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Recycling Practices of E-Waste and Associated Challenges: A Research Trends Analysis

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ABSTRACT

In this fast-moving world, we use many electronic items daily to fulfill our daily work. Also, in the fast-growing economy, electronic items play key roles. India's e-waste is projected to be around 18 lakh metric tons. According to industry sources, electronic trash will climb to almost 50 lakh metric tons in the next three years. According to government sources, only ten percent of electronic waste is gathered. These electronic items and batteries contain many heavy metals that are hazardous to humanity's and the environment's health. These heavy metals should be retrieved from the disposed of e-waste, so the resource can be reused or recycled, rather than continuously extracting heavy metals from the earth's crust. In 2015, The "Initiative on Environmental Threats of Electronic Waste" was introduced by the Ministry of Electronics and Information Technology (MeitY). This project is part of the Indian government's 'Digital India' strategy. There is an immediate need to implement green supply chain management and resource recovery from electronics waste so that circular material management (SDG 12) & sustainability can be achieved. This article demonstrates the problems and presents E-Waste recycling procedures, Life cycle assessment of E-waste, and EPR practices, along with potential areas for improvement. The bibliometric analysis was performed using R-studio biblioshiny tools for the last 53 years and 1243 published articles to understand the research trends.

INTRODUCTION

Large volumes of e-waste have caused worldwide issues, including degradation of the environment and food chains, mineral shortages, and a significant risk to human health. Metal and metalloid buildup in people can cause bodily harm: copper can harm the liver, and lead can affect a person's behavior and ability to learn. Lung cancer and kidney damage risk are increased by cadmium exposure (Gao et al. 2019). Because Guiyu is China's e-waste recycling town, statistical analysis revealed that children living there had considerably increased blood mercury levels compared to Chendian residents ($p < 0.01$) (Huo et al. 2007). The early findings show that in soil from a Guiyu printing rolling waste dump, the overall amount of polycyclic aromatic hydrocarbons (PAHs) was 595 $g.kg^{-1}$ dry weight (dry wt.) and 514 $g.kg^{-1}$ in silt from a crane lake (dry wt.) of Guiyu. The number of polychlorinated biphenyls (743 $g.kg^{-1}$) in drainage from the Lianjiang River was discovered to be close to three times the 277 $g.kg^{-1}$ Canadian Environmental Quality Guidelines likely impact guideline (Leung et al. 2006).

Electronic waste makes the biggest universal waste problem. According to United Nations worldwide, approximately 53.6 metric tons of electronic waste are produced (Forti et al. 2020). Approx. 25% of e-waste is recycled formally in centers located in Asia & Africa (Perkins et al. 2014). Most of the waste disposal is either unknown or done at home. This leads to adverse health effects for residents in developing countries like India, China, Bangladesh, Pakistan, Ghana, and Kenya. There are 13 types of e-waste, cell phones being the largest. The others include washing machines, refrigerators, computers, televisions, and air conditioners. The market would increase due to emerging products like Fitbits, Bluetooth gadgets, and technological advancements.

Valuable metals recuperation is mindboggling to companies due to their endless mechanical applications in different industries, huge market costs, and the constrained resource of these metals. E-waste and used converters have various hazardous elements in addition to precious metals (e.g.,

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toxic metals, smokeless materials, and organic compounds). These hazardous substances might contaminate the earth and groundwater and affect people's health; with the increment in environmental awareness, the disposal of unsafe waste has become a significant concern for industries and governments. Recouping and reusing a few industrial wastes containing metals (Au, Ag, Pt, Pd, Rh, etc.) is assessed as a financial and environmental security opportunity (Castro & Bassin 2022).

The amazing physical and chemical characteristics of precious metals (PMs), such as their capacity for catalysis, exceptional electrical conductivity, and corrosion resistance, have led to a wide range of applications. Electronics (e-waste) and the catalyst business, which utilize more than 90% of precious metals, are the two key sectors needed. Electronic garbage, or "e-waste," has been produced in enormous quantities in recent years due to device obsolescence. In the electronics industry, contacts, bonding wires, and switches are made of gold, silver, and palladium, while hard disc drives are made of this metal. 2015 experienced 254 tons, 12,816 tons, and 40.18 tons, respectively, increased demand for gold, silver, and palladium in electronics worldwide. By 2016, there has been an approximate global e-waste production of 44.7 million tons (Mt) (Ilankoon et al. 2018). In sum, only around 20% of the e-waste was adequately processed; 71 tons of gold, 3275 tons of silver, and 15 tons of palladium were recycled in 2016. (Onete et al. 2018).

Fig. 1 shows generated electronic garbage globally from 2010 to 2019 (in a million metric tons). It is rapidly increasing; in 2019, the e-waste was 53.6 million metric tons (Statista 2020).

Valuable metals are often used as dynamic components in the catalyst industry. Most catalysts are employed in refining oil, fine chemicals, medicines, and automotive exhaust. Additionally, the net PGM (elements gather in platinum) utilizations are even now quite expensive because of the booming car and other catalytic industries. Catalytic converters used over 66% of palladium (182.64 tons), 44% of platinum (98 tons), and 84% of rhodium (25.7 tons) (Onete et al. 2018). Many analysts have been investigating replacement materials to reduce the need for expensive metals in products. Different catalysts were used, and the number of valuable metals changed from 200 ppm to 100%. Catalysts also have a variety of carrier materials, which complicate attempts to reuse them.

However, valuable metal concentrations in Troposphere are negligible, with the majority below 0.01 ppm. Over 30% PGMs were recovered for used catalysts, specifically 35 tons of Pt, 60 tons of Pd, and 7 tons of Rh (USGS 2017). It was shown that potentials processed the majority of e-waste before being placed in landfills or basic recycling systems. A scarcity of professional recyclers, problems with the dependability of remanufactured devices, and harmful impacts on the climate and people's life are also associated with illegal e-waste management (Chi et al. 2011). E-waste can be harmful, is not recyclable, and builds up in the land, air, water, and other living things in the environment. In recovering precious items from electronic components, open-air burning and acid baths are two methods that emit harmful substances into the atmosphere and adversely affect people's health. These effects include cancer, miscarriages,

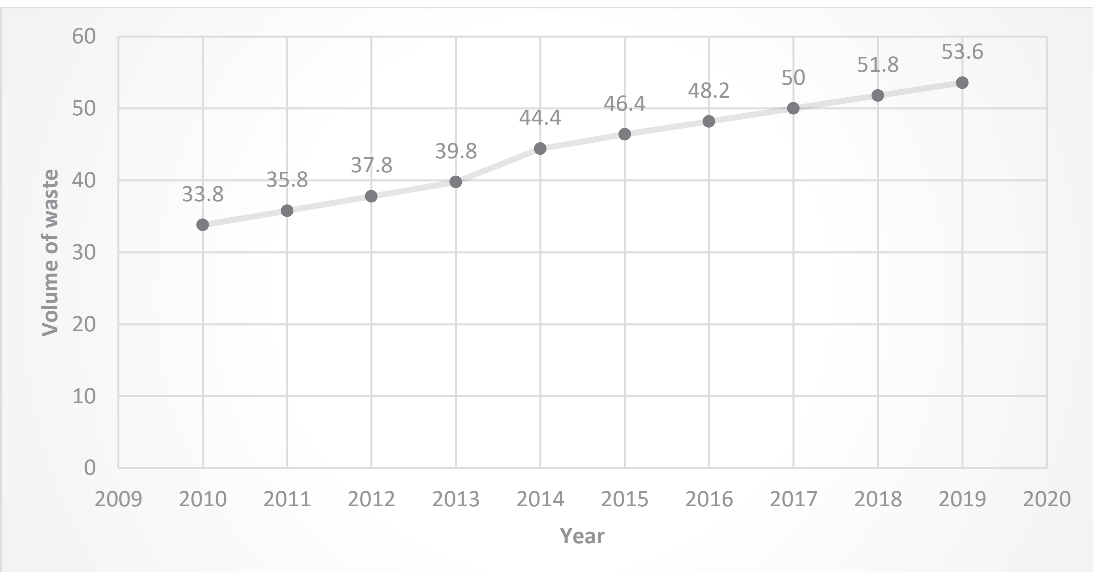

Fig. 1: Produced electronic garbage globally from 2010 to 2019 (in a million metric tons) (Statista 2020).

neurological damage, and lowered IQs. It is important to take into account how technological products affect climate change. Every piece of machinery created has a carbon output, leading to human-caused global climate change. Most CO_2 emitted over a device's lifetime happens during manufacturing before a client buys a product. Reducing carbon production techniques and inputs—such as using recycled raw materials and product lifespans—are key factors in determining the total environmental effect. According to Brianna (2022), between 2014 and 2020, the release of greenhouse gases from electronic gadgets and the trash they produce rose by 53%. According to the experts, this involves 580 metric tons of carbon dioxide in 2020. They predict that by 2030, e-waste sources will be responsible for the yearly emission of around 852 million metric tons of CO_2 compounds if there is no legislation or legal framework to extend the usable life of information and communication technology (ICT) equipment (Brianna 2022).

