A cost-benefit analysis of the downstream impacts of e-waste recycling in Pakistan

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Abstract

This paper presents downstream cost-benefit analysis for electronic waste (e-waste) recycling workers in Pakistan, a country that both generates large quantities of e-waste domestically and imports a significant amount from developed countries. Financial cost-benefit elements - reduction in productive capacity, lost wages, medical expenses, wages (and meals) and non-financial cost-benefit elements – opportunity cost, cost of illiteracy and value of life have been quantified. Primary data collected on site was analyzed using quantitative and qualitative methods. The estimated total net economic cost to recycling workers is between Rs.34,069 – Rs.85,478 (US$ 203 - 510[1]) per month or an average of Rs.50,363 (US$ 300) per worker. This main finding suggests that cost exceeds by 2.6 – 4.7 times the estimated economic benefits derived by these workers. Related qualitative data suggests government and owners of recycling businesses are largely blind to many of the less visible costs of this industry, while recycling workers and their families appear trapped in a vicious cycle of poverty. Understanding that what can be measured can be managed and improved, a systematic assessment of informal recycling based on identified impact factors may help mitigate and ideally also motivate a shift towards formal processing that would reduce the downstream negative impacts, both visible and hidden.

[1] PKR to US$ conversion rate of 167.686 was used as of 1 July 2020.

Keywords

Electronic waste (e-waste), Social impact, Economic, Cost-benefit analysis, Social Life Cycle Assessment (S-LCA), Pakistan

1. Introduction

Electronic waste (e-waste), known to be hazardous to environment and human health, is the fastest growing stream of waste in the world (Fu et al. 2018; Oleszek et al. 2018). It is estimated that 44.7 million tons of e-waste was generated globally in 2016 with an annual increase of4.2 percent each year from 2010 to 2016 and it is expected to continue growing at about 3.2 percent per annum, to 52.2 million tons each year by 2021 (Abdelbasir et al. 2018; Alghazo et al. 2019; Baldé et al. 2017). Compounding the rising volume of e-waste is the associated complexity of this waste that can contain up to 1000 different elements (Puckett et al. 2002; Sepúlveda et al. 2010). Arguably, the hidden and greater social and environmental challenge concerns the uncertain fate of discarded equipment, with only 15-16 percent of the total e-waste reported as collected and formally recycled in 2014, rising to just 20 percent in 2016 (Baldé et al. 2017; Heacock et al. 2016; Kumar, Holuszko & Espinosa 2017; Sahajwalla & Gaikwad 2018). The remaining e-waste is undocumented and likely goes to landfill in municipal dumps or is recycled informally (Baxter et al. 2016; Ikhlayel 2018; Speake & Yangke 2015) or to a lesser degree is exported to countries for further processing using informal methods (Christian 2017; Illés & Geeraerts 2016; Kirby & Lora-Wainwright 2015; Sabbaghi et al. 2019; Salehabadi 2013).

Studies suggest that developing countries, such as Pakistan, India, China and Nigeria import about 50-80 percent of the e-waste generated in developed countries (Gollakota, Gautam & Shu 2020; Illés & Geeraerts 2016; Sthiannopkao & Wong 2013), while Pakistan alone receives 8% of the global e-waste in the categories of laptops and desktop PCs, and also generates large volumes domestically (Baldé, Wang & Kuehr 2016). The reality for Pakistan and other recipient countries is that they lack the necessary resources, infrastructure and technology to adequately process e-waste (Ikhlayel 2018; Nnorom & Osibanjo 2008; Schluep 2014). The effect is that recycling in Pakistan is based on informal and hazardous methods such as open burning and acid baths (Ackah 2017; Awasthi, Zeng & Li 2016; Cesaro et al. 2019; Vaccari et al. 2019), with minimal control and involvement by governments and local authorities. As related studies show, such methods often pose less visible and serious consequential risks to both humans and the environment (Cesaro et al. 2017; Zhou & Liu 2018). For example, burning metals and plastics emit metal fumes, furans, Polycyclic aromatic hydrocarbons (PAHs), Polychlorinated biphenyl (PCBs) and Polybrominated diphenyl ethers (PBDEs), and dioxins (Anh et al. 2018; Cao 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 et al. 2018), where heavy metals persist (Chakraborty et al. 2018; Song & Li 2015) and ultimately enter the food chain via plants (Guala, Vega & Covelo 2010). The downstream impact for both humans and animals is 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).

