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A Comprehensive Review on Challenges and Opportunities of e-waste Management Practices in Ethiopia

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Abstract
In this paper, the review of the challenges and opportunities of e-waste management practices around the globe in general and in Ethiopia, in particular, was discussed thoroughly. Recently published papers in a reputable national and international journal: original papers, review papers, short communication papers and national and international policies were reviewed. The definition, amount, effect, management practices, challenges and opportunities of e-waste were also described well. Electronic waste (e-waste) denotes all kinds of electrical electronic equipment (EEE) and its components that have been rejected or donated by their owner as waste without the intent of reuse. Recently, e-waste is also generated from nanoelectronics devices and systems. EEE generation is increasing daily and distributed throughout the world including developing and underdeveloped countries like Ethiopia. In Ethiopia, education institutions, industries and individuals' homes are the major consumers of EEE so they can generate an equivalent amount of e-waste. There are proclamations in Ethiopia regarding hazardous wastes in general and e-waste in particular management and disposal control practices but are not functioning at all. E-waste has resulted in environmental pollution by polybrominated diphenyl ethers and polychlorinated biphenyl, human health problems range from kidney and liver injury to neurological illness. Even human cancer will also be caused by e-waste. Therefore proper and better e-waste management mechanisms should be designed and implemented in our country, Ethiopia. There should also be separate legislation regarding nano e-waste management in the country.
Keywords: E-waste, Legislation, Ethiopia, WEEE, Nano e-waste

Introduction

Electronic waste(E-waste) has several definitions based on different experts from different organizations(Vats, Singh, and Vats 2014). Generally, electronic waste, or e-waste, denotes all kinds of electrical and electronic equipment (EEE) and its components that have been rejected, discarded or donated by their owner as waste without the intent of re-use(Subbramaniam 2013: Shaikh 2008). E-waste is also referred to as Waste of Electrical and Electronic Equipment (W-EEE) mainly in Europe(Adrian et al. 2020), electronic waste, or e-scrap in different regions and under different circumstances in the world. It includes a wide range of products: almost any household or business item or its part with circuitry or electrical components with power or battery supply as bulk or in the nanoscale(Musee 2011; Kim 2014; Suman and Pei 2021). Partnership on Measuring ICT for Development classifies e-waste into six categories namely temperature exchanging equipment, screens and monitors, lamps, large equipment, small equipment and small IT and telecommunications(Shaikh 2008; Subbramaniam 2013; Madkhali et al. 2023).

The fast growth of the manufacturing of electrical and electronic equipment in the bulk or nanoscale has resulted in the fast growth of electronic waste throughout the world(Awasthi, Zeng, and Li 2016). The UN report showed that there were about more than 41.5 million metric tons of e-waste in 2014 across the globe. Furthermore, the globe generated about 50 million metric tons of e-waste in 2018(Work and Centres 2020) and 53.6 million metric tons (Mt) of e-waste in 2019. EEE consumption is increasing by 2.5 million metric tons (Mt)(except for photovoltaic panels) annually(Adrian et al. 2020). In 2030, the world's W-EEE is estimated to be more than 74.5Mt. Asia produced 24.9Mt of e-waste in 2019 the highest quantity, followed by America (13.1 Mt) and Europe (12 Mt), while Africa generated 0.7 Mt only. Generating 16.2 Kg of e-waste per capita, Europe ranked first in the world followed by Oceania, America, and Asia with 16.1 Kg, 13.3 Kg and 5.6 Kg, respectively. The least e-west per capita produced in Africa was 2.5 Kg in 2019(Adrian et al. 2020). Ethiopia's stored e-waste was about 4,300 tons of non-functioning computers, mobile phones, refrigerators and televisions in 2013, which was generally located in Urban areas and can be considered relatively small. However, it may be rapidly increasing while there is no effective and efficient way of e-waste management(Schleicher et al. 2015; Abebe 2017; Krishna and Saha n.d.; Lema et al. 2019).

There are many components or chemicals of e-waste. Chemicals in e-waste can be classified into four categories. These are persistent organic pollutants, dioxins, polyaromatic hydrocarbons and elements. The persistent organic pollutants consist of Brominated flame retardants, Polybrominated diphenyl ethers and Polychlorinated biphenyls whereas dioxins include Polychlorinated dibenzodioxins and dibenzofurans, Dioxin-like polychlorinated biphenyls and Perfluoroalkyl. On the other hand, polyaromatic hydrocarbons and elements contain Acenaphthene, acenaphthylene, anthracene, benz[a] anthracene, benzo[a]pyrene, benzo[e]pyrene, benzo[b]fl fluoranthene, benzo[g,h, i]perylene, benzo[j] fluoranthene, benzo[k]fl fluoranthene, chrysene, dibenz[a,h]anthracene, fluoranthene, fluorene, indeno[1,2,3-c,d]pyrene, phenanthrene, and pyrene and lead, chromium, cadmium, zinc, nickel, barium, beryllium respectively(Grant et al. 2013). Some of the components are useful(Pineda-Vásquez et al. 2023; Hernández-Saravia et al. 2023; Mondal, Paul, and Rhaman 2023) and others are toxic or dangerous.

