient representing the fraction that is dismantled, reused and functional checking and repaired/refurbished • Weight of all main components resulting from dismantling • Substance flows • Final disposal	
SQ2. **What are the downstream impacts of e-waste recycling practices in Pakistan?** **RO3**. Estimate the costs and benefits of e-waste recycling for businesses.	**Recycling businesses:** • Working conditions • Secure employment **Recycling Businesses**: Revenues and costs	**Recycling Businesses**: • Registered? (Y/N) • Set-up costs • Maintenance costs • Informal costs such as bribes <u>Company *revenues & profits* from</u>: • Sale of second-hand EEE, • Usable accessories, • Recovered materials, • Fees to customers, <u>*Technical costs* of:</u> • Access (materials), • Collection, • Transportation, • Treatment (materials, energy, labour, equipment, real estate/ building, administration, financing costs (interest) • Taxes? <u>*Impacts:*</u> • Impacts not covered elsewhere (qualitative) • Decision of formal/informal recycling	Qualitative and quantitative assessment from primary and secondary sources Materials Flow Analysis (MFA) and/or Economically extended materials flow analysis (EE-MFA) Cost-benefit analysis (CBA)

RO4. Assess the drivers and social implications of working in the e-waste recycling sector (social costs and benefits).	**FINANCIAL** **Consumers**: Costs and benefits **Workers**: Earnings and expenses **Local Community, Society and Supporting Industries:** Indirect and induced impacts **Government Regulators**: Enforcement costs, auditing costs, awareness raising, guarantees Economic: aggregating the relevant subset of financial (distributional) impacts and external impacts. **NON-FINANCIAL (SOCIAL)** **Consumers:** • Safety • Awareness **Workers:** • Safety • Health • Working conditions • Child labour • Worker rights • Fair wages • Education, skills and training • Social benefits **Family members** • This subject remains silent (hidden businesses) **Local community:** • Employment • Health • Community satisfaction **Society:** • Awareness • Commitment to social issues	**FINANCIAL** **Workers**: • Wages, • Healthcare expenses, cost of treating work-related injuries • Consumer spending (food, clothing, household expenses) • Income – all expenses (ability of income to cover all expenses for an average paid worker and the lowest paid worker) • Any taxes paid (direct or indirect) **Local Community, Society and Supporting Industries** Indirect and Induced impacts: • Employment, • Contribution to economic growth/GDP, • Consumer spending, • Taxes, • Output/productivity, • Infrastructure development **NON-FINANCIAL (SOCIAL)** **Drivers:** • Motives for working in e-waste • Other employment opportunities (if any) **Safety (workers):** • Presence of occupational safety measures and standards (training and policies) • Frequency of training provided on OHS, and implementation of policies. • Use of protective equipment and clothing • The number (and type) of injuries occurred and reported at the workplace • Reading the user manual and following safety instructions (consumers) **Health (workers, local community & society)**: • Concentration of heavy and toxic metals in human body • Level of toxicity • Number of premature deaths • Number of sick leaves taken **Working conditions (recycling businesses and supporting industries)**: • Availability of proper sanitation, • Availability of proper ventilation • Availability and appropriate use of safety equipment • Availability of emergency protocols • Policies and procedures employed to minimize environmental, social and human health impact. • Power on pricing and market	Qualitative and quantitative assessment from primary and secondary sources Cost-benefit analysis (CBA) Social Lifecycle Assessment (S-LCA)

	• Health	• Presence and the nature of employment contracts, terms and conditions of employment, employee benefits
		
		Child Labour (workers):
		
		• Percentage of children in the workforce
		• Percentage of working children attending schools
		• Opportunity cost of not getting education (reduction in lifetime earnings)
		• Wage level of children compared to adult workers
		
		Worker rights
		
		• Presence of labour unions
		• Presence and access to dispute resolution system
		• Conditions and restrictions on the right to collective bargaining
		• Freedom to terminate employment within prevailing limits
		• Employee turnover
		• Percentage of women workers/participation
		
		Working Terms
		
		• Number of hours worked
		• Number of holidays (paid and unpaid)
		• Work flexibility (hours, days, place)
		• Voluntary agreement to employment terms
		