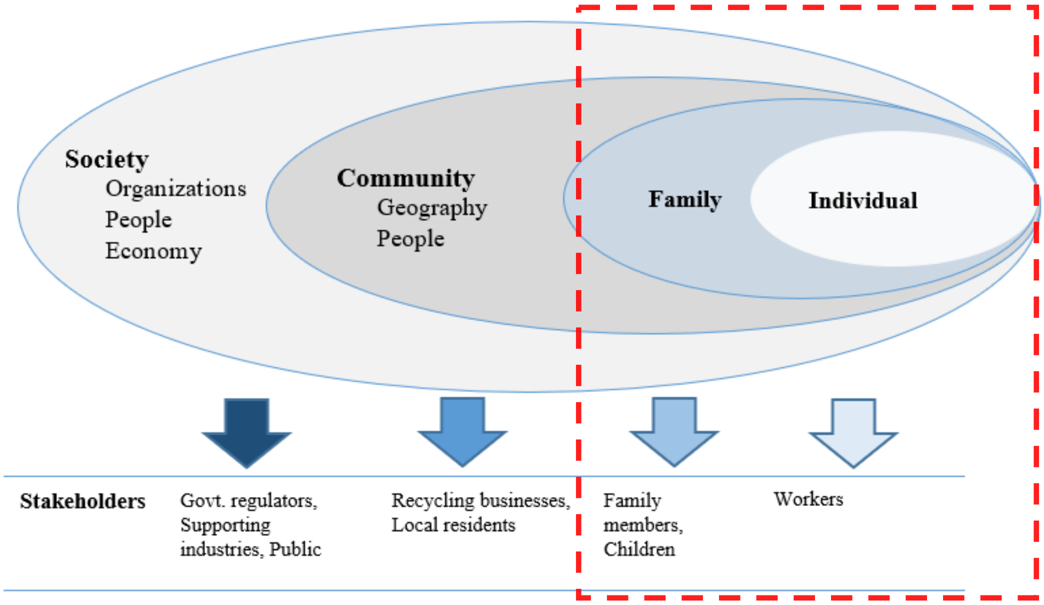
In order to move towards a less hazardous and more sustainable recycling environment, there is a need to consider impact assessment throughout the life cycle. Many previous research have used Life Cycle Assessment (LCA) to study the impacts in different contexts, including transition towards bio-based economy (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). In e-waste management, 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), but also the social (positive and negative) impacts through Social Life Cycle

Assessment (S-LCA). For instance, Umair, Björklund and Petersen (2015) followed UNEP guidelines on SLCA to assess the social impacts of informal e-waste recycling in Pakistan and found negative impact in terms of working hours, child labor, 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. This paper builds on the findings of 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 for e-waste recycling workers who are at the forefront of e-waste recycling activity and are affected directly and indirectly. Social impacts have been assessed taking a life cycle perspective, using S-LCA. More specifically, economic impact, including financial and non-financial (social) variables have been quantified using cost-benefit analysis (CBA), which is a well-known tool to examine the economic viability in a variety of contexts (Brent 2009; Campbell & Brown 2015), such as for 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), and in the context of 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).

The contribution of this paper is twofold. Firstly, by building on the studies of Umair, Björklund and Petersen (2015) that uses S-LCA and Shaikh, Thomas and Zuhair (2020) that uses an eco-system and lifecycle view at upstream stages, this paper fills the gap in literature by identifying and measuring the hidden and invisible costs, such as 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, especially for Pakistan. Secondly, noting the primacy of informal recycling practices in Pakistan, this study outlines a consolidated framework to enable the systemic estimation of known and also the less visible, financial and non-financial costs of handling and processing e-waste for the multiple stakeholders.

The multiple stakeholders' inputs in a LCA are captured using an ecosystem framework (Figure 1) that incorporates items in the value chain from upstream production to downstream processing of e-waste, where the costs of informal practices has remained silent because of a lack of data. . The eco-system framework, which has been used successfully in complex health and other social interventions (Thomas 2019; World Health Organization 2002), helps to illustrate the complexity in many socio-economic issues. Multiple levels of stakeholders in the ecosystem with corresponding and overlapping interests of these stakeholders in e-waste recycling are shown in Figure 1, with the boxed area denoting the focus of this study.

