Current Status of Electronic Waste in Information Communication Technology (ICT) and its Environmental Management – A Review

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Abstract

The production of electronic devices in the Information and Communication Technology (ICT) sector has seen a massive increase in the past few decades due to changes in the lifestyle of individuals across the globe. The Covid-19 pandemic has been like a catalyst in this process, where the demand has reached its peak due to work-from-home activities. A huge amount of electronic waste generated is by the ICT sector which is not efficiently managed and ultimately risks human health and the environment. The challenges arise in the pathway of efficient and sustainable recycling of electronic waste due to improper defined rules and regulations, unskilled personnel handling electronic waste, high cost of recycling, poor coordination between manufacturers, customers, and government bodies, and the prevailing of informal sector. The present review investigates the current scenario of electronic waste around the globe, strategies developed to manage the electronic waste and methods to be adopted for achieving sustainable goals in managing waste from the ICT sector. An attempt is also made to cover the data related to the approaches made by manufacturers to overcome the issue of electronic waste management.

Introduction

Rapid urbanization has played apropitious role in sustainable economic development and industrialization around the globe in both developed and developing countries. Urbanization has also been a driving force in changing the lifestyle of individuals across the globe. The demand for electronic goods has seen an increase in the past few years, to meet this demand many players entered the market and due to the increase in supply, the new trend of the lower price of these electronic goods flourished in the market leading to an increase in the purchase ability of these goods. This led to an increase in a large amount of electronic waste, and the increase has reached its peak in the last 10 years.[1] The electronic waste generated globally has crossed the 50 million metric tons mark in 2019 from 44.7 million metric tons in 2016 and by 2050 it is estimated to increase to 120 metric tons every year.[2,3] The amount of electronic waste generated in different regions of the world is variable and it solely depends on factors like population, economic status of consumers, social factors, the lifestyle of individuals, and resource availability. Among all continents, Asia alone has produced 24.8 million metric tons of electronic waste followed by America, Africa, and Europe. Globally, the average per capita electronic waste generated was approximately around 5 kg in Asia, 13 kg in America, 16kg in Europe, and 3 kg in Africa. The outburst of the Covid-19 pandemic across the world has also contributed to an increase in the demand for Information and Communication Technology devices namely smartphones, tablets, laptops, desktops, etc. To stop the spread of Covid-19, the concept of work from home was introduced in all sectors including the education sector resulting in an enormous rise in Information and Communication Technology devices.[4] So, it is more likely that the burden of electronic waste will increase in society in the years to come and proper strategies should be planned to manage this electronic waste without harming the environment and human health.

In developing countries like India, a large number of the young population rely on smartphones. Approximately 7,8,12 and 70% of ICT waste comes from healthcare, electronic devices, telecommunication, and information technology devices respectively. The difficulties related to proper management of generated waste without adverse effect on the environment is of great concern not only for the producers but also for the consumers and government agencies.[5]

A recent LokSabha report presented by the Union Minister of state, on September 23, 2020, says that in India the electronic waste generated has increased by 43% in just a period of three years.[5] This is a great concern for developing nations like India and could be overcome by adopting a proper pathway to recycle this waste cost-effectively. The current scenario, practiced for disposal and recycling of electronic waste in countries like India is non-scientific which results in potential threats to the environment and human health. One of the recent studies by Arya *et al.,*[6] showed electronic waste as threat to the environment and human health. The author reported that the soil of sites where electronic waste was burned showed an increase in the content of heavy metals, the condition was worst in the Mandoli, New Mustfabad, and Seelampur regions of Delhi, India. Hence, it is need of an hour to use electronic waste to generate some value-added products or to recycle those adopting green principles without posing threat to the flora, fauna, and the environment. The objective of writing this review is to provide the reader with comprehensive information on the electronic waste generated in the ICT sector, possible toxins generated in the environment by improper disposal, probable strategies which could be adopted to manage the increasing electronic waste, new horizon for the management of electronic waste sustainably.

