Electrical and electronic waste in Pakistan: the management practices and perspectives

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12.1 Introduction

The burgeoning use of electrical and electronic equipment (EEE) and their decreasing service life are generating a significant quantity of obsolete EEE. The discarded obsolete or end-of-life EEE are considered as the E-waste (Pathak et al., 2019). However, there is not a fix definition of E-waste. The EU Directive on Waste Electrical and Electronic Equipment (WEEE) defines E-waste as the obsolete equipment that could work while supplying the electric/electromagnetic currents. It includes the large and small household electrical appliances and equipment for information and communications use (European Commission, 2003; Ilyas and Lee, 2014). The Swedish Environmental Protection Agency defines E-waste as the disposed electrical or electronic items those are no longer able to perform its assigned purpose (Swedish EPA, 2011; Tanskanen, 2013). Whereas, the United Nations Environment Programme (UNEP) defines E-waste as the electronics destined for "*reuse, resale, salvage recycling and disposal*" (UNEP, 2011). Pakistan has not its own definition of E-waste, and hence, by considering the E-waste and WEEE both as the same, the items/goods defined in the aforementioned definitions are taken into account under the E-waste in this chapter. Notably, E-waste contains approximately one thousand substances, including metals, plastics, and glass (Vadoudi et al., 2015; Wang and Xu, 2014; Widmer et al., 2005). Further, the metals components contained in E-waste can be subdivided into several types of ferrous, nonferrous, toxic, hazardous, valuable, and precious metals.

Due to the technology loving era of the current time, a fast rate of discarding EEE has presented E-waste as the fastest growing problematic waste of the globe (Ilyas and Lee, 2014). Mainly in the developed countries, the E-waste is mounting pressure for its sustainable solution; however, yet the full proof environment-

Handbook of Electronic Waste Management. DOI: https://doi.org/10.1016/B978-0-12-817030-4.00007-3

friendly solution could be reached that can also be fitted with the economy. The reason that is why a large amount of E-waste is being dumped from the developed countries to under-developing or developing countries (Puckett et al., 2002; Terazono et al., 2006; Umwelthilfe, 2007; Cobbing, 2008). E-waste is a heterogeneous mixture of several hazardous and toxic chemicals belongs to ceramics, polymers, metals, glass, and others. Legally the transboundary movement of these hazardous substances restricts the shifting of E-waste under the umbrella of the Basal convention. Nevertheless, the waste of developed countries is transferred to elsewhere destination countries in other forms than the E-waste (Pathak et al., 2017). Usually as the used EEE (UEEE) donation for their reuse purpose.

12.2 E-waste generation in Pakistan

Although Pakistan is a signatory of the Basal Convention, the country is one of the largest receivers of E-waste. Pakistan has emerged as a major dump-yard for the large volume of E-waste coming from the United States, EU, Japan, UK, Australia, and Gulf countries (as shown in Fig. 12.1). E-waste gets the entry in the form of donations by charities or second-hand used items for the resale and reuses purposes. On the contrary, only 2% of the total amount of imported goods as the second-hand used item is going for reuses. The rest is directly sent for the dismantling and informal recycling works (BAN, 2002; Sthiannopkao and Wong, 2013).

The import of computers from foreign countries as UEEE has found to be in the following order: US > UK > Canada > UAE > Singapore > Australia > EU > China > Korea. The highest 70% of which is from the United States alone (BAN, 2002; Greenpeace, 2009; Sthiannopkao and Wong, 2013; Today, 2014). This situation is not only serious for the environmental and health hazards associated with E-waste but more serious is that the threat remains unaccounted with the unquantified volume of it. One of the

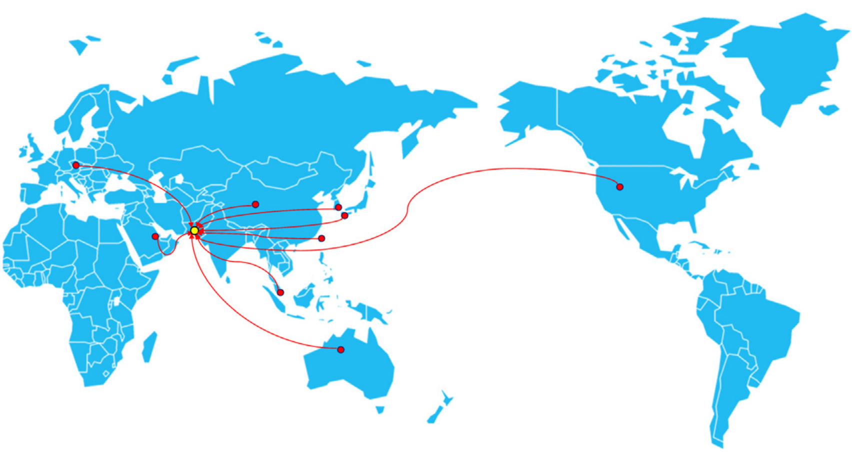

Figure 12.1 The illegal flow of E-waste to Pakistan in the name of second-hand UEEE.

Table 12.1 The average quantities of the major items imported to Pakistan, mainly in the name of UEEE.

Items' name	Average imported unit (million)	Average imported weight (tons)	Average plastic in imported items (tons)
PCs	1.42	35,522	1174
Laptop	0.25	889	28
Monitors	1.03	14,577	2452
TVs	0.20	6414	508
Printers	0.19	1270	317

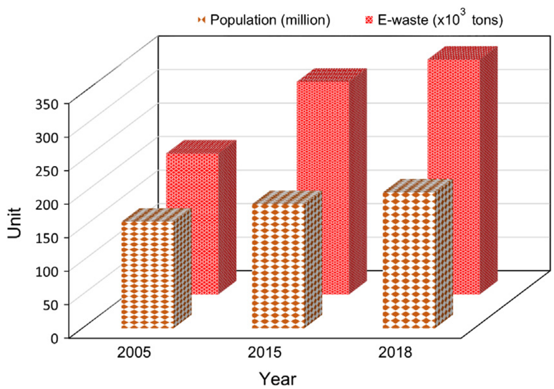

Figure 12.2 The increase in population and E-waste volume in Pakistan as a function of year.

estimations is that more than over 50,000 tons of E-waste dumping by developed countries (Sajid et al., 2019), while other is for 95,400 tons of E-waste per year (Imran et al., 2017). The average quantities of the major items imported to Pakistan (as with the reported data) is summarized in Table 12.1 (Imran et al., 2017).

