Waste Management Bulletin 1 (2024) 41–51

Contents lists available at ScienceDirect

Waste Management Bulletin

journal homepage: www.elsevier.com/locate/wmb

Electronic waste (E-waste) generation and management scenario of India, and ARIMA forecasting of E-waste processing capacity of Maharashtra state till 2030

Wasim Ayub Bagwan

School of Rural Development, Tata Institute of Social Sciences, Tuljapur 413601, Maharashtra, India

ARTICLE INFO

Keywords:
ARIMA
Circular economy
E-waste
E-waste processing
Recycling
Sustainable Development Goals

ABSTRACT

This article addresses a critical environmental issue largely attributed to Gen-Z, namely Electronic waste (E-waste). The modern human lifestyle has significantly impacted waste management, with new technological advancements posing both environmental challenges and economic opportunities. E-waste, generated due to the disposal or end-of-life of electronic products, is now one of the fastest-growing domestic waste streams. Proper E-waste management and monitoring are essential for achieving maximum resource utilization and reducing the adverse impacts of E-waste, in line with the Sustainable Development Goals. India has laws and legislation in place to ensure the safe handling, management, and treatment of E-waste, with the pollution control board serving as the monitoring and tracking authority. This study focuses on the state of Maharashtra, investigating past and future trends using Auto Regressive Integrated Moving Average (ARIMA) models, commonly used in time series analysis and forecasting. The study predicts that the average E-waste processing capacity (recycling/dismantling) from 2023–2030 will be 163563.15 MT (metric tons), with forecasted values increasing steadily over the years, reaching 248 recyclers by the year 2030. By analysing rate of change in E-waste processing capacity from 2023–2030, there will be chances of 6.86 % annually. This is also highlighting the scope of entrepreneurship in E-waste recycling industries by detecting average expansion of recyclers by 7.23 % per year. The study emphasizes the significant role of policy and decision-making in managing this rapidly growing waste stream from an environmental management and circular economic perspective.

Introduction

Innovations in material science and technology have led to the development of feature-rich consumer products that are challenging to recycle using current technologies. As a result, these products often end up in landfills or incineration plants instead of being recycled (Sahajwalla and Hossain, 2023). The circular economy (CE) is an intentional and designed industrial system that aims to be restorative and regenerative. It replaces the concept of end-of-life with restoration and regeneration, embraces the use of renewable energy, eliminates the use of harmful chemicals that hinder reuse and return to the environment, and strives to eliminate waste through innovative material design, product development, system implementation, and business model creation (MeitY, 2021a). Advancement in technology generates many Electrical And Electronic Equipment (EEE) products in the market and, due to traditional economic methods, EEE-waste has become a massive stream, creating many issues in the world (Ramanayaka et al., 2020). India is one of the largest electronics consumer markets in the Asia-Pacific region. India emerges as the leader in Electronic System Design and Manufacturing (ESDM) across the globe. India's share of the global electronic system manufacturing industry has grown from 1.3 % in 2012 to 3.6 % in 2019 (Invest India. 2022a). Electronic gadgets are made to make human life simpler and happier, but their disposal and recycling pose a threat to the human environment because of the presence of toxic substances in them (Needhidasan et al., 2014). According to the Basal convention, wastes are objects or substances that are disposed of, intended to be disposed of, or are required to be disposed of by the provision of national law (Basal convention, 1999). Electrical and

Abbreviations: ARIMA, Auto Regressive Integrated Moving Average; E-waste, Electronic waste; EPR, Extended Producer Responsibility; WEEE, Waste Electrical and Electronic Equipment; CPCB, Central Pollution Control Board; ISWA, International Solid Waste Association; MPCB, Maharashtra Pollution Control Board; MeitY, Ministry of Electronics and Information Technology; MoEFCC, Ministry of Environment, Forest and Climate Change.

E-mail address: wasim.bagwan16@gmail.com.

https://doi.org/10.1016/j.wmb.2023.08.002

Available online 18 August 2023

electronic equipment (EEE) has become an essential component of modern life. Because of its wide range of applications and availability, it enabled the global population to enjoy a higher standard of living. However, the manner in which it is produced, used, and disposed of is unsuitable and generates E-waste (Forti et al., 2020). E-waste comes from basic kitchen appliances to computers to smart phones. Also, these come from transport, security systems, energy supply, and health facilities. This equipment is part of modern human society (Parajuly et al., 2019). The rapid growth of technology, the upgradation of technological innovation, and the growing rate of obsolescence in the electronic industry have led to the fastest generation of E-waste, which thus focuses on the Life Cycle Impact Assessment and End-of-Life solutions (Bhagat-Ganguly, 2021). Technological advancement has changed the nature of E-waste over the decades. The current economy is based on the linear principle that follows the "take-make-dispose" order. The Government of India's Ministry of Electronics and Information Technology (MeitY) established an E-waste awareness programme to raise awareness at various levels of society with the goal of reducing negative environmental and health impacts caused by polluting technology used in recycling e-waste in an unrecognised sector (MeitY, 2021b). The recycling of E-waste has multiple benefits, including its positive impact on the environment and the potential to create job opportunities for impoverished rural communities. The Indian government has recognized the importance of scientifically recycling E-waste (Swachh Digital) as a component of the Swachh Bharat initiative (Parthsarathy and Bulbule, 2017). The present study focuses on the E-waste generation in India and trend analysis and recycling data the fluctuations at national level. Further, the study was also intended to investigate the role of E-waste recycling/dismantling capacity and number of recyclers of E-waste in Maharashtra state and forecasting by using ARIMA equation till 2030. E-waste recycling capacity forecasting involves predicting future capacity requirements for recycling E-waste, technological advancements, policies, and market trends. Furter, it will help for stakeholders to plan and allocate resources effectively to meet the growing demand for E-waste recycling in a sustainable manner.

Search for literature

The present study is based on scientific data collection of E-waste generated in India and recycling capacity, E-waste collection, E-waste recycled/dismantled and material recovered from it in Maharashtra state. Reference retrieved using structured keywords from online platform including Scopus and Web of science, with searching the articles published on "Electronic waste", "E-waste", "Waste Electrical and Electronic Equipment (WEEE", "Circular Economy", and so on. E-waste related books, proceedings, comments, reports, review articles, research papers from peer-reviewed journals from the publishers like Nature, Elsevier, Springer, Taylor and Francis, Wiley etc. has been considered to carry out the literature survey. Considering the objectives of the present study, the annual reports available on public domain of Central Pollution Control Board and Maharashtra Pollution Control board, Directorate of Economics and Statistics of Maharashtra state annual reports has been collected and the necessary data was used for the forecasting of E-waste capacity.

