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E-waste in Information and Communication Technology Sector: Existing scenario, management schemes and initiatives

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ABSTRACT

The expeditious developments in technology along with the demand for a high-standard living have resulted in massive production of electronic gadgets, which eventually lead to the generation of huge quantities of obsolescence. With the exponential expanding output of computer hardware, efficient disposal of the electronic waste (E-waste) generated by the Information and Communication Technology (ICT) sector has become a serious concern. The ICT sector generates a major amount of E-waste, but its management strategies are not well defined. The present study explored the current status, challenges, and initiatives faced by the ICT sector in handling E-waste. Thereby, a framework of use case diagram has been put forth to develop a web-based model for recycling companies for solving E-waste recycling issues. This review also described the management strategies adopted by various ICT and electronic companies that have faced the challenge to mitigate the problems associated with E-waste.

1. Introduction

Rapid technical advancement, economic development, urbanization, and rising demand for consumer electronics as well as a lower trends in pricing pattern are the major factors that have led to the huge generation of E-waste over the last two decades (Budd et al., 2020). According to the United Nation report, 2019, Global electrical and electronic waste (E-waste) generation reached 53.6 million metric tons (Mt) in 2019 and is projected to expand to 120 Mt annually by 2050 (World economic forum, 2019; Rautela et al., 2021). Recycling processes, such as hydro, pyro, and bio-metallurgy are employed to recycle and recover valuable materials from E-waste in developed countries, such as Germany, Belgium, and South Korea (Wang et al., 2013), whereas, some developed countries like Japan, U.S., and Europe have used entirely automated, cost-effective E-waste recycling technologies (Abalansa et al., 2021). To handle hazardous emissions while processing the E-waste, large safety facilities are required. As E-waste contains valuable, precious, and rare earth metals, therefore, it can boost the world economy (Vidyadhar and Das, 2013).

On-going COVID-19 pandemic has increased the demand for electronics, especially in ICT equipments in IT sector (Nayak et al., 2019). Due to global lockdown situation, the work-from-home concept was introduced by almost all

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the sectors, resulting in a huge rise in ICT products by providing computers, tablets, laptops, and smart phones to employees for productive output (Dutta and Goel, 2021). Therefore, the manufacturers, consumers, collectors, recyclers, and policymakers will face increased obstacles as well as opportunities in E-waste management.

In India, there are different kinds of E-waste generated which constitutes approximately 70% computer, 12% telecommunication, 8% electrical, 7% medical, and 3% other equipment's, including household E-scrap (Garg and Adhana, 2019; ASSOCHAM, 2018; Ahuja and Bhaskar, 2018). In developing countries, such as India, Nigeria, China, etc., the increase in the amount of E-waste generated by the IT sector leads to the difficulties in recycling and management (Ilankoon et al., 2018). According to the Lok Sabha report on 23rd September 2020, India has had a 43% growth in E-waste generation in the next three years (Borthakur, 2022). The ICT equipment composed of valuable, precious, and rare earth metals (Arya and Kumar, 2020b; Arduin et al., 2020). However, the problems or difficulties associated with the generation and handling of E-waste are of major concern (Meit, 2021).

E-waste recycling is one of the long-term solution to the massive volume of E-waste in the environment, both in developed and developing countries (Abalansa et al., 2021). However, the existing E-waste recycling treatments are mostly crude and unscientific in most of the developing countries like in India approximately 95% of E-waste is treated in the backyard without any expert personnel, equipment, technologies, and infrastructure (Arya et al., 2021). In such scenarios, the composition of hazardous metals becomes a matter of concern as an occupational health hazard and potential threats to the environment, such as cadmium (Cd), lead (Pb), mercury (Hg), hexavalent chromium (Cr), etc. (Rautela et al., 2021).

Based on the research gap found in the literatures, the research questions on which further studies can be carried out are: How to quantify the E-waste generated in the ICT sector?; How to manage the E-waste in the ICT sector?; What are the management schemes and initiatives formulated to mitigate the challenges of E-waste generated in ICT sector? Therefore to fulfil the research gap, the present study has been prepared.

The aim of this study was to provide an overview of E-waste generation and its management in ICT sector along with various challenges and opportunities related to sustainable E-waste management. A use case diagram has been developed and recommended for mitigating the E-waste issues faced by the IT industries. A use case diagram is the interaction between humans in different roles (operator, customer, E-waste collector, employee, and researcher) with the E-waste management processes. The diagram consists of the interaction between the system and its users.

2. E-waste in ICT sector

The ICT services depend on EEE products, which include toxic substances with a less life span and turns into electronic residue at their end of life. The sustainable ICT waste management is need of the hour to reduce adverse impact on environment as well as on human being. ICT product contains different types of metal that can be extracted by using proper techniques. The non-hazardous substances like glass, aluminium, rubber, etc. can be recovered using appropriate methods which are further utilized in industries for manufacturing products. The toxic substances, such as Hg, Pb, lithium, Cd, selenium, chromium, nickel, etc. need more precise method to get recovered. Some ICT products which contain hazardous substances are battery (Pb, Hg, Cd), CRTs (europium, yttrium, Pb), LCDs (indium tin oxide), gas discharge lamp (Hg), etc. (Khaliq et al., 2014; ITU, 2018) and their exposure into the environment leads to serious pollution problem including human and animals. Thus, to solve the issues related to E-waste, different methods can be followed which includes Take Back system/EPR, formal collection system, and recycling of E-waste. A flow diagram has been shown in Fig. 1 which provided the complete scenario of E-waste management and its effects, if handled improperly.

The salient E-waste management policies of different IT and electronic companies based on its high demand and popularity in the market have been presented in Table 1.

2.1. Quantification

Various methods are available for quantifying the E-waste generation rate for the evaluation of E-waste as provided in Table 2. The quantification methods can be classified into four groups (Wang et al., 2013). For estimating the E-waste generation rate, two types of material flow analysis (MFA) are present i.e., dynamic and static. There are two methods discussed for dynamic MFA: a stock-based model and a sales-stock-lifespan-based model. The stock-based model necessitates a sizeable consumer-based survey and the sales-stock-lifespan-based model requires sales of electronics products. A static analysis refereed as an E-waste estimation for a single year and fixed lifespan is considered. A report from United Nations University stated that in particular year use of average E-waste lifespan underestimates the E-waste generation (Islam and Huda, 2019).