W-EEE have resulted in environmental(Gangwar et al. 2019) and health problems(Ceballos and Dong 2016; JK et al. 2017). Some of the environmental hazards are pollution by polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls (PCBs). Dioxins, furans, and heavy metals are also released from the informal e-waste recycling process and are harmful to the surrounding environment(Osibanjo and Nnorom 2007; Koloseni and Shimb 2012; Luo et al. 2011; Mmereki, Heeks, Subramanian, and Jones 2015; Baldwin, et al. 2016; Mmereki, Awasthi et al. 2016; Li, et al. 2016;). These chemicals directly or indirectly damage human or other living systems' health. For instance, in China, Findings from most studies showed increases in spontaneous abortions, stillbirths, premature births, and reduced birth weights and birth lengths associated with exposure to e-waste. People living in e-waste recycling towns or working in e-waste recycling had evidence of greater DNA damage than those living in control towns. Studies of the effects of exposure to e-waste on thyroid function were not consistent(Kim et al. 2014). The health hazards of e-waste range from kidney and liver injury to neurological illnesses(Work and Centres 2020). E-waste chemicals such as Pb, Hg, Cd, As and chlorinated dioxins as well as carcinogens are toxic and leak into underground aquifers thereby degrading the quality of local groundwater and rendering the water unhealthy for human consumption, animal consumption, bird consumption and agricultural purposes(Mmereki, Li, et al. 2016). Therefore, in this paper, the definition, sources, types, amount and disposal practices of e-waste are discussed in the globe in general and in Ethiopia in particular. Finally, the conclusion and personal recommendations are done.

Methodology

Overall, 55 recent papers related to E-waste management and disposal control practices were collected from different reliable sources. The sources were Research Gate, Scopus, Google, web of Science and Google Scholar. Among them, five were discarded because they were irrelevant to the task. Then the remaining 49 papers were analysed and synthesized. The place names and the number of papers downloaded are shown in Table 1.**Error! Reference source not found.** Number of papers downloaded in different countries in t he world

No.	Name of the places	Number of useful papers downloaded	Remark
1	India	9	
2	China	5	
3	USA	2	

4	Bangladesh	1	
5	Korea	1	
6	Finland	1	
7	Indonesia	1	
8	Ethiopia	6	
9	Other African countries	9	Tanzania, Ghana, Nigeria, South Africa
10	Other countries in the world	18	Asian countries

E-waste and its management practices in the global scenario

Recently, electrical and electronic equipment (EEE) manufacturing has grown exponentially around the globe. According to the Global E-waste Monitors 2020 report, the global average annual growth rate of consumption of EEE in weight (excluding photovoltaic panels) is more than 2.4 million metric tons (Mt)(Sumasto et al. 2019; Adrian et al. 2020). However, the lives of EEE have become increasingly shorter and shorter(Ylä-Mella, Keiski, and Pongrácz 2022). Most of them end up in garbage dumps and recycling centres, posing a new problem for society and the environment(Bhutta, Omar, and Yang 2011). In the following sections, e-waste experiences in China and India are discussed. These two countries are growing rapidly as consumers and generators of huge EEE and e-waste respectively.

China discards 160 million electronic devices per year. In the past, China had been considered the largest e-waste dumping Centre in the globe (Mmereki, Li, et al. 2016). China decarded more than 6 Mt of WEEE in 2014(Baldé, Wang, and Huisman 2015). It is the 2nd largest generator of e-waste in the world (Fu et al. 2018). Hundreds of thousands of people are experts in dismantling electronic junk in China. Valuable metals such as copper, silver, gold and platinum could be recovered from e-waste if they are scientifically processed (Work and Centres 2020). E-waste recycling in China is a serious challenge to human health. The following study shows this fact. Kristen Grant et al. systematically searched 5 electronic databases namely PubMed, Embase, Web of Science, PsycNET, and CINAHL to deal with the assessment of the relationship between exposure to e-waste and consequences related to mental health and neurodevelopment, physical health, education, violence and criminal behaviour, from Jan 1, 1965, to Dec 17, 2012, and yielded 2274 records in south-east China. Findings from those studies showed increases in spontaneous abortions, stillbirths, and premature births, and reduced birth weights and birth lengths associated with exposure to e-waste. People living in e-waste recycling towns or working in e-waste recycling had evidence of greater DNA damage than those living in control towns. Studies of the effects of exposure to e-waste on thyroid function were not consistent(Kim et al. 2014). The health hazards of e-waste range from kidney and liver injury to neurological illnesses(Work and Centres 2020).