Literature review

E-waste generation and management scenario in India

Since 2011, India has been the only country in South Asia with a dedicated E-waste regulation in effect. The E-waste rules, formerly known as the E-waste (Management and Handling) Rules, established requirements for trash transportation, storage, and recycling, as well as the idea of Extended Producer Responsibility (EPR) (Jain and Tarun, 2021). Only authorised dismantlers and recyclers have been allowed to gather E-waste. The E-Waste (Management) Rules 2016 covered a manufacturer, a dealer, a refurbishers, and a Producer Responsibility Organization (PRO) (Forti et al. 2020). According to Global E-waste Monitor report 2014, India shares 1.7 Mt (million metric tonnes) of E-waste, this constitute 10.62 % of the Asia's E-waste generations (Baldé et al., 2015). In India's largest cities, the formal E-waste recycling business is currently being created. Informal recycling activities, on the other hand, have existed for a long time in India, with over 1 million poor people participating in manual recycling operations. The majority of these people have relatively low literacy levels and are unaware of the treatment plans' hazards. In the year 2016, India's E-waste shares contributes 11.11 % of Asia's E-waste generation (Baldé et al., 2017). After the United States, China, Japan, and Germany, India is rated fifth in the world among top E-waste producing countries, recycling less than 2% of the total E-waste it generates annually. Since 2018, India has produced over two million tonnes of E-waste per year and imports massive volumes of E-waste from other countries (Manish and Chakraborty, 2019). In India, the formal E-waste recycling sector is regulated by the Central Pollution Control Board (CPCB) and employs educated and trained individuals. It consists of authorised and registered recycling centres across India that process E-waste without harming the environment. No government agency has authorised the informal E-waste recycling business, and no laws or regulations are observed. It employs low-wage, uneducated men, women, and children from slum areas as E-waste handlers. They make a living by retrieving metals using dangerous techniques and practises that pollute the environment and pose occupational health risks to themselves and others (Dutta and Goel, 2021).

Study area

The Fig. 1 shows the location of Maharashtra state in India. It covers 307713 km^2. The state lies in the western and central peninsular regions of India, covering a substantial part of the Deccan Plateau. It has a 720-kilometer coastline along the Arabian Sea and is fortified by the Western Ghats and Satpuda mountain ranges. From administrative convenience point of view, the state has been divided into 36 districts and six revenue divisions. The urban population makes up 45.2 percent of the total. The state has a pioneering role in changing the business environment by adopting various measures to enhance the "Ease of Doing Business". The newly launched scheme of Start-Up policy is being initiated by innovative and creative industrial sectors which aims at giving institutional and intellectual support for new budding entrepreneurs. Maharashtra is the third-most populous state with a projected total population (2020) of 123,144,223 people. (https://uidai.gov.in/images/state-wise-aadhaar-saturation.pdf). Accessed on Jan. 29, 2022.

Material and methodology

Data

For the present study, secondary data inputs in the form of E-waste annual reports have been used by MPCB (Source: https://mpcb.gov.in/waste-management/electronic-waste Accessed on December 30, 2021. The CPCB published annual reports (https://cpcb.nic.in/annual-report.php) accessed on 10 Feb 2022, included the numerical data of E-waste recycled and its capacity. The list of dismantlers has been downloaded from the CPCB website (Source: https://cpcb.nic.in/e-waste-recyclers-dismantler/ Accessed on May 18, 2023. Electronic waste data was collected from annual reports from 2013 to 2022 published by the Directorate of Economics and Statistics, Planning Department, Government of Maharashtra, https://mahades.maharashtra.gov.in/publications.do?pubId=ESM [Accessed on the 11 January 2022]. To showcase the E-waste generation and process status across the India, E-waste management system portal was accessed (Link: https://eprewastecpcb.in/dashboard-guest, Accessed on 10 June 2023).

Fig. 1. Location of Maharashtra state in India.

Methodology

The role of circular economy in E-waste management

The UN report stated that, the global amount of E-waste is predicted to increase; there is an increasing urgency to encourage recycling, urban mining and a circular economy. The presence of hazardous compounds and scarce and valuable elements in E-waste necessitates recycling and treating it in an environmentally sound manner. By doing so, we may avoid the discharge of harmful substances into the environment as well as the loss of environmentally and economically valuable resources (Megget, 2021).There are four economic benefits to recycling E-waste. First, the recovery of E-waste is worth an estimated £48 billion, and based on its value, the recovered rare metals like gold, silver, palladium, and others like copper, iron, etc. Second, the concentration of metals from the E-waste stream is considerably higher as compared to traditional mining. Third, E-waste contains rare natural elements like gallium and indium, which have potential use. And finally, the E-waste processing industry provides employment opportunities by creating jobs at its various states of management (Kazancoglu et al., 2020). The emerging role of the circular economy arose from the consumption of natural resources in a more efficient, sustainable, and comprehensive manner. Circular economy in the field of electronics can provide more environmental and health benefits, such as reducing climatic change through resource optimization by shifting substandard E-waste management to high-standard recycling, removing hazardous waste, replacing virgin material and new production with recycled content, and extending product life (PACE, 2021). The adoption of a circular economy approach can effectively address climate change by enhancing resource efficiency, reducing inputs, and minimizing emissions (Yang et al., 2023).

India's picture of E-waste generation and recycling with connection to SDG

E-waste, containing toxic metals like lead, mercury, cadmium, and more, poses risks to soil and water ecosystems when improperly disposed. Effective management requires employing proper metal extraction methods and careful dismantling with component segregation based on their chemical properties (Rajesh et al., 2022). A better understanding of E-waste, as well as more data, will help to accomplish various goals of the 2030 Agenda for Sustainable Development. It will contribute to achieving the SDGs for environmental protection and health. It will also address employment and economic growth, as proper e-waste treatment can lead to new job opportunities and entrepreneurship. Goal 3 (Good health and well-being), Goal 6 (Clean water and sanitation), Goal 11 (Sustainable Cities and Communities), Goal 12 (Responsible Consumption and Production), Goal 14 (Life Below Water), and Goal 8(Decent Work and Economic Growth) are all linked to a better knowledge management of E-waste (Baldé et al., 2017).E-waste is treated in a way that protects human health and the environment from any negative consequences that may arise from it. Based on sales data from 1380 companies, the CPCB has estimated the approximate E-waste generation for the financial year 2019–20 to be 1014961.213 tonnes. There are 312 authorized Dismantlers/Recyclers with an annual processing capacity of 782080.62 tonnes. The amount of E-Waste dismantled/ recycled in the country during Financial Year 2019–20 was 164,663 tonne, according to annual reports submitted by 32 SPCBs/ PCCs (MoEFCC, 2021). Targeting to SDG 12.5: By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse; the quantity of hazardous waste recycled/ utilized to total hazardous waste generation (%), the value of respected target was computed (NITI Aayog, 2021). Table 1 shows the installed capacity of recycling at state and Union Terriory level in metric tons (MT). Table 2 shows the E-waste Generation and Processed data for the years 2017–18 to 2020–21 in India (Source: Source: https://eprewastecpcb.in/dashboard-guest [Accessed on 19 May 2023].

Table 1
E-waste handling capacity of states and UTs of India in 2023. (Source: CPCB, May 2023).

Name of the states	Installed Capacity Metric tons per annum (MTA)
Andhra Pradesh	44002.5
Assam	120
Chhattisgarh	6750
NCT of Delhi	1989
Gujarat	128604.92
Goa	153
Haryana	128837.67
Himachal Pradesh	1500
Jammu & Kashmir	705
Jharkhand	660
Karnataka	126015.48
Maharashtra	118031.5
Kerala	1200
Madhya Pradesh	13,600
Punjab	10,092
Odisha	9050
Rajasthan	82007.67
Tamil Nadu	130,636
Telangana	148,115
Uttar Pradesh	624219.47
Uttarakhand	153068.06
West Bengal	2640
Andaman & Nicobar Island	INP
Arunachal Pradesh	INP
Bihar	INP
Chandigarh	INP
Dadara & Nagar Havelli	INP
Daman & Diu	INP
Lakshadweep	INP
Manipur	INP
Meghalaya	INP
Mizoram	INP
Nagaland	INP
Puducherry	INP
Sikkim	INP
Tripura	INP

Note: Jammu and Kashmir (UT) and Ladakh (UT) data is combinely provide. INP: Information not provided.