Moreover, the local generation of E-waste data is also not quantified, which is supposed to be 317,000 tons in 2015. As per the recent report, 72% of the total population of the country has mobile phones which are accounted for over 140 million by the year 2017 (http://pas.org.pk/digital-in-2017-global-overview/). Purchasing of televisions is forecasted to increase at a rate of 12% per annum resulting mainly because of the rapid change in technologies (International, 2015). The sales of personal computers are also increasing at a rate of 5.8% per annum due to increasing demand from individuals, enterprises, and the public sectors (International, 2015). Rapid urbanization and increasing population of the country are overall the major factors driving the EEEs consumption, as newer technologies attract people to buy the products. Further, the local gray market of second-hand items is also contributory, by which the quantification of E-waste generation in the country is a tough task. The large population of the lower middle-income group is a big consumer of this gray market, which is actually the user of refurbished items more than a second time. It eventually leads to generate a higher volume of domestic E-waste (as shown in Fig. 12.2). Lacking proper discard or

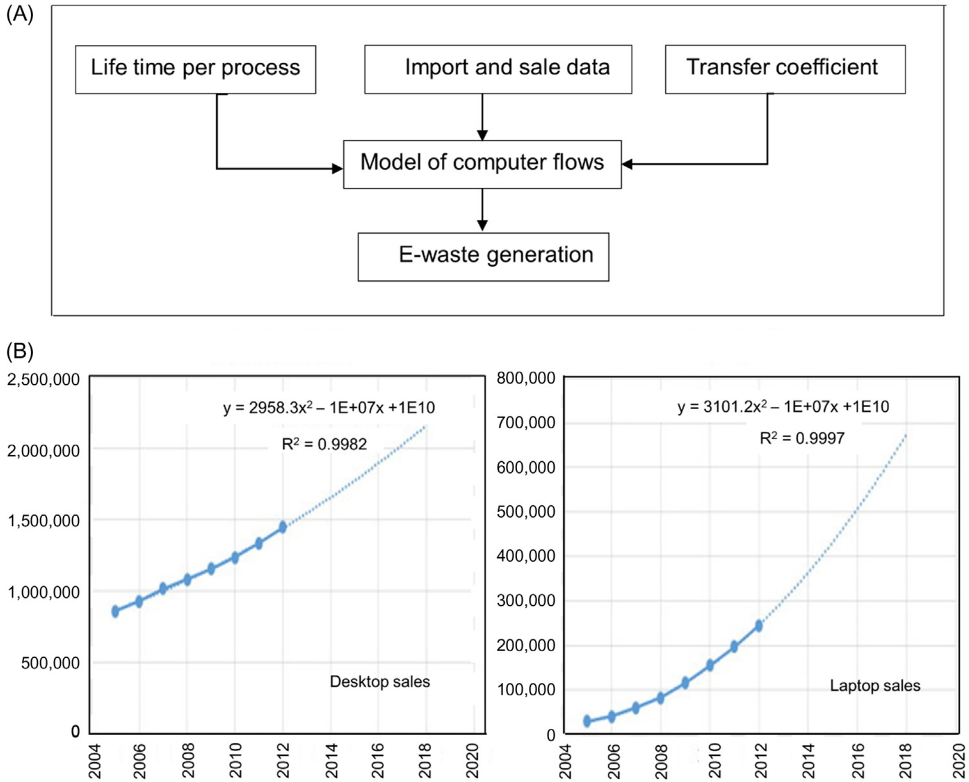

Figure 12.3 A typical assumption for the material flow analysis (A), and sales data of desktops (B) and laptops (C) and its extrapolation for quantifying the volume of E-waste generation after their consumptions in Pakistan.
Source: Adapted from Sajid, M., Syed, J.H., Iqbal, M., Abbas, Z., Hussain, I., Baig, M.A., 2019. Assessing the generation, recycling and disposal practices of electronic/electrical-waste (E-Waste) from major cities in Pakistan. Waste Manag. (in press). Available from: https://doi.org/10.1016/j.wasman.2018.11.026.

Table 12.2 The average quantities of the major items imported to Pakistan, mainly in the name of UEEE (Sajid et al., 2019).

Source from	Source to	Desktop (%)	Laptop (%)	Average (%)
Import/sales	Corporate organizations	25	20	25
	Small businesses	35	35	35
	Households	40	45	40
Corporate and business organizations	Storage after first use	65	53	60
	Reuse	27	34	30
	Disposal	8	13	10
Small businesses	Storage after first use	40	42	40
	Reuse	35	31	30
	Disposal	25	27	30
Households	Storage after first use	38	25	30
	Reuse	32	47	40
	Disposal	30	28	30
Storage after first use	Reuse	50	50	50
	Disposal	50	50	50
Reuse	Storage after first use	50	50	50
	Disposal	50	50	50
Storage after second use	Disposal	100	100	100

collection facility is also responsible for this because people throw the E-waste after running off the working condition of UEEE.

A recent study on the assessment of E-waste generation using the material flow analysis methodology is reported by Sajid et al. (2019). The flow of E-waste in the country is considered to follow the route of material imported as UEEE→distribution→consumption→disposal. Soon after reaching the end-of-life (Fig. 12.3A), they are not supposed to be disposed of and after a time being they are sold to scraper (through the direct sale or donation or auction). A significant part of them eventually ends up and disposed of as E-waste. Using the statistical model, the sales data of the majorly sold items (PCs and laptops) within the periods of 2005−12 are accounted and extrapolated up to the year 2016. Thus fitted polynomial trend line is shown in Fig. 12.3B, based on which the waste generation data for desktop and laptops are projected. Moreover, with some preliminary assumptions, the transfer coefficient is also tabulated (as presented in Table 12.2).