This article discusses the current practices of recycling E-Waste and challenges along with the improvement scopes. A bibliometric analysis was conducted in the current study to reveal the underlying trends in research publications concerning e-waste. An analysis of the top nations, journals, authors, academic institutions, and keyword co-occurrences is presented using the Scopus database.

MATERIALS AND METHODS

A bibliometric analysis was conducted for the current study to reveal the underlying trends in research publications on e-waste. An analysis of the top nations, journals, authors, academic institutions, and co-occurrences of keywords is presented using data from the famous research database Scopus.' With the keywords "Electronic waste" in the article title, a total of 1853 documents were found in the Scopus database. Further, filtering criteria were used, like only articles and the year 2023 was excluded from the search. The search was performed on 29th November 2022. The bibliometric analysis was performed using the R-studio software Biblioshiny module. A total of 1243 articles were found with these filtering criteria from 1969 to 2022 (last 53 years), 518 publication sources, and 3709 authors with an annual growth rate of 9.55% (Fig. 2). Fig. 3 shows the publication rate annually in the 'Electronic waste' domain. Fig. 4 shows the most relevant journal sources in the 'Electronic waste domain. Waste Management (81 articles) has been shown as a prominent journal in this domain focusing on E-waste management.

Fig. 5 shows the most relevant authors in the 'Electronic waste' domain. Wang, J, Xu, X, Zhang, and Y are the most influential authors in the field. Each of them has published 20 research articles. Fig. 6 shows the most relevant affiliations in the 'Electronic waste' domain. Guangzhou Institute of Geochemistry (90 published articles) is the most prominent affiliation in the research area of e-waste.

Table 1 shows the most influential published articles in this domain, along with the influential authors' names, their countries, citations per year, and journal names. In the Electronic waste research domain, most citations were received from the article Strategies to managing electronic waste: An summary written by Kiddee et al. (2013) from the University of South Australia, Australia.

Fig. 7 shows the most cited countries in the 'Electronic waste' domain. China is more focused in this area than other countries. Hence other countries need to come forward for more collaborative research work to enhance the handling of e-waste. Fig. 8 shows the most occurred words in the 'Electronic trash' domain. E-waste, Recycling, waste management, electronic machinery, China, and waste disposal are mostly co-occurring words in this research domain.

RESULTS AND DISCUSSION

E-waste has become increasingly significant as precious metals supplier. The most significant use of precious metals in the economy is in the electronics and catalysts sectors, which account for almost 90% of total consumption. Recycling valuable metals from alternative resources is crucial because of disputes over finite natural resources, rising demand, and the importance of valuable metals to the economy. In recent years, electronic devices that have outlived their usefulness have generated enormous amounts of electronic trash (also known as e-waste). The total volume of electronic garbage produced worldwide in 2016 was 44.8 million tons (Mt) (Baldé et al. 2017). An estimated 30% of the world's mining output during the past ten years was from recycled precious metals. Research into creating efficient recycling methods for valuable metals, notably from e-waste and used catalytic systems, has increased during the past ten years. Environment-friendly precious metal recycling technologies have steadily emerged. Several methodologies have been developed to manage e-waste, particularly in industrialized nations. These include Life Cycle Assessment (LCA), Material Flow Analysis (MFA), Multi-Criteria Analysis (MCA), and Extended Producer Responsibility (EPR) (Kiddee et al. 2013).

Based on current technology, numerous methods for recycling precious metals have been considerably enhanced. Precious metal losses should be kept to a minimum because they have the highest value in the recycling of e-waste. However, in e-waste industrial processing, valuable metals

Table 1: The most influential published articles in the electronic waste domain.

Title	First Author	Affiliation	Country	Total Citations	TC per Year	Journal name	Year
Challenges, facilitators, and governmental considerations in the use of circular economy ideas in the electrical and electronic equipment (EEE) area	Vasileios Rizos Rizos and Bryhn (2022)	Centre for European Policy Studies (CEPS)	Belgium	17	17	Journal of Cleaner Production	2022
Study on medical waste tracking: Historical development, contemporary issues, and ideas on the transformation to a circular economy	Meisam Ranjbari Ranjbari et al. (2022)	Henan Agricultural University	China	41	41	Journal of Hazardous Materials	2022
To use the grey-theory and DEMATEL paradigm to evaluate the e-waste reduction solutions	Chandra Prakash Garg Garg (2021)	Indian Institute of Management Rohtak	India	57	28.5	Journal of Cleaner Production	2021
An assessment focusing on the treatment of electronic trash in the EU regarding behavior interventions for the circular economy	Keshav Parajuly Parajuly et al. (2020)	United Nations University	Germany	75	25	Resources, Conservation & Recycling	2020
Strategies to managing disposal: A summary	Peeranart Kiddee Kidee et al. (2013)	University of South Australia	Australia	466	46.6	Waste management	2013
Kids in Guiyu, a Chinese town that recycles disposal, had higher serum levels	Xia Huo Huo et al. (2007)	Shantou University Medical College	China	423	26.44	Environmental Health Perspectives	2007
Analysis of U.S. Facilities and technological solutions for reusing electronic trash	Hai-Yong Kang Kang and Schoenung (2005)	University of California	USA	397	22.06	Resources, Conservation, and Recycling	2005

are disseminated throughout each resulting process. With no mechanical processing, almost all precious metals and other significant metals can be recovered through direct smelting. Fume treatment needs to receive a lot of attention because this process may produce dangerous gases (such as dioxins and bromide). When working with used catalysts, metallic stage concentrations of valuable metals might minimize the reagents required for the subsequent dissolving and purifying processes. Hydrometallurgical, economic, and creative approaches have been devised to significantly lessen the

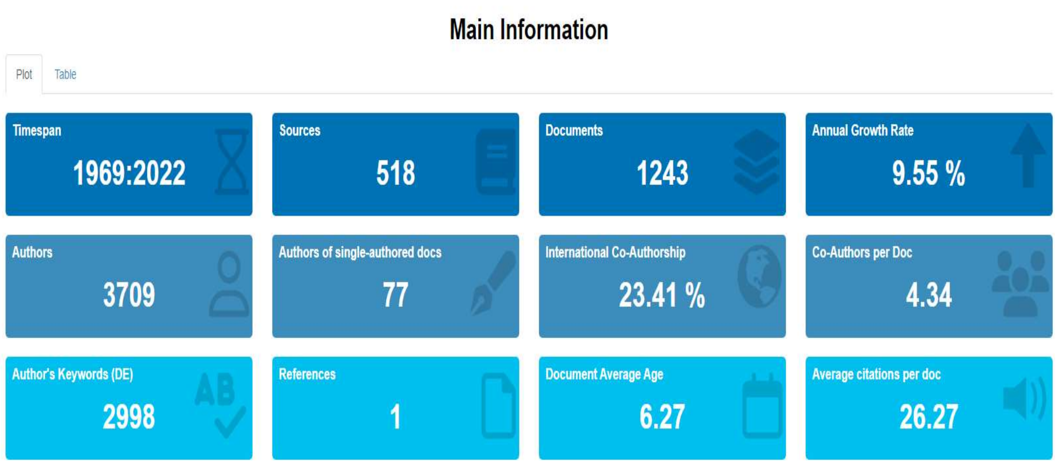

Fig. 2: Main information of the Scopus (.csv) file used for bibliometric analysis.