Table 2
E-waste Generation and Processed data for the years 2017–18 to 2020–21 in India (Source: Source: https://eprewastecpcb.in/dashboard-guest [Accessed on 19 May 2023].

E-waste management components	2017–18	2018–19	2019–20	2020–21
E-waste generation in India	708,445	771,215	1,014,961	1,346,496
E-waste processed in India	69413.61	164,663	224,041	354540.7
Hazardous waste recycling indicator (%)	9.80	21.35	22.07	26.33

$$\text{Hazardous waste Indicator Value in } (\%) = \frac{\textit{Quantity of hazardous waste recycled or utilized in MT}}{\textit{Total quantity of hazardous waste generated in MT}} \times 100 \quad (1)$$

Installed E-waste recycling capacity and its forecast

There are three basic reasons to recycle: a) economic benefits; b) environmental benefits; and c) social benefits. b) environmental advantages; c) benefits to public health and safety (Kumar et al., 2017). E-waste is a good source of rare earth metals and plastics. Such non-biodegradable waste in the environment acts as a pollutant if mishandled (Zhang et al., 2012). Whereas the negative side of E-waste is that when inadequately treated, it poses a serious threat to public health and environmental segments like air, water, and soil as it contains hazardous components (Baldé et al., 2017). Maharashtra state has played a crucial role in building and increasing its capacity for recycling E-waste material. The data collected from the Directorate of Economic and Statistics from 2014 to 2022 shown in Table 3 indicates that, the state has exponential growth in its waste recycling capacity.

E-waste and legislation

Around the world, legislation is a key to create and implement effective and sustainable E-waste collection, recycling, and transportation methods. Many countries in the world are facing the challenge of huge piles of E-waste. So, countries have adopted the E-waste management laws and regulations have been strictly implemented in India as it was formed in 2011 (MeitY, 2022). E-Waste (Management) Rules: The E-Waste (Management) Rules, 2016 (MoEF&CC, 2016) were passed on March 23, 2016, and their scope has been expanded to include manufacturers, dealers, refurbishers, E-retailers, and Producer Responsibility Organizations (PROs) in order to address E-waste leakage to the informal sector at any point along the supply chain. It also includes a measure for Extended Producer Responsibility (EPR) (MoEFCC, 2021). Last year, in 2022, Indian central government come up with E-waste (Management) Rules 2022 (eprewastecpcb.in, 2023). This guides further responsibilities for EPR about E-waste handling, refurbishing, storage, and management of solar PV waste, and plastic waste management etc.

Urban mining and recycling of E-waste

In the absence of a proper mechanism and standard of disposal, toxic-laden high-tech E-waste often ends up as solid waste, either by recycling or landfill (Mundada et al., 2004).The electronics market in India is one of the world's fastest expanding sectors. In India's largest cities, the formal E-waste recycling business is currently being created (Baldé et al., 2017). By recycling waste material, environmental protection is achieved as E-waste is not used for landfill activity and the environmental hazard related to disposal is minimised (Kumar et al., 2017). Recovery of precious metals and base metals from EEE waste is simply urban mining. Urban mining saves landfilling of E-waste, extraction of mineral resources and industrial practises (Ramanayaka et al., 2020). Table 3 show the E-waste recycling/dismantling capacity in MT of Maharashtra State from 2014 to 2022. E-waste is considered as a potential source for expanded business opportunities because it is one of the secondary resources for many metals and non-metals. According to

Table 3
E-waste recycling capacity of recyclers/dismantlers in Maharashtra state from 2014 to 2022.

Report name	Period considered for Recycling capacity	E-waste dismantling / recycling capacity in MT	Number of Recyclers
Economic Survey of Maharashtra 2014–15	E-waste recycling capacity 2013–14	35,310	24
Economic Survey of Maharashtra 2015–16	E-waste recycling capacity 2014–15	48,060	32
Economic Survey of Maharashtra 2016–17	E-waste recycling capacity 2015–16	55,410	38
Economic Survey of Maharashtra 2017–18	E-waste recycling capacity 2016–17	74,650	64
Economic Survey of Maharashtra 2018–19	E-waste recycling capacity 2017–18	77,525	78
Economic Survey of Maharashtra 2019–20	E-waste recycling capacity 2018–19	63,879	73
Economic Survey of Maharashtra 2020–21	E-waste recycling capacity 2019–20	85,800	99
Economic Survey of Maharashtra 2021–22	E-waste recycling capacity 2020–21	89,355	111
Economic Survey of Maharashtra 2022–23	E-waste recycling capacity 2021–22	117,392	136

estimates, the global E-waste output is in high demand, and when properly treated, it contributes to the country's economic growth and eliminates the need for virgin raw materials mining (Arya and Kumar, 2020). Table 4 is showing E-waste received, recycled and material recovered from the dismantlers/recyclers in Maharashtra state from 2018 to 19 to 2021–22.

E-waste generation forecasting by using ARIMA and tracking change

It was observed that in countries with functioning E-waste recycling markets like India, There were well-established formal and informal economies that were closely linked with each other. The formal economy operated mostly in the processing stage of the value chain, and could hardly compete with the informal sector in the stages of collection, dismantling, and preprocessing. Moreover, it found that the informal sector was more organised than was commonly perceived and was slowly moving towards formalisation (ILO, 2014). Based on this obsolescence rate and installed base, India's E-waste inventory for 2005 was estimated to be 146180.00 tonnes (CPCB, 2008). The E-waste stream in India has been amplified by five times in seven years and is expected to reach up to 8,00,000 tonnes by the year 2012 (Agoramoorthy and Chakraborty, 2012). According to a report published by sdgindex.org India E-waste generation per capita is 2.4 kg (sdgindex, 2021). As per the reports of CPCB, in the year 2018–19, total 69,414 MT was recycled and as per the annual report of the year 2019–20, 1,64,663 MT of E-waste has been successfully recycled. Based on the E-waste processing capacity data, the future condition till 2030 was predicted by using 'forecast' package in R Studio platform (Hyndman et al., 2023; Hyndman and Khandakar, 2008). ARIMA (Auto Regressive Integrated Moving Average) is a time series forecasting model that can be used to make predictions based on historical data. It is a popular and widely-used model that can be very effective for forecasting time series data. A review conducted by Kaur et al., (2023) reflects that, there exists a strong correlation between ARIMA and the environment, with forecasting being essential in various environmental fields, including pollution studies. ARIMA processes, which are stochastic techniques, are employed to analyze the behavioral patterns in time series data.

$$y(t) = c + \phi(1)y(t-1) + \cdots + \phi(p)y(t-p) - \theta(1)e(t-1) - \cdots - \theta(q)e(t-q) + e(t) \tag{2}$$