12.3 Policy framework

It is evident from Fig. 12.2 that the generation of E-waste keeps growing, still there is no specific work done on its proper management. In order to ratify the Basel Convention, Pakistan has some indigenous environmental laws; however, effective legislation that explicitly deals with E-waste is required yet.

12.3.1 Legislations dealing the E-waste in Pakistan

The journey toward environmental conservation in the country started with the formation of Pakistan Environmental Protection Council in 1984 following the Pakistan Environmental Protection Ordinance enacted in 1983 (GISW, 2010). Thereafter, the National Conservation Strategy was adopted in 1992 that was also presented in Rio Earth Summit and later endorsed by the United Nation by granting through the International Union for Conservation of Nature for the Sustainable Development Networking Programme. The milestone for the policy on environmental safeguard in the country came with the Pakistan Environmental Protection Act (PEPA) that was enacted in December 1997. Section 11 of which prohibits the discharge/emission of any hazardous chemical into the environment; Section 13 prohibits the import of any hazardous substance; and Section 14 does not allow the handling of hazardous elements in the territory of Pakistan (PEPA, 1997; Abbas, 2010). The National Environment Policy 2005 defines the hazardous materials and their import restriction including those mentioned in the Basal Convention is enacted by the Import Policy Order 2007−08. The recent edition of the Import Policy Order 2016 clearly indicates that air conditioners, refrigerators, monitors, CCTVs, and other home appliances in UEEE or second-hand condition are not allowed to be imported (IPO, 2007, 2016). The aforementioned laws/regulations only guiding the basic constraints on E-waste, but the generalized form of elements involved and principles restricts their implementations. The reason is therefore the flow of E-waste in other forms is to continue and increase as well. It can only be handled by framing specific legislation on E-waste to regulate the E-waste volume, its management, and informal recycling as well. Preparations on the quantitative inventories of EEEs, and E-waste being produced, imported, consumed, recycled, and dumped are the basic need for developing the E-waste specific regulation/law (Iqbal et al., 2015). The collection of E-waste at the local level up to municipal level, and also by implementing the extended producer responsibility (EPR) system, their transportation to the formal recycling centers should be made possible. In that manner only, the best practices can be ensured in the country to deal with this growing problem of the globe. EPR is presently the foremost policy worldwide, intending to provide incentives to EEE manufacturer for integrating the environmental considerations during the product design and have assigned the obligation for environmental impacts throughout the life-cycle of products, including recycling, reuse, and disposal of E-waste (Ongondo et al., 2011). Furthermore, a legislative framework for effective E-waste management in Pakistan can be developed by incorporating the existing tools as shown in Fig. 12.4 (Pathak et al., 2017).

12.3.2 International legislations and status-quo of Pakistan

As with the developed countries, Pakistan needs a national registry system along with a strong collection network and legislative framework (Sthiannopkao and Wong, 2013). Pakistan can learn from the global regulations like the Avoidance of Packaging Waste of Germany to put the financial obligations on manufacturers for

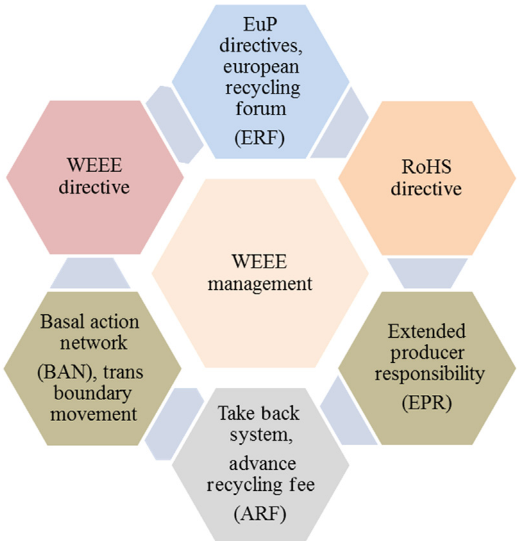

Figure 12.4 The tools for legislative framework on E-waste management.
Source Adapted from Pathak, P., Srivastava, R.R., Ojasvi, 2017. Assessment of legislation and practices for the sustainable management of waste electrical and electronic equipment in India. Renew. Sust. Energ. Rev. 78, 220–232.

the collection and reduction of packaging waste (Ongondo et al., 2011). It has also been adopted by several other European countries (in Norway, Taiwan, Sweden, and Switzerland) and extended to EEE manufacturer. The strong legislative of the EU restricting the use of hazardous substances in EEE (Directive 2002/95/EC, the RoHS Directive), and promotes their recycling. Table 12.3 identifies the important initiatives for managing the E-waste by the international organizations and summarizes their key features as well.

Pakistan can also learn from the legislative gaps remained in the neighboring countries (China and India), where the EPR system has been implemented but they do not have the national registry system to track the produced EEE for the purpose of eventual manufacturer take-back. Therefore the quantification and trace of E-waste generation is still a difficult task. The big gray markets available for the second-hand UEEE in Pakistan are also making the situation vulnerable. The domination of private players, availability of cheap labour, a large rate of E-waste growing volume (by both import and domestic generation), and the costlier technology for its benign disposal, are the factors supposed to keep hurdles despite the enactment of environmental regulations. Henceforth, it is impossible to neglect the informal sector and Pakistan has to make its legislative framework on E-waste management by including the informal sector with the formal and organized practices. In order to make a clear understanding, the status-quo of E-waste management in Pakistan is compared with other relevance countries and presented in Table 12.4.

Table 12.3 Important legislations and initiatives with their key features for the E-waste management (Ilankoon et al., 2018).