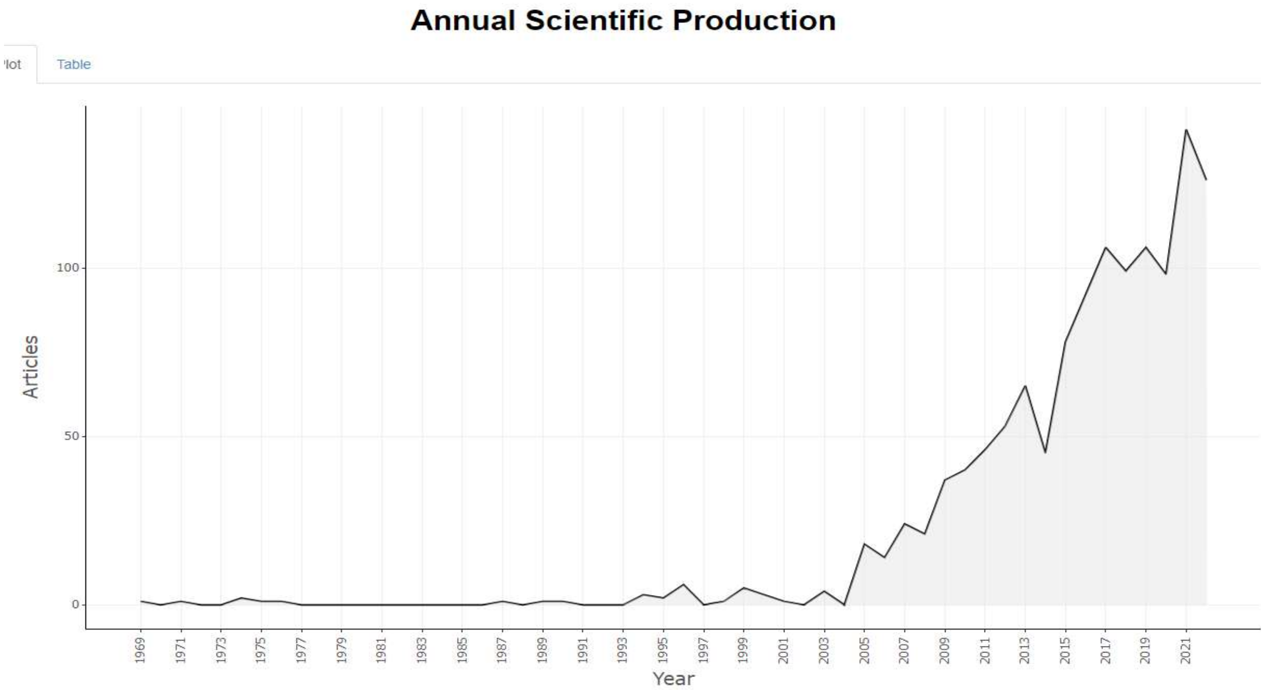

Fig. 3: Publication rate annually in the 'Electronic waste' domain.

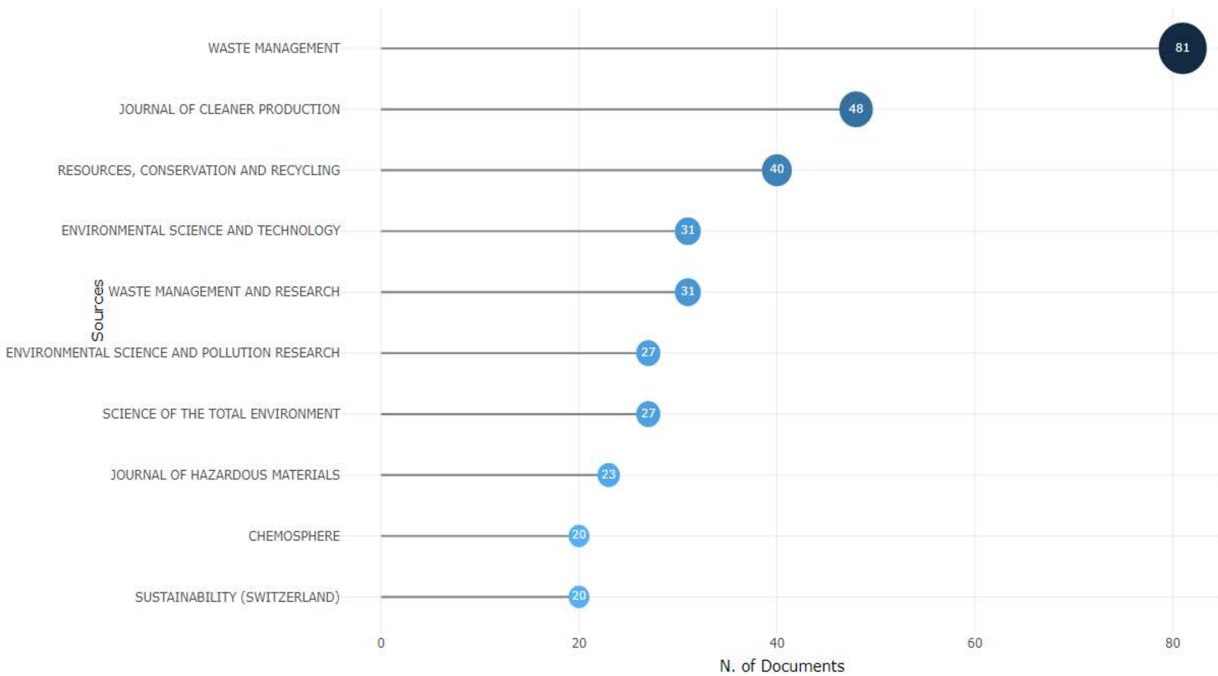

Fig. 4: Most relevant journal sources in the 'Electronic waste' domain.

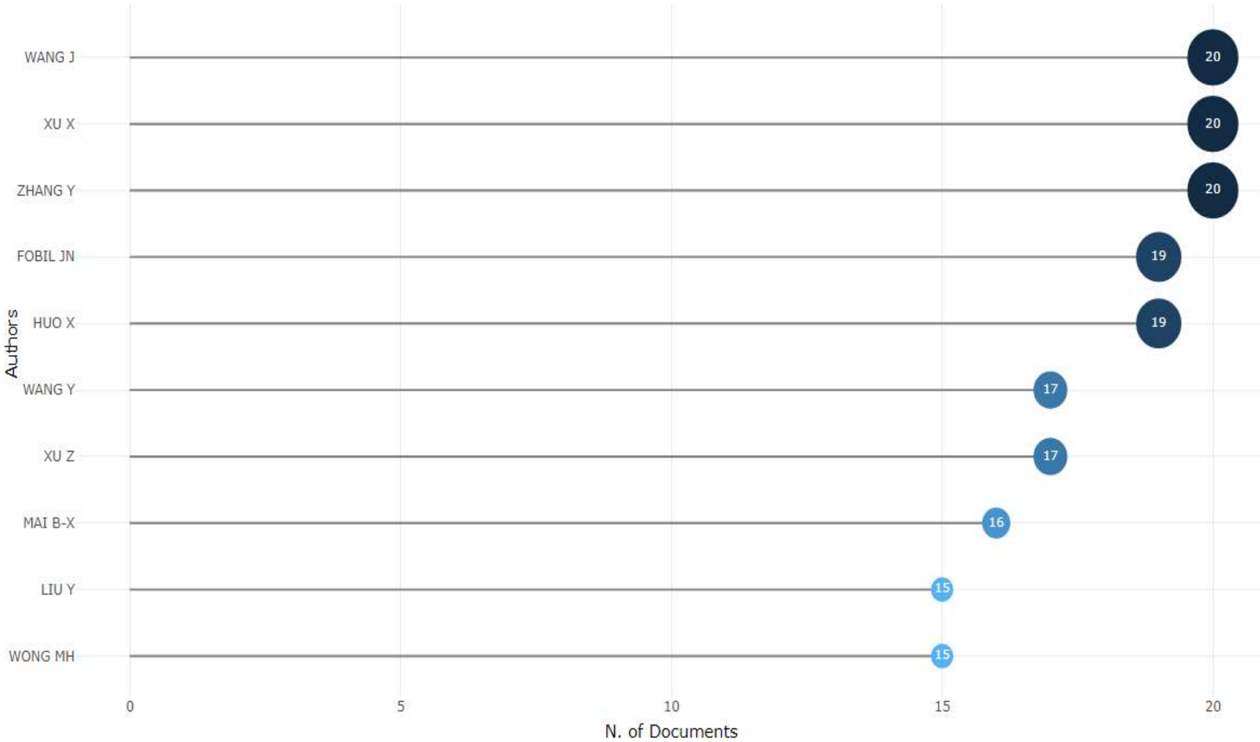

Fig. 5: Most relevant authors in the 'Electronic waste' domain.