2.2. Exploring new technologies

With the advent of a new concept i.e., micro-factory suggested by the Mechanical Engineer Laboratory (MEL), Japan, in 1990, there was a disruptive change in the manufacturing industry (Turaga et al., 2019). A micro-factory is a small-scale industry that can create small-scale products while conserving resources viz. space, time, energy, and materials. These small manufacturing factories achieve more output with less usage of resources (Claessen and Codourey, 2002). Micro factory is more focussed because it produces the component having less than 100 μm size or just slightly greater than

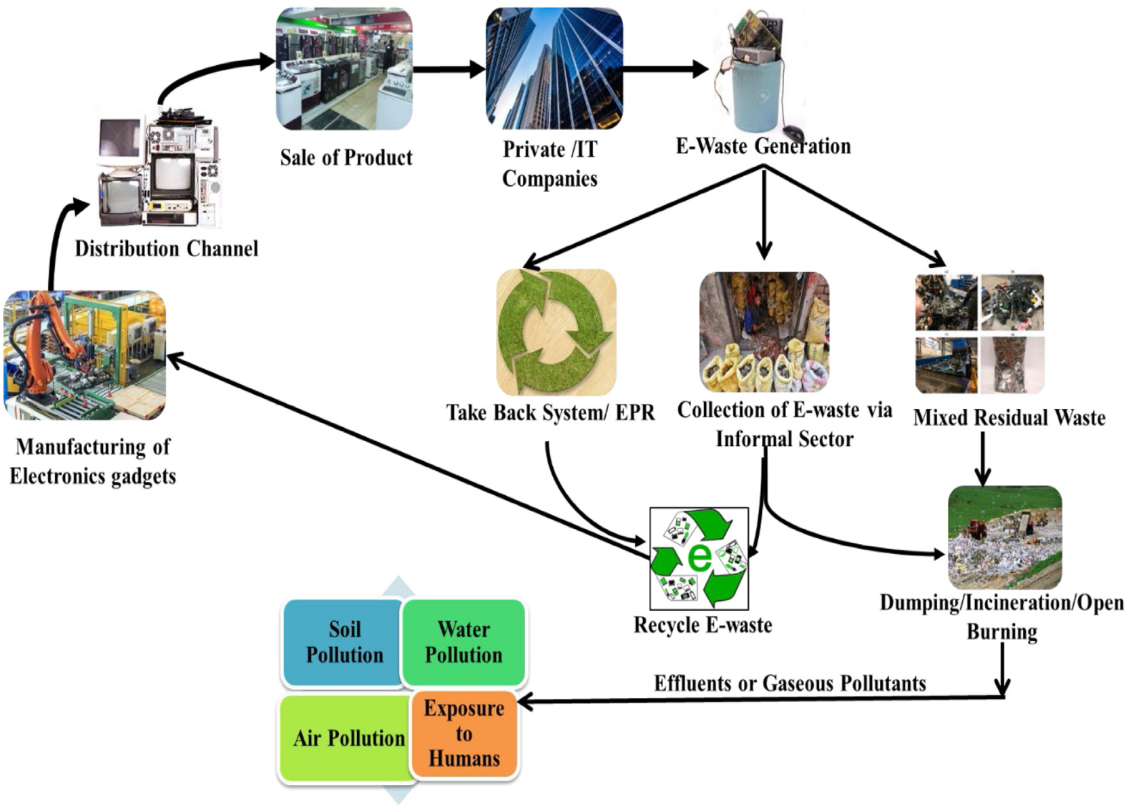

Fig. 1. Flow diagram of E-waste management in corporate sector.

human hair (Qin et al., 2008). Micro factories require full automation due to their small size, including quality inspection systems, automatic machine tools, material feed systems, assembly systems, waste elimination systems, etc. (Razali and Qin, 2013). A similar strategy may be used for trash processing, commencing with collecting, sorting, dismantling, recycling, and material recovery. At these specified locations, technological solutions would assure effective E-waste treatment while also being environmentally beneficial. Micro-factories must have access to the amount of material needed to maintain long-term economic viability. Managing the emission of greenhouse gas throughout the manufacturing process in such firms may necessitate a considerable expenditure, which may be difficult for small businesses to afford.

On the other hand, low logistic costs may assist in reducing the emissions mentioned above. Micro factories have the potential to create a lot of jobs, enhance people's lives, and recycle waste (UNSW, 2022). The initiative would undoubtedly aid the government in achieving the targeted SDGs, promoting a circular economy, and kicking off the resource efficiency discussion. As some waste is dangerous and requires specialized knowledge, all waste cannot be handled locally. To build a viable eco-system of a recycling business, Indian R&D organizations should develop technologies on an industrial scale for recycling plastics, PCBs, lithium-ion, and rare earth metal recovery accessible to entrepreneurs in the formal sector. However, managing processes that include technology necessitates a certain level of scale (Turaga et al., 2019).

2.3. Economic perspectives in ICT

To support and regulate the E-waste recycling enterprises in ICT sector towards circular economy, an efficient strategy and factors like technical aspects including economic, logistics, environmental, and sociocultural aspects are required to be taken into consideration (Van Yken et al., 2021). Capitalization on the economic values by turning waste into wealth can be done by concerted and strategic efforts by ICT sector. Several strategies are used to manage the E-waste to boost the economy in IT sector. The 5R's concept (reuse, reduce, recovery, refurbish, and recycle) was implemented to reduce the waste and improve the recycling activities.

2.4. Role of PRO in ICT

Unfortunately, for many manufacturers, the sole criterion for choosing a Producer Responsibility Organization (PRO) is the recycling fee per kilogramme of E-waste accumulated and recycled, which prevents PROs from pursuing deep-rooted

Table 1
Salient E-waste management policies of different IT companies.

Sl. No.	Companies involved	Ranking	Country of origin	Products & Services offered	Salient features	E-waste management policy	References
1.	TCS	3rd most-valued IT services brand globally	Mumbai, Maharashtra, India	TCS provides a comprehensive portfolio of business, technology, and engineering services and solutions. This is accomplished through its unique Location Independent Agile ™ delivery approach, which has been regarded as a gold standard in software development.	TCS' internal IT team has the mandate of EPR and also has a transparent process to identify and work with recyclers. They even have a bidding process; Destruction certificates are obtained from vendors on data and are maintained at locations	Take back/buy-back policy	TCS (2016)
2.	Infosys	3rd ranking on the Forbes list of The World's Best Regarded Companies for 2019	Pune, Maharashtra, India	Companies in the finance, insurance, manufacturing, and other industries turn on Infosys for software development, maintenance, and independent validation. Finacle, a universal banking system with many modules for retail and corporate banking, is one of its most well-known solutions.	E-waste is disposed only through KSPCB/CPCB authorized vendors. To collect the E-waste generated, bins with grey colour code is placed at prominent locations. The employees and contractual staff can put the E-waste into this bins, which prevent E-waste mixing with commercial waste.	E-Parisara Pvt. Ltd.	Infosys (2021)
3.	LG	25th rank of the 2018 Reputation Quotient Rankings	Yeonji-dong, Busan, South Korea	Offer products, such as home appliance, vehicle, business solutions, commercial display solutions, solar solutions, energy storage systems (ESS) and energy management solutions (EMS)	LG Electronics India provides an E-waste take-back service for old LG Products in compliance with the EPR (Extended Producer Responsibility). Upon request by a customer to our centralized call centre no., they will call back & schedule a visit for collecting E-waste products from the designated venue.	Committed to reuse or recycle an equivalent product for every product a customer buys.	LG (2021)
4.	DXC	Ranked 224 out of 750 companies – the top third – represented on the World's Best Employers survey	Ashburn, Virginia, US	Analytics and engineering, applications, cloud, consulting, insurance BPaaS and BPO, modern workplace, security, and insurance goods are just a few of the items available.	Refurbishing equipment to lengthen its life by up to three years. After reconditioning, the devices are repackaged and placed into 'customer-owned' stock for call-off as needed, or they are sold on popular auction websites or through IT brokers, or they are donated to charity. They however ensure that IT equipment is reused for a second life.	Take back and applies 3R's for their products	DXC (2020)