		Fair wages
		
		• Wage of lowest paid worker compared with minimum wage
		• Wage of lowest paid worker compared with all household needs
		• Amount and frequency and any deduction in wages
		• Difference between the wage level of women and men workers
		
		Education and training
		
		• The level of education (literacy) of the workforce
		• Training provided for required skills (whether or not, the frequency, quality)
		
		Social benefits
		
		• Availability of counselling services
		• Provision of social benefits such as:
		    ○ health insurance (comprehensiveness, coverage),
		    ○ pension plans
		    ○ childcare
		    ○ maternity leave
		
		Local community
		
		• Percentage of workforce locally hired
		• Number of new jobs created in local community each year
		• Quality of locally grown food
		• General reasons for visits to local doctors
		• Number of community complaints or legal suits
		• Donations (time and money) to community
		• Efforts to minimise the use of hazardous substances/methods
		• Noise and air pollution	

		Society • The level of awareness of creation of e-waste • The level of awareness of hazards of e-waste • The level of awareness and commitment to social issues (what is being given up). **Social implications (workers):** • Implications not covered elsewhere (qualitative) • Health impacts • Hidden and unknown impacts • Impact on the family (hidden – not included)	
RO5. Identify a framework for e-waste impact assessment for developing countries.			

APPENDIX 2

Informal E-Waste Recycling Processes in Pakistan

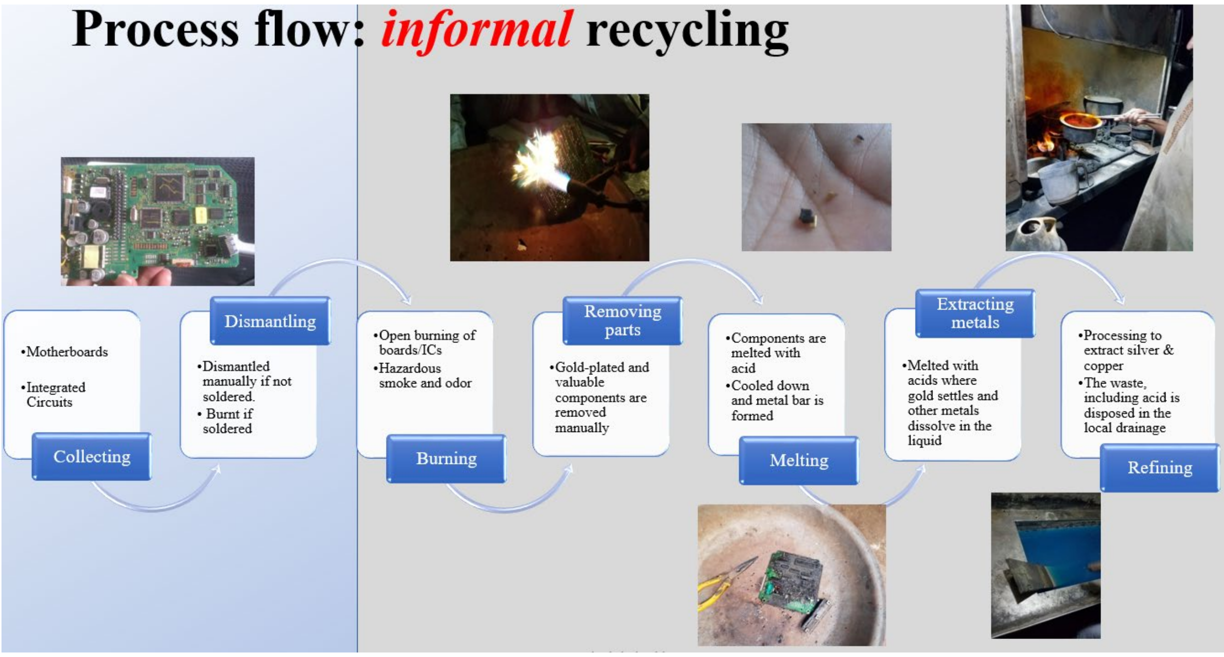

Figure 53: Informal e-waste recycling process

Photos taken by the researcher during field visits between September-November 2018 (Location: Shershah and Saddar)

The Burning Process

1. If the board is soldered, it will have to be burnt.
2. If the board is not soldered, first components have to be removed without burning. From the coated board, remove resistors, copper and excess carbon. In short, remove everything which will reduce the ratio of gold or make it impure.
3. Then burn the board which is just left with the chips, Integrated circuits (ICs), Vertical interconnect access (B-daane)
4. After burning, the green part of the card also burns and wires turn white, so we need to remove (pull) that, B-daana also disappears. The remaining fibre (white), after burning causes itchiness on the hands so we have to use gloves, to prevent itchiness. (Burning will cause the fibre to turn white and we will just remove it and throw it away.)
5. We will take the connecting wires.