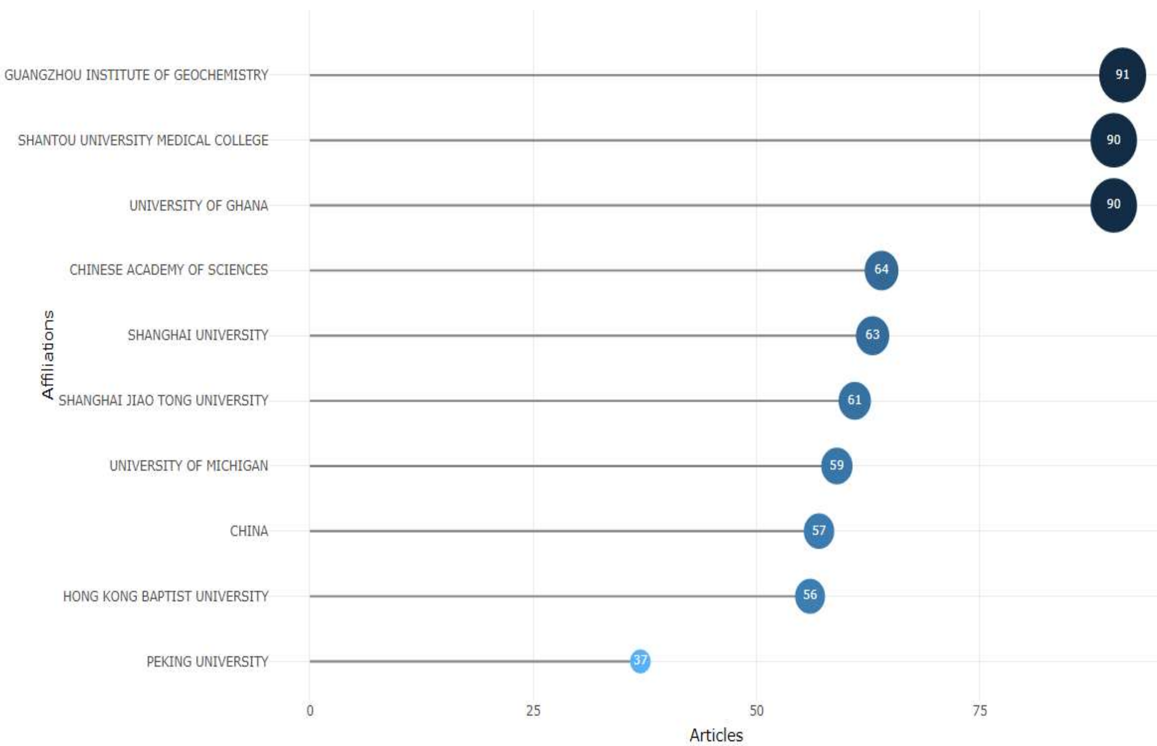

Fig. 6: Most relevant affiliations in the 'Electronic waste' domain.

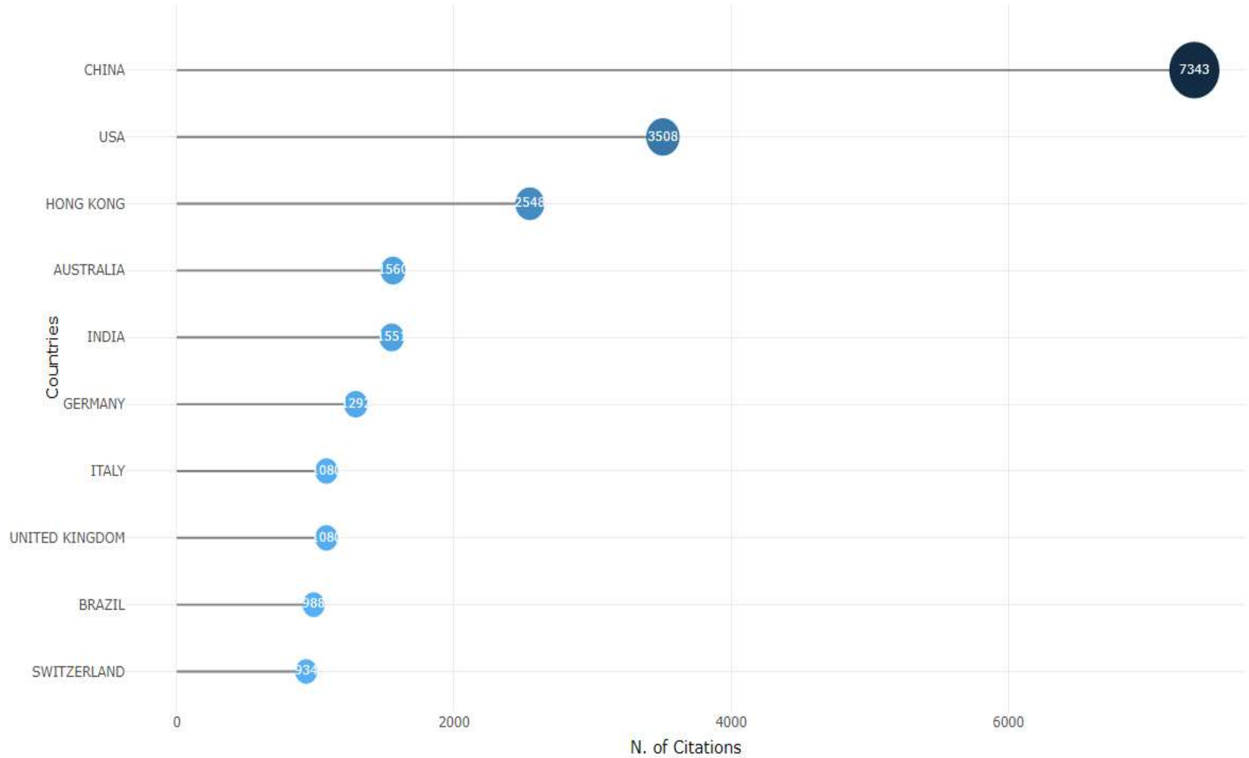

Fig. 7: Most cited countries in the 'Electronic waste' domain.

Fig. 8: Most occurred words in the 'Electronic waste' domain.

influence on the environment. Some cyanide-free lixiviants that have shown the ability to leach precious metals include S_2O_3, CH_4N_2S, chlorination, iodine-iodide, and HCl in the influence of an oxidizing agent (Ding et al. 2019).

E-waste importation and recycling have increased manifold in a decade in China, so their government has passed regulations to ensure imported e-waste is reduced and disappears by 2023. Per head, the estimated yearly generated e-waste is 5 kg per Chinese whereas 29.5 kg per US citizen (Li & Achal 2020). Guiyu, a town in China, is famous for the informal disassembling and recycling of e-waste, which supports the livelihood of locals. It gives rise to other problems like increasing social gaps. The e-waste contributes to a large Chinese GNP, leading to the involvement of Chinese children in informal e-waste disposal at home by dumping and burning in the backyard. Due to this, the Chinese government has wisely stepped in to streamline and regulate the e-waste disposal sector by bringing in more awareness, regulations, and funds from governments and NGOs. China launched plants in 29 provinces over a decade for formal e-waste disposal. Workers directly involved with e-waste disposal without proper protection have serious health risks. However, informal recycling leads to regaining valuable materials, which can be greedy for workers. This informal disposal also leads to the release of more air pollutants which enter the water and soil, too, thus indirectly entering the human body and affecting aquatic life. The plastics used in gadgets are complicated to process, and studies indicate that heavy metals enter the food chain through vegetables and aquatic life and can increase in the body.

Additionally, burning and disposal leads to releasing POPS, PCBs, PAHs, and dioxins in the surroundings and migrating through the food chain by living inside them. China abandoned areas where the PCB concentration was more than twice the tolerable threshold. Capacitors also release PCB when dismantled by hand (Li & Achal 2020).