Where, $_{(t)}$ is the value of the time series at time t, c is a constant (or intercept),$\phi_{(1)}, \ldots, \phi_{(p)}$ are the autoregressive parameters of the model, $_{(t-1)}, \ldots, y_{(t-p)}$ are the lagged values of the time series, $\theta_{(1)}, \ldots, \theta_{(q)}$ are the moving average parameters of the model, $e_{(t-1)}, \ldots, e_{(t-q)}$ are the lagged errors of the model (residuals), $e_{(t)}$ is the error (residual) at time t, which is assumed to be normally distributed with mean 0 and constant variance. The parameter d in $ARIMA_{(p,d,q)}$ specifies the degree of differencing required to make the time series stationary. If $d > 0$, the time series is differenced d times to make it stationary before applying the $ARMA_{(p,q)}$ model. A study conducted by Rashmi and Sathish Kumar (2022) utilized the ARIMA model for forecasting future waste growth, offering crucial insights to improve waste management practices in the smart city of Bengaluru. This model has applicability in bio-medical waste also, a study by Chauhan and Singh (2017) has done ARIMA forecasting proves to be a valuable tool for healthcare waste treatment firms in the sector, enabling improved planning and infrastructure development. To track the change in E-waste recycling capacity following formula was used.

$$Rate\ of\ change\ (\%) = [(Current\ Value - Previous\ Value)\ /\ Previous\ Value] \times 100 \tag{3}$$

Where: "Current Value" is the value of the variable at the end of the time period and "Previous Value" is the value of the variable at the beginning of the time period.

Table 4
E-waste received, recycling and material recovery data of Maharashtra state. (Source: MPCB E-waste annual reports).

E-waste management in Maharashtra	2018–19	2019–20	2020–21	2021–22
E-waste received	9475	11033.18	INP	INP
E-waste dismantled/recycled	9139.03	11015.48	14,546	18559.3
Material recovery	5442.48	7750.3	9969	14,344

Note: INP- Information Not Provided.

Results

Visualization of India's E-waste installed capacity and change tracking

Instead of using histogram of state wise distribution of E-waste recycling capacity, Geographical Information System (GIS) based approach has been implemented to map the capacity of each state. From the data collected from CPCB, Fig. 2 was plotted by using online platform- https://app.datawrapper.de/. E-waste regulations are intended to improve the ability to repair and reuse items, as well as recover materials that can be reused in new gadgets, as policy is a fundamental enabler of the circular economy (Althaf et al., 2019). The circular economy potential of each state can be help to identity using the map. Moreover, the parts or region of the country can be easily identified using the same map. Using circular economy in the electronics and E-waste sector might result in the creation of millions of employment around the world (PACE, 2021). E-waste recycling capacities was found highest in Uttar Pradesh with 624,219.47 metric tonnes per annum (MTA), which reflects its ability to process a significant amount of E-waste. Uttarakhand follows closely with a capacity of 153,068.06 MTA. These two states have substantial infrastructure and facilities to manage and recycle E-waste efficiently. Other states like Tamil Nadu, Telangana, Gujarat, and Karnataka also demonstrate considerable E-waste recycling capacities ranging from 130,636 to 148,115 MTA. This suggests that they have invested in robust recycling systems and technologies to address the growing E-waste challenges in their regions. On the other hand, states such as Assam, Goa, Himachal Pradesh, Jammu & Kashmir, Jharkhand, and Kerala have relatively lower capacities, ranging from 120 to 1,500 MTA. These states might have lower levels of E-waste

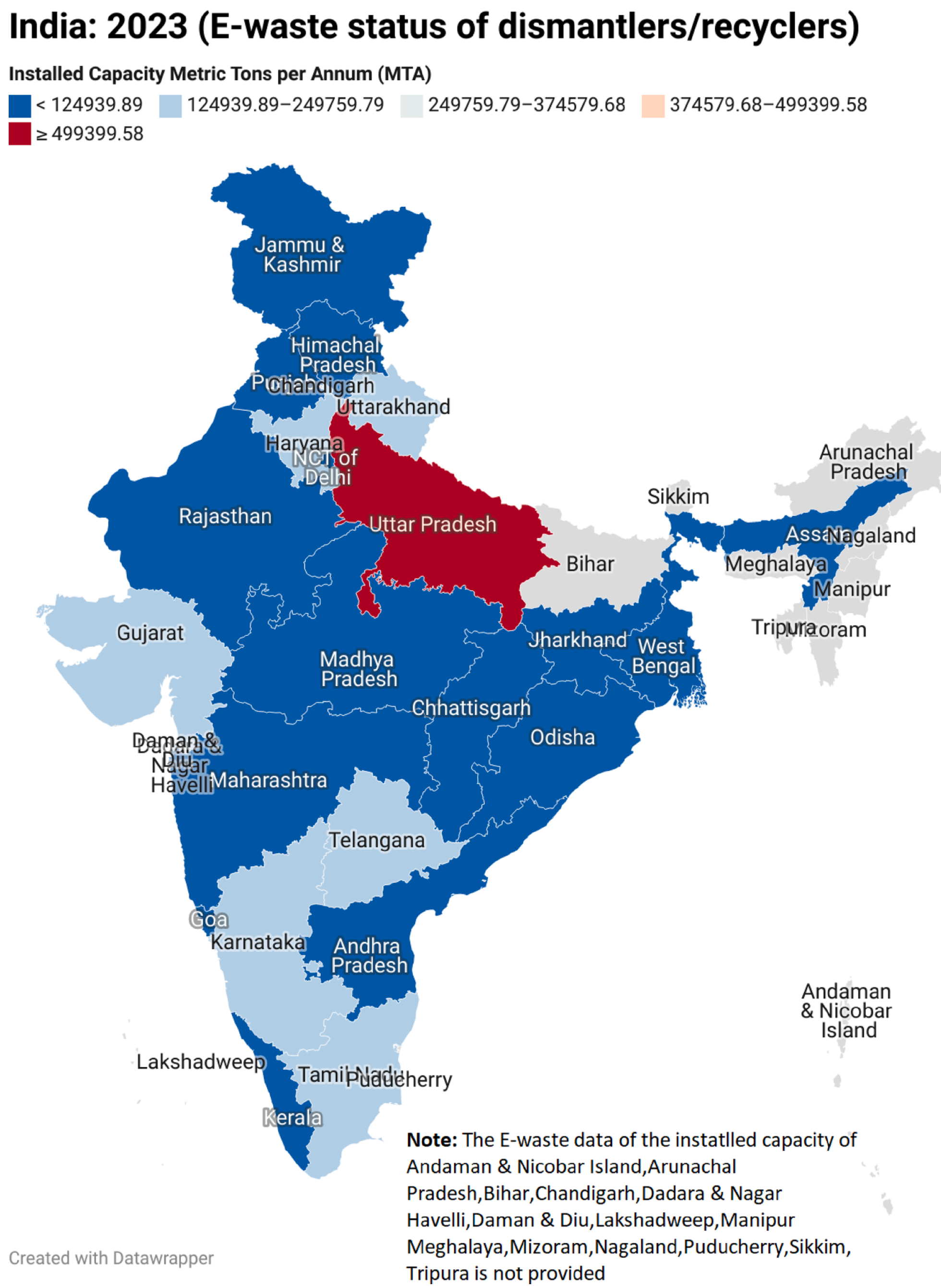

Fig. 2. Installed capacity of E-waste recycling in the states and UTs of India in MTA in 2023. (Map not to scale)

generation or are in the early stages of developing their E-waste recycling infrastructure.