a

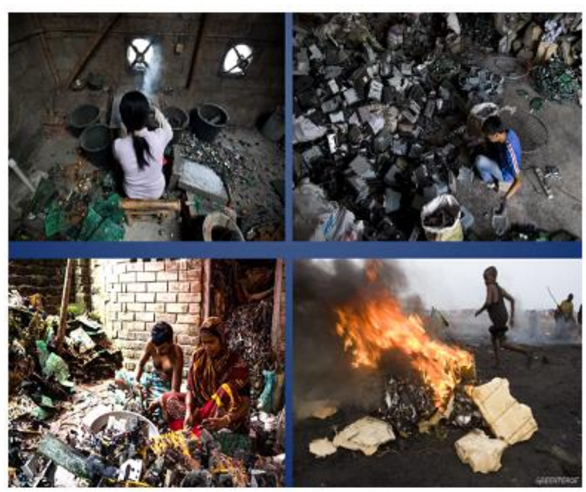
b

Figure 1 Dicarded E-waste(a) and traditional dismantling of E-waste in China (b) (china.org, edition. cnn)

Informal e-waste recycling is the most common practice in China to extract metals and other important materials by exploiting very cheap manpower in primitive circumstances, exposing Workers to extensive health dangers(Terazono et al. 2006)(Aneesha Raj, Chirstine Crute, Connie Xiong, Elizabeth Lamb, Julia Murphy n.d.). Informal e-waste recycling is not only related to serious environmental and health problems but also the shortage of supply for formal recyclers and the safety difficulties of recycling electronic products. From an experience point of view, simply inclusion or opposing the informal collectors and recyclers is not an effective solution. Rather, new formal e-waste recycling systems should take the available informal sectors into account, and more policies need to be formed to improve recycling rates, working conditions and the efficiency of involved informal players(Chi et al. 2011). Discarded e-waste and traditional dismantling of e-waste in China are shown in Figure **1**.

In India, e-waste is defined under the E-waste (Management) Rules of 2016—issued by the Central Pollution Control Board (CPCB)-as electrical and electronic equipment (EEE), whole or in part, discarded as waste by consumers as well as rejects from manufacturing, refurbishment and repair processes(Balakrishnan and Rachel Priya 2016). The primary identification of e-waste is that used EEE is no longer fit for its originally intended use and is ready to be discarded. All the end-of-life equipment which we intend to discard for dismantling and recycling will fall under the category of e-waste. If any equipment is not discarded and is kept as it is in a household, repository or warehouse, it will not be referred to as e-waste. World Economic Forum 2018 stated, that India was ranked fifth in the world among the top e-waste producing countries next to the USA, China, Japan, and Germany and recycles less than 2% of the total e-waste it produces by using the formal method. However, the main e-waste recycling technique in India is informal(Jain et al. 2023). India generated 146 thousand tons of e-waste per year in 2013(Borthakur and Sinha 2013). Starting in 2018, India generated more than 2 million tons of e-waste per year and also imports large amounts of e-waste from remaining countries all over the world(Mmereki, Li, et al. 2016). Discarding in open e-waste sites is a common sight which results in groundwater contamination, poor health and more(Work and Centres 2020). Discarded e-waste and the traditional dismantling process of e-waste in India are shown in Figure **2**.

a



b

Figure 2 Dicarded E-waste(a) and traditional dismatling of E-waste in india(b)(Wikipedia, (Chen and Kim 2018)

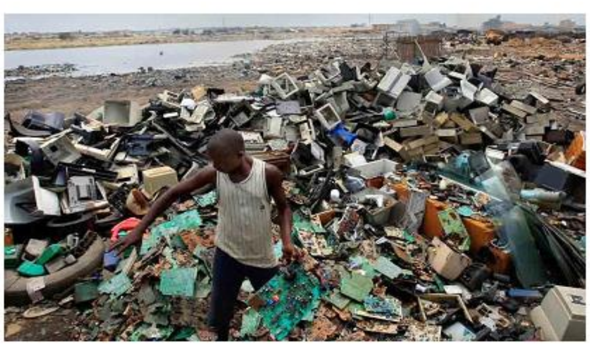
The usage of EEE in Africa is increasing tremendously due to the expansion of local electronic device manufacturing industries and the importation of used EEEs(Avis 2021). Hence, WEEE is increasing rapidly in Africa(Heeks et al. 2015; JK et al. 2017; Mmereki, Baldwin, et al. 2016; Orisakwe et al. 2019; Osibanjo and Nnorom 2007; Sthiannopkao and Wong 2013; World Economic Forum 2019). In most African countries, e-waste is generated by end-of-use EEE by their citizens, imported e-waste and imported refurbished/used EEE(Koloseni and Shimb 2012). In Africa, thirteen countries were identified as having a national e-waste legislation/policy in 2017, Western Africa, including Nigeria and Ghana, had the highest regional coverage of e-waste legislation but are also sites for significant amounts of imported e-waste but despite legislation in place, illegal importation of e-waste continues to occur through poor adherence and weak enforcement of laws(Avis 2021). African countries like Ghana, Nigeria, Tanzania, Botswana and others are practising informal(traditional) WEEE recycling practices to extract important components of e-waste(Koloseni and Shimb 2012; Mmereki, Li, and Li'ao 2015). Some of the important components of e-waste are metals and plastics. The traditional (classical) method of recycling e-waste is a hazardous practice for both the environment and human health. In most African countries, there are no separate e-waste management policies, well-trained e-waste collectors or recyclers, formal e-waste processing organizations and so on. Many researchers strongly recommend that African countries' governments establish clear and separate e-waste management policies, e-waste recycling sites, well-trained e-waste collectors and a strong memorandum of understanding(MoU) with the main EEE vendors regarding their e-waste management strategies(Koloseni and Shimb 2012; Mmereki et al. 2015; Awasthi et al. 2016; Mmereki, Li, et al. 2016; Orisakwe et al. 2019; Yong, Lim, and Ilankoon 2019; Lema et al. 2019; Kang et al. 2020). Discarded e-waste and the traditional dismantling process of e-waste in Nigeria and Ghana respectively are shown in Figure **3** and Figure **4** respectively.