(*continued on next page*)

and long-term systemic reform initiatives. The fee of recycling is determined by a number of elements, including the cost of procurement through various channels, the cost of channel creation, logistical expenses, ecosystem development costs, and recycling returns, which may be positive or negative but not limited to these. The expenses of collection and treatment are different for each of these products. E-waste offers a lot of re-use potential in terms of functionality both

Table 1 (*continued*).

Sl. No.	Companies involved	Ranking	Country of origin	Products & Services offered	Salient features	E-waste management policy	References
5.	Cognizant	Ranked 193 on the Fortune 500	Teaneck, New Jersey, US	Provides digital solutions to advance your business, application services & Modernization, Digital Strategy. Enterprise Application Services, Enterprise Services, Industry Quality Engineering & Assurance, Intelligent Process Automation, Infrastructure Services, Security.	CTS will provide reputable service providers, who possess all required licenses and approval for the recycling and disposal of E-waste.	Have bonded with CTS (Corporation and its Subsidiaries), It applies to employees responsible for management of E-waste at all CTS locations.	Cognizant (2021)
6.	Xiaomi	Xiaomi ranked 4th in top 50 Global Brand List in China	Yingu Building, Beijing, China	Xiaomi produces and markets smartphones and other gadgets as well as internet services and perhaps other electronic products.	Under take back — the company credits a 1.32 USD (100 INR) discount coupon on customer's Mi account. Under karo-sambhav, the company has set up a total number of 1150 recycling units all over India. They collected 400 tons of E-waste in past three years.	Take back and Karo sambhav	Xiaomi Sustainability Report (2021)
7.	Amazon	Forbes ranked Amazon 2nd on its newly released World's Best Employers 2020 list	Bellevue, Washington, United States	Compute, storage, databases, analytics, networking, mobile, developer tools, management tools, IoT, security, and corporate applications are among the services offered by Amazon Web Services. (Books, DVDs, music CDs, videotapes, and software), clothes, baby products, consumer electronics, cosmetic products, gourmet cuisine, consumables, health and personal-care items, and a wide range of other products are among the product lines available.	They are minimizing waste, increasing recycling, and providing options for customers to reuse, repair, and recycle their products sending less material to the landfill and more back into the circular economy loop.	Reuse, repair, and recycle their products.	Amazon (2021)

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at the level of the product and the component (from detachable assemblies and modules). As a result of multiple features present, it stands to reason to categorize E-waste using both individual attributes and the characteristics as a whole.

The addition of PROs, on the other hand, introduces some formal working systems as well as a discussion about responsibility, confronting a number of problems, and commitments. The responsibility of PROs must build deep-rooted ecosystems and make considerable expenditures in order to enable collection and implement systems that provide full transparency and traceability and across the value chain. As a result, if manufacturers place an excess of emphasis on collection/recycling fees as a factor for selecting a PRO, significant and dangerous waste materials may not be collected by any stretch of the imagination. There are currently no methods, criteria, or frameworks that producers might utilize to select PRO (Singhal, 2020).

3. Challenges associated with effective ICT management

Efficient and effective E-waste recycling technologies may necessitate substantial capital investments that may not be necessary for private companies in the absence of clarity about E-waste procurement. In the developing countries, the

Table 1 (*continued*).

Sl. No.	Companies involved	Ranking	Country of origin	Products & Services offered	Salient features	E-waste management policy	References
8.	Dell	Dell is presently ranking 4th in the list of the technology Fortune 500 companies.	Austin, Texas, United States	Dell offers PCs, servers, data storage devices, network switches, software, computer peripherals, HDTVs, cameras, printers, and other equipment made by other companies.	Dell has used plastic recycled from outdated machines to create new components over the course of a decade. In more than 75 countries and territories, they provide free end-of-life management directly to consumers. They have set up E-waste drop-off points in around 23 locations in India.	They are using plastic recycled from outdated machines to create new components over the course of a decade. There are also expectations to reuse or recycle an equal product for any product a consumer purchases by 2030.	Coca (2019)
9.	Panasonic	Panasonic ranked 10th in The Forbes Global 2000 List	Osaka, Osaka, Japan	Services offered are included Education, Energy & Utilities. Entertainment, Media & Sports, Food Service & Food Retail and the products offered are home entertainment, beauty care, cameras accessories, and home appliances.	Objective is to reach out to the communities with a variety of programmes aimed at engaging youth and raising consciousness about environmental concerns, including E-waste.	Recently engaged Residential Welfare Association (RWAs) and students from over 200 schools as part of its 'Harit Umang' campaign to promote responsible E-waste and plastic waste disposal.	Panasonic (2019)
10.	HCL	Ranked 30th as the only multinational company that is headquartered in India to be featured in the top 50	Noida, Uttar Pradesh, India	HCL provides experience-centric digital services and outcome-driven integrated offerings of Digital & Analytics, IoT works, Cloud Native Services, Cyber Security & GRC Services.	E-waste Policy aims at providing efficient and easy product recovery options to its consumers to facilitate responsible product retirement of all its manufactured EEE products.	Govt. Authorized Recyclers since 2010 and filing the returns regularly with the Pollution Control Boards.	HCL (2020)
12.	Wipro	Ranked 11th	Bangalore, Karnataka, India	Products offered are Personal care Health care Lighting Furniture and services, Information technology Consulting, Outsourcing.	Focusing to put effort for their customers, which will enable disposal of E-waste in an appropriate and environment friendly way. The service covers all areas of E-waste collections, monitoring, recycling and compliance with applicable pollution control legislation.	Take back and safe processing.	Krishnadas and Pillai (2013)

construction and operation of formal E-waste recycling facilities require high capital and maintenance costs which pose a major economic constraint. As a result, the informal sector is more active in collecting and handling of E-waste throughout the world. The workers involved in the informal sector include men, women, and children and they performed crude recycling activities without appropriate safety facilities and were highly exposed to dangerous and unhealthy conditions (Dutta and Goel, 2021). At present, there is a massive gap between recycling and collection facilities and the quantum

Table 2
Various quantification methods for estimation of E-waste generation.