One study showed 2510 e-waste studies were done between 2009 and 2018, making up 89.65% of all research taken into account (Gao et al. 2019). With 40.93% of the papers covered, China authored the most research, followed by the United States (345 publications, 12.32 percent), India (190 publications,6.79 percent), the United Kingdom (147 publications, 5.25 percent), and Japan (135 publications, 4.82 percent). There were 9282 keywords, but only 18 had a frequency greater than 120. A co-occurrence frequency analysis found that the most prevalent keywords were e-waste, polybrominated, diphenyl ethers, China, brominated flame retardants, management, recycling, recovery, printed-circuit boards, and heavy metals. The top 10 scientists are all Chinese, showing that Chinese researchers are engaged in this subject and have produced a large number of research findings (Gao et al. 2019). The Chinese government should deploy proper and sustainable methods for metal recycling from e-waste (Li & Achal 2020).

Treatment Methods

Table 2 summarizes different studies on electronic waste treatment methods. Micro-factories are a new type of technology that can turn polymers from e-waste into high-value goods (BBC 2016). Micro-factory technologies stand out because they convert and repurpose electronic waste polymers into new and more expensive items instead of making them into plastic again. In traditional manufacturing industries like steel production, power storage, rising metals, copolymers, and many others, the systems in this class are designed to benefit from various characteristics of plastic trash, including its carbon content, binding properties, chain organization, engineering, thermodynamic properties, etc. Micro-factories might represent the fifth type of polymer recycling, absorbing the growing volume of plastic waste while working with current technologies. Although micro-factories may handle waste from ceramics, glass, and metals, this evaluation focuses mostly on the plastics sector (Sahajwalla & Gaikwad 2018). Decentralized manufacturing, which allows lean, agile, and customizable technology, lies at the micro-factories' heart.

Table 3 shows the electronic waste usage in value-added product making. The "Waste to wealth" strategies are important to reduce e-waste. To stop the degradation of gold materials, guarantee a steady supply of precious metal sources, and lessen the environmental effect of harmful metals, a method to precisely extract and purify gold from additional resources is necessary. 95% of gold is recycled using the TCLP test from e-waste (Panda et al. 2020). For application in the recycling of gold in total e-waste, Magnetic core spinning poles with excellent selectivity and redox activity (MCSR-ATU) were created. The MCSR-ATU demonstrates improved adsorption capability and kinetics attributable to the rotating magnetic field, achieving the maximum adsorption capacity for Au(III) after 30 minutes at pH 3.0 and 313 K (Li et al. 2022).

Machine learning can be applied in e-waste management. Firstly, the MEPH (Magnetic separation, Eddy current, Pyrometallurgical, and Hydrometallurgical) method handles metal removal, filtration, and segregation. In the second section, the cleaned metal is photographed using a camera. The acquired picture is then processed to remove noise before being sent to a CNN classifier. There are two techniques to classify information; the first involves accepting input and classifying output. Secondly, determining the degree of resemblance to the specific class (Senthilselvi et al. 2020). Fig. 9 shows recycling different techniques of e-waste.

Life Cycle Assessment (LCA) Analysis of E-Waste

A useful method for evaluating the environmental effects of e-waste from "cradle to grave" is life cycle assessment

Table 2: Different treatment techniques for electronic waste.

AIM	Composition of Waste	Methods of Treatment	Findings	References
To know the existing and emerging technologies of e-trash plastic recycling	Plastics	Micro-factory; Waste to energy process	The annual growth rate of e-waste is 3-4%; 15% of e-waste recycled	Sahajwalla & Gaikwad (2018)
To evaluate the toxicity of E-trash plastics	Plastics; huge metals; brominated flame retardants (BFRs)	Electronic trash is utilized as raw materials in closed-loop regeneration.	44.7 MT E-waste produced in the US in 2016	Singh et al. (2020)
To investigate the production of E-waste and various management practices	Heavy metals, i.e., Fe, Al, Cu, Cd, Ag, Au, Pd	Sustainable E-waste recycling management	4100 t E-waste produced in Chandigarh annually	Ravindra and Mor (2019)
To describe behavioral reasoning theory perspectives on E-waste recycling and management	Electrical and electronic waste materials		41.8 MMt e-waste generated in 2018 and 50 MMt generated in 2018 worldwide	Dhir et al. (2020)
To recycling of WEEE (Waste from Electronic and Electric Equipment)	LCD notebooks, LED notebooks, TVs, CRT monitors, Cell phones, Smartphones, PV panels, tablets	Collection of materials; pre-treatment; recovery of valuable materials and disposed of nonrecyclable ones	30-50 million tons of WEEE disposed of per year	Cucchiella et al. (2015)
To study the determinants of an individual's E-waste recycling decision	Waste from electronic and electric equipment	Economic E-waste recycling	In the European Union, 10960799 tons of E-waste generated in 2020	Delcea et al. (2020)
To recycle copper and gold from E-waste	Circuit boards of mobile phones containing gold and copper	Two stages leaching process and solvent extraction process	30% of E-waste is recycled using these processes	Rao et al. (2021)
To enhance the accuracy of the mobile phone reprocessing method	Mobile phones waste	Using Machine learning method; MEPH (Magnetic separation, Eddy current, Pyrometallurgical, and Hydrometallurgical)	140 million cell phones landfilled per year	Senthilsevi et al. (2020)
To know policies on E-waste in the emerging economics	Waste from electronic and electrical equipment	Recycling of E-waste supply chain	1975 kt of E-waste produced in India in 2016; South Africa produced 321 kt in 2016	Borthakur (2019)
To recycling of gold from electronic devices waste	Electronic devices	TCLP test	95% of gold recycled using this process	Panda et al. (2020)

(LCA). Regarding all phases of the system boundaries, LCA may concurrently, methodically, and successfully analyze and identify environmental survey, effect, critical variables, choices, and development prospects. Numerous studies have used life cycle assessments (LCAs) to examine the environmental effects of treating e-waste (Song et al. 2012, Niu et al. 2012). Since the system boundaries include steps for collecting, pre-processing, and processing tiny WEEE (electronic toys). Solé et al. (2012) utilized LCA to enhance the process of gathering and recycling. Disposable cell phones are the most frequently used and are thought to have the poorest lifespan of all WEEE (waste electrical and electronic equipment).

Consequently, smartphones will be a key study topic for LCA studies as a specialized tiny electronic and electrical item. The LCA findings suggest a 70%

Table 3: Micro-factory waste inputs and value-added products (Sahajwalla & Gaikwad 2018).

Waste input	Waste resources	Value added items
Plasma LCD TVs. Smart Phone screen.	Waste electrical and electronic equipment	Metals manufacturing
Computer, Laptop, and smartphone circuit board. E-waste plastics.		Construction and built environment and automotive industry.

possibility that recycling used smartphones would have no emissions or negative emissions. Throughout the entire life cycle of treatment, the metal electronic secondary treatment will have the largest environmental implications (He et al. 2021).

Extraction of PMs from Electronic Waste

Electronic applications' average lifespan is shortened, and their revamp is accelerated by technological innovation and market need. As a consequence, e-waste has emerged as one of the fastest-production trash sources. Numerous literary works have described the repurposing of precious metals from e-waste. Over the past 20 years, various reusable innovations have been developed, many of which have already been applied commercially. Smelting in the furnace, Alkali smelting, Traditional Leaching, Non-Cyanide Leaching, Chlorination Leaching, and Iodination Leaching are a few techniques for recovering PMs from e-waste (Cui & Zhang 2008). PMs are recovered from used catalysts.

In contrast to mine generation, recovering valuable metals from wasted catalysts has advantages such as minimal preparatory requirements, quick production cycles, low levels of speculation, and minimal environmental impact. Furthermore, other catalyst transporters are also applied in various applications, and between 100 ppm to 100% of utilized converters contain PMs. Many analysts have worked to reuse valuable metals from used catalysts.