E-waste recycling and its connection with SDG

By proper E-waste recycling the target of SDG 12.5 can be achieved. Recycling is a sustainable practice that ensures safe disposal of hazardous material while promoting the green job and contributing to the circular economy (NITI Aayog, 2021). The average value of SDG 12.5 performance indicator from 2017–2021 that is recycling of hazardous waste is by using Eq. (1) was found 19.88 %. Higher value represents better the performance in the goal of responsible consumption and production. Additionally, the advanced techniques like bioleaching can significantly contributes to SDG target 3.9, 8.3, 8.8, 11.6, 12.4,and 12.5 (Arya and Kumar, 2020). Understanding the possibilities for E-waste recycling and refurbishing operations allows for a forecast of prospective green job development in the recycling and refurbishment sectors (Forti et al., 2020). Based on the data presented in Table 2, it provides information on the quantity of E-waste generated and processed in India from 2017 to 18 to 2020–21, along with the percentage of hazardous waste that underwent recycling. In 2020–21, India produced 1,346,496.31 MT of E-waste, out of which 354,540.7 MT were processed. The hazardous waste recycling indicator reached 26.33%, indicating an improvement in recycling practices. These numbers highlight the increasing concern for E-waste management in India and the efforts being made to reduce the environmental impact of improper and unscientific E-waste disposal by promoting formal sector of E-waste recycling/dismantling. Fig. 3 portrays the E-waste generation and processing in India from 2017 to 2021. The hazardous waste recycling indicator, represented as a percentage, shows the proportion of E-waste processed in the formal sector from 2017 to 18 to 2020–21. The indicator values increased from 9.80% in 2017–18 to 26.33% in 2020–21. This indicates a positive trend in recycling hazardous E-waste in the formal sector. Higher indicator values reflect increased proper processing and recycling of E-waste, leading to reduced environmental impact. These findings highlight advancements in implementing effective recycling measures and promoting sustainable E-waste management practices during the specified period.

ARIMA forecasting of E-waste processing capacity till 2030 in Maharashtra state

Forecasting the E-waste recycling has significance from the waste management strategy. It will give us the glimpse of the possible amount of E-waste that can be recovered. Fig. 4 shows the E-waste recycling/dismantling capacity during 2014–2022. Fig. 5 shows the future trend till 2030 of E-waste processing capacity scenario of Maharashtra State. Table 5 shows the forecasted value till 2030, the recyclers will be reach up to 248 with recycling capacity in 199474.0 MT. The forecast of E-waste processing capacity in Maharashtra state is expected to increase steadily over the next few years. The forecasted E-waste processing capacity for the given period shows an increasing trend. The estimated values gradually rise from 127,652.3 in 2023 to 199,474.0 in 2030. However, the prediction intervals suggest that there is uncertainty around this point estimate, and the actual values could range from 110745.3 to 151654.0 MT (Lo 80% prediction interval) and from 144559.2 to 247294.0 (Lo 95% prediction interval). Considering the lower and upper bounds at different confidence levels, we can observe that the forecasted values have a range of uncertainty. For example, in 2023, there is an 80% confidence that E-waste processing capacity will fall between 110,745.3 and 144,559.2, while at a 95% confidence level, it is expected to be between 101,795.3 and 153,509.2. As we move towards 2030, the uncertainty range widens, indicating greater variability in the forecasted values. For instance, in 2030, there is an 80% confidence that E-waste processing level will be between 151,654.0 and 247,294.0, while at a 95% confidence level, it is expected to fall between 126,339.6 and 272,608.4. Itis important to note that these are forecasts based on historical data and assumptions made by the forecasting model, and the actual values could differ from these predictions due to unforeseen changes or events. A study on micro-computer waste produced at time-series scale done by Yang Yang et al., (2010) was a good indicator of predicting recycling volume of E-waste.

ARIMA forecasting of E-waste recyclers till 2030 in Maharashtra state

As recorded in Table 6, it shows the point forecast and prediction intervals (with 80% and 95% confidence levels) for the number of recyclers in Maharashtra from 2023 to 2030. As displayed in Fig. 6, the E-waste recyclers in Maharashtra from 2014 to 2022.The point forecast indicates the expected value of the number of recyclers for each year, while the prediction intervals give a range of plausible values within the specified confidence levels. The forecasted values suggest an increasing trend in the number of recyclers over the given period. The estimated values gradually rise from 150 in 2023 to 248 in 2030. Considering the lower and upper bounds at different confidence levels, we can observe the range of uncertainty associated with the forecasted values. For example, in 2023, there is an 80% confidence that the number of recyclers will fall between 135.68 and 164.32, while at a 95% confidence level, it is expected to be between 128.10 and 171.90. As we move towards 2030, the uncertainty range widens, indicating greater variability in the forecasted values. For instance, in 2030, there is an 80% confidence that the number of recyclers will be between 207.50 and 288.50, while at a 95% confidence level, it is expected to fall between 186.06 and 309.94. To protect the environment and human health, it is crucial to combine local-level pre-processing technology with globally standardized end processing methods (Awasthi and Li, 2017). It is important to consider these confidence intervals to understand the level of uncertainty associated with the forecasted number of recyclers. These values provide a range within which the actual number of recyclers is likely to fall with a given level of confidence. The forecasting of recycles is portrayed in Fig. 7, the number of recyclers of E-waste in Maharashtra till 2030. Overall, the forecast suggests an increase in the number of recyclers over time, with wider confidence intervals as we move further into the future.Knowing what will happen in the future can aid policymakers, industries, and other stakeholders in making better strategic decisions. Forecasting is also required in relation to strategic concepts for sustainable development, such as the circular economy and the United Nations' Agenda 2030 (Parajuly et al., 2019).

Observing the rate of change in E-waste processing capacity and recyclers

According to the current and forecasted data of E-waste processing capacity and recycles provided in Table 7 and by applying Eq. (3) we can narrate that, the processing capacity of E-waste has been steadily increasing from 2014 to 2021. Each year, the amount of E-waste generated has shown a consistent rise, indicating the growing impact of electronic devices on our environment. Furthermore, utilizing the ARIMA forecasting method, we were able to project E-waste recycling capacity until 2030, revealing a continued upward trend in the volume of E-waste expected in the coming years. To gain further insights, we examined the rate of change in E-waste recycling/dismantling capacity, which represents the annual percentage increase or decrease in the amount of E-waste produced. This analysis demonstrated fluctuating rates of change over the years, illustrating variations in the growth patterns of E-waste processing. On a positive note, the data also reflected an increasing E-waste processing capacity. The rate of change in E-waste processing capacity demonstrated positive trends for most years, indicating a growing ability to handle and recycle E-waste. This emphasizes the importance of implementing efficient waste management systems and promoting recycling initiatives to address the mounting challenge of E-waste. The forecasted data for E-waste processing capacity along with expected recyclers/dismantlers provides valuable insights for researchers and policymakers involved in waste management and environmental sustainability. These projections serve as essential tools for understanding the future challenges and opportunities in E-waste management. They highlight the urgency of implementing effective strategies to manage the growing volume of E-waste, encourage responsible disposal practices, and promote sustainable recycling methods. The data provided represents the number of recyclers of E-waste from 2014 to 2030, along with the corresponding rate of change in each year. Analyzing the data, we observe a gradual increase in the number of recyclers over the years. In 2014, there were 24 recyclers, and by 2022, this number had reached 136, indicating a positive trend in E-