Sl. No.	Method	Description	Products	Reference
1.	Input–Output Analysis	It is the most commonly used analysis with numerous variations in models, which can aid in estimating the generation rate of E-waste in different regions and countries. The sources, routes, and disposal facilities can be quantified in this analysis.	E-waste	Towa et al. (2020) and Parajuly et al. (2017)
2.	Time Series Analysis (projections)	In this analysis, the generation trend of E-waste can be predicted. This prediction is done by collecting data from past records and extrapolating them in the future. This analysis also helps in filling the gaps in the dataset of unknown years from the present dataset.	E-waste	Habuer et al. (2014) and Navarro-Esbrı et al. (2002)
3.	Factor Models (using determinant factors for correlation)	For this analysis, data regarding E-waste are collected from the collection networks, treatment facilities, and disposal locations. Estimating the total E-waste generation rate requires research data obtained from parallel disposal streams	E-waste	Agrawal et al. (2018)
4.	Disposal Related Analysis	For this analysis, data regarding E-waste are collected from the collection networks, treatment facilities, and disposal locations. Estimating the total E-waste generation rate requires research data obtained from parallel disposal streams	E-waste	Agrawal et al. (2018)
5.	Secondary Data Analysis And framework Development	It helps to assess the usefulness of E-waste policy	–	Morris and Metternicht (2016)
6.	Field Research	Contamination of soil near formal E-waste recycling site	E-waste	McGrath et al. (2018)
7.	Secondary Data Analysis and Model Development Field research	Per capita estimation of E-waste Generation and quantification of metal value Collection of waste mobile Phone through social Marketing initiative	All products available under UNU in the UN COMTRADE* Mobile phones	Golev et al. (2016) and Lodhia et al. (2017)

of E-waste which requires a bridge to facilitate the E-waste management process sustainably. Some of the challenges associated with effective ICT management are discussed in this section.

3.1. Poor E-waste collection rate

In the last few decades, numerous developments were achieved in E-waste recycling. Still, the primary problem for E-waste management is the lack of a proper collection system (Arya and Kumar, 2020a). Moreover, the lack of knowledge and expenses of returning the E-waste to formal sectors are responsible for reducing the interest of consumers and companies to return their E-waste to the formal sector (Parajuly et al., 2020). The informal sectors provide an easier mode of recycling through which consumers sell their E-waste to scrap dealers or shops directly. A large population is dependent on the informal sector for their livelihood.

Table 3
Life span and mass of various E-waste generated in the ICT sector.

E-waste	Life span (years)	Mass (kg)	References
Computer	3	25	Premalatha et al. (2014) and Herat and Agamuthu (2012)
Laptop	4	5	Bisoyi and Das (2018)
Mobile phone	2	0.1	Premalatha et al. (2014) and Herat and Agamuthu (2012)
Telephone	5	1	Premalatha et al. (2014)
Air conditioner	10	40	Karkour et al. (2021)
Photocopier	8	60	Premalatha et al. (2014)
Refrigerator	10	58.4	Lewandowska et al. (2021)
Television	10	30	Premalatha et al. (2014) and Herat and Agamuthu (2012)
Microwave	7	15	Premalatha et al. (2014)
Printer	4	–	Bisoyi and Das (2018)
Videorecorder & DVD player	5	5	Premalatha et al. (2014)

3.2. Short lifespan, complexity, and design

The increasing demand for more efficient and cheaper electronic products has resulted in shorter life spans and these products are discarded in the waste stream before their end-of-life. The life span of the E-waste along with their respective mass (kg) which gets discarded from the ICT sector has been presented in Table 3.

E-wastes comprise a complex mixture of metals, plastics, glass, and ceramics. It contains precious metals (Au, Ag, Pd, and Pt), hazardous metals (Pb, Cd, Cr, Hg, As, Ni, Cu, Co, and Li), non-hazardous materials (Fe and steel) as well as rare earth metals (Nd, Ta, Pr, and In) (Dutta et al., 2018). E-wastes also contain organic and inorganic chemicals (Polycyclic aromatic hydrocarbon). More than 100 metals and materials are present in E-wastes (Garlapati, 2016). Eco-friendly and sustainable processes are yet to be developed, as E-waste has a complex structure of polymer, metals, non-metals, etc. (Hsu et al., 2019). Electronic products constitute 20.6% plastics, 47.9%. iron and steel, and 12.7% non-ferrous of which 7% Cu by weight (ETC/RWM, 2003; Bandyopadhyay, 2008).

3.3. Malpractices within the E-waste sector

As reported in Global E-waste Monitor, 2020, a major portion i.e., 82.6% of the total E-waste generated is usually collected and managed by the informal sector in the middle- and low-income countries (Rautela et al., 2021; Forti et al., 2020). Different types of malpractices occur in formal and informal sectors. In developing countries, most of the E-waste generated is either transported to other countries through illegal channels or dumped to landfill sites (Xavier et al., 2021; Ilankoon et al., 2018). Regarding the role of producers, there is presently no process to assess whether the data shared by the producer for approving the EPR plan are accurate. This practice leads to the mutilation of sales data and finally misinterpreted the actual collection target (Turaga et al., 2019).

3.4. Consumer behaviour

Consumers in larger groups or institutions are often ignorant of their legal responsibilities regarding E-waste management. Different departments of government are reluctant to provide PROs access since the idea of PROs is not widely accepted. For example, a stage like Metal Scrap Trading Corporation (MSTC), utilized by most governmental foundations to sell scrap material, including E-waste, does not presently enable PROs to use it (Karnasuta and Lao-Anantana, 2021). Experts are presently recognized by the CPCB, which awards approvals as a seal of endorsement. It has not, however, been relayed to the MSTC. Businesses, banks, and educational organizations, other large consumers have unrealistic expectations for monetary benefits from ethical E-waste recycling (Turaga et al., 2019). In India, household customer is not driven enough to drop off E-waste at collection areas for free without getting any incentives. Despite extensive awareness and engagement programs, responsible PROs cannot collect E-waste from people (Manhart et al., 2011).