Some ways to recuperate PMs from spent catalysts are the pyrometallurgical process, Cyanide (weight) leaching, $HCl+Cl_2/NaClO_3/NaClO$ $HCl+H_2O_2$, Supercritical liquids extraction, Microwave-assisted leaching. The most useful recycling processes are those that concentrate valuable metals by pyrometallurgy or through selective leaching. Recently, efforts have been undertaken to advance the recovery rate and reduce the natural contamination of important metals from e-waste and used converters. Through purifying and refining, pyrometallurgy may reuse expensive and base metals (such as Cu, Pb, Sn, etc.) with high virtue for e-waste (Islam et al. 2020). A few projects in industrialized countries have been linked to cutting-edge refining advances. The majority of purifying plants in poor nations still are unable to meet the emission requirements, although these pyrometallurgical plants have completed the criterion of tight contamination outflow. However, more than 80% of electronic garbage is dumped in developing nations. Despite the advancements and improvements in smelting technologies in developing countries, contamination problems are still unavoidable. The transmission of gaseous fuel and sludges needs to be carefully considered. Considering the production and emission of particulate matter (PM) 2.5 and carcinogens is important. Devices for treating smoke are necessary for moving dangerous gases and burning residue. Due to the high operating temperature, the release of dangerous gases, and PM 2.5, word-related security is essential. It is not reasonable for small and medium-sized projects because they are large and the supplies are expensive. Perspective and conclusion The business world relies heavily on valuable metals in many sectors. Reusing important metals from secondary assets is crucial due to the conflicts between constrained characteristic

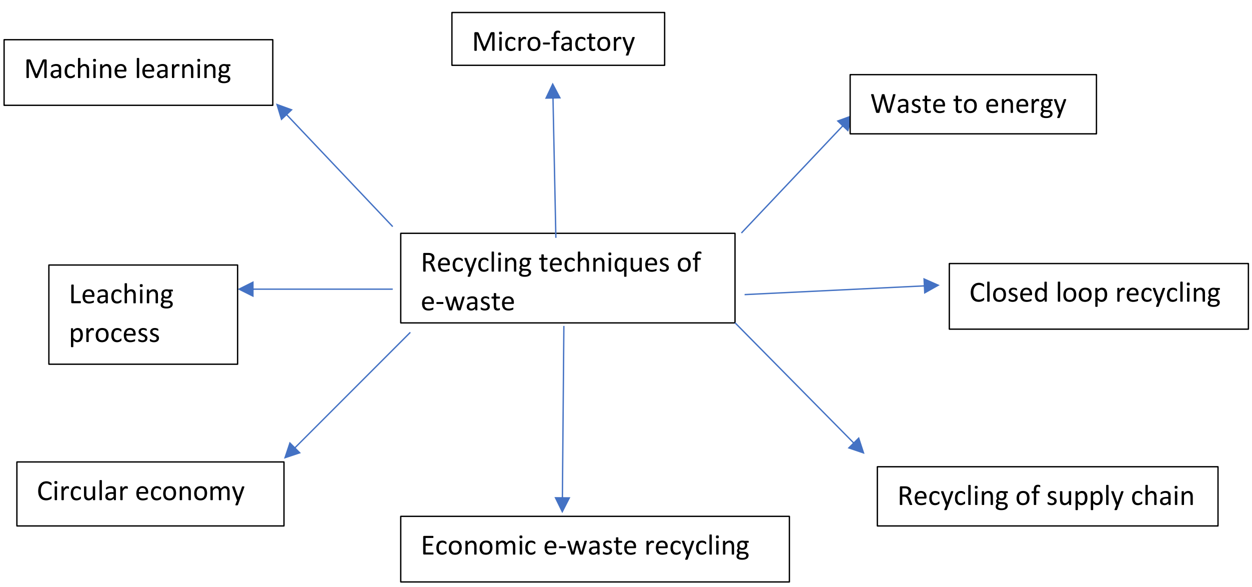

Fig. 9: Some recycling techniques of e-waste.

assets and growing needs and their financial value. Over the last ten years, it has been estimated that the total amount of recycled important metals accounts for 30% of global mining production. In the past ten years, interest has risen in projects that aim to develop effective reuse techniques for valuable metals, particularly e-waste and used catalysts. Environmentally friendly developments for refining priceless metals have evolved throughout time. Different strategies have been developed due to the usual advancements for refining valuable metals, which at the time commanded the highest regard for reusing e-waste.

In underdeveloped countries and regions, pyrometallurgical innovations are less commonly used than hydrometallurgical forms. Although technologies for recovering important metals have undergone self-evident alterations, certain obstacles remain to future promotion. Several considerations have been made to accomplish the economically viable and environmentally responsible refining of valuable metals with a large recovery speed. First, it is important to develop sophisticated advancements from a commercialization perspective in terms of cost and speculation. Second, reusing passageways should be modified and planned in accordance with the physical and chemical characteristics of various materials. Third, a few assisted techniques or pre-treatments are crucial due to increased leaching effectiveness and less contamination. Future advancements for recycling valuable metals can be more effective and have a less natural influence, lower fetched, and greater recuperation rate with over-inquiry direction.

Advantages of Recycling E-waste with Respect to the Circular Economy

Self-reliance, or Atmanirbhar Bharat, becomes increasingly important as India recovers from the effects of COVID-19, particularly on society and the economy, to solve these issues and rebuild through stable economic models. The policies for India's economic recovery must foster sustainable circumstances for people, the environment, and the economy to reconstruct. Achieving long-term affluence for humanity and a sustainable planet might require increasing investment in knowledge, industries, products, business models, procedures, digitalization, and technology.

Because of the increasing usage and quick dumping of electronic devices as well as a lack of infrastructure for proper disposal, electronic trash is an issue that exists everywhere. India is no exception. A staggering 53.6 Mt of electronic garbage, or 7.3 kg per person on average, was produced worldwide in 2019, the Worldwide E-Waste Report 2020 claims. E-waste is on the rise due to the increased use of electrical and electronic equipment (EEE), shorter product life spans, rapid technological advancement, and fewer options for repair. India now generates more than 3.23 million tons of e-waste yearly, ranking third behind China and the United States, as reported in the Worldwide E-Waste Report 2020 (Sengupta et al. 2022). Only 10% of the expected amount of electronic garbage created in India in 2018–19 was recovered (CPCB report). To make resource efficiency successful in India, the gap between e-waste creation and collection for recycling needs to be evaluated. According to the FICCI Circular Economy Report (2017), there is a $0.7 to $1 billion market capacity to extract gold from e-waste.

Moreover, a ton of ore has an extractable gold resource of roughly 1.4 g, but a ton of mobile phone PCBs may yield about 1.5 kg. The Worldwide E-Waste Report 2020 claims just 17.4% of electronic trash was collected and recycled in 2019, resulting in the loss of almost $47 billion in recyclable materials, including gold, silver, copper, platinum, and other high-value materials. The importance of natural sources in the e-waste must be used to construct the remanufacturing supply chain, and developed economic devices must be used to make it economically feasible. A circular economy (CE) strategy for managing e-waste will be crucial for resource utilization, reducing waste, increased product life, restoration of rare and valuable materials, reduction of occupational and health risks, and the development of the recycling sector, which will result in formalization and employment opportunities. At every stage of the material's life span, the CE process in the EEE sector has the potential to generate employment. The CE strategy can promote domestic resource security, leading to increased production and the creation of skilled employment in the industry (MeitY 2021).

Indian Policies, EPR and Regulations Related to the Handling of E-waste

Extended producer responsibility (EPR) stresses companies that come after the consumption phase of products regarding waste treatment (Chung & Murakami-Suzuki 2008). India's importance in the world is anticipated to increase in the next years as a member of the BRICS group, especially from an economic standpoint (Shen et al. 2017). India has significant environmental difficulties as it advances in economic development and prosperity. In contrast, India faces a substantial E-waste challenge due to high production and insufficient management techniques. India has developed and implemented regulations during the past ten years to address the e-waste produced in the nation. The "Guidelines for Environmentally Sound Handling of E-waste" are guidelines for managing e-waste in India that was announced by the Ministry of Environment and Forest (MoEF) in 2008 (Borthakur 2020). Under the March 22, 2018, G.S.R. 261(E) notice, the E-Waste Management Regulations 2016 have been revised (Vikaspedia 2016). The laws have been changed to formalize the e-waste recycling industry by directing the electronic garbage produced in the nation toward approved recyclers and reconstructors. The updated e-waste recovery objectives under EPR will take effect on October 1, 2017. The sequence collection goals for e-waste in weight during 2017–18 must be 10% of the waste-generating amount as mentioned in the EPR Plan, with a 10% rise each year until 2023. The objective has been set at 70% of the waste generated, as stated in the EPR Plan after 2023 (PIB 2018). The guidelines for managing e-waste were issued by the environment ministry in draught form in 2022 for public comment. In accordance with it, manufacturers of consumer goods and electronics must make sure that by 2023, a minimum of 60 percent of their electronic trash will be gathered and reused, with goals to raise those percentages to 70% and 80% in 2024 and 2025, respectively (MeitY 2021). The regulations establish a system of certificate trading that will let businesses temporarily fill gaps. This system is like the trade of carbon credits. According to a draught notification, companies must pay environmental compensation for failed objectives. The CPCB monitors the entire procedure.