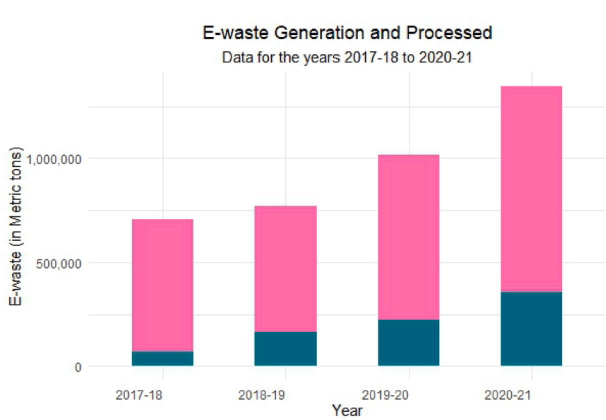

Fig. 3. E-waste generation and processing in India from 2017 to 2021 (Source: https://eprewastecpcb.in/dashboard-guest [Accessed on 19 May 2023]).

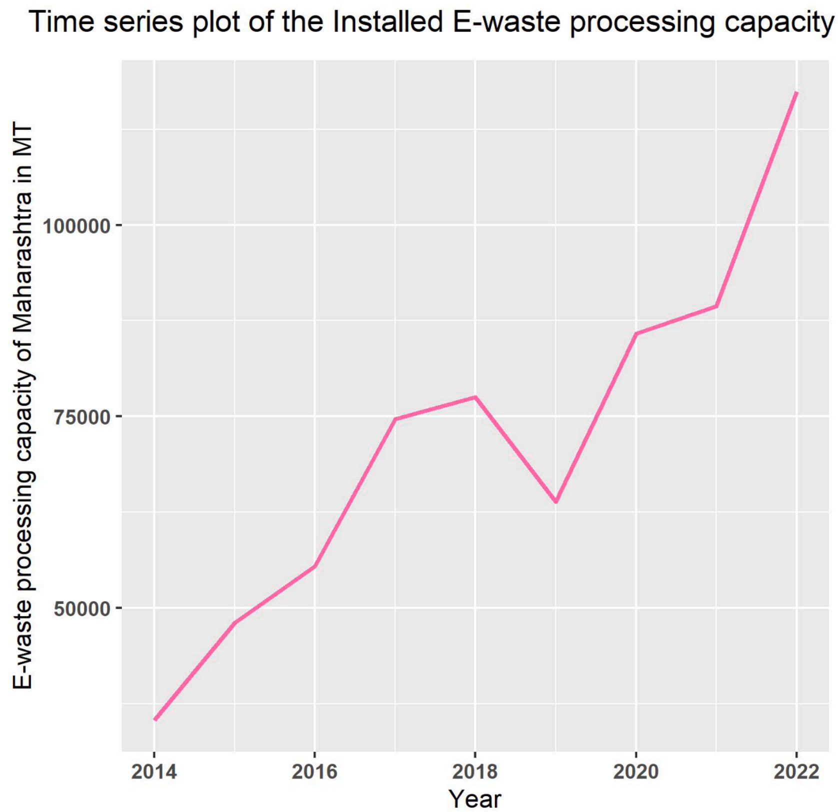

Fig. 4. E-waste recycling/dismantling capacity of Maharashtra state from 2014–2022.

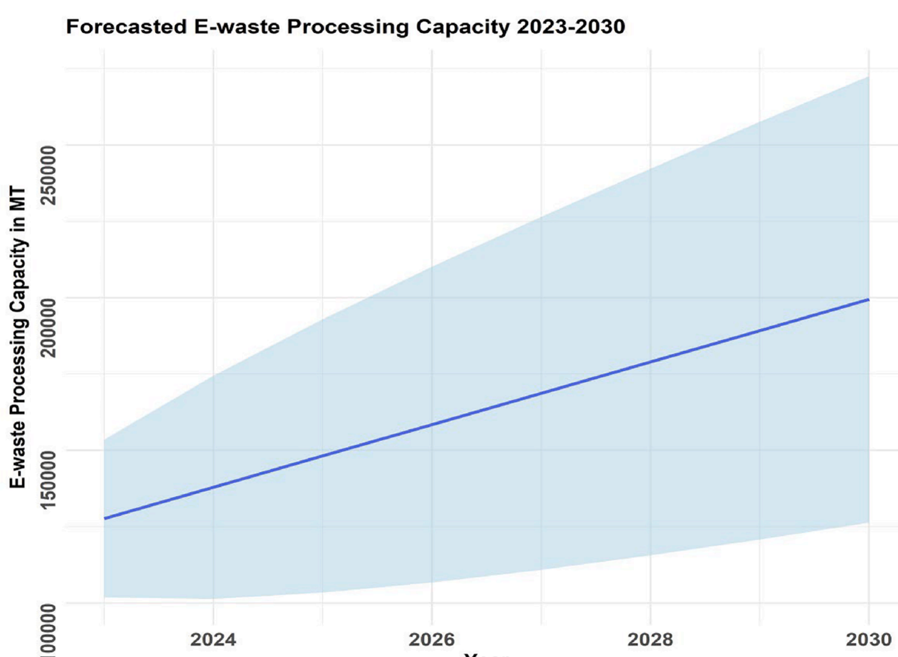

Fig. 5. E-waste processing capacity trend scenario of Maharashtra state from 2023–2030.

waste recycling efforts. The rate of change in the number of recyclers provides insights into the annual percentage increase or decrease in recycling capacity. In some years, we observe significant growth, such as a 40.63% increase in 2017, indicating a rapid expansion in the number of recyclers. However, there were also years with smaller increases or even a slight decrease, such as a −6.85% rate of change in 2019. Looking ahead, the forecasted data from 2023 to 2030 suggests a continued upward trend in the number of recyclers, albeit with a more moderate rate of change. The projected rates of change range from 5.65% to 26.26%, indicating steady growth in the recycling capacity of E-waste over the forecasted period. These findings highlight the importance of promoting and supporting E-waste recycling initiatives. It is essential to encourage responsible disposal of electronic devices and raise awareness about the benefits of recycling. By increasing the number of recyclers

Table 5
E-waste recycling capacity forecast in Maharashtra using ARIMA from 2023 to 2030.

Year	Forecast	Lo 80	Hi 95	Lo 95	Hi 95
2023	127652.3	110745.3	144559.2	101795.3	153509.2
2024	137912.5	114002.5	161822.5	101345.3	174479.7
2025	148172.8	118889.1	177456.4	103387.3	192958.2
2026	158433.0	124619.2	192246.8	106719.2	210146.8
2027	168693.3	130888.2	206498.3	110875.5	226511.0
2028	178953.5	137540.2	220366.8	115617.3	242289.7
2029	189213.8	144482.2	233945.3	120802.8	257624.7
2030	199474.0	151654.0	247294.0	126339.6	272608.4

Table 6
Forecasted number of recyclers forecast in Maharashtra using ARIMA from 2023 to 2030.