Studies tracked down that worldwide EEE monsters Microsoft, Apple, Sony, Panasonic, Philips, PCS Technology, Sharp, Sony Ericsson, and Toshiba had no take-back administrations working in India. Many organizations showed take-bake administrations, including Hewlett–Packard (HP), Dell, LG Electronics, Acer, Lenovo, Motorola, HCL, Nokia, Samsung, WIPRO, and Zenith (AIP Conference, 2010). These companies provide working support to collect or recycle E-waste from consumer or clients through huge metropolitan networks whereas, these brands do not have essential facilities to train their clients E-waste management and not many had put resources into preparing their staff for reclaim and recycling administrations.

It was tracked down that 59% of respondents had some information about the wellbeing and natural effects of E-waste and that 65% considered ecological components when buying gadgets for family use. Sadly, not very many respondents appeared to put this information to its full use, as just 2%–3% was associated with recycling E-waste (Shah and London, 2014). Awareness among the public should be increased through social media, campaigns, and education regarding E-waste (Islam et al., 2021). Thus, there seemed, by all accounts, to be an absence of mindfulness from the base (overall public), an absence of exertion from the top government controllers, and carelessness in the centre (from makers).

4. International WEEE management schemes and initiatives

4.1. Basel convention

This convention was introduced to reduce the impacts of crude recycling, strengthen take-back systems, promote sustainable management methods, and prohibit the illegal transboundary movement (Kuehr, 2012). The Basel Convention has established two E-waste initiatives:

• Partnership for Action on Computing Equipment (PACE), which unites governments, industry, academic organizations, and common society; PACE has created numerous sets of technical recommendations for computer equipment repair, recovery, refurbishment and recycling, just as criteria for labelling refurbished equipment and certifying environmentally solid repair, reconditioning, and recycling facilities (UNEP, 2011). PACE was launched at the 10th meeting of the Parties to the Basel Convention Conference, held in Bali, Indonesia, from 23 to 27 June 2008 (Bergesen et al., 2019). It serves as a stage for governments, non-governmental associations, academia, and industry leaders to discuss ecologically appropriate management, restoration, recycling, and removal of end-of-life IT equipment as a multi-stakeholder coordinated effort. PACE strives to improve the ecologically solid management of such equipment by including social responsibility and the idea of sustainable development, just as fostering data sharing on the life cycle concept. This permits it to take a comprehensive way to deal with EEE and WEEE. New partners with specific knowledge, manufacturers, refurbishing or recycling firms, academic foundations, environmental gatherings, international associations, and governments, in general, are primarily welcome to join PACE. Its distinctive characteristic is that it encourages creative management techniques, for example, extending equipment life cycles, boosting maintenance and overhaul, supporting the area principle, encouraging ultimate open removal, and debilitating transportation to developing countries. These technical recommendations are useful and should be considered as supporting resources for the different worldwide E-waste management projects.

• Mobile Phones Partnership Initiative (MPPI) was introduced in 2002 at the Conference of Parties to the Basel Convention's 6th meeting to develop and promote sustainable waste mobile phones management, which expects to cover the ICT sector in collaboration with the Basel Convention and other stakeholders (Torres et al., 2016). Mobile phone companies, such as Philips, Nokia, Europe, NEC (Nippon Electric Company), Motorola, Mitsubishi, Panasonic, and LG signed a declaration to promote the good collection and recycling options, creation of the public–private partnership, promote reuse, repair, and refurbishment of used mobile phones, and awareness towards the design and complexity of mobile phones (step Initiative, 2010).

The MPPI Work Programme's main goal, which included numerous stakeholders and partners, was to support the convention's objectives in an environment friendly management of waste mobile phones. The MPPI Work Programme was created to the following (UNEP, 2008):

- Improve the stewardship of products;
- Persuade customers to take more ecologically beneficial actions;
- Promote the best solutions for refurbishing, recycling, and disposal;
- Activate political and institutional support for environmental stewardship;
- As a result of this project, a new public–private partnership for the environmental friendly management of hazardous and other waste streams has been formed.

4.2. StEP initiative to solve E-waste problem

StEP was launched worldwide in 2007 to provide knowledge, reasoning, advancement, awareness, and development in the management of electronic waste reuse, recovery, recycling, and prevention (step Initiative, 2010). To ensure the reception of good practices in the direction of waste from the ICT business, the International Telecommunication Union (ITU) offers technical guidelines, environmental principles, and recommendations.

4.3. Extended producer responsibility

The extended producer responsibility (EPR) method was used to create more effective E-waste management in 2012 which was further amended in 2016. The country's overall E-waste management system has had a limited impact after seven years of implementation (E-waste Rules, 2016). On the positive side, the laws may have resulted in the development of legally registered hundreds of new recycling and dismantling facilities. The establishment of collection rate objectives for electronic product manufacturers appears to have increased companies' commitment to complying with the laws as enumerated in 2016.

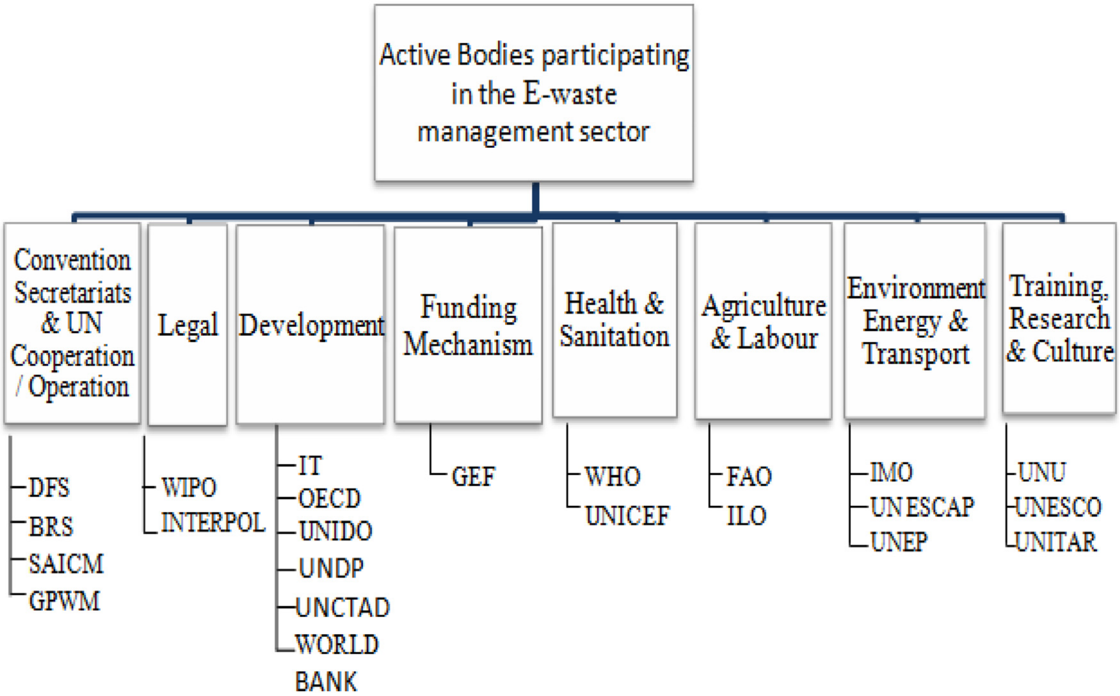

Fig. 2. Active bodies participating in the E-waste management sector (Balde et al., 2017).