Figure 1: The eco-system framework (adapted using Thomas (2019); World Health Organization (2002))



The rest of the paper is organized as follows. Section 2 describes the methods used in this study including details of data, variables, data collection, analysis and calculations. Section 3 summarizes some qualitative findings and cost-benefit analysis. Section 4 discusses the implications findings. Section 5 concludes the study while also recommending policy actions.

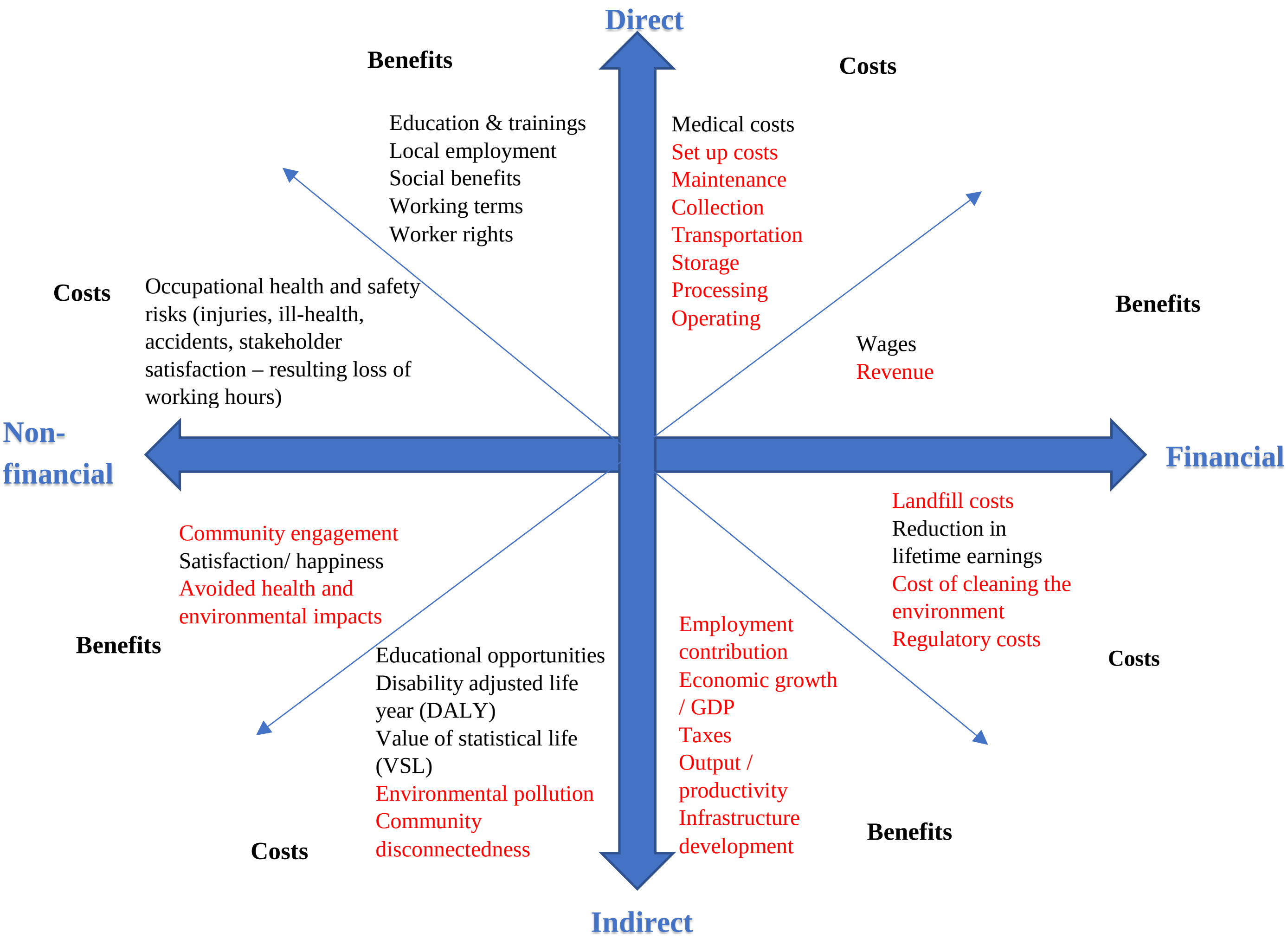
2. Methods

Primary data was collected by visiting e-waste recycling sites in Karachi, Pakistan, while other major cities where e-waste is recycled include Lahore, and Rawalpindi. 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. Participation in the study was voluntary and workers were interviewed after receiving permission from their employers (business owners)."