The major challenges to efficient e-waste management practices in most African countries are insufficient legislative frameworks and government agencies, lack of capacity to enforce regulations, limited infrastructures to manage the e-waste, lack of operating standards and transparency, presence of illegal imports, security issues, data gaps, lack of trust, absence of formal workers in the e-waste management practices and high-cost requirement for the proper e-waste management system(Avis 2021).

a

b

Figure 3 Discarded e-waste (a) and traditional recycling (b) in Nigeria (Source: E-Terra, ser-limited)



a

b

Figure 4 Discarded e-waste(a) and traditional recycling(b) in Ghana (European Commission, wired.co.ltd)

According to Widmers et al(Widmer et al. 2005) and Ari(Vidyadhar 2016) research results, electronic waste is composed of 60 percent metals, 15 percent plastics, 5 percent metals plastic mixture and 2 percent printed circuit board(PCBs). Again 30 percent of PCBs is metal of which Cu is the dominant one(Kumar et al. 2014)(Manikandan et al. 2023). Resins, ceramics and plastics are also found in PCBs. Hence, e-waste has a lot of potential advantages for a nation(Yong et al. 2019). Some of them are the following.

i. It is the main metal source next to mining. E-waste recycling for metal extraction is commonly referred to as urban mining.
ii. It is also used as a source of plastics
iii. It creates job opportunities starting from e-waste collectors to recyclers.

Suthipong Sthiannopkao and Ming Hung Wong stated that developed countries set conventions, directives, and laws to control their e-waste disposal. Certain developed countries exercise modern home WEEE management systems(Kang et al. 2020). But most of the time, the manufacturers take responsibility for the corresponding e-waste. Manufacturers take back wasted items to destroy or recover them safely(Sthiannopkao and Wong 2013). These countries send their e-waste mainly to Pakistan, India, Peru, Nigeria, and China(Mmereki, Li, et al. 2016). Recycling e-waste scrap is polluting the water, soil, and air. Burning to retrieve metal from wires and cables has led to the emission of brominated and chlorinated dioxins as well as carcinogens which pollute the air and, thereby, cause cancer in humans and other animals. Toxic chemicals that have no economic value are simply dumped during the recycling process. These toxic chemicals leak into underground aquifers thereby degrading the quality of local groundwater and rendering the water unhealthy for human consumption and agricultural purposes. When e-waste is discarded in e-waste storage sites, the Pb, Hg, Cd, As, and printed circuit boards make the soil toxic and unhealthy for agricultural purposes(Mmereki, Li, et al. 2016).

Park JK et al. stated that the speed of growing e-waste generation in developing countries is the main concern. Unsafe (informal) disposal of e-waste is a rising problem and environmental and human health problems are very serious(Orisakwe et al. 2019; Sthiannopkao and Wong 2013). They propose several recommendations for e-waste management in developing countries. Some of them are:

i. Take advantage of the collection network that the informal recycling sector has created
ii. An Incentive system will be needed to create the link between the informal and formal recycling methods
iii. Informal recyclers will then be more eager to bring their collected e-waste to the formal recyclers where it will be treated properly
iv. Manufacturers and producers need to become more involved by implementing more successful take-back systems for their electronic devices so that they will be recycled properly at formal facilities that will alleviate environmental and health negative impacts(JK et al. 2017).

E-waste and its management practices in the Ethiopian Scenario

The Ethiopian rural population is more than 70% of the total population. Among them, more than 25% have been using cell phones and other electrical and electronic equipment. The average lifespan of cell phones is about 4-5 years. Hence e-waste is increasing rapidly due to the rural population in addition to the urban population which is the major source of e-waste in Ethiopia(Haile, Wossen, and Kalkuhl 2019)(Article 2020)(Tadesse and Bahiigwa 2015).