The Technical Aspect of Electronic Waste

The electronic waste consists of various organic, inorganic, metallic, and non-metallic components in it. The inorganic fraction present in electronic waste includes copper, iron, tin, aluminum, palladium, silver, tantalum, gallium, and heavy metals like cadmium, nickel, zinc, mercury, and lead. The presence of toxic components in electronic waste makes this process highly complex and difficult to deal with. Copper and lead are almost present in all electronic waste and both of them are hazardous for the environment and humans. Computer monitors, printed wiring boards contains 732, 705mg/kg copper respectively, whereas the permissible level is 1.3 mg/L'. Similarly, computer monitors and wiring board contains 9900 and

300mg/kg lead respectively, whereas the permissible level is 10 μg/L.[7] Many electronic wastes are burned in the open environment releasing various toxic components which have adverse effects on the environment and human health.[8] There is continuous changes in electronic gadgets making their usage easier for end users. For example proportion of metals like copper, silver, and nickel have also increased in the android phone because of advancement in their features.[9] It is reported in the literature that only a smaller amount of electronic waste is recycled but a larger portion remains as it is and is dumped in landfills.[10] This issue needs to be addressed and the producer of electronic goods should make sure that the goods they are producing should pose no threats to humans, animals, and the environment at any stage of their use.

Electronic Waste Management Policies of Big Players
The Information Technology sector is growing continuously at a faster rate to cater to the increasing demand, due to rapid industrialization, globalization, and urbanization across the globe. There are many big players in the information technology sector which include Infosys, Cognizant, Xiaomi, Dell, Panasonic, HCL, Amazon, Wipro, etc. and these players are continuously trying to develop and adopt a sustainable method overcome the threats associated with the disposal of electronic waste. Most of the players have been focusing on capitalization by conversion of electronic waste into wealth, this will help to uplift the economy in the Information Technology sector. Most of the producers don't have proper criteria for selection of Producer Responsibility Organization; rather as of now there are no properly defined standards, criteria, or framework which could help manufacturers to make a proper selection of Producer Responsibility Organization. Table 1 gives detailed information on the big players, their products, and the policies adopted by them to manage their electronic waste.

Table 1: Big players in IT and their electronic waste management scenario

Company	Product/ services	Electronic waste management strategies	Policy name
Xiaomi	Smartphones, and internet services.	Karo *sambhav* – Through this policy, the company has managed to set up recycling centers across India, and in the last 3 years they were able to manage 400 tons of electronic waste. Take back – Company started paying 1.32 USD to customers.	Karo *Sambhav* and Take back
Cognizant	Services related to processing automation, Quality, engineering, infrastructure, and security services.	Waste will be managed by providing service providers having valid licenses/ approvals on proper recycling and managing of electronic waste.	Collaborated with corporations for managing electronic waste.
LG	Home appliances like refrigerators, television, coolers, air conditioners, microwave ovens, etc.	LG follows an extended producer's policy, in which a toll-free customer care number is provided to the customer, through which a customer can schedule the time for collection of electronic waste by LG	Extended Producers Responsibility policy

		from the customer.	
Amazon	Computers, management tools, Web services offered by amazon, networking, analytics, etc.	They are following the criteria of the circular economy by encouraging customers to follow 3R (reuse, repair and recycle) which will reduce the burden of electronic waste.	3R policy
Dell	Dell provides computers, laptops, and all the accessories related to computers and laptops.	Dell provides end-of-product management free of cost to customers across 75 different countries and in India they have more than 25 points where customers can drop their electronic waste. Dell is also recycling their electronic waste and using plastics generated through this in designing new devices.	3R policy
Wipro	Wipro provides products personal care, lightening devices, LEDs, etc	Wipro has focused on the collection and proper management of electronic waste by recycling its waste following the norms laid by the pollution control department.	Take back policy, recycling policy
HCL	HCL provides digital services to customers, IoT services, cyber security services, cloud-native services, etc.	The electronic waste management policies of HCL provide their customers with the easy option of product recovery. They work in association with the pollution control board and are among the authorized recyclers of electronic waste since 2010.	Product recovery policy

Factors Affecting Management of ICT Cost

The designing and implementation of strategies to competently recycle electronic waste require a huge amount of capital investment. The scenario may be different in developed and developing countries. In developed countries the capital can be easily arranged based on their government policies and regulations but in the case of developing nations like India, the development and maintenance of recycling stations for electronic waste require huge capital which is the major concern and burdens the economy of developing nations. Due to this, the collection and management of electronic waste are done in informal ways, wherein this waste is collected by untrained/non-qualified individuals who recycle waste without any safety measures.[4] The stakeholders, policymakers, and government

agencies should come forward and can work in coordination to develop cost and energy-efficient recycling techniques which will help to reduce electronic waste from society without much burden on the economy of the nation.