The EPR is a strategic environmental approach that supports all-out life cycle ecological improvements of product systems by extending the manufacturer's responsibilities to different parts of the product life cycle, particularly take-back, recovery, and the item's final removal (Lindhqvist, 2000). Each country's law provides a legal framework in an EPR system and assigns responsibilities for sorting out and processing WEEE to producers, manufacturers, assemblers, or importers (Patil and Ramakrishna, 2020). In most cases, this results in firms or affiliations in which producers contribute to a shared asset that covers collecting and removal costs.

The following principles are the three cornerstones of EPR:

- Polluter pays;
- Pollution prevention;
- Considering the life cycle;

EPR is an environmental arrangement approach based on the premise that a manufacturer's extended responsibilities are not limited to the final stage of the item life cycle but also include other steps in the process where traditional responsibilities are insufficient to ensure optimal environmental protection (Manomaivibool et al., 2007). It provides a viable substitute to the assessment-based and a free market-based systems. Producers pay a duty to the stakeholders under the assessment-based plan. The stakeholders are responsible for organizing the collection and final disposal systems through businesses with the necessary environmental certification. These businesses are compensated for their services through the assets created by the assessment collected. Legislation in a free market-based system (free regulatory system) specifies objectives to be met but does not identify who is responsible for the process. In these systems, small groups of collectors buy old technology from customers and sell it to others, who disassemble and segregate the different parts of the E-waste. These segregated parts are sold to the recyclers for recovering plastics, metals, and other components.

4.4. UN and related entities active in E-waste management

The diagram in Fig. 2 summarizes the participating organizations and functional entities/bodies involved in the E-waste management sector. Depending on the intensity of the analysis process and subsequent survey responses, organizations were grouped into broad thematic categories as outlined in Fig. 2.

The categories and sub-categories show the main thematic fields where these organizations are involved and where their initiatives are most likely to interact with E-waste. A significant number of programs will likely deal with more than one of the thematic areas due to the complex existence of responsibilities and mandates of agencies. Each entity undertake aspects of E-waste programs that may deal with areas which involve hygiene and sanitation, including legal aspects, agriculture and labour, etc. (Balde et al., 2017).

Fig. 3 presents the various international parties that are actively included in E-waste management and a corresponding number of initiatives taken by the respective class of the bodies.

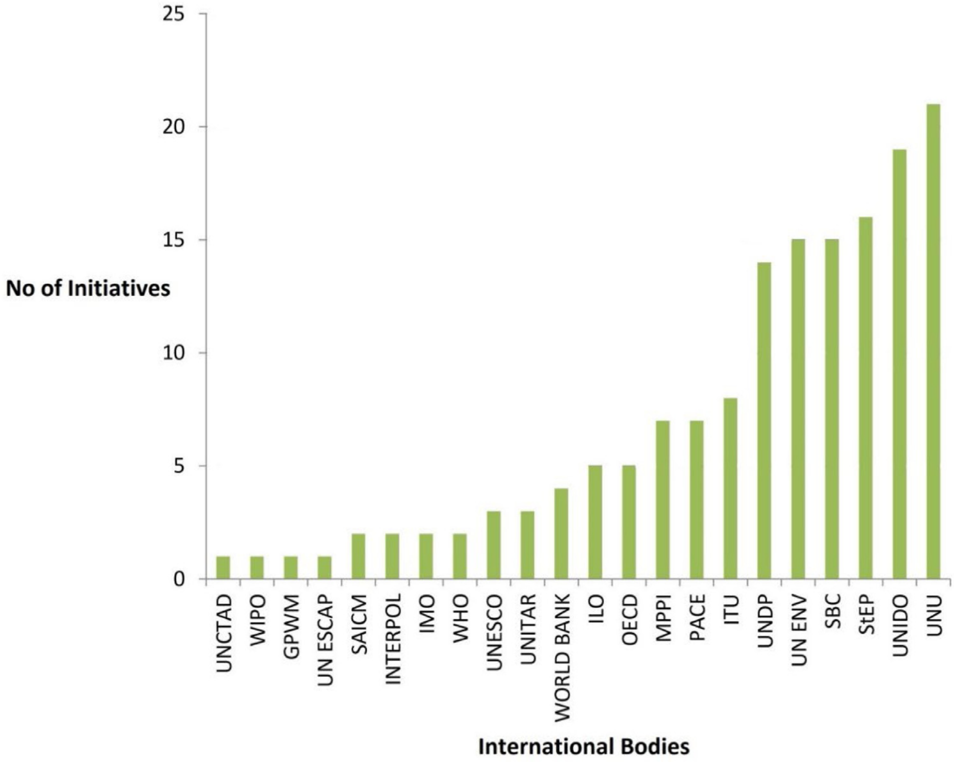

Fig. 3. International entities in E-waste management sector and a number of initiatives (Balde et al., 2017).

4.5. Initiatives stepped up by IT and electronic industries

Companies would require robust cooperation from all stakeholders in the supply chain to regulate the performances of E-waste management activities in order to achieve the desired goals. Various on-going awareness campaigns will help to create a sustainable environment for the management of E-waste (Adanu et al., 2020). Several smartphone companies like Panasonic and Xiaomi organized varieties of programmes to engage the society to create awareness and raising knowledge about E-waste and its consequences to the environment (Xiaomi Sustainability Report, 2021). A "HaritUmang" campaign organized by Panasonic company engaged over 200 school students and residential welfare associations (RWAs) to spread the knowledge towards the disposal of E-waste as well as plastic waste (Chaman, 2019).

Xiaomi has launched a Product Take Back & Recycling Program, which credits a customer's Mi account with an Rs.100 discount voucher in exchange of any old electronic product. In addition, the organization has partnered with KaroSambhav to provide over 1150 E-waste collection points for old computers and other electronic devices at all Xiaomi Mi Homes and Mi Authorized Service Centres in over 500 cities (Bureau, 2019). Xiaomi announced that it had met its E-waste collection goal for financial year 18–19 in the Indian industry. It has produced over 400 tons of E-waste in the last three years, and they recognize the unique ability of our end-of-life goods to promote responsible E-waste management, and want others to join unified E-waste campaign.