A report on an efficient and effective e-waste collection system for Ethiopia conducted in 2014 showed that there was no formal e-waste collection mechanism in Addis Ababa(Schleicher et al. 2015). Abenezer Wakuma Kitila and Solomon Mulugeta Woldemikael conducted a study on Electronic waste management in Addis Ababa: The case of Bole and Nefas Silk Lafto sub-cities recently and they got the breakage of electronic appliances, lack of proper operation skills, increasing of uselessness rate, and the demand for the extra and new design were the major causes for the e-waste generation in the area. The administrative, economic and socio-cultural related factors are the major challenges of e-waste management in the area. Consumers with higher incomes tend to generate obsolete electronic equipment earlier than the lifetime of the equipment than the respondents with middle and lower incomes. Commonly storing is the extensively practised discarding method there. There are little or no other disposal methods such as reusing, donating, refurbishing, and recycling. Findings showed that the absence of appropriate disposal methods and recyclers are considered factors for the lengthy storage and improper disposal(Kitila and Woldemikael 2020).

Abenezer Wakuma Kitila also studied e-waste management and disposal practices on four campuses at Addis Ababa University. The names of the four campuses are the main campus, Institute of Technology (IoT), Science Faculty and FBE. The numbers of e-waste obtained in these four campuses are 2648, 903, 648 and 783 respectively. His study was qualitative. The major causes of these wastes were the rapid obsolescence rate, lack of maintenance, and demand for new products. The typical e-waste management practices they used here were storing and donating. They did not use other modern management practices like recycling, reusing, refurbishing, and reselling. They just stored the waste because of poor maintenance and refurbishing facilities, the absence of well-prepared disposal methods and procedures and poor upgrading mechanisms. Even there was no awareness created regarding e-waste for the general service department officers. There was also no legal framework to manage e-waste in the university(Wakuma 2014).

Massreshaw Asnakew Abebe reported that more than 32 million Kg per year of e-waste was generated in 2016 at Addis Ababa city in selected areas alone. These wastes were mainly generated by importers, manufacturers, retailers, traders, consumers, scrap dealers and recyclers. The wastes were mixed with other wastes and disposed of in the environment without any precaution. There were not also any legally registered organizations regarding e-waste handling in Ethiopia(Abebe 2017).

In Ethiopia, there are proclamations regarding hazardous waste management and disposal control and E-waste management and disposal control namely proclamation number 1090/2018 and 425/2018 respectively (FDRE 2018; FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA 2018). But in practice, they are not functioning well.

There is no in-depth study conducted in different parts and regions of Ethiopia about the type and amount of E-waste, management and disposal practices of E-waste and the effects of E-waste except Addis Ababa Nifas silk Lafto ketema and Addis Ababa University though E-waste production is increasing daily throughout the nation. Generally, the major causes of E-waste production in Ethiopia are breakage, high uselessness rate, absence of proper operation skills and knowledge of the devices, new devices demand and lack of proper maintenance centres. The main management and disposal control methods of E-waste are donating and storing. E-waste stored in different parts of Ethiopia is shown in **Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**.

Figure 1 Stored E-waste in Ambo University [57]

Figure 2 E-Waste observed at the site of the compound (Winget TVETs)[58]

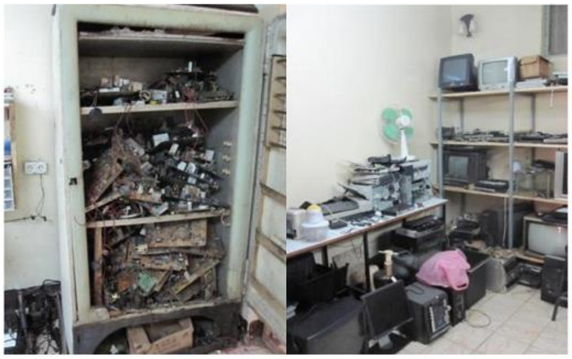


Figure 1 Spare parts stored in one repair enterprise for electric and electronic equipment in Hawassa[11]

Figure 2 The Storaed E-waste at Addis Ababa University[54]

Conclusions and Recommendation

WEEE production is increasing exponentially around the globe due to the high production of EEE in number and kind. E-waste production is also increasing daily in underdeveloped and developing countries including Ethiopia due to manufacturing and importing old EEE. Due to the incorporation of Nanomaterials in EEE, there is also an existence of nanoe-waste which is very toxic. Developed countries use different mechanisms to manage and properly dispose of WEEE. Some of the methods they used are recycling, refurbishing and donating. In the case of Ethiopia, there is no in-depth study about the amount, type, management, disposal methods and effects of e-waste. Some studies carried out in Addis Ababa Ethiopia revealed that the amount of E-waste production is increasing rapidly due to breakage, lack of proper operational skills, high uselessness rate, new device demand and lack of proper maintenance centres. The common management and disposal methods in the area are storing and donating. There are government proclamations in the country regarding WEEE management and disposal control even though they are not functioning very well. Therefore it requires a lot of studies about the type, amount, effect and management and disposal control mechanisms in different parts of the country.

References

Abebe, M. A. 2017. "Electronic Waste Management Practices and Development of Electronic Waste Management Guidelines in Addis Ababa." *International Journal of Scientific Engineering and Science* 1(8):56–65.