Usable Life

In the Information and Communication sector, the focus is given to develop new devices which are user-friendly and handy. The ICT devices available in market and which are used by most of us are very easy to operate even by children, this has increased our dependency on electronic devices which has directly affected their usage. The usage of electronic devices has increased tremendously affecting their usable life. The continuous use of these devices has affected their lifespan, and their lifes pan has reduced drastically, contributing to an increase in electronic waste in a shorter period. For example, the landline phones which were used in the early 80s in India had a life span of more than 10 years but with innovation and advancement in technology smartphones took their place and these smartphones hardly gave a life span of 3 years, after which it contributes to electronic waste. So, with innovations and advancements, the usable life of electronic devices has decreased. Additionally, in making devices more compatible and user-friendly, the use of hazardous components has increased which after disposal of this waste poses serious harm to human health and the environment. The usable life of some of the commonly used ICT devices are laptops – 4 years,[11] television– 10 years, smartphones – 2 – 3 years, computers – 3 years, microwaves- 7 years, a photocopier – 8 years, DVD players – 5 years.[12]

Informal Sector

Due to the lack of proper infrastructure for the management of electronic waste from the ICT sector, the informal sector is continuously dealing with electronic waste in non-ethical ways, these practices are more pronounced in developing countries. The informal sector illegally disposes of this waste in the landfills or this waste is burned in an open area which releases toxic compoundswhich make the land unsuitable for agricultural practices. The smoke coming out from the burning of this waste contains toxic compounds that when inhaled by humans pose a danger to their lives. Many carcinogenic compounds start accumulating in the body which leads to serious diseases like cancer. It is also the responsibility of the manufacturer to share the data of raw materials used in the manufacturing of ICT devices, but unfortunately, there is no provision in which manufacturers share or display data on the toxicity of raw materials used and their impact after disposal on humans and the environment.

Attitude of Customers

The society comprises different kinds of individuals having variable attitudes toward a particular issue. This is the duty of the customer to become aware of the management of electronic waste and the harm it is posing to the environment and their health through food, water, air, and land. In many countries including India, there are no booths to collect electronic waste for their proper disposal, hence customers just throughout this waste along with the other waste, and this entire thing is just disposed of in landfills. The critical review of the literature showed that international players like Sony, Microsoft, Apple, Philips, and Toshiba do not have any take-back facilities provided in India,and those companies who have this facility in India do not have trained professionals to collect this electronic waste. Hence, it has become the need of the hour to increase awareness about the ill effects of this electronic waste among customers. This can be done by customer awareness campaigns, social media platforms, or companies should provide customers with a small book*let al*ong with the product highlighting all the information regarding electronic waste and its management. This will surely help in reducing the problem associated with electronic waste.

Global Level Initiatives to Tackle Electronic Waste
Basel Treaty

The convention came into force in the late 80s, when the awareness about the environment accelerated in developed nations. The concept of Not In My Backyard (NIMB) was practiced by the customers to promote the recycling of electronic waste. This convention was established to decrease the process of crude recycling of electronic waste, restrict the illegal movement of electronic waste from one country to another, promote methods to manage the issuesustainably, and give more power to the take-back systems. The second initiatives established by the Basel Conventionwere Partnership for Action

on Computing Equipment (PACE), and Mobile Phones Partnership Initiative (MPPI). Government agencies, industries, academic institutes, and common societies were united for tackling the issue of electronic waste. The tenth meeting of the Basel convention was held in Bali Indonesia from 23 June to 27 June 2008, where the PACE initiative came into existence. PACE gave a single platform to all the government, and non-government agencies to discuss and come out with the possible solution to tackle the issue related to electronic waste. PACE made attempts to promote the concept of sustainable development in managing electronic waste. The Pace initiative encouraged manufacturers to manufacture a product with a longer life span and reduce the transportation of electronic waste to developing nations. New manufacturers, academic organizations, non-government agencies, recycling units, policymakers, and international associations involved in managing electronic waste are always encouraged to join this initiative (PACE). Just before PACE, the MPPI initiative was introduced. It was introduced in 2002 to encourage the sustainable management of discarded mobile phones, the companies like Nokia, Motorola, LG, and Philips, signed a declaration to promote the concept of reuse, repair, and reducing the demolition of mobile phones. As a result of such initiatives, there was creation of a public-private partnership that focused

on the management of toxic and hazardous waste in an environment-friendly manner.[13]

Extended Producer Responsibility (Epr) and other Agencies Involved in Electronic Waste Management

The process of management of electronic waste was strengthened by adopting methods like EPR in the year 2012 with an amendment done in 2016. This is an environmental approach that extends the responsibility of the manufacturer to various segments of the product lifecycle most particularly the take-back policy. A recent review by Patil *et al.,*[14] reported that every country has different legislations governing the EPR system. Apart from this, there are various active agencies involved in the efficient management of electronic waste. These bodies work on the international platform may be individually or in collaboration with government agencies to tackle the issue related to the generation, recycling, and efficient management of electronic waste. Some of the important bodies working at an international level are the World Bank, UNICEF, WHO, UNESCO, UNITAR, UNIDO, UNDP, OECD, INTERPOL, WIPO, etc. They deal with different areas like legal responsibility, health, sanitation, Agriculture, development, training research, and culture (Figure 1).