Year	Forecast	Lo 80	Hi 95	Lo 95	Hi 95
2023	150	135.68	164.32	128.10	171.90
2024	164	143.75	184.25	133.03	194.97
2025	178	153.20	202.80	140.07	215.93
2026	192	163.36	220.64	148.20	235.80
2027	206	173.98	238.02	157.03	254.97
2028	220	184.92	255.08	166.35	273.65
2029	234	196.11	271.89	176.06	291.94
2030	248	207.50	288.50	186.06	309.94

and improving recycling infrastructure, we can effectively manage the growing challenge of E-waste and contribute to a more sustainable future.

Future Perspectives

From the mapping of the E-waste recycling plants, we can see that such recycling plants are located in the belts of major cities. From the start-up India programme, an E-waste recycling plant can be established in the semi-urban area located nearby major cities in Maharashtra State. There is a need for awareness of refurbished electronic devices on e-commerce websites. Such activities can play a dual role by benefiting both economically and environmentally.

Recommendation

- The central Pollution Control Board has monitored the Bio-Medical waste generation during the COVID-19 pandemic with the help of an Android based COVID19BMW application. For the monitoring of E-waste, such application can play an important role in the identification of hotspots. The statistical analysis and report generation at dismantler/recycler can be made easy and less time consuming by adoption of such real time monitoring system.
- Digitalisation can help with the circular management of E-waste, including prevention, collection, and treatment.

Conclusion

In conclusion, this research article delves into the progress of E-waste management in India, specifically examining the potential of E-waste processing capacity in Maharashtra state, while emphasizing the significance of adopting a circular economy approach. The circular economy theory, which aims to optimize resource utilization and minimize waste, is crucial in the context of E-waste management. By embracing the circular economy principles, such as restorative and regenerative processes, the transformation of waste into valuable resources becomes feasible. This approach not only contributes to job creation within the E-waste recycling sector but also promotes sustainable practices and safe disposal methods. It replaces the traditional end-of-life concept with restoration and regeneration, emphasizing the value of materials throughout their life cycles. Furthermore, the circular economy approach facilitates the integration of renewable energy sources and the

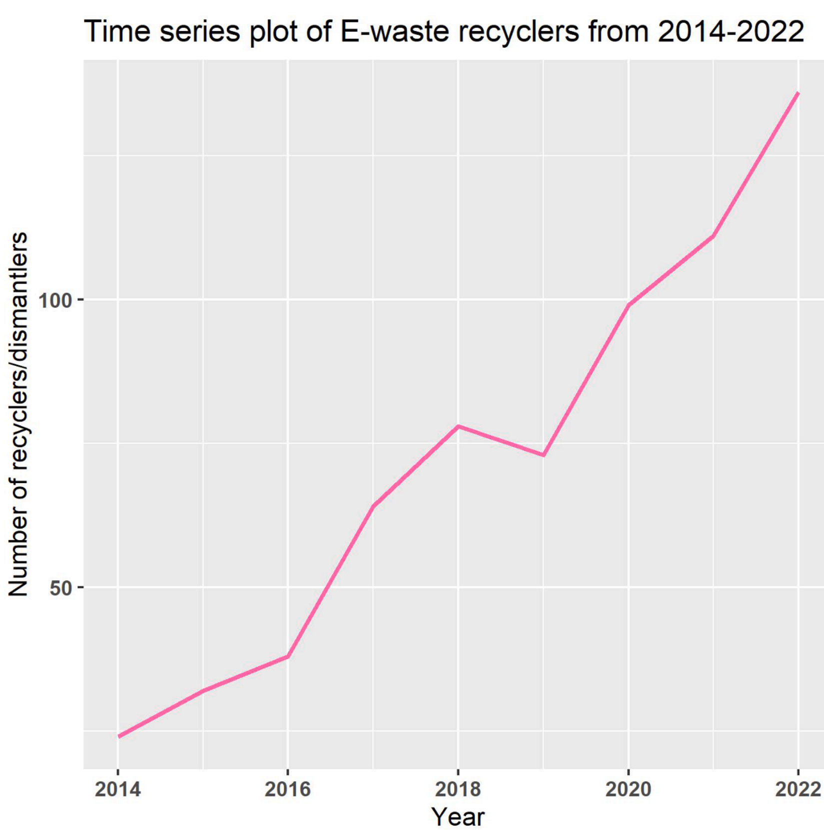

Fig. 6. Number of recyclers/dismantlers in Maharashtra state from 2014 to 2022.

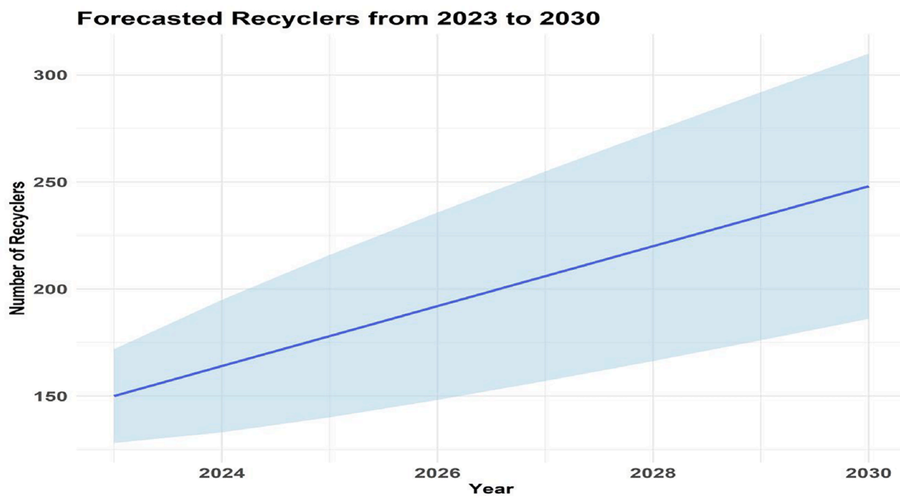

Fig. 7. Forecasting of E-waste recycles in Maharashtra state from 2023–2030.

Table 7
Rate of change will occur in waste processing capacity and number of recyclers from 2014 to 2030.

Year	E-waste dismantling / recycling capacity in MT	Rate of change in %	Number of Recyclers	Rate of change in %
2014	35,310	–	24	–
2015	48,060	36.11	32	25.00
2016	55,410	15.29	38	15.79
2017	74,650	34.72	64	40.63
2018	77,525	3.85	78	17.95
2019	63,879	−17.60	73	−6.85
2020	85,800	34.32	99	26.26
2021	89,355	4.14	111	10.81
2022	117,392	31.38	136	18.38
2023	127652.3	8.74	150	9.33
2024	137912.5	8.04	164	8.54
2025	148172.8	7.44	178	7.87
2026	158,433	6.92	192	7.29
2027	168693.3	6.48	206	6.80
2028	178953.5	6.08	220	6.36
2029	189213.8	5.73	234	5.98
2030	199,474	5.42	248	5.65

elimination of toxic chemicals, enhancing the potential for reusing and returning materials to the biosphere. This not only reduces environmental impacts but also offers economic benefits through the superior design of materials, products, systems, and business models. The utilization of ARIMA forecasting in this research strengthens the foundation of the circular economy approach by providing reliable insights into the future demand for E-waste recycling enterprises. The confidence intervals offered by ARIMA forecasting aid investors in making informed decisions, promoting investment and growth in the recycling sector. Overall, the rate of change in E-waste processing capacity acts as an important indicator, showcasing the efficiency and capabilities of recyclers in the formal sector. This, in turn, presents opportunities for job creation and highlights the importance of continuous improvements and advancements in E-waste management practices. In conclusion, this research article emphasizes that the circular economy, combined with ARIMA forecasting and a focus on E-waste processing capacity, is essential for achieving sustainable and environmentally conscious E-waste management. It showcases the potential for job creation, economic growth, and reduced environmental impacts through the efficient utilization of resources and the adoption of innovative recycling practices. This study is crucial to develop comprehensive policies and initiatives that focus on reducing E-waste, promoting recycling, and adopting a circular economy approach.