Legislation and initiatives	**Key features**
The Basal Convention	• Reduction of hazardous waste generation and the promotion of sustainable handling techniques at the place of disposal • The restriction of transboundary movements of hazardous wastes • Form legislative frameworks where transboundary movements are permissible
The EU WEEE Directives	• Free take-back schemes for consumers • Reduce WEEE to landfills through collection and recovery targets • WEEE to be collected separately from other wastes • Stimulate "eco-design"—product design that reduces WEEE and increases its ease of recovery • Producer responsibility for end-of-life treatment of their products
Solving the E-waste Problem	• Research and piloting on E-waste treatment • Strategy and goal-setting to eliminate the E-waste problem • Training and development on E-waste issues • Establish communication and awareness among members and throughout the industry
G-8 3Rs Initiative	• Promoting 3Rs: reduce, reuse, recycle • Building a "sound-material-cycle society"
National Strategy for Electronics Stewardship, United States	• Improve design of electronic products • The Federal government leads by example • Enhance the handling and management of used or discarded electronic equipment in the United States • Reduce harm caused by used or discarded electronic equipment in developing countries
Global e-Sustainability Initiative	• Bring together ICT companies, industry associations and non-governmental organizations • One of the key focus area is E-waste • Achieving sustainable objectives and manage risks associated with ICT through innovative technology
International Environmental Technology Centre—UNEP	• Application of environmentally sound technologies (ESTS) in developing countries and countries in transition on waste management

Table 12.4 A brief comparison of the status-quo for E-waste management in Pakistan and some other countries (Imran et al., 2017).

Factors	Australia	Canada	China	EU countries	Ghana	India	Pakistan
E-waste specific rule	Yes	Yes	Yes	Yes	No	Yes	No
Management studies on E-waste	Yes	Yes	Yes	Yes	Average	Yes	No
Import regulation	Well implemented	Well implemented	Well implemented	Strictly implemented	No	Poorly implemented	No
Informal recycling activities	No	No	Very less	Strictly banned	Very high	High (~95%)	Very high (98%)
Implementation of labor law (informal)	Yes	Yes	Yes	No evidence of informal activity	No	Poorly implemented	No
Public awareness	High	Very high	High	Very High	No	Poor	No

12.4 Existing practices for E-waste handling in Pakistan

As mentioned that only 2% of the total amount of imported UEEE is usable material, while all others directly sent for recycling, in most of the ceases by the informal sector. The flow of E-waste in current practices for Pakistan is shown in Fig. 12.5. Only ~2% of formal recycling is being practiced of the total E-waste, including the amount of domestic generation. The practices are vulnerable and unhealthy. From hand-picking/sorting to dismantling are being done without any proper protection to avoid any contact to the hazardous and toxic substances (Ahmed et al., 2018), while burning of the wires, PCBs, and other plastics to detach the metals from polymer substance in the open area (see Fig. 12.6A and B) is causing much pollution to the environment. The practices of this sector are unorganized but pacing with an internal management system in a chain from rag pickers to collectors wherefrom it reaches to scrap collectors and after dismantling and sorting finally reaches to informal recyclers. Earlier the volume reduction by dismantling and sorting was the major part for the informal sector, which was sold to the traders again in an illegal manner to the metal recyclers in China. Slowly, they have also started to strip the metals, targeting copper and gold of the most important in this practice. By providing the heat through torch blowing to melt the plastic substances, metals are subjected to acid bath again in the open environment using the nitric and hydrochloric acids, emitting the hazardous NOx and gaseous chlorine compounds. In the entire practices, not only the workers involved but also the local inhabitants residing in that vicinity are not well-informed of the associated hazards therein. The aforementioned lacking of any specific regulatory to look the occupational exposure and environmental pollution due to the informal recycling practices; make it easy to be continued. Moreover, some of the peoples do understand the associated problems

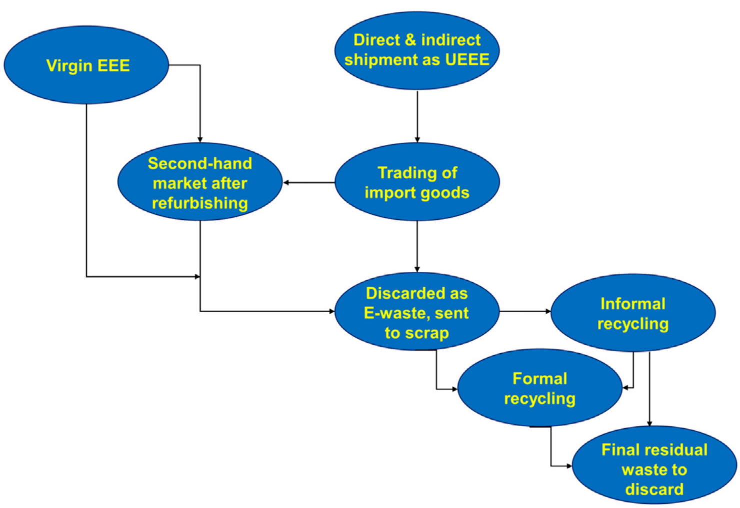

Figure 12.5 Pictorial presentation of the typical E-waste flow in Pakistan.

Figure 12.6 The representative pictures of the E-waste business, showing the vulnerable practices for segregation, manual dismantling, and informal recycling practices without any protective measures.
Source Adapted from Sajid, M., Syed, J.H., Iqbal, M., Abbas, Z., Hussain, I., Baig, M.A., 2019. Assessing the generation, recycling and disposal practices of electronic/electrical-waste (E-Waste) from major cities in Pakistan. Waste Manag. (in press). Available from: https://doi.org/10.1016/j.wasman.2018.11.026.

but as these practices are the only source of their income, they have no option except to ignore the vulnerability with this business.

12.4.1 E-waste receiver and processing sites

In Pakistan, Lahore and Karachi are the main activity centers in terms of E-waste dumping (http://citeseerx.ist.psu.edu). The quantities of major E-waste destination cities in the country by altering the name as UEEE, are summarized in Table 12.5 (Imran et al., 2017). Karachi is the largest economic hub of Pakistan and the end-point of most of the E-waste due to being located at the coastal side of the Arabian Sea (https://www.dawn.com/news/290400; https://www.downtoearth.org). The E-waste from various developed and OECD countries reached in the Karachi port in the name of UEEE. Lyari is the largest recycling site of Karachi along with Sher Shah. The recycling practices herein are informal and with complete disregard, to the grave risks, they pose to human and environmental health. However, the neighbouring countries are also the major destination sites of such E-waste but the legislative development in those countries has somehow diverted the more hazardous

Table 12.5 The major cities receiving the E-waste quantities in the name of UEEE (Imran et al., 2017).