2.1. Data and variables

A questionnaire 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 a developing country, Pakistan. These financial and non-financial (social) variables were consolidated in terms of direct and indirect costs/ benefits to develop consolidated impact factors (see Figure 2). Costs and benefits in Figure 2 are for multiple stakeholders identified earlier in Figure 1; 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. The variables shown in red are shown for conceptual completeness, but either not in the scope of this study or not deemed practical for inclusion.

Figure 2: Consolidated Impact Factors



2.2. Data collection

Data was collected by field visits to recycling businesses in order to interview workers such as e-waste collectors, dismantlers/scrappers and metal extractors. There was some initial hesitation by workers invited to participate, 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 permission from employers. Responses were mostly transcribed on hard copies 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 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.

Multiple recycling sites were visited in Karachi. Some sites were open, but there is considerable evidence that there are other hidden and 'below the ground' dismantling and extracting sites. Other sites visited include warehouses and commercial workplaces of importers and recyclers in Shershah, recycling sites in the residential slum streets of Shershah, and gold extraction and refining facilities also in Saddar (in Karachi).

2.3. Data analysis

Qualitative data was transcribed, coded and classified in themes for analysis using NVivo software. The qualitative findings related to social and environmental aspects were consolidated into four quadrants – "known", "unknown", "hidden" and the "blind spot" – based on 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 technique is similarly useful to raising awareness and investigating less visible issues such as the attitudes, knowledge and motives of e-waste recycling workers. In the context of this study, we do not attempt to study the awareness for one group with respect to the other. Rather, the focus is on awareness and social dynamics of each group of stakeholders separately. Qualitative findings are further consolidated based on systems thinking using Vensim software, in order to examine how parts of a system interrelate and how systems work over time and within a larger system. This analysis of findings that explain the dynamics of a poverty trap are not in the scope of this paper and so is excluded.

2.4. 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 US$ are calculated using the conversion rate of PKR 167.686/US$ (correct as of 1 July 2020).

2.4.1. Financial costs

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

2.4.1.1. 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, the lifespan of e-waste recycling workers is almost half of the normal population. Assuming an average lifespan of 66 years (The World Bank 2017) 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 age 50. Thus, the total number of productive years is estimated as 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[2] (US$ 48 – 298).

2.4.1.2. 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

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

(US$ 2 – 167) per month. However, as an example, if workers were bedridden for weeks, no upper boundary to lost wages was calculated.

2.4.1.3. Medical expenses

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

2.4.2. 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.

2.4.2.1. 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 alternate work as a laborer for daily wages, which pays Rs.800-1,200 (US$ 5 – 7) per day. Multiplying this daily wage rate by 25 days in a month, likely monthly wage as a laborer is around Rs.20,000-Rs.30,000 (US$ 119 – 179). Therefore, this is a potential opportunity cost for e-waste recycling workers.

2.4.2.2. Cost of illiteracy

Most of the workers in e-waste recycling 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 percent-42 percent 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 (2017) as Rs.35,662 (US$ 213). The minimum and maximum illiteracy cost was calculated as 30 percent and 42 percent of the average monthly income, estimated to be Rs.10,699 and Rs.14,978 (US$ 64 – 89), which is lost each month throughout their lives. Moreover, as they have limited opportunity for promotion and growth, the income of these workers remains static over their lives. In contrast, the income of educated workers can grow two-fold or three-fold 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 2) is the cost of illiteracy to society, which was estimated for Pakistan by Cree, Kay and Steward (2012) as US$ 5.86 billion per annum. Equivalent (PKR) illiteracy cost to the society in can be estimated as PKR 982.64 billion each year or PKR 81.887 billion each month.