6. Remove the useful components (ICs, chips, connecting wires, etc.) and burn again.
7. Make the powder (ash) which consists of burnt components.
8. It is ready for the next stage of uthali (which means, melting it in a pot)

The Melting Process

Palta/uthali is an oven, usually underground, burnt using furnace oil. Ustaad (the boss) used 46 kg of burnt and powdered kekra ICs during the process

1. Input (burnt and powdered):
   i. Gold plated pins
   ii. Green ICs
   iii. Chip ICs
   iv. Connectors (big thick pins of connectors)
   v. Male/female plugs (have gold plated pins)
   vi. Some components (purzay) which are made of brass or copper, but are gold plated with good quality of gold
2. Add:
   i. "Khar" (Dust/sand) composed of mitti (sand) and sikka (lead)
   ii. Caustic soda
   iii. Nitric acid (choray ka tezaab)
   iv. Sodium carbonate (soda)
   v. Borax (sohaga)
   vi. Potassium nitrate (Saltpetre/kalmi shora in local language)
3. Heat and melt all these ingredients for at least 3 hours in uthali
4. Once melted, turn the liquid over into a pot (palta)

5. Let it cool for about 1-1.5 hours. Pour water to cool it down, which will sizzle and evaporate.
6. The impurities (called kaanch) will start to turn black.
7. Use a hammer to remove all black impurities. Make sure no khar or impurities are left or attached to the gold, which will be in the form of a bar (solid).

Refining

Adda: It is like a fireplace/oven, made of special clay (mixture of cow dung ash and chalk), burnt using wood or coal

1. In the adda, add:
    i. The solidified and cleaned metal from previous stages
    ii. Lead (sikka)
2. Melt the added ingredients
3. Some impurities will not melt, so use an iron rod to remove it from the molten metal
4. Let it heat/melt until the lead (sikka) evaporates along with some copper
5. The resulting molten metal will consist of:
    i. Gold
    ii. Silver
    iii. Copper (tanba)
    iv. Pd (palladium)
6. A bar (called chakki or raini in local language) will be formed of the remaining metals. Chakki will be smaller in size than the original metal bar the adda process started from (due to removal of impurities).
7. **To extract gold**: In a steel utensil (acid does not dissolve the steel), add this metal bar in nitric acid (shoray ka tezaab) and let it rest (no boiling). This acid liquid will be green in colour.

8. The reaction will cause silver, copper and pd to melt in the acid (liquid) and gold will settle down as dust
9. Add nitric acid (shoray ka tezaab) to the gold dust and simmer twice or thrice.
10. Add water and wash to the stage where water turns from green colour to milky white. When you add water to the green acid, it will turn milky white.
11. Separate the gold dust (in a steel bowl) and liquid acid.
12. Wash the gold dust with spring water continuously (very carefully and gently) until it turns red in colour and water turns from milky white to colourless.
13. The liquid acid now has three metals: silver, copper and palladium
14. **To extract Palladium (Pd):** Take a small bar of potassium (used in manufacturing of bombs), make powder and add in the acid
15. Stir and let it rest until Pd settles down as dust.
16. Transfer the liquid acid to another container.
17. **To extract silver**:
    a. Add salt (not iodised) in the liquid acid, stir and let it rest until silver settles down as dust.
    b. Alternatively, place a copper bar/rod in the acid liquid (electrolyte method) to attract silver on the bar, which can then be separated.
18. **To extract copper**: The remaining copper in the acid is so low in quantity that it is useless to extract
    a. Place an iron rod in the liquid (electrolysis) and copper will be attached to the iron rod, which can then be separated.
19. The acid will turn green in colour just like that of grapes.
20. **Discarding:** kaanch, acid
    a. Discard the acid in local drain OR

b. Use it to clean the tiles or floor because it still has strength, and there is no harm reusing it for cleaning. "*I clean my floors and toilets all the time using that acid*."