Adrian, Contributions S., M. Brune Drisse, Y. Cheng, L. Devia, and O. Deubzer. 2020. *The Global E-Waste Monitor 2020*.

Aneesha Raj, Chirstine Crute, Connie Xiong, Elizabeth Lamb, Julia Murphy, and Yan Sun. n.d. "Electronic Waste in China:Regulation VS. Reality."

Article, Original. 2020. "ASSESSMENT OF THE SOCIOECONOMIC EFFECTS OF CELL PHONE TECHNOLOGY ON HUMAN LIVELIHOOD : OROMIA RADIO AND TELEVISION ORGANIZATION IN." 1(2):410–24.

Avis, William. 2021. "Drivers , Barriers and Opportunities of e-Waste Management in Africa."

Awasthi, Abhishek Kumar, Xianlai Zeng, and Jinhui Li. 2016. "Environmental Pollution of Electronic Waste Recycling in India: A Critical Review." *Environmental Pollution* 211:259–70. doi: 10.1016/j.envpol.2015.11.027.

Balakrishnan, C., and J. Rachel Priya. 2016. "E-Waste Management in India." *Pollution Research* 35(3):539–43. doi: 10.17148/ijireeice.2020.8802.

Baldé, C. P., F. Wang, and Huisman. 2015. *THE GLOBAL E-WASTE MONITOR 2014 Quantities, Flows and Resources*.

Bhutta, M. Khurrum S., Adnan Omar, and Xiaozhe Yang. 2011. "Electronic Waste: A Growing Concern in Today's Environment." *Economics Research International* 2011:1–8. doi: 10.1155/2011/474230.

Borthakur, Anwesha, and Kunal Sinha. 2013. "Electronic Waste Management in India: A Stakeholder's Perspective." *Electronic Green Journal* 1(36). doi: 10.5070/g313618041.

Ceballos, Diana Maria, and Zhao Dong. 2016. "The Formal Electronic Recycling Industry: Challenges and Opportunities in Occupational and Environmental Health Research." *Environment International* 95:157–66. doi: 10.1016/j.envint.2016.07.010.