Issues and Recommendations

Rigid regulatory frameworks are necessary without conflicting waste management goals, such as collecting home e-waste, to help advance waste disposal in poor countries. These regulations and adjusted EPR plans that consider the local economy might offer readily deployable waste management solutions that would benefit all parties as much as possible. It would significantly reduce negative environmental effects, promoting the Sustainable Development Goals (SDGs), including life below the ocean, balanced urban and rural areas, clean water and sanitation, and ethical ingestion and manufacturing. All manufacturers of EEE specified by the 2016 E-Waste (Governance) Regulations, including manufacturers, e-retailers, online sellers, eBay, etc., must receive an EPR authorization. A manufacturer can execute its EPR by establishing hubs, a take-back program, or both to direct e-waste and end-of-life items to licensed junkyards and recycling plants.

A fundamental change is required to focus on transformation as a reform program for the electronics and electrical industry to enable a circular economy in e-waste. Although precious metals recovery technologies have progressed noticeably, there are still some obstacles to overcome in terms of future promotion. Several considerations for environmentally friendly and sustainable precious metals recycling with a high recovery rate have been offered. New technologies should be developed with the goal of commercialization in mind, both in terms of investment and cost. Recycling technologies should be changed and combined depending on the physicochemical properties of various materials. Various aided procedures or pretreatments should be used to improve leaching efficiency and deduct pollution.

The livelihood and the local economy of provinces like Guiyu depends on e-waste recycling. Thus, formal banning is not an option. Several provinces' environment – soil, water, air – has been completely contaminated and carcinogenic, thus making it irreversible for human life to sustain on the hazardous lands. High technological advancements, high demand for recycled electronics, and a considerable GNP of China depending on the informal e-waste disposal sector make it extremely hard to ban it completely. Recommendations: Since informal recycling contaminates the environment and neonatal and human health, there should be government intervention to reduce the difference in e-waste recycling between regular and irregular, not simply trying to ban it since the livelihood of many depends on the income from it. Pyrometallurgy is still the most conventional and widely-used treatment, and hydrometallurgy is the primary metal separation and recovery method. With the rapid development of numerous hydrometallurgical procedures, such as bioleaching, hydrometallurgy has recently advanced and gained popularity. Pyrometallurgy comprises burning, smelting in plasma arc or coke ovens, roasting, melting, and gas-phase processes at extreme heat. It is the most conventional and widely used metal separation and recovery method. Hydrometallurgy is easier to regulate than pyrometallurgy, more precise, reliable, and ecologically beneficial. To separate and gather the metals from the extractable mixtures and condense them., electroplating techniques typically include a series of acid or corrosive dissolves of e-waste. These leaches are then followed by purification methods like adhesion, solvent evaporation, electro-dialysis, and adsorption using activated carbon. Polymers and flame-retardant plastics comprise most non-metallic fractions (NMF) in Printed circuit boards (PCBs). Polymers and plastics may be transformed into premium fuel; therefore, many physical and chemical methods have been studied in the NMF that are separated and recovered from used PCBs.

a) Management system should supervise to prevent risk from the origin of e-waste.

b) Government – state & central - and NGOs involved in environmental protection should provide ample funds to deploy the best recycling and disposal technologies.

Policymakers in advanced and emerging economies have concentrated a large portion of their legislative and policy efforts since the Worldwide E-waste Report 2017 on establishing funding and advertising programs to encourage greater engagement from business entities and private citizens. Here, the goal is to ensure improved recycling and recovery rates as well as to provide the money needed to cover treatment expenses. Most legislative measures encourage resource recovery through recycling and protection against the negative effects of human health and environmental contamination at the end of a product's life. E-waste volume reduction and significant repair and reuse of EEE have thus far been confined. This is consistent with worldwide legislative initiatives to advance the recycling industry.

CONCLUSION

The recycling trend is significant from the standpoint of maximizing precious metals recovery and minimizing environmental damage. Noble metal separation can potentially be an economic engine for sustainable growth. Historically, pyro-metallurgy has been applied to retrieve valuable metals from e-waste. This research on e-waste has improved our knowledge of the amount of e-trash produced by the fast-improving world. The huge amount of e-trash has caused degradation of the environment and food chains, shortage of minerals and nutrients, and impact on human health. The process emits harmful dioxin fumes that negatively affect the ecosystem. The general rise of electronic gadget users and the global economy has increased the amount of electronic garbage worldwide during the previous few decades.

However, e-waste and its continued use in the present and future can not be ignored. But all e-waste cannot be ignored. This study also reveals some recycling techniques for e-waste. But all e-waste cannot be composted or recycled, and some waste will be landfilled. That landfilled e-waste can be used in energy generation.

If the growing amount and flow of electronic garbage are not handled soon, it will undoubtedly negatively affect the environment and people. The supply of easily extractable materials, notably metals, declines as more PCBs are disposed of in landfills, disrupting the entire material cycle. Reprocessing of e-trash is still motivated by the high economic worth and presence of a base and precious metals in PCB. There is an immediate need for new, ecologically acceptable methods to recycle and recover energy elements from waste PCBs since PCBs' current manufacturing and handling are not sustainable. As shown by the thorough assessments of the alternative treatments, the processing and recycling of PCB is a complex problem. Engineers, politicians, and other sectors must collaborate to close the loopholes and create a more cost-effective and ecologically pleasant recycling process.

Waste control progressively shifts from a "reduction of waste" focus to a "sustainable materials policy" objective that views certain wastes as resources. The literature review highlights environmental circumstances, governance structures, and policy perspectives, advancing waste management toward the ecological agenda's emphasis on resource and material systems theory. Each time, the trash unit was combined with an environmental agency, demonstrating the advantages of incorporating trash management into a larger viability initiative. The value may be obtained from considering the instances as synergistic garbage and materials administration improvements, feasible at various levels of governance instead of examining them in opposition to one another. San Francisco's Zero Waste project illustrates building a superior recycling approach through landfill reduction (Silva et al. 2017). The e-waste dump should be considered a significant source of additional raw resources related to the circular economy. The need to enhance secondary asset mining and lessen the demand for virgin materials has arisen due to problems with primary mining, market rate changes, material shortage, affordability, and accessibility. Countries might reduce their material consumption safely and sustainably by recycling their electronic trash.

There has been a great deal of e-waste research recently due to nations and academics' rising concern for environmental protection. Due to a strong positive correlation between the series of studies and the year of publication, we may expect e-waste research to expand in the next few years.

REFERENCES

Baldé, C.P., Forti, V., Gray, V., Kuehr, R. and Stegmann, P. 2017. The Global E-Waste Monitor 2017: Quantities, Flows, And Resources. United Nations University, International Telecommunication Union, and International Solid Waste Association.

BBC 2016. The rise of miniature 'microfactories'. https://www.bbc.com/future/article/20161117-the-rise-of-miniature-microfactories

Borthakur, A. 2020. Policy approaches on e-waste in the emerging economies: A review of the existing governance with special reference to India and South Africa. J. Clean. Prod., 252: 119885.

Brianna, Aldrich 2022. Emissions from e-waste spiked 53% in 6 years. https://www.gcn.com/emerging-tech/2022/10/emissions-e-waste-spiked-53-6-years/379043/

Castro, F.D. and Bassin, J.P. 2022. Electronic waste: Environmental risks and opportunities. Hazard. Waste Manag., 11: 421-458.

Chi, X., Streicher-Porte, M., Wang, M.Y. and Reuter, M.A. 2011. Informal electronic waste recycling: A sector review with special focus on China. Waste Manag., 31(4): 731-742.