City name	Imported quantity (tons)	Imported quantity (%)
Karachi	85,291	89.4
Lahore	5807	6.1
Rawalpindi	1403	1.5
Islamabad	1155	1.2
Peshawar	1075	1.1
Faisalabad	583	0.6

and toxic materials to the Karachi port. In general, the older the E-waste the higher level of hazardous elements therein. The aforementioned informal recycling practices left significant pollutant in solid, liquid and gaseous forms. The bulk of them is either landfilled or trashed into Lyari River, which falls into the Arabian Sea and disturbing the marine ecosystem. The second largest metro city Lahore is also facing the same challenges due to the informal recycling. Beadon road, Hall road, Hafeez center, Misri shah, and the GT road area near to Mayo Hospital and Pakistan mint are the known areas for E-waste trading. Here the people working inside their small rooms, often without lacking ventilation facility, causes the potential health problems to the workers. Although small in size than Lahore and Karachi, Rawalpindi and Faisalabad is also a hub for E-waste recycling. Time-to-time the district administration drives do penalize and shuts such informal ventures, but this not sufficient when compared to the vulnerabilities of E-waste. Asthma, skin diseases, and nausea are very common in the localities of these areas. The influence of E-waste recycling on the molecular ecological network of soil microbial communities has been studied using the samples collected from Karachi, Multan, and Lahore (Jiang et al., 2017). It is observed that the composition of the microbial community and diversity at the whole and core community levels is significantly affected by the footprints of heavy metals, polybrominated diphenyl ethers, and polycyclic aromatic hydrocarbons. The air quality of Lyari and Sher Shah areas of Karachi have found highly contaminated with the organic flame retardants emitted by the informal recycling practices (Iqbal et al., 2017).

12.5 Research and developments for transitioning towards the formal recycling

The aforementioned only 2% recycling rate practiced by the formal sector is very poor and measurable. Even within the 2% of formal recycling not much information is available and no big recycling company exists that can be a role model in this field. Not only is the lacking of governmental regulatory legislation but in absence of the adequate technical expertise and support also the formal recycling remains un-nurtured. The higher consultation fee, costlier technology, and requirement of expensive set-ups are often a bottleneck for practicing the formal recycling in Pakistan. It indicates for the requirement of the indigenous management and recycling technology. The slow but growing awareness in this field has paid attention to the research communities of the country, and initiative works have been started for exploring the sustainable management of E-waste problem in Pakistan. Several research works have been reported in recent times focusing on the E-waste management system (Iqbal et al., 2015; Imran et al., 2017; Sajid et al., 2019). On the other side, for metal recovery, which has been considered as the integrative part of the sustainable E-waste management, some interesting works have been reported, however, a few in quantity. Interestingly, they are of a wider spectrum using the convention chemical to advance microbial technologies.

Spent lithium-ion batteries (LiBs) are one of the main contributor associated with E-waste and today Pakistan is supposed to consume 7 million units of LiBs. As the spent LiBs contains a significant amount of valuable rare metals like cobalt, nickel, and lithium, its recycling other than dumping as the municipal waste has been proposed by Sattar et al. (2019, 2020). The combined heat treatment–acid

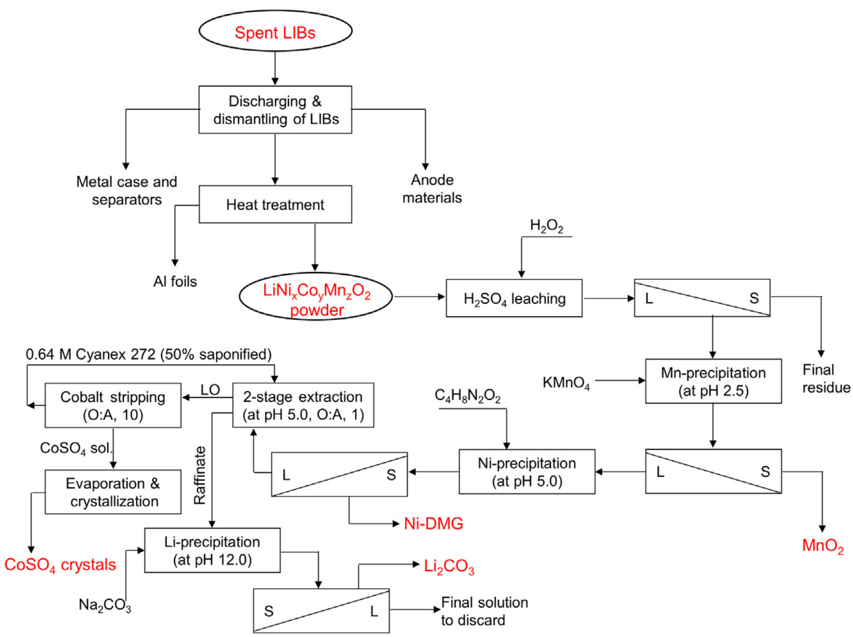

Figure 12.7 An indigenous developed process flow-sheet for the entire recycling of EoL-LiBs at the Mineral and Material Chemistry Lab, University of Agriculture Faisalabad. *Source* Adapted from Sattar, R., Ilyas, S., Bhatti, H.N., Ghaffar, A., 2019. Resource recovery of critically-rare metals by hydrometallurgical recycling of spent lithium ion batteries. Sep. Purif. Technol. 209, 725–733; Sattar, R., Ilyas, S., Kousar,S., Khalid, A., Sajid, M., Bhkhari, S.I., 2020. Recycling of end-of-life LiNix$_C$oy$_M$nz$_O$2 batteries for rare metals recovery. *Environ. Eng. Res.* 25 (1), 88–95. Available from: https://doi.org/10.4491/eer.2018.392.

leaching—precipitation—solvent extraction—crystallization process for the recycling of metals from cathode materials is shown in Fig. 12.7. In presence of H_2O_2 at moderately increased temperature, the enhanced leaching of cobalt that undergoes to solvent extraction for its separation and enrichment of metal concentration, above 99% of metals recovery has been reported. The process advantage is also with the efficient recovery of other rare metals like nickel and lithium (more than 99%) presents the recycling process better than the robust smelting technique, which requires high calorific energy and losing lithium into slag. Moreover, the entire process has been analyzed to be economically viable with a margin of $476 per ton of the cathode powder processing (Sattar et al., 2020). Looking at the need of the time for the recycling of spent LiBs, the University of Agriculture Faisalabad has included the work as the technology for commercialization (101 Innovations Catalogue-UAF, unpublished).