Fig. 1: Various international agencies involved in the management of electronic waste.

Industries Initiatives

Industries play a significant role in developing strategies and adapting them to efficiently manage electronic waste at the global level. Recently, many electronic companies like Panasonic and Xiaomi started interacting with the customers/common public, these companies started conducting awareness programs to educate society about the ill effects of electronic waste on human health and the surrounding environment. Panasonic company has also conducted an event among school children, this event was named 'Haritumang' in which more than two hundred students were involved. The student was made aware of electronic waste and plastic waste disposal (https://delhigreens.com/2019/02/24/panasonic-launches-harit-umang-joy-of-green-initiative/). A good initiative by Xiaomi was launched which focused on the take-back of smartphones from customers and in return customers were paid Rs 100. Xiaomi also came up with more than 1000 electronic waste collection centers to collect waste like smartphones, and other electric waste including laptops and desktops. They were able to manage the recycling of 400 tons of electronic waste from 2019 onwards. Looking at these initiatives other big companies also stepped forward in addressing the issues related to electronic waste. Apple has stop production of some of its older version smartphones in 2017 to cut off its market supply. In India companies like LG have constructed a network of around 40 recycle stores where LG has been able to recycle around l00 metric tons of electronic waste. Dell also has around 23 centers across India where electronic waste is collected for recycling. They have recycled electronic waste and the plastic generated from recycling was used in the development of new components. Retail companies like Flipkart have also taken initiative in managing electronic waste. In 2019 Flipkart has received EPR authorization and they were successful in meeting the deadline for the collection of electronic waste (https://timesofindia.indiatimes.com/archive/year-2019.cms). The concern and the awareness campaign conducted by various active agencies have made companies come forward and take initiative in collecting and managing electronic waste. The key factor which can be adopted by other companies is to engage their working staff in activities related to electronic waste.

Sustainable Approach to Electronic Waste Management

The developing nations receive a huge amount of electronic waste from the developed nation as this electronic waste requires high processing costs and it is not economical, the developed nation prefer to send this to developing countries. In developing countries, the use of low-cost methods has lowered the processing cost but these methods are not human and environment-friendly, and hence they areneed for developing and sustainable solutions. The efficient management of electronic waste to maintain sustainability requires a balance between the developed policies and their impact on the economy.[15] Electronic waste management in a sustainable way depends on various factors like the formation of efficient policies, capacity building, and the development of green technologies for recycling electronic waste policies. With the adoption of policies like EPR, all the responsibilities forthe management of electronic waste has been shifted from the government bodies to the manufacturer and seller of the electronic devices.[16] In Japan, they follow Consumer Pay Model (CPM) which allows customers to bring their electronic devices to the retailer from whom it is being purchased, once that device becomes non-operational.[17] The strategies developed for electronic waste management should be closely linked with the availability of peripheral technologies, should be economical, and should not harm humans, animals, and the environment in any way. The sustainable approach along with the strategic intervention is very important in developing electronic waste management plans. The peripheral technologies like bio hydrometallurgy connected with the sustainable and economical approach. Bio hydrometallurgy is the best to restrict the entry of toxic and hazardous material into the environment. Electronic waste should be segregated from other waste efficiently so that it can be processed efficiently, but the present scenario is something different than this and needs to be changed to attain the sustainability goal. In a recent report by Forti *et al.,*[18] the authors reported that only 17.5% of electronic waste was taken and more than 80% of electronic waste was rejected, which clearly shows the improper functioning of the electronic waste management system.