Apple confirmed in 2017 that it had purposefully slowed down some iPhone versions as they became older. LG has developed a pan-India network of 40 recyclers that have collected and recycled nearly 100 kilo MT of E-waste between 2017 and 2020 (Sandra, 2021). In addition while implementing swap programmes, the organization has aligned its call centres to register take-back orders. Dell has used plastic recycled from outdated machines to create new components over the course of a decade. In more than 75 countries and territories, they provide free end-of-life management directly to the consumers. They have set up E-waste drop-off points in 23 locations around India. Dell expects to reuse or recycle an equal product for any product a consumer purchase by 2030 (Dell Technologies, 2021). Microsoft contends the expense of collecting and recycling of end-of-life products and the manufacturer should be responsible for its management. However, the firm makes no clear proposal to achieve this goal.

Apart from electronic firms, retailers like Croma and Flipkart have also entered the competition. EPR authorization for E-waste has been received by Flipkart in February 2019 and for the financial year 2018–19, the collection deadline has been met (The times of India, 2019). As per regulation, Croma has taken a number of measures, including e-care zones in the shops where consumers can dispose off their E-waste and with other electronic associations encouraged

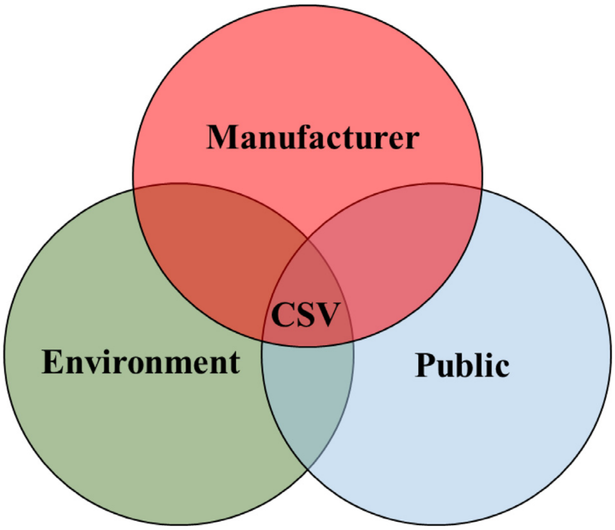

Fig. 4. Creation of shared value among manufacturers, public, and the environment.

people about E-waste and its management programs (Verve, 2020). An E-waste management practice in TCS is looking for use of second-hand products, separation, and recycling at the source. The hazardous waste is regulated with the help of government as per regulatory acts. The main key method for this strategy is to engage employees and increase their responsibility towards E-waste.

5. Shared value creation: Empowering opportunity towards innovation

Implementation of policies in E-waste value chain can be an important part at every stage of product lifecycle and its associated stakeholders. If proper rewards can be paid to the workers involved in informal sector or scrap dealer then it would help to generate circular economy (Gall et al., 2020). Identification of the dismantler chain in informal sector and conversion of it into the supplier section of formal sector would help the manufacturers, public, and the environment resulting in creation of shared value (CSV) (Fig. 4)

By regulating small entrepreneurs into the informal sector, the value-added proposal seeks to redefine CSV validation, thus protecting the environment while still maintaining its original value. Proper and scientific recycling and metal extraction processes help to recover the rare elements, but improper recycling processes lead to the loss of valuable elements. Shift towards circular economy is difficult without the change in consumer behaviours. The consumer should change their thinking towards purchasing green products, adapting innovative business models, and accepting upgradation of products by repairing and refurbishing processes (Planing, 2015). This involves the extrinsic attributes, such as incentives and infrastructure; and intrinsic attributes viz. values and personal ethics of human behaviour (Parajuly et al., 2020). One such innovation institutionalized in 1994 was Ricoh's Comet Circle, which implemented resource recirculation strategy in E-waste management process, thus, enhancing the efficiency of E-waste reverse channelization (Turaga et al., 2019).

6. Future challenges and opportunities in ICT sector

With a steady stockpile of smartphones, workstations, refrigerators, and other gadgets, the prevalence of consumer electronics and home appliances is expected to continue in the coming years. By 2030, more PCs are expected to be dumped in the developing countries, which will create more opportunity to make business in recycling and recovery of value-added products from E-waste. It is predicted that the rate of E-waste generation will exceed 74 Mt globally by 2030 (Murthy and Ramakrishna, 2022). As reported by Davis and Garb (2015), though 70% of the E-waste should be collected from 2023 onwards, yet 30% would directly get transported to the informal sector. The formalization of the sector has been encouraged by policy makers, however, their attention must also be drawn to the contribution and role of the informal sector. For instance, the constructive potentials of the E-waste informal sector have been reported along with its relationship to formal policies and actors (Davis and Garb, 2015). Considering the enormous volumes of E-waste as yet being brought into such countries, both formally and illegally, the situation is quite alarming, representing various health and environmental risks (Borthakur, 2022).

There are several challenges regarding the policies and management strategies of E-waste, which have been described in the present paper. These challenges include the reluctance of consumers to pay the recycling fee for the waste electronic items; non-cooperation and unorganized; significant amount of E-waste imported as second hand devices; absence of awareness among consumers; absence of awareness of the possible risks of E-waste among collectors and recyclers; absence of assets and investment to improve finance in E-waste recycling facilities; absence of recycling infrastructure or inappropriate management of E-waste; absence of efficient take-back programs; absence of interest by companies or incentives for management of E-waste; and failure of implementation of E-waste-specific legislation (Nivedha and Sutha, 2020; Borthakur, 2022; Murthy and Ramakrishna, 2022). There are, nevertheless, several opportunities connected with E-waste management system. The rising demand for rare earth elements present in electronic products might enhance E-waste recycling and metal recovery processes in the future (Van Yken et al., 2021). Green design, innovative recycling processes, life-cycle analysis, and social approach provide further alternatives for opportunities in the field of E-waste management (Borthakur, 2022).

7. Recommendations

In view of the present study, some recommendations can be made to accelerate the process of solving E-waste issues in a sustainable manner.

• Use case diagram: The illustration provided is a model of a use case diagram (Fig. 5) Recycling firms may utilize this graphic to create a web-based system for efficiently running their operations on handling large quantity of E-wastes with the required adjustments based on their business activities, which might be beneficial to the long-term growth of information technology. Such platform that allows recyclers to simply customize their functions is highly required.