Chung, S.W. and Murakami-Suzuki, R. 2008. A comparative study of e-waste recycling systems in Japan, South Korea, and Taiwan from

the EPR perspective: implications for developing countries. Kojima. Chiba, 21: 11-23.
Cucchiella, F., D'Adamo, I., Koh, S.L. and Rosa, P. 2015. Recycling of WEEEs: An economic assessment of present and future e-waste streams. Renew. Sustain. Energy Rev., 51: 263-272.
Cui, J. and Zhang, L. 2008. Metallurgical recovery of metals from electronic waste: A review. J. Hazard. Mater., 158(2-3): 228-256.
Delcea, C., Crăciun, L., Ioanăș, C., Ferruzzi, G. and Cotfas, L.A. 2020. Determinants of Individuals' E-Waste Recycling Decision: A Case Study from Romania. Sustainability, 12(7): 2753.
Dhir, A., Koshta, N., Goyal, R.K., Sakashita, M. and Almotairi, M. 2021. Behavioral reasoning theory (BRT) perspectives on E-waste recycling and management. J. Clean. Prod., 280: 124269.
Ding, Y., Zhang, S., Liu, B., Zheng, H., Chang, C. C. and Ekberg, C. 2019. Recovery of precious metals from electronic waste and spent catalysts: A review. Resources, conservation and recycling, 141: 284-298.
FICCI Circular Economy Report, 2017. Accelerating India's Circular Economy. https://ficci.in/spdocument/22977/FICCI-Circular-Economy.pdf
Forti, V., Baldé, C.P., Kuehr, R. and Bel, G. 2020. The global e-waste monitor 2020. Quantities, flows, and the circular economy potential, UN. Bonn, Geneva, pp. 1-119.
Gao, Y., Ge, L., Shi, S., Sun, Y., Liu, M., Wang, B. and Tian, J. 2019. Global trends and future prospects of e-waste research: a bibliometric analysis. Environ. Sci. Pollut. Res., 26(17): 17809-17820.
Garg, C. P. 2021. Modeling the e-waste mitigation strategies using Grey-theory and DEMATEL framework. J. Clean Prod., 281: 124035.
He, P., Feng, H., Chhipi-Shrestha, G., Hewage, K. and Sadiq, R. 2022. Life Cycle Assessment of e-Waste–Waste Cellphone Recycling. In Holuszko, M.E., Kumar, A. and Espinosa, D.C.R. (eds), Electronic Waste: Recycling and Reprocessing for a Sustainable Future, Wiley, NY, pp. 231-253.
Huo, X., Peng, L., Xu, X., Zheng, L., Qiu, B., Qi, Z. and Piao, Z. 2007. Elevated blood lead levels of children in Guiyu, an electronic waste recycling town in China. Environ. Health Persp., 115(7): 1113-1117.
Ilankoon, I.M.S.K., Ghorbani, Y., Chong, M.N., Herath, G., Moyo, T. and Petersen, J. 2018. E-waste in the international context: A review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery. Waste Manag., 82: 258-275.
Islam, A., Ahmed, T., Awual, M.R., Rahman, A., Sultana, M., Abd Aziz, A. and Hasan, M. 2020. Advances in sustainable approaches to recover metals from e-waste-A review. J. Clean. Prod., 244: 118815.
Kang, H.Y. and Schoenung, J. M. 2005. Electronic waste recycling: A review of US infrastructure and technology options. Resour. Conserv. Recycl., 45(4): 368-400.
Kiddee, P., Naidu, R. and Wong, M.H. 2013. Electronic waste management approaches: An overview. Waste Manag., 33(5): 1237-1250.
Leung, A., Cai, Z.W. and Wong, M.H. 2006. Environmental contamination from electronic waste recycling at Guiyu, southeast China. J. Mater Cycl. Waste Manag., 8(1): 21-33.
Li, H., Pan, Y., Wu, F., Zhou, Y. and Pan, J. 2022. Turning waste into wealth: efficient and rapid capture of gold from electronic waste with thiourea functionalized magnetic core stirring rod adsorbent and its application for heterogeneous catalysis. Green Chem., 24(19): 7592-7601.
Li, W. and Achal, V. 2020. Environmental and health impacts due to e-waste disposal in China–A review. Sci. Total Environ., 737: 139745.
MeitY 2021. Circular Economy In Electronics And Electrical Sector. https://www.meity.gov.in/writereaddata/files/Circular_Economy_EEE-MeitY-May2021-ver7.pdf
Niu, R., Wang, Z., Song, Q. and Li, J. 2012. LCA of scrap CRT display at various scenarios of treatment. Proced. Environ. Sci., 16: 576-584.
Onete, C. B., Albăstroiu, I. and Dina, R. 2018. Reuse of electronic equipment and software installed on them–an exploratory analysis in the context of circular economy. Amfiteatru Economic, 20(48): 325-339.
Panda, R., Jadhao, P.R., Pant, K.K., Naik, S.N. and Bhaskar, T. 2020. Eco-friendly recovery of metals from waste mobile printed circuit boards using low-temperature roasting. J. Hazard. Mater., 395: 122642.
Parajuly, K., Fitzpatrick, C., Muldoon, O. and Kuehr, R. 2020. Behavioral change for the circular economy: A review with a focus on electronic waste management in the EU. Resourc. Conserv. Recycl., 6: 100035.
Perkins, D.N., Drisse, M.N.B., Nxele, T. and Sly, P.D. 2014. E-waste: a global hazard. Annals Glob. Health, 80(4): 286-295.
PIB 2018. E-Waste Management Rules amended for effective management of E-Waste in the country: Union Environment Minister. https://pib.gov.in/newsite/PrintRelease.aspx?relid=177949
Ranjbari, M., Esfandabadi, Z.S., Shevchenko, T., Chassagnon-Haned, N., Peng, W., Tabatabaei, M. and Aghbashlo, M. 2022. Mapping healthcare waste management research: Past evolution, current challenges, and future perspectives towards a circular economy transition. J. Hazard. Mater., 422: 126724.
Rao, M.D., Singh, K.K., Morrison, C.A. and Love, J.B. 2021. Recycling copper and gold from e-waste by a two-stage leaching and solvent extraction process. Sep. Purif. Technol., 263: 118400.
Ravindra, K. and Mor, S. 2019. E-waste generation and management practices in Chandigarh, India and economic evaluation for sustainable recycling. J. Clean. Prod., 221: 286-294.
Rizos, V. and Bryhn, J. 2022. Implementation of circular economy approaches in the electrical and electronic equipment (EEE) sector: Barriers, enablers, and policy insights. J. Clean. Prod., 338: 130617.
Sahajwalla, V. and Gaikwad, V. 2018. The present and future of e-waste plastics recycling. Curr. Opinion Green Sustain. Chem., 13: 102-107.
Sengupta, D., Ilankoon, I.M.S.K., Kang, K.D. and Chong, M.N. 2022. Circular economy and household e-waste management in India: Integration of formal and informal sectors. Minerals Eng., 184: 107661.
Senthilselvi, A., Sellam, V., Alahmari, S.A. and Rajeyyagari, S. 2020. Accuracy enhancement in mobile phone recycling process using machine learning technique and MEPH process. Environ. Technol. Innov., 20: 101137.
Shen, L., Shuai, C., Jiao, L., Tan, Y. and Song, X. 2017. Dynamic sustainability performance during the urbanization process between BRICS countries. Habitat Int., 60: 19-33.
Silva, A., Rosano, M., Stocker, L. and Gorissen, L. 2017. From waste to sustainable materials management: Three case studies of the transition journey. Waste Manag., 61: 547-557.
Singh, N., Duan, H. and Tang, Y. 2020. Toxicity evaluation of E-waste plastics and potential repercussions for human health. Environ. Int., 137: 105559.
Solé, M., Watson, J., Puig, R. and Fullana-i-Palmer, P. 2012. Proposal of a new model to improve the collection of small WEEE: A pilot project for the recovery and recycling of toys. Waste Manag. Res., 30: 1208-1212.
Song, Q., Wang, Z. and Li, J. 2013. Sustainability evaluation of e-waste treatment based on emergy analysis and the LCA method: a case study of a trial project in Macau. Ecol. Indic., 30: 138-147.
Statista 2020. Electronic waste generated worldwide from 2010 to 2019 (in million metric tons). https://www.statista.com/statistics/499891/projection-ewaste-generation-worldwide/
USGS 2017. Mineral commodity summaries 2017: U.S. Geological Survey, 202 p., https://doi.org/10.3133/70180197.
Vikaspedia 2016. E-Waste Management Rules, 2016. https://vikaspedia.in/energy/environment/waste-management/e-waste-management/e-waste-management-rules-2016