2.4.2.3. 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 (10.5 percent of the total 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 (US$ 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 US$30 per month). Interestingly, the value of life is the lowest of all non-financial (social) costs in Table 2, meaning the life of these workers is the least costly. These workers seek financial benefits over health considerations. What drives this behavior 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.

2.4.2.4. Other non-financial (social) costs

Other non-financial or social costs include firstly, the cost of not being able to interact or socialize due to long working hours. This cost is particularly applicable to Pakistan, a collectivist society that places a high value on interaction. 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 overtime or on weekends as identified in Section 3.1 Demographics. The official overtime rate is double the normal wage rate. However, the reality is that the wages for recycling workers are calculated either on a daily, weekly or monthly rate, without overtime allowances. This appears to be normal practice in much of Pakistan, so it has again not been included as a social cost.

2.5. Estimation of benefits

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

2.5.1. Financial benefits

2.5.1.1. Wages and meals

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

2.5.2. 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, 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, respectively are recognised but also seen as out of the scope of this study.

2.6. Present values of costs and benefits

Present value of all costs and benefits has been calculated as total cost or benefit for the 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 for males (The World Bank 2017) 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 percent per annum, taken from the websites of different banks (HBL 2019; UBL 2019). The other two discount rates used in calculations were 20 percent and 38 percent.

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 (US$ 6,402-30,376), with an average of Rs.2,075,958 (US$ 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.

3. Findings

3.1. Demographics

The sample workforce comprised largely illiterate males, aged 18 to 60 years (see Table 1). 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. While the government has established regulations for child labor 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 another provinces (typically Punjab) in search of work. 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 proportion of the workers (58 percent) reported working for 6 days in a week, with some (37 percent) indicating they worked all 7 days in a week. Normal working hours were 10-12 hours, but some workers (36.8 percent) 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 the act, 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 act entitles workers to overtime compensation that is twice the ordinary rate if they work for more than 9 hours in a day.

In reality, however, the wages of e-waste recycling worker ranges from Rs.8,000 to Rs.50,000 per month (US$ 48 – 298) without any allowance or compensation for overtime work. This appears 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 percent) or even larger groups of 7-10 members (53 percent). 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, even over health considerations.

Table 1 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 by workers to toxic fumes and to lead inhalation (Nie et al. 2015).

Table 1: Demographics and socio-economic factors of e-wase recycling workers

Demographics	**Frequency (N = 19)**	**Percentage of sample**
Gender		
Male	19	100%
Female	0	0%
Tasks (Multiple response)	9	47%
Collector	14	74%
Dismantler	8	42%
*Metal extractor**	9	47%
*Metal refiner**		
Age		
18-24 years	7	36.80%
25-34 years	7	36.80%
35-44 years	1	5.30%
45 and older	4	21.10%
Education		
No schooling	8	42.10%
Primary (grades 1-8)	6	31.60%
Secondary (grades 9-12)	5	26.30%
Contract		
Permanent	0	0.00%
Temporary	0	0.00%
Local residence		
Yes	6	31.60%
No	5	26.30%
Punjab (another province)	8	42.10%
Experience		
Less than 1 year	2	10.50%
1-10 years	7	36.80%
11-20 years	5	26.30%
21-30 years	2	10.50%
31-40 years	3	15.80%
Wages (PKR)		
Rs.8, 000-10,000	2	10.50%
Rs.11, 000-20,000	3	15.80%
Rs.21, 000-30,000	5	26.30%
Did not disclose	9	47.40%
Income from other sources		
No	6	31.60%
Yes, family income	13	68.40%

3.2. Working conditions and risks

All recycling sites, from dismantling to extracting and refining were engaged in informal recycling practice using crude and primitive methods. Facilities observed were open spaces or shop floors with natural light and air access (sometimes fans). Workers, without any protective equipment, sat around the piles of e-waste and used their bare hands to dismantle, burn and recycle e-waste. There was no awareness of occupational health and safety, and a first-aid kit was noted at only one workplace. Metal extracting and refining sites had large ovens to melt the metal and temperatures were extremely high. Chimneys were installed at these sites to remove the smoke and vapors originating from boiling acids, but conditions were generally dangerous given the toxicity of materials and the absence of protective masks and clothing. There is a general awareness of risk as is evident in the words of one worker:

> *"…during the process, acid and copper evaporate and we inhale that smoke. The heat is so high that not everyone can work in such conditions; one must be very strong physically. Chimneys and ventilation help a bit, but it is still extremely dangerous."*

Due to the toxic processes involved in extraction and refining, workers reported suffering from stomach, heart, lung diseases and worst of all, sometimes cancer. As one remarked:

> "*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."*

The tendency, however, by the majority of the workers, mainly in dismantling and extraction but sometimes also in refining, is to exhibit a form of 'cognitive dissonance' in order to cope with the reality of poor health, working conditions and other wellbeing considerations. There was a tendency by some to diminish the risks, perhaps out of fear or misplaced loyalty to the employer: "*…we do not get sick and there is no need of improving the working conditions*". However, it seems clear that the majority of workers are conscious that informal methods of recycling are hazardous, and the consequences could just take a few years to manifest.

Regardless of known and unknown consequences, workers and their family members tend to be attracted to and continue to work in e-waste recycling, because they need work and have no other 'skills'. In effect, there is a sense of being trapped in e-waste recycling by poverty and the need to provide for the family:

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

3.3. Results of the cost-benefit analysis

Table 2 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 (US$ 490) and average economic benefits amount to Rs.31,875 (US$ 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 (US$ 300) per month and Rs.2,075,958 (US$ 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 2: Economic (financial and social) costs and benefits

ECONOMIC COSTS AND BENEFITS						
	PKR per Month			Present Value (PKR)		
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)**

4. Discussion

Analysis of downstream cost-benefits for e-waste recycling workers suggests the e-waste recycling industry provides employment and a livelihood for a significant number. These workers accrue economic benefits of around Rs.9,250 – Rs.52,500 (US$ 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 (US$ 258 - 823) per month. After netting the costs and benefit, the effect is economic cost of Rs.34,069 – Rs.85,487 (US$ 203 - 510) per month. Besides these quantitative estimates, interviews reveal social effects for recycling workers that are not easy to quantify. These hard to quantify and sometimes less visible costs/ benefits have been consolidated across the social, economic and environmental dimensions at both business owner and worker level, using categories of "known", "unknown", "hidden" and the "blind spot" (Figure 3) that help identify and assess overall impact. This heightened awareness of factors that impact is suggested as a necessary first step to better management of the industry.

4.1. Assessing impact

What is "known"

As Umair, Anderberg and Potting (2016) identified, profitability is the driving force in the e-waste recycling market and all involved from importers to recyclers make large profits. While they also suggest recycling workers benefit with wages the equivalent or slightly above the minimum wage and poverty line, this study contests that estimation. Wages disparity notwithstanding, what is known is that workers are at the forefront of e-waste recycling activity and the most vulnerable. Seeking income for the family, they work in hazardous working conditions using informal recycling practices. Being illiterate and living in poverty, these workers appear to see few alternatives and are glad to simply have regular employment.

Another "known" in e-waste recycling is the informal methods employed to process materials. The lack of suitable technology and informal processes adopted are known by business owners and by the workers. Both groups, however, appear blind or apathetic to downstream health and environmental implications. Some workers, specifically those involved in metal extraction are aware of the risks from open burning and related extracting processes, but they appear satisfied by good air circulation and chimneys. The health consequences of informal processes are also known in general terms. For example, most workers reported experiencing symptoms such as stomach pains and breathing difficulties, as well as low energy. These workers also reported major illnesses like cancer that they know have caused the premature deaths of a number of their peers. If unwell, their usual recourse is to treat any health-related problems using home remedies like eating jaggery (raw sugar).

Business owners are knowingly complicit in the informal recycling practices used to process e-waste material. While not openly acknowledged, owners seem aware of the health issue for the workers they employ. Reflecting this awareness, some provide ventilation and chimneys at extracting and refining worksites. 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 clearly need for regulatory corrective actions locally, but in a full LCA the stakeholders in this system are really international.