The objective of system/actor (user) interaction is represented using a use-case diagram. It defines one primary flow of event (principal scenario) as well as possible alternate flows (alternatives), known as user scenarios/paths. As far as the use case diagram is concerned, this framework has two separate sorts of actors (one on the right side called primary actor and the others on the left called secondary). Primary actors are the one who initiates a use case and are thus fairly self-contained. On the other hand, secondary actors are used by the system but do not engage with it on their own and is therefore do not initiate any use-case under the system boundary. Similarly in Fig. 5, operator being in one side plays a role of primary actor from where the flow of operation begins, an entity who requests that the system provide one of its operations. Such functionalities are described in a system boundary that defines the scope of what exactly the system will be, and the actors on another side of framework are defined as supporting actors. Any entity performing a role in one given system or in another terms, getting involved in the system, can be an individual, organization or any other external system represented by customer, E-waste collector, employee and researcher. Entirely, their interactions make a well-developed design by using some set of specialized symbols and connections through which a high-level system can be developed. Furthermore, the lines that are connecting number of use-cases together basically shows relationship between them and has a different categories of it. In this framework three various relations i.e., includes, extends and association are presented. In precise, the line labelled with <extends> signifies that one use-case is a variation of other and it could be even optional, <includes> indicates a dependency on another use-case such as collecting money from buyers in the above framework is depending on billing and invoicing step and an actor's association indicates the link/interaction between two entities. All of the ancestor's use cases are passed on to the descendant. One or more use cases relevant to that position exist in the descendent. By putting this layout of use-case one developer or web designer can easily opt making a web-based E-waste management system.

- The second-hand EEEs should be labelled differently from that of the end of life EEE. This would separate them easily for processing further.
- Creating a bridge between the formal and informal sector would nullify the problem of E-waste collection and its transference to the formal recycling sector.
- Government should introduce incentives for scrap dealers, reward and attractive schemes for better performance for E-waste management.

8. Conclusion

The ICT sector contributes to the economic growth of the country in terms of generation of employment, GDP increase, and earnings from foreign exchange. E-waste management is a huge challenge and provides risk to the techno-enabled world. To combat the E-waste issues, the ICT sectors have formulated several corporate policies and stakeholder management strategies. From the present study, it can be concluded that the ICT sector should involve stakeholders for the development of a well-managed E-waste management system. In this study, a use case diagram was developed and suggested for proper management of E-waste by creating an efficient system and elaborate measures adopted by a number of the world's leading IT companies. Development of a comprehensive strategy for E-waste management involves complexity as it considers technical aspects including economy, environment, and socio-cultural features. However, with the concerted and strategic efforts, an elusive economic values can be capitalized by transforming E-waste into wealth. To conclude, it is presently clear that different initiatives have been started worldwide to solve the problem of E-waste. In particular, more research work should be undertaken to explore innovative approaches to deal with E-waste to make it more eco-friendly, persistent, and sustainable.

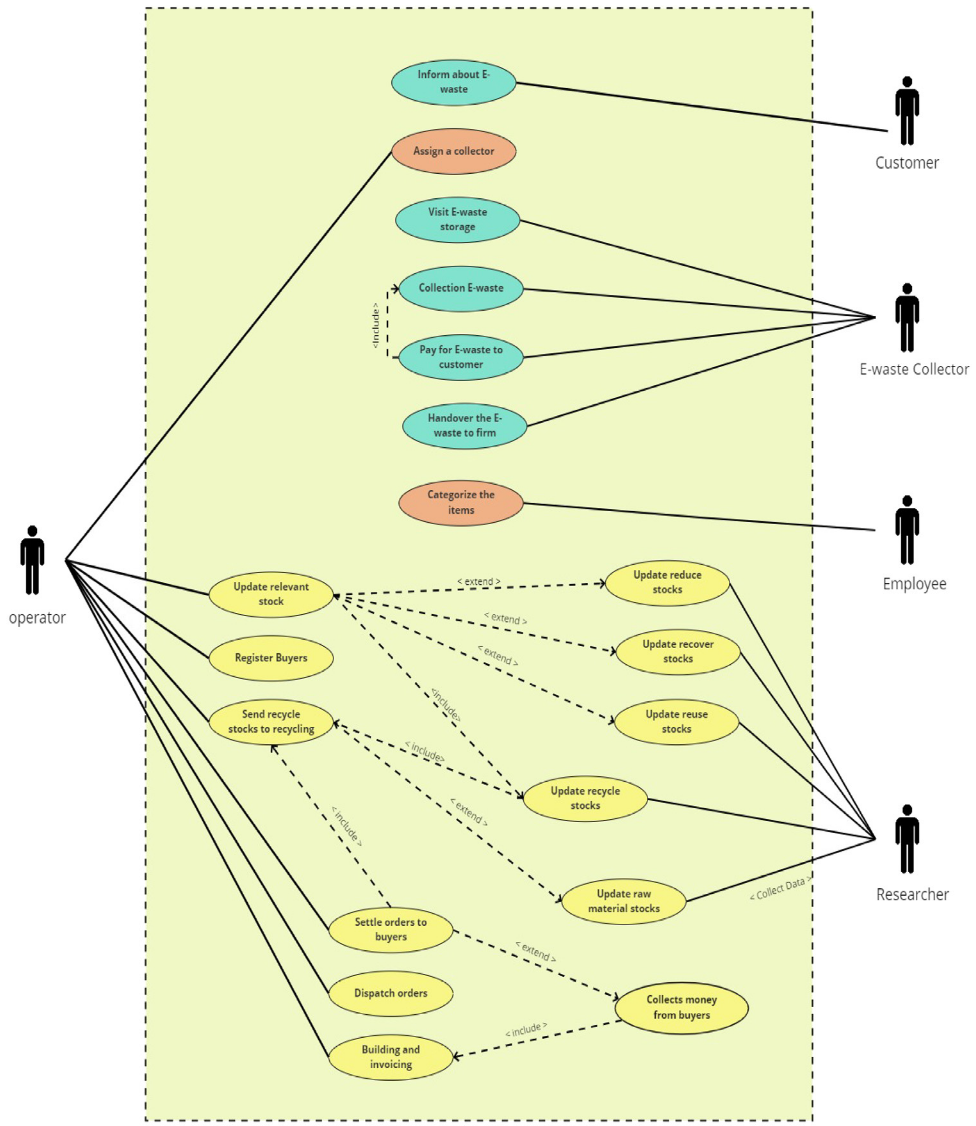

Fig. 5. Use case diagram for solving E-waste recycling issues.

CRediT authorship contribution statement

Shilpa Vishwakarma: Conceptualization, Methodology, Investigation, Writing – original draft. **Vimal Kumar:** Formal analysis, Writing – original draft. **Shashi Arya:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. **Mamta Tembhare:** Formal analysis, Writing – original draft. **Rahul:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. **Deblina Dutta:** Conceptualization, Investigation, Formal analysis, Writing – original draft. **Sunil Kumar:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.eti.2022.102797.

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