Sarafa Bazaar (Purification):

1. Heat sohaga (Borax) in the bhatti (coal oven with different types of coals - pakka coal from steel mill) in small uthalis (pots),
2. Add 100g gold and 200g silver bar which have been made after melting the jewellery.
3. Melt and keep on mixing.
4. Pour on a plate flattened to cool (metal/silver) plate.
5. Use a hammer.
6. Add Nitric acid (shoray ka tezaab) and metal (plate) in a steel pot and cook (liquid).
7. Maroon/brown coloured smoke will be released.
8. Boil and add water so the tezaab (acid) works better and faster; as the acid works, colour gradually turns green/blue.
9. Silver melts in the acid liquid and gold settles down.
10. Rust coloured gold in layers is formed.
11. Heat the gold again in oven after placing a piece of newspaper on it so the particles do not fly off.
12. After melting, add nishtar (some powder) to cool it down and give it a shiny texture; the newspaper will turn into ashes and fly off.
13. To extract silver: place copper rod in the acid and this will cause silver to solidify and water will evaporate.

APPENDIX 3 – Ethics application approval documents

Questionnaires

Consumers of Electrical and Electronic Equipment (EEE)

1. How often do you buy new ICT and telecommunication equipment? (please mention the number of equipment) **(Volumes of EEE)**

	Never	Within 1 year	1-2 years	2-5 years	5-10 years	10-15 years
Screens						
Televisions						
LCD (photo frame)						
Monitors						
Laptops						
Notebooks						
Mobile phones						
GPS						
Pocket calculator						
Routers						
Personal computers						
Printers						
Telephones						

2. What is the preferred condition of the equipment you buy? **(Source of EEE)**

	Not Applicable	Brand New	Used (functioning)	Indifferent
Screens				
Televisions				
LCD (photo frame)				
Monitors				
Laptops				
Notebooks / tablets / iPads				
Mobile phones				
GPS				
Pocket calculator				
Routers				
Personal computers (desktop)				
Printers				
Telephones				

3. Where do you buy your equipment from? **(Source of EEE)**
   a. Local mobile shop / market

b. Direct from the company (outlet or online)
c. Online (third party supplier)
d. Other (please specify): ____________________

4. What are the main reasons for new purchase decisions? Please rank with the order of importance (1 being the most important and 5 being the least important) **(Creation of e-waste)**

Upgrade to new model	
Lost/stolen	
Broken down/fault rendering it non-functional	
Other (please specify)	

5. What is your course of action if any of your equipment stops functioning/breaks down? (rank from 1 to 5, where 1 is the most applicable and 5 is the least) **(Disposal of e-waste)**

Try to keep using (if still working somehow)	
Try to get it repaired/fixed for reuse	
Discard and buy another new/used one	
Other (please specify)	

	Not Applicable (a)	Keep at home (store) (b)	Give it to someone for re-use (c)	Sell it to: (d)	Dispose with municipal waste (e)	It gets stolen (f)	Other (please specify) (g)
Screens							
Televisions							
LCD (photo frame)							
Monitors							
Laptops							
Notebooks / tablets / iPads							
Mobile phones							
GPS							
Pocket calculator							
Routers							
Personal computers (desktop)							
Printers							

Telephones							

6. What do you do with your used/old equipment? **(Disposal of e-waste – formal/informal methods)**

7. Yes in 6b: Eventually how do you dispose or plan to dispose the stored equipment?
   a. Give it to someone for re-use
   b. Sell it
   c. Dispose with municipal waste
   d. Other: please specify ________________

8. Yes in 6d and 7b: Who do you sell it to?
   a. Local mobile shop
   b. Friend/family
   c. Local electronic waste collector (*kabari wala*)
   d. Other: please specify ________________

9. There are environmental and human health hazards due improper disposal and treatment of waste electrical and electronic equipment. Do you agree or disagree? **(Awareness)**
   a. Agree, yes I know of the potential hazards
   b. Agree, but I do not know of the potential hazards
   c. Disagree
   d. Don't know

10. If 9a is selected: Please list some of the potential risks and hazards you are aware of that result from improper e-waste disposal and recycling practices.