What is "unknown"

The primary "unknown" in e-waste recycling is the numbers of workers engaged in recycling. Given the labor-intensive nature of the work and the seasonal volume, it is likely that this industry employs a large number of workers. What is also unknown is the number of actual businesses and the future intention by business owners to, for example, access suitable technology in order to adopt more efficient, even formal recycling processes. The primary obstacles are cost, willingness and the absence of regulatory incentive. In the absence of regulations and governance in the industry, any prospective remedial action by business owners remains latent. Rather, the unquantified downstream costs from informal recycling are borne by workers, their families, community, and also the environment.

The community wide impacts in relation to the use of acid baths and chemicals are unknown. Reflecting gaps in worker awareness and in governance, for example, residual acid liquid is treated like any normal liquid and allowed to flow into local 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 end up in normal drinking water via sewerage lines or freshwater pipes that are broken, or even through normal seepage. In sum, both humans working in the industry, and animals in the vicinity of processing plants are exposed to and likely ingest toxins directly by drinking water and breathing polluted air, and indirectly by toxic waste entering the food chain through contaminated water used for cultivation or from eating fish from polluted waters.

A final unknown concerns work opportunities forgone by workers who enter and remain in the e-waste recycling industry. Many of these workers start in e-waste recycling from an early age and have not considered other less hazardous jobs. The related unknown is lost economic opportunity represented by 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 are unable to recover these materials, which end up in landfill or wastewater. This is a significant unrealised lost business opportunity.

What appears "hidden"

There is a degree of secrecy in recycling. It is also likely that some workers engage in unethical practices like stealing to supplement their incomes. As a result, 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 causes workers to believe they have no choice or that it is their fate. This social or religious belief contributes to a lack of agency in terms of looking for other work. Another hidden feature in recycling of e-waste is the sense of fear – of being exposed by government authorities, to being fired, particularly if they speak out against their employers and the 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".

This is a brief summary of hidden effects that impact the lives of recycling workers. The reality is a wider hidden evident in the implicit involvement of families via child labor and possibly female members of household's in backyard processing in their houses. Wider still, anecdotally it would appear that there are many commercial businesses operating illegally in hidden places where some may have the power as a local "mafia". These businesses are generally unregistered so as to evade taxes and avoid any government regulations.

"Blind spot"

A blind spot suggests not seeing or understanding how important something may be, including factors that might be in the subconscious of workers. Workers confronted by evident work-related hazards and resultant illnesses explain things away or are defensive in face of this information saying, "…*we do not get sick and there is no need to improve the working conditions*". Job protection, loyalty to owners and plain inability to be open are all factors that support this apparent blindness. As well, many workers believe good ventilation was adequate for safety and health, while appearing blind to the pervasive health effects for their families and community, and the wider environmental implications of the business.

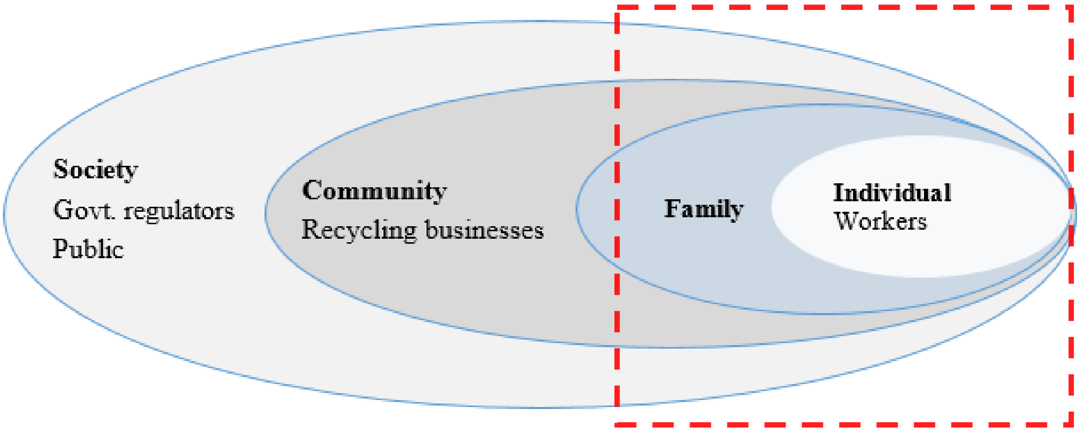
Similarly, business owners appear conveniently blind to their wider responsibilities or are unable to act in terms of the best health interests of their workers. There is similarly a blind spot in terms of the quality of life for workers and even basic health and safety measures to protect workers via ventilation and protective clothing were uncommon and not standard practice. There was no health care benefits, job security, paid leave or other forms of social benefits. Governments mirror this apathy towards the plight of workers.