Other than the chemical leaching, Ilyas et al. (2007, 2010) have extensively worked in the bioleaching of E-waste, and certainly, one of the leading work has been carried out. Using the selected moderately thermophilic strains of acidophilic chemolithotrophic and acidophilic heterotrophic bacteria (including the *Sulfobacillus thermosulfidooxidans*), the mixed consortium of the metal adapted culture exhibited the maximum leachability of metals from e-scrap. At the laboratory scale, 81% nickel, 89% copper, 79% aluminum, and 83% zinc recovery has been reported through the bioleaching (Ilyas et al., 2007). This has been further upscaled to column level of study (as the schematic is shown in Fig. 12.8) and the results have been found to be promising (Ilyas et al., 2010, 2018).

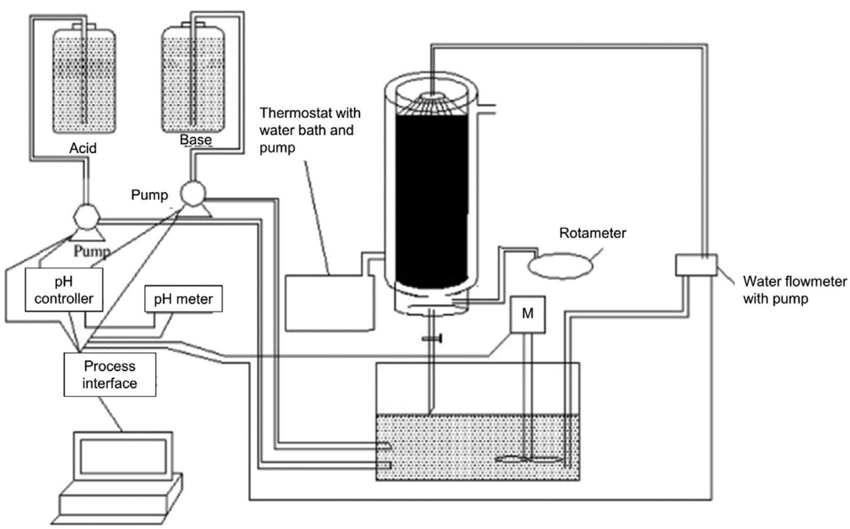

Figure 12.8 A sketch of the column set-up specifically designed for E-waste bioleaching. *Source* Adapted from Ilyas, S., Ruan, C., Bhatti, H.N., Ghauri, M.A., Anwar, M.A., 2010. Column bioleaching of metals from electronic scrap. Hydrometallurgy, 101 (3—4), 135—140.

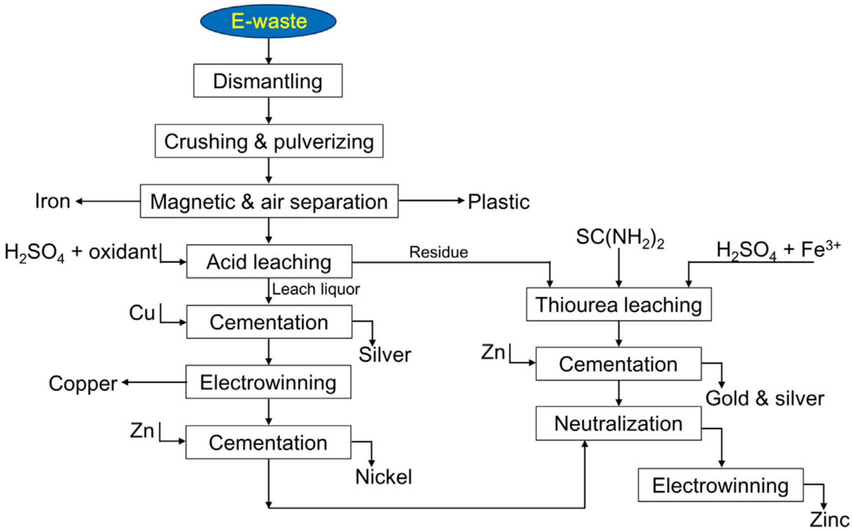

Figure 12.9 A typical recycling of E-waste through the scientific approach for the maximum recovery of base, valuable, and precious metals.

Although a few R&D works have been initiated with encouraging results of metal extraction from E-waste, the government needs to take necessary action to promote the research on E-waste recycling at the higher level to switch from the informal recycling to formal recycling. The government can play a catalytic role by connecting the academic and industrial linkage by providing the market for the recovered value-added products from E-waste recycling. For a country struggling for achieving the self-reliance on the economic front, the recycling of E-waste converting its waste to the wealth can be a leading way toward the circular economy (Ilyas, 2018a,b). Notably, an approximately 146 kg gold of worth 600 million Pakistani Rupee is supposed to be available in the amount of E-waste dumped on yearly basis in Pakistan that contains a total 29,262 tons of metals therein (Imran et al., 2017). One of the possible recycling routes for metals recovery from E-waste is shown in Fig. 12.9.