    ____
    ____
    ____
    ____

<u>Workers</u>

1. Gender
2. Age
3. Qualifications (years of schooling)
4. Do you live in the same area as you work? (locally hired workforce)
5. What tasks do you perform? (collector, scrapper, dismantler, metal extractor)
6. How long have you been working in this position? (experience)
7. What is your wage level?
8. Do you have income from other sources?
9. What motivated you to join informal e-waste recycling business? (the reasons)

   Opportunity cost
10. What other type of employment opportunities do you have?
11. How much would it pay you?
12. What are the normal working hours? Are there any paid/unpaid leaves? How many?

    Health and Safety Costs
13. Do you have any illness or injuries?
14. What are the number of leaves or sick leaves taken by you every month? (to calculate the loss of earnings)
15. How much are you willing to pay to reduce the risk of (specific) injuries? (willingness to pay for value of life)
16. The amount of medical costs incurred per month or year in: (cost of illness)
    a. Visit to doctors
    b. Medicines,
    c. Hospitalisation
    d. Treatment costs
    e. Other costs of illness
    f. Loss of earnings
    g. Impaired productivity
    h. Avoidance costs associated with actions taken to prevent or mitigate the risk of illness (safety equipment)

Recycling Businesses

1. Where do you buy the e-waste from?
2. What type of e-waste do you buy (and process)? why?
3. Please provide the estimates of following (per tonne or kg):
    a. Set up costs
    b. Maintenance costs
    c. Access (materials): cost of buying e-waste – for every type if segregated
    d. Collection costs
    e. Transportation costs
    f. Storage costs
    g. Treatment (materials, energy, labour, equipment, real estate/ building, administration, financing costs (interest), taxes
    h. Other informal costs
    i. Revenues from the sale of recovered material
    j. Other revenues
4. What are the processes of recycling?
5. Who do you sell the recovered material to?
6. What happens to the unrecovered material?
7. Have the workers had any work-related injuries? The type and number of injuries reported by workers in a year.
8. Is the business registered?

Information to participants involved in research

You are invited to participate

You are invited to participate in a research project examining the "**Socio-economic impact of electronic waste disposal practices in Pakistan**". Participation is voluntary and will help improve e-waste policy and business practices.

This project is being conducted by a student researcher Salsabil Shaikh as part of a PhD study at Victoria University under the supervision of Dr. Keith Thomas and Dr. Segu Zuhair, both academics from the College of Business.

Project explanation

Electronic waste or e-waste is an emerging problem. This is due to the volumes of e-waste being generated and to the toxic nature in some waste. It is also a business opportunity as e-waste is composed partly of valuable material. However, in many developing economies such as Pakistan, informal recycling practices are common, which bring with them a low awareness of the business opportunities and also the possible harm done to the environment and to human health. This research aims to develop a measure of the socio-economic impact of e-waste disposal and recycling practices. The findings will inform policy and practices in the e-waste industry to minimise the negative environmental impacts and possibly enable business opportunity.

What will I be asked to do?

You will be asked to complete a questionnaire. This will take approximately 10 minutes or respond to interview questions that will take no more than 30 minutes.

What will I gain from participating?

There will be no direct benefits to you. However, the findings will create awareness of the costs (and opportunities) associated with current e-waste recycling practices. The assessment of socio-economics impacts of e-waste recycling practices in Pakistan will seek to inform policy and business practices. Hence, the main benefit to participants is indirect, through the minimisation of social and health impacts. The findings may also help improve recycling procedures to maximize returns.

How will the information I give be used?

The information provided by participants will be coded to maintain anonymity and then analysed using quantitative and qualitative methods.

What are the potential risks of participating in this project?

There are minimal risks for participating in this study. Informed consent, anonymity and confidentiality will be maintained to further minimize any perceived risk.

How will this project be conducted?

An integrated framework has been developed to identify the indicators of socio-economic costs and benefits. The study will use a questionnaires and personal interviews to collect data.

The results will be analysed, and the findings of the study will be reported in the thesis and if accepted also in future journal publications and conference presentations.