A sustainable masterplan for the proper collection of electronic waste needs to be designed which can include sharing equal responsibility for collecting electronic waste among all the stakeholders. The mutual relationship among the manufacturer, consumer, waste collector, and recycler should be maintained and there have to be some regulatory agencies most probably government organizations who should be responsible for the supervision of this mutual connection. A large magnitude of electronic waste is generated in the urban areas, so the local bodies from these areas should come forward and plan a sustainable approach for the proper management of electronic waste right from collection till it is recycled. Sustainable movement of electronic waste can be accomplished through a proper channel from the cities up to the recycle stations just similar to the waste management by municipal corporations. The most important factor which will help in attaining a sustainable goal is a conversion of informal handling of waste to formal handling and treatment. There are many informal practices noticed in developing countries leading to improper transport and improper recycling of waste leading to serious health and environmental threats. A simple approach can be the collection of electronic waste at the collection centers which should be present in every locality. The collected electronic waste can be transferred from collecting centers to the manufacturer at the lowest price and then the manufacturer can use this electronic waste in the construction of useable goods, thus the concept of a circular economy will also be satisfied.

The electronic waste management system in developing countries is suffering badly or is developed poorly due to improper implementation of legislation. An awareness campaign needs to be undertaken by the government bodies to make people aware of the entire process of electronic waste management from the collection of electronic waste to recycling. The employees associated with the companies producing ICT devices should be trained in the handling of electronic waste, and short seminars or workshops in companies can be arranged to train skilled and unskilled employees in companies.[19] This will help in designing a proper pathway for the management of electronic waste without affecting human health and the environment.

Future Pathways

In the present era, almost everyone is using smartphones, android phones, televisions, refrigerators, air conditioners, coolers, laptops, computers, etc electronic gadgets, and it is expected that the demand for electronic devices will increase in the coming years. It is expected that by 2030, more electronic waste will be generated which will possibly provide a good business opportunity for recycling and recovering valuable components from electronic waste. As reported by Murthy *et al.*,[20] the electronic waste generated across the globe will cross 74 metric tons. It is accepted that from 2023 onwards only 70% of electronic waste will be collected and there are chances that the remaining 30% would go to the informal sector.[21] The attempts should be made to formalize the informal sector so that it will reduce the informal ways of electronic waste disposal and will reduce its negative impact on the environment. Policy makers and government organizations should come forward and should take strict action against the informal sector, but unfortunately, it is found that the informal sector works in coordination with the formal sector illegally.[21] The situation is very serious and is alarming the threats that it poses to the environment and human health. There are many challenges in the path of a proper framework for recycling of electronic waste, this includes unwillingness of customers to pay fees for the recycling of electronic waste, lack of awareness among the customers, continuous import of waste from developed countries to developing countries, non-proper organization of entire electronic waste recycling sector, informal sector, electronic waste recycler are not aware of the threats of electronic waste to the environment, lack of recycling infrastructure, lack of interest shown by the companies producing electronic device to promote take back strategy, failure in the implementation of legislations about proper recycling of electronic waste.[5,22] The increasing demand for the rare earth elements present in electronic waste could be a good opportunity for recycling and recovering these elements from electronic waste. In the future, the demand for rare earth elements will be the driving force for the recycling and recovery of economically important components from electronic waste.[23] The future opportunities in the area of electronic waste can be enhanced by

designing green approaches for recycling electronic waste, life-cycle analysis, positive responses from society, and good coordination between customers, employees, manufacturers, and government bodies.

Conclusion

The ICT sector has largely contributed to the economy of the nation. In many countries, there is a proper channel for the disposal of municipal waste but they failed/ignore to develop good strategies for recycling of electronic waste. The developed nations transfer their electronic waste to developing countries where it is recycled using crude methods posing harm to humans and the environment. Customers in developing nations are still unaware of the policies, rules, and regulations related to recycling electronic waste. The informal and illegal recycling of electronic waste is dominating in the developing nation which is an alarming situation. The ICT sector should step forward and involve customers, stakeholders, and international agencies in developing a green process for the recycling of electronic waste. The proper way of electronic waste management along with the sustainable development system will help to achieve the goal of sustainability in this area. Conversion of the informal sector involved in recycling electronic waste into small entrepreneurs will help inthe formalization of this sector and will also help in providing employment, helping inthe economic growth of the nation, protecting the environment, will maintain human health, and will develop a sustainable nation and society. The sustainable roadmap for the efficient processing of electronic waste will help in bridging the gap between the legal and illegal processing of electronic waste. To achieve many attempts have started across the globe, but there is a need for extensive research in this area most important to design a green and environmentally friendly process for the recycling of electronic waste economically and sustainably.

Conflict of Interest

The authors confirm that they have no conflicts of interest concerning the work described in this manuscript

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