Chen, Aimin, and Stephani Kim. 2018. "Niehs Peph Webinar: E-Waste and Environmental Health." 20.
Chi, Xinwen, Martin Streicher-Porte, Mark Y. L. Wang, and Markus A. Reuter. 2011. "Informal Electronic Waste Recycling: A Sector Review with Special Focus on China." *Waste Management* 31(4):731–42. doi: 10.1016/j.wasman.2010.11.006.
FDRE. 2018. "Electronic and Electrical Waste Management and Disposal. Council of Ministers Regulation No. 425/2018." *Federal Negarit Gazeta*.
FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA. 2018. *Hazardous Waste Management and Disposal Control Proclamation, Proclamation No.1090/2018*.
Fu, Jianjie, Haiyan Zhang, Aiqian Zhang, and Guibin Jiang. 2018. "E-Waste Recycling in China: A Challenging Field." *Environmental Science and Technology* 52(12):6727–28. doi: 10.1021/acs.est.8b02329.
Gangwar, Charu, Ranjana Choudhari, Anju Chauhan, Atul Kumar, Aprajita Singh, and Anamika Tripathi. 2019. "Assessment of Air Pollution Caused by Illegal E-Waste Burning to Evaluate the Human Health Risk." *Environment International* 125(November 2018):191–99. doi: 10.1016/j.envint.2018.11.051.
Grant, Kristen, Fiona C. Goldizen, Peter D. Sly, Marie Noel Brune, Maria Neira, Martin van den Berg, and Rosana E. Norman. 2013. "Health Consequences of Exposure to E-Waste: A Systematic Review." *The Lancet Global Health* 1(6):e350–61. doi: 10.1016/S2214-109X(13)70101-3.
Haile, Mekbib G., Tesfamicheal Wossen, and Matthias Kalkuhl. 2019. "Access to Information, Price Expectations and Welfare: The Role of Mobile Phone Adoption in Ethiopia." *Technological Forecasting and Social Change* 145(April):82–92. doi: 10.1016/j.techfore.2019.04.017.
Heeks, Richard, Logakanthi Subramanian, and Carys Jones. 2015. "Understanding E-Waste Management in Developing Countries: Strategies, Determinants, and Policy Implications in the Indian ICT Sector." *Information Technology for Development* 21(4):653–67. doi: 10.1080/02681102.2014.886547.
Hernández-Saravia, Lucas Patricio, Erico R. Carmona, Aliro Villacorta, Felipe S. Carevic, and Ricardo Marcos. 2023. "Sustainable Use of Mining and Electronic Waste for Nanomaterial Synthesis with Technological Applications: State of the Art and Future Directions." *Green Chemistry Letters and Reviews* 16(1). doi: 10.1080/17518253.2023.2260401.
Jain, Muskan, Depak Kumar, Jyoti Chaudhary, Sudesh Kumar, Sheetal Sharma, and Ajay Singh Verma. 2023. "Review on E-Waste Management and Its Impact on the Environment and Society." *Waste Management Bulletin* 1(3):34–44. doi: 10.1016/j.wmb.2023.06.004.
JK, Park, Hoerning L, Watry S, Burgett T, and Matthias S. 2017. "Effects of Electronic Waste on Developing Countries." *Advances in Recycling & Waste Management* 02(02). doi: 10.4172/2475-7675.1000128.
Kang, Kai Dean, Harnyi Kang, I. M. S. K. Ilankoon, and Chun Yong Chong. 2020. "Electronic Waste Collection Systems Using Internet of Things (IoT): Household Electronic Waste Management in Malaysia." *Journal of Cleaner Production* 252. doi: 10.1016/j.jclepro.2019.119801.
Kim, Young Ran, Fiona A. Harden, Leisa Maree L. Toms, and Rosana E. Norman. 2014. "Health Consequences of Exposure to Brominated Flame Retardants: A Systematic Review." *Lancet Glob Health* 106:1–19. doi: 10.1016/j.chemosphere.2013.12.064.
Kim, Younghun. 2014. "Nanowastes Treatment in Environmental Media." *Environmental Health and Toxicology* 29:e2014015. doi: 10.5620/eht.e2014015.
Kitila, Abenezer Wakuma, and Solomon Mulugeta Woldemikael. 2020. "Electronic Waste Management in Addis Ababa: The Case of Bole and Nefas Silk Lafto Sub-Cities." *African Journal of Science, Technology, Innovation and Development* 0(0):1–12. doi: 10.1080/20421338.2020.1712014.
Koloseni, Daniel, and Faith Shimb. 2012. "E-Waste Disposal Challenges and Remedies: A Tanzanian Perspective." *Waste Management - An Integrated Vision*. doi: 10.5772/48094.
Krishna, Ram, and Sampa Saha. n.d. "E-Waste Management." 0–23.
Kumar, Manoj, Jae Chun Lee, Min Seuk Kim, Jinki Jeong, and Kyoungkeun Yoo. 2014. "Leaching of Metals from Waste Printed Circuit Boards (WPCBs) Using Sulfuric and Nitric Acids." *Environmental Engineering and Management Journal* 13(10):2601–7. doi: 10.30638/eemj.2014.290.
Lema, Gorfnesh, Million Getachew Mesfun, Amade Eshete, and Gizachew Abdeta. 2019. "Assessment of Status of Solid Waste Management in Asella Town, Ethiopia." *BMC Public Health* 19(1):1–7. doi: 10.1186/s12889-019-7551-1.
Luo, Chunling, Chuanping Liu, Yan Wang, Xiang Liu, Fangbai Li, Gan Zhang, and Xiangdong Li. 2011. "Heavy Metal Contamination in Soils and Vegetables near an E-Waste Processing Site, South China." *Journal of Hazardous Materials* 186(1):481–90. doi: 10.1016/j.jhazmat.2010.11.024.
Madkhali, Hatim, Salahaldeen Duraib, Linh Nguyen, Mukesh Prasad, Manu Sharma, and Sudhanshu Joshi. 2023. "A Comprehensive Review on E-Waste Management Strategies and Prediction Methods: A Saudi Arabia