Who is conducting the study?

Dr Keith Thomas (The chief investigator)

Senior Lecturer, College of Business

Email: Keith.Thomas@vu.edu.au

Phone: +61 (03) 9919 1954

Dr Segu Zuhair

Adjunct Fellow, College of Business

Email: Segu.zuhair@vu.edu.au

Phone: +61 (03) 9919 1472

Salsabil Shaikh

PhD Student, College of Business

Email: Salsabil.shaikh@live.vu.edu.au

Any queries about your participation in this project may be directed to the Chief Investigator listed above.

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

Consent form for participants involved in research

INFORMATION TO PARTICIPANTS:

The research aims to assess the social and economic impacts of electronic waste disposal (and recycling) practices in Pakistan by:

1. Identifying the factors that contribute to rising electronic waste,
2. Identifying the factors that influence the formal and informal disposal practices,
3. Estimating and assessing the social and economic costs and benefits to stakeholders.

There are no potential risks involved in your participation in this study.

CERTIFICATION BY PARTICIPANT

I, (Name)____

of (area, city and country) ____

certify that I am at least 18 years old and that I am voluntarily giving my consent to participate in the study:

"Socio-economic impacts of electronic waste disposal (and recycling): a case study of Pakistan" being conducted at Victoria University by Dr Keith Thomas.

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Salsabil Shaikh

and that I freely consent to participation involving the below mentioned procedures:

- Completion of the survey questionnaire and/or
- Participating in the semi-structured interview

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed:

Date:

Any queries about your participation in this project may be directed to the researcher

Dr Keith Thomas

+61 (03) 9919 1954

Keith.thomas@vu.edu.au

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email Researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

Letter of introduction and consent (additional for companies/workers)

You are invited to participate

You are invited to participate in a research project examining the "**Socio-economic impact of electronic waste disposal practices in Pakistan**". Participation is voluntary and will help improve e-waste policy and business practices.

This project is being conducted by a student researcher Salsabil Shaikh as part of a PhD study at Victoria University under the supervision of Dr. Keith Thomas and Dr. Segu Zuhair, both academics from the College of Business.

Project explanation

Electronic waste or e-waste is an emerging problem. This is due to the volumes of e-waste being generated and to the toxic nature in some waste. It is also a business opportunity as e-waste is composed partly of valuable material. However, in many developing economies such as Pakistan, informal recycling practices are common, which bring with them a low awareness of the business opportunities and also the possible harm done to the environment and to human health. This research aims to develop a measure of the socio-economic impact of e-waste disposal and recycling practices. The findings will inform policy and practices in the e-waste industry to minimise the negative environmental impacts and possibly enable business opportunity.

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How will the information I give be used?

The information provided by you will be coded to maintain participant anonymity and then analysed using quantitative and qualitative methods.

What are the potential risks of participating in this project?

There are minimal risks for participating in this study. Informed consent, anonymity and confidentiality will be maintained to further minimize any perceived risk.

How will this project be conducted?

An integrated framework has been developed to identify the indicators of socio-economic costs and benefits. The study will use a questionnaires and personal interviews to collect data.

The results will be analysed, and the findings of the study will be reported in the thesis and if accepted also in future journal publications and conference presentations.

Withdrawal without prejudice

Participation in this study is voluntary. You are also free to withdraw consent and discontinue your participation in this project at any time without prejudice or penalty. You are also free to not answer any question that the researcher may ask you.

Further Questions and Follow-up

You are welcome to ask the researchers any questions that occur to you during the survey or interview. If you have further questions once the interview is completed, please contact the researchers using the contact information given below.

Who is conducting the study?

Dr Keith Thomas (The chief investigator)

Senior Lecturer, College of Business

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Adjunct Fellow, College of Business

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Phone: +61 (03) 9919 1472

Salsabil Shaikh

PhD Student, College of Business

Email: Salsabil.shaikh@live.vu.edu.au

Informed consent and approval

I, ____ (name; please print clearly), have read the above information.

I freely agree to participate in this study. I understand that I am free to refuse to answer any question and to withdraw from the study at any time. I understand that my responses will be kept anonymous.

______________________________ ______________________

Participant Signature Date