12.6 Summary and recommendations

In the name of UEEE, Pakistan has become the major destination of E-waste from the exporting countries, which is accounted up to ~94,000 tons per year. Karachi is the largest hub for E-waste trading that receives 89% of total UEEE. The current practices of their handling are totally nonsustainable. In lacking any specific legislation on E-waste management, almost all E-waste is handled by the informal sector. For preparing the specific framework on E-waste management, the government can just follow their neighbouring countries and examples of some developed countries

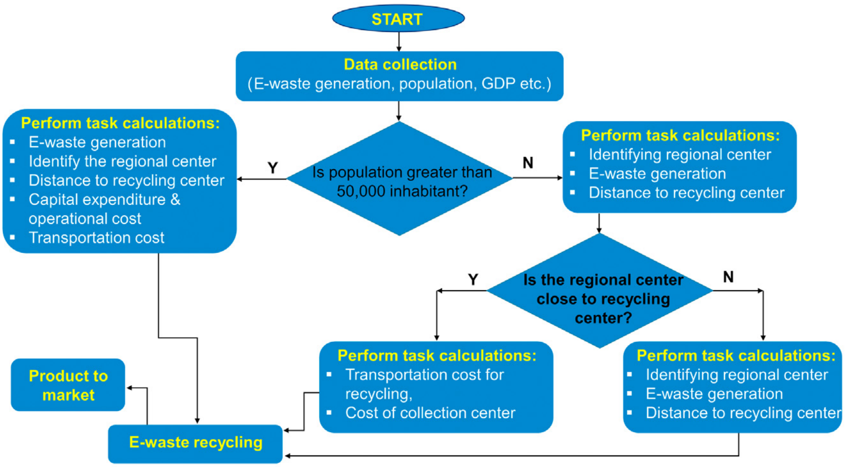

Figure 12.10 An algorithm for the proposed model of E-waste recycling.

like Japan and Sweden. The illegal trade of UEEE in the name of second-hand items and charity work must be controlled by ensuring to obey the Import Policy Order (IPO, 2016) in Pakistan. Legislation like EPR should be imposed on the manufacturers and retailers with obligations of take-back/buy-back of the EoL-EEE/UEEE that can be reused, recycled, and disposed of the residual waste.

At present, only 2% of the total E-waste is being recycled through the formal route, therefore no reliable data are available on E-waste generation and their ways of management. Although a handful of researchers have shown their interests to present solutions of this invited problem of the globe, in absence of governmental direction and encouragements, the benefits of indigenous R&D on E-waste recycling is yet to reach for switching the informal sector toward the formal recycling. The making of coordination between the entities like collectors, scrappers, refurbishers, recyclers, manufacturers, retailers, academia, and governmental bodies, is the need of the hour. They must be educated and well-trained on the collection, handling, and disposal work. For this, time-to-time awareness drive for the common public will be valuable to keep E-waste separate from other municipal solid waste.

The plenty of peoples involved in this business can be benefited more in terms of their good health, sustainable environment, and more earning due to the high yield of valuable metals by adopting scientific practices. Moreover, Pakistan can move forward to the circular economy through the formal recycling of E-waste that can mitigate the major supply risks of several metals recovered from the burgeoning waste volume. To ensure the sustainable management of E-waste, an algorithm is being proposed that can be developed according to the waste generation volume and the provincial population ratio, because it significantly varies from one province to another. In the algorithmic flow shown in Fig. 12.10, a population of 50,000 peoples has been considered for an example that may change. Certainly, this cannot be the only way to handle the E-waste problem but any such initiative can move toward the achievement of all components of the sustainability: societal, economic, and environmental.

Acknowledgments

This work was supported by Brain Pool Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (Project grant number: 2019H1D3A2A02101993). The author S. Ilyas is thankful to the NRF for providing the Brain Pool Scientists award.

References

Abbas, Z., 2010. In: E-waste management in Pakistan. Regional Workshop on E-Waste/WEEE Management, Osaka, Japan, pp. 6−9.

Ahmed, I., Usman, A., Nazir, M.S., Shaukat, M.Z., 2018. Safety practices in informal industrial segment of Pakistan. Saf. Sci. 110, 83−91.

Basel Action Network (BAN), 2002. Exporting harm the high tech trashing of Asia. <http://www.ban.org/E-waste/technotrashfinalcomp.pdf>. Retrieved on August 31, 2018.

Cobbing, M., 2008. Toxic tech: not in our backyard: uncovering the hidden flows of e-waste. Report from Greenpeace International.

EU RoHS Directive, 2002/95/EC. <http://eur-lex.europa.eu/homepage.html>. Retrieved on August 31, 2018.

European Commission, 2003. Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. Off. J. Eur. Union L3, 24−38.

GISW-Pakistan, 2010. In: Finlay, Alan (Ed.), Global Information Society Watch 2010 Report Focus on ICTs and Environmental Sustainability. APC and Hivos, pp. 187−190. ISBN 92-95049-95-0.

Greenpeace, 2009. Where does e-waste end up? <http://www.greenpeace.org/international/en/campaigns/toxics/electronics/the-e-waste-problem/where-does-e-waste-end-up/>. Retrieved on August 31, 2018.

<http://citeseerx.ist.psu.edu/viewdoc/download?doi = 10.1.1.620.6726&rep = rep1&type = pdf>.

<http://pas.org.pk/digital-in-2017-global-overview/> Retrieved on August 15, 2018.

<https://www.dawn.com/news/290400>. Retrieved on September 6, 2018.

<https://www.downtoearth.org.in/news/pakistan-mulls-ban-on-ewaste-import-651>. Retrieved on September 6, 2018.

Ilankoon, I.M.S.K., Ghorbani, Y., Chong, M.N., Herath, G., Moyo, T., Petersen, J., 2018. E-waste in the international context—a review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery. Waste Manag. 82, 258−275.

Ilyas, S., 2018a. Metal recycling. <https://www.dawn.com/news/1444937>. Retrieved on November 12, 2018.

Ilyas, S., 2018b. Waste management and circular economy. <https://nation.com.pk/16-Nov-2018/waste-management-and-circular-economy>. Retrieved on November 17, 2018.

Ilyas, S., Lee, J.C., 2014. Biometallurgical recovery of metals from waste electrical and electronic equipment: a review. Chem. Bio. Eng. Rev. 1 (4), 148−169.