There is a blind spot also in terms of the quality of the number of healthy years in a lifetime, which are greatly reduced; while it is likely older workers spend their remaining years suffering with work-related illness and unable to meet basic necessities. Quality of life assessed through Disability Adjusted Life Years (DALYs) of 19,468,399 for Pakistan by World Health Organization (2016) shows 19,468,399 years of healthy lives are lost due to environmental factors. This is equivalent to the total healthy lives of 294,976 people given a normal life expectancy of 66 years for males. Moreover, based on the life expectancy ranging from 33 to 66 years, it can be estimated that some 294,976-589,951 e-waste recycling workers lose their lives due to the toxic effects of their work environment.

Mapping downstream impacts

Figure 3 summarizes the downstream impacts in terms of known, unknown, hidden and blind spot for workers across three dimensions: financial, non-financial (social) and to a lesser degree environmental costs as this was not the focus of this study. All key stakeholders are added for completeness, to illustrate the across industry impacts, particularly “social” costs. The table shows that stakeholders in the community, including recycling businesses, and society levels are largely “blind” or apathetic to the downstream impacts, while workers can be characterized as being caught in a poverty trap driven by economic need and compounded by illiteracy. The challenge in the informal recycling industry is to increase the area “known”, and decrease the “unknown”, “hidden” and “blind” through efforts that ensure greater transparency and accountability. In the immediate term this would mean reduced exploitation of workers and children. The longer-term goals would be to remove the veil that enables systemic blindness to the long-term health and environmental costs from less visible second and third order effects from hazardous disposal practices that are presently condoned or tolerated by key stakeholders in the industry. A lesser, but nevertheless valuable outcome would be to capture the lost business opportunity represented by valuable rare earths that currently end up in landfill because of an incapacity to recover these materials.

Figure 3: Summary of downstream unknown, hidden and blind spot in e-waste recycling



Stakeholders / Costs	Government, regulators, public	Recycling businesses & society	Family and children	Recycling workers
Financial				
Known	Use of Informal method in recycling industry	Profitability Employs three generations of family members (Umair, Anderberg & Potting 2016)	Employment	Wages and meals
Unknown		**P**recious/ rare earth elements		Precious/rare earth elements
Hidden		Overtime wages avoided	Processing of sourced materials	Unpaid overtime 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	Proper (formal) methods of recycling		Illnesses

	Toxic impact of recycling process			Unexplored work opportunities Toxicity
Hidden		Hidden / illegal operations Mafia (business/political)	Fear (income loss)	Work related hazards Social norms Helplessness / no choice
Blind spot		Health impacts Minimal social welfare: Employee benefits Job security (no contracts) Health and safety rights	Illiteracy Low value of life	Long-term health costs Low quality of life External locus of control (fate)
Environment				
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 from landfill, air, water, soil	Impact of informal recycling Toxic waste in waterways/ drains		Air pollution (metal extraction) Second-order environmental effects

5. Conclusion

The study outlines a framework to enable a systemic estimation of known and also less visible, financial and non-financial costs of informal recycling in a LCA, which so far has no visibility because of a lack of data. Estimating economic costs (financial and non-financial or social) across four dimensions: those known, unknown, hidden or in a blind spot to the relevant stakeholders, the focus is on downstream effects on recycling workers. Using estimates that are modest as it only relies on known and quantifiable cost, the study identifies 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 (US$ 300), while for a lifetime, it accumulates to about Rs.2,075,958 (US$ 12,380).

Behind the façade of financial benefits are unknown first order (immediate) social costs, while second 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 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 to reduce the negative net economic (financial and social) costs, this paper advocates the need for government intervention at multiple 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 formalization of industry. Secondly, to facilitate the process of formalization, investment from the government and business owners is required in technology.

6. Acknowledgements

The authors would like to acknowledge the support of Dr Peter Kinrade and Dr Christine Millward in designing the interview questionnaire and data collection support provided by Najam us Saqib. Also, the authors would like to thank the reviewers for valuable feedback.

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