Perspective.” *Knowledge* 3(2):163–79. doi: 10.3390/knowledge3020012.
Manikandan, S., D. Inbakandan, C. Valli Nachiyar, and S. Karthick Raja Namasivayam. 2023. “Towards Sustainable Metal Recovery from E-Waste: A Mini Review.” *Sustainable Chemistry for the Environment* 2(February):100001. doi: 10.1016/j.scenv.2023.100001.
Mmereki, Daniel, Andrew Baldwin, Liu Hong, and Baizhan Li. 2016. “The Management of Hazardous Waste in Developing Countries.” *Management of Hazardous Wastes*. doi: 10.5772/63055.
Mmereki, Daniel, Baizhan Li, Andrew Baldwin, and Liu Hong. 2016. “The Generation, Composition, Collection, Treatment and Disposal System, and Impact of E-Waste.” *E-Waste in Transition - From Pollution to Resource*. doi: 10.5772/61332.
Mmereki, Daniel, Baizhan Li, and Wang Li’ao. 2015. “Waste Electrical and Electronic Equipment Management in Botswana: Prospects and Challenges.” *Journal of the Air and Waste Management Association* 65(1):11–26. doi: 10.1080/10962247.2014.892544.
Mondal, Moni Sankar, Ayon Paul, and Mukitur Rhaman. 2023. “Recycling of Silver Nanoparticles from Electronic Waste via Green Synthesis and Application of AgNPs-Chitosan Based Nanocomposite on Textile Material.” *Scientific Reports* 13(1):1–15. doi: 10.1038/s41598-023-40668-7.
Musee, N. 2011. “Nanowastes and the Environment: Potential New Waste Management Paradigm.” *Environment International* 37(1):112–28. doi: 10.1016/j.envint.2010.08.005.
Orisakwe, Orish Ebere, Chiara Frazzoli, Cajetan Elochukwu Ilo, and Benjamin Oritsemuelebi. 2019. “Public Health Burden of E-Waste in Africa.” *Journal of Health and Pollution* 9(22):190610. doi: 10.5696/2156-9614-9.22.190610.
Osibanjo, O., and I. C. Nnorom. 2007. *The Challenge of Electronic Waste (e-Waste) Management in Developing Countries*. Vol. 25.
Pineda-Vásquez, Tatiana, Leidy Rendón-Castrillón, Margarita Ramírez-Carmona, and Carlos Ocampo-López. 2023. “From E-Waste to High-Value Materials: Sustainable Synthesis of Metal, Metal Oxide, and MOF Nanoparticles from Waste Printed Circuit Boards.” *Nanomaterials* 14(1):69. doi: 10.3390/nano14010069.
Schleicher, Tobias, Andres Manhart, Tadesse Amera, Atalo Belay, and Zamanu Genet. 2015. “An Efficient & Effective E-Waste Collection System for Ethiopia.” *Consultancy Service for UNIDO within the E-Waste Management Project in Ethiopia (EWAMP)* 1–69.
Shaikh, Tanveer. 2008. “Electronic Waste What Is Electronic Waste ?”
Sthiannopkao, Suthipong, and Ming Hung Wong. 2013. “Handling E-Waste in Developed and Developing Countries: Initiatives, Practices, and Consequences.” *Science of the Total Environment* 463–464:1147–53. doi: 10.1016/j.scitotenv.2012.06.088.
Subbramaniam, Theepa. 2013. “Chapter 1 What Is E-Waste?”
Suman, Thodhal Yoganandham, and De Sheng Pei. 2021. “Nanomaterial Waste Management.” *Nanomaterials Recycling* (November):21–36. doi: 10.1016/B978-0-323-90982-2.00002-0.
Sumasto, F., T. Y. M. Zagloel, R. Ardi, and Zulkarnain. 2019. “Estimation Lifespan of Home Electronic Appliances in Indonesia: The Case Study of Java Island.” *IOP Conference Series: Earth and Environmental Science* 219(1):0–6. doi: 10.1088/1755-1315/219/1/012008.
Tadesse, Getaw, and Godfrey Bahiigwa. 2015. “Mobile Phones and Farmers’ Marketing Decisions in Ethiopia.” *World Development* 68:296–307. doi: 10.1016/j.worlddev.2014.12.010.
Terazono, Atsushi, Shinsuke Murakami, Naoya Abe, Bulent Inanc, Yuichi Moriguchi, Shin Ichi Sakai, Michikazu Kojima, Aya Yoshida, Jinhui Li, Jianxin Yang, Ming H. Wong, Amit Jain, In Suk Kim, Genandrialine L. Peralta, Chun Chao Lin, Thumrongrut Mungcharoen, and Eric Williams. 2006. “Current Status and Research on E-Waste Issues in Asia.” *Journal of Material Cycles and Waste Management* 8(1):1–12. doi: 10.1007/s10163-005-0147-0.
Vats, Mahesh Chander, S. K. Singh, and M C Vats. 2014. “E-Waste Characteristic and Its Disposal.” *International Journal of Ecological Science and Environmental Engineering* 1(2):49–61.
Vidyadhar, Ari. 2016. “A Review of Technology of Metal Recovery from Electronic Waste.” *E-Waste in Transition - From Pollution to Resource*. doi: 10.5772/61569.
Wakuma, Abenezer. 2014. “Electronic Waste Management and Disposal Methods in Addis Ababa University : Challenges and Prospects.” *International Journal of Science and Research* 3(11):1164–68.
Widmer, Rolf, Heidi Oswald-Krapf, Deepali Sinha-Khetriwal, Max Schnellmann, and Heinz Böni. 2005. “Global Perspectives on E-Waste.” *Environmental Impact Assessment Review* 25(5 SPEC. ISS.):436–58. doi: 10.1016/j.eiar.2005.04.001.
Work, O. U. R., and O. U. R. Centres. 2020. “E-Waste Management in India: Challenges and Opportunities.” *Creating Innovative Solutions For A Sustainable Future* 1–9.

World Economic Forum. 2019. “A New Circular Vision for Electronics Time for a Global Reboot.” (January):24.
Ylä-Mella, Jenni, Riitta L. Keiski, and Eva Pongrácz. 2022. “End-of-Use vs. End-of-Life: When Do Consumer Electronics Become Waste?” *Resources* 11(2). doi: 10.3390/resources11020018.
Yong, Yun Siew, Yi An Lim, and I. M. S. K. Ilankoon. 2019. “An Analysis of Electronic Waste Management Strategies and Recycling Operations in Malaysia: Challenges and Future Prospects.” *Journal of Cleaner Production* 224:151–66. doi: 10.1016/j.jclepro.2019.03.205.