Ilyas, S., Anwar, M.A., Niazi, S.B., Ghauri, M.A., 2007. Bioleaching of metals from electronic scrap by moderately thermophilic acidophilic bacteria. Hydrometallurgy 88 (1−4), 180−188.

Ilyas, S., Ruan, C., Bhatti, H.N., Ghauri, M.A., Anwar, M.A., 2010. Column bioleaching of metals from electronic scrap. Hydrometallurgy 101 (3−4), 135−140.

Ilyas, S., Kim, M.S., Lee, J.C., 2018. Integration of microbial and chemical processing for a sustainable metallurgy. J. Chem. Technol. Biotechnol. 93 (2), 320−332.

Imran, M., Haydar, S., Kim, J., Awan, M.R., Bhatti, A.A., 2017. E-waste flows, resource recovery and improvement of legal framework in Pakistan. Resour. Conserv. Recycl. 125, 131−138.

International, B. M, 2015. Pakistan Consumer Electronics Report, February 26, 2015, p. 64.

IPO, 2007. In: Import Policy Order, Ministry of Commerce, Government of Pakistan (Ed.), Islamabad, Pakistan.

IPO, 2016. In: Import Policy Order, Ministry of Commerce, Government of Pakistan (Ed.), Islamabad, Pakistan.

Iqbal, M., Breivik, K., Syed, J.H., Malik, R.N., Li, J., Zhang, G., et al., 2015. Emerging issue of e-waste in Pakistan: a review of status, research needs and data gaps. Environ. Pollut. 207, 308−318.

Iqbal, M., Syed, J.H., Breivik, K., Chaudhry, M.J.I., Li, J., Zhang, G., et al., 2017. E-waste driven pollution in Pakistan: the first evidence of environmental and human exposure to flame retardants (FRs) in Karachi City. Environ. Sci. Technol. 51 (23), 13895−13905.

Jiang, L., Cheng, Z., Zhang, D., Song, M., Wang, Y., Luo, C., et al., 2017. The influence of e-waste recycling on the molecular ecological network of soil microbial communities in Pakistan and China. Environ. Pollut. 231, 173−181.

Ongondo, F.O., Williams, I.D., Cherrett, T.J., 2011. How are WEEE doing? A global review of the management of electrical and electronic wastes. Waste Manag. 31 (4), 714−730.

Pathak, P., Srivastava, R.R., Ojasvi, 2017. Assessment of legislation and practices for the sustainable management of waste electrical and electronic equipment in India. Renew. Sust. Energ. Rev. 78, 220−232.

Pathak P., Srivastava R.R. and Ojasvi, 2019. Environmental Management of E-waste. In: Electronic Waste Management and Treatment Technology, Prasad M.N.V. and Vithanage M. (Ed.), Elsevier, Oxford, UK, pp. 103−135. Available from: https://doi.org/10.1016/B978-0-12-816190-6.00005-4.

PEPA, 1997. In: Pakistan Environmental Protection Act, Government of Pakistan (Ed.), p. 29. Pakistan.

Puckett, J., Byster, L., Westervelt, S., Gutierrez, R., Davis, S., Hussain, A., et al., 2002. Exporting Harm: The High-Tech Trashing of Asia, Vol. 3. Basel Action Network, Seattle.

Sajid, M., Syed, J.H., Iqbal, M., Abbas, Z., Hussain, I., Baig, M.A., 2019. Assessing the generation, recycling and disposal practices of electronic/electrical-waste (E-Waste) from major cities in Pakistan. Waste Manag. Available from: https://doi.org/10.1016/j.wasman.2018.11.026 (in press).

Sattar, R., Ilyas, S., Bhatti, H.N., Ghaffar, A., 2019. Resource recovery of critically-rare metals by hydrometallurgical recycling of spent lithium ion batteries. Sep. Purif. Technol. 209, 725−733.

Sattar, R., Ilyas, S., Kousar, S., Khalid, A., Sajid, M., Bukhari, S.I., 2020. Recycling of end-of-life $LiNix_{C}oy_{M}nz_{O}2$ batteries for rare metals recovery. Environ. Eng. Res. 25 (1), 88−95. Available from: https://doi.org/10.4491/eer.2018.392.

Sthiannopkao, S., Wong, M.H., 2013. Handling e-waste in developed and developing countries: Initiatives, practices, and consequences. Sci. Total Environ. 463, 1147−1153.

Swedish EPA, 2011. Recycling and disposal of electronic waste. Health hazards and environmental impacts. Report 6417 of the Swedish Environmental Protection Agency. March 2011.

Tanskanen, P., 2013. Management and recycling of electronic waste. Acta. Mater. 61 (3), 1001−1011.

Terazono, A., Murakami, S., Abe, N., Inanc, B., Moriguchi, Y., Sakai, S.I., et al., 2006. Current status and research on E-waste issues in Asia. J. Mater. Cycles Waste 8 (1), 1−12.

Today, C., 2014. Imports Historical Custom Clearence Data, 2014 Edition.

Umwelthilfe, D.E.U.T.S.C.H.E., 2007. Hamburg: gate to the world for illegal waste exports? Part 1. How Hanseatic City of Hamburg Tries to Get Rid of Its Liability, Berlin.

United Nations Environmental Programme (UNEP), 2011 Recycling e-waste to resources. <http://www.unep.org/pdf/Recycling_From_ewaste_to_resources.pdf>.

Vadoudi, K., Kim, J., Laratte, B., Lee, S.J., Troussier, N., 2015. E-waste management and resources recovery in France. Waste Manag. Res. 33 (10), 919−929.

Wang, R., Xu, Z., 2014. Recycling of non-metallic fractions from waste electrical and electronic equipment (WEEE): a review. Waste Manag. 34 (8), 1455−1469.

Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., Boni, H., 2005. Global perspectives on e-waste. Environ. Impact Assess. Rev. 25 (5), 436−458.

Further reading

http://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6417-4.pdf. Retrieved on August 15, 2018.