CRediT authorship contribution statement

Wasim Ayub Bagwan: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing.

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.

Acknowledgement

Author is thankful to anonymous reviewers and Co-Editors-in-Chief for their constructive comments, which helped in improvement of the final version of this manuscript. Also, I am grateful to online platform https://app.datawrapper.de, which helped in mapping choropleth plot.

Availability of data and materials

The numerical data is available on the public domain/website of the respective executing body.

References

Agoramoorthy, G., Chakraborty, C., 2012. Control electronic waste in India. Nature 485, 309. https://doi.org/10.1038/485309b.

Althaf, S., Babbitt, C.W., Chen, R., 2019. Forecasting electronic waste flows for effective circular economy planning. Resources, Conservation and Recycling 151, 104362. https://doi.org/10.1016/j.resconrec.2019.05.038.

Arya, S., Kumar, S., 2020. Bioleaching: urban mining option to curb the menace of E-waste challenge. Bioengineered 11, 640–660. https://doi.org/10.1080/21655979.2020.1775988.

Awasthi, A.K., Li, J., 2017. Management of electrical and electronic waste: A comparative evaluation of China and India. Renewable and Sustainable Energy Reviews 76, 434–447. https://doi.org/10.1016/j.rser.2017.02.067.

Baldé, C.P., Forti, V., Gray, V., Kueh, R., Stegmann, P. 2017. The Global E-waste Monitor – 2017, United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna. https://www.itu.int/en/ITU-D/Climate- Change/Documents/GEM%202017/Global-E-waste%20Monitor%202017%20.pdf [Accessed on 14 Dec. 2021].

Baldé, C.P., Wang, F., Kuehr, R., Huisman, J., 2015. The global e-waste monitor – 2014, United Nations University, IAS – SCYCLE. Bonn, Germany.

Basal convention, 1999. Basal convention on the control of transboundary movements of hazardous wastes and their disposal. http://www.basel.int/TheConvention/Overview/LiabilityProtocol/tabid/2399/Default.aspx [Accessed on 12 Dec 2021].

Bhagat-Ganguly, V., 2021. E-Waste Management: Challenges and Opportunities in India, 1st ed. Routledge India, London. https://doi.org/10.4324/9780429285424.

Chauhan, A., Singh, A., 2017. An ARIMA model for the forecasting of healthcare waste generation in the Garhwal region of Uttarakhand. India. IJSOI 8, 352. https://doi.org/10.1504/IJSOI.2017.086587.

CPCB, 2008. Guidelines for Environmentally Sound Management of E-Waste (As approved vide MoEF letter No. 23-23/2007-HSMD dt. March 12, 2008).

Dutta, D., Goel, S., 2021. Understanding the gap between formal and informal e-waste recycling facilities in India. Waste Management 125, 163–171. https://doi.org/10.1016/j.wasman.2021.02.045.

eprewastecpcb.in, 2023. E-waste management system. https://eprewastecpcb.in/pdf/e-waste_rules_2022.pdf.

Forti V, Balde CP, Kuehr R, Bel G, 2020. The global E-waste monitor 2020: Quantities, flows and the circular economy potential. United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam.

Hyndman, R., Athanasopoulos, G., Bergmeir, C., Caceres, G., Chhay, L., O'Hara-Wild, M., Petropoulos, F., Razbash, S., Wang, F., Yasmeen, F., 2023. forecast: Forecasting functions for time series and linear models. R package version 8, 20. https://pkg.robjhyndman.com/forecast/.

Hyndman, R.J., Khandakar, Y., 2008. Automatic Time Series Forecasting: The **forecast** Package for *R*. J. Stat. Soft. 27. https://doi.org/10.18637/jss.v027.i03.

ILO, 2014. Tackling informality in e-waste management: The potential of cooperative enterprises. http://www.ilo.org/wcmsp5/groups/public/@ed_dialogue/@sector/documents/publication/wcms_315228.pdf.

Invest India. (2022a)., 2022a. Amplifying growth https://www.investindia.gov.in/sector/electronic-systems. [Accessed on 15 Jan 2022].

Jain, S., Tarun, 2021. E-Waste: India Must Take a Closer Look at Extended Producer Responsibility.

Kaur, J., Parmar, K.S., Singh, S., 2023. Autoregressive models in environmental forecasting time series: a theoretical and application review. Environmental Science and Pollution Research 30, 19617–19641. https://doi.org/10.1007/s11356-023-25148-9.

Kazancoglu, Y., Ozkan-Ozen, Y.D., Mangla, S.K., Ram, M., 2020. Risk assessment for sustainability in e-waste recycling in circular economy. Clean Technologies and Environmental Policy. https://doi.org/10.1007/s10098-020-01901-3.

Kumar, A., Holuszko, M., Espinosa, D.C.R., 2017. E-waste: An overview on generation, collection, legislation and recycling practices. Resources, Conservation and Recycling 122, 32–42. https://doi.org/10.1016/j.resconrec.2017.01.018.

Manish, A., Chakraborty, P., 2019. E-Waste Management in India: Challenges and Opportunities. https://www.teriin.org/article/e-waste-management-india-challenges-and-opportunities.

Megget, K., 2021. e-waste crisis. Chemistry & Industry 85, 26–29. https://doi.org/10.1002/cind.856_8.x.

MeitY, 2021a. Circular economy in electronics and electrical sector : Policy paper. https://www.meity.gov.in/writereaddata/files/Circular_Economy_EEE-MeitY-May2021-ver7.pdf.

MeitY, 2021b. Ministry of Electronics and Information Technology (MeitY) Govt. of India EWM Rules 2016 MoEFCC https://greene.gov.in/wp-content/uploads/2018/01/EWM-Rules-2016-english-23.03.2016.pdf [Accessed on 11 Dec.2021].

MeitY, 2022. e-waste Management and Handling Rules 2011. https://www.meity.gov.in/writereaddata/files/1035e_eng.pdf. 2022. [Accessed on 18 Jan 2022].

MoEF&CC, 2016. The Gazette of India 22 March 2018. greene.gov.in/wp-content/uploads/2019/09/2019091847.pdf.

MoEFCC, 2021. Annual report 2020-21. https://moef.gov.in/wp-content/uploads/2017/06/Environment-AR-English-2020-21.pdf.

Mundada, M.N., Kumar, S., Shekdar, A.V., 2004. E-waste: a new challenge for waste management in India. International Journal of Environmental Studies 61, 265–279. https://doi.org/10.1080/0020723042000176060.

Needhidasan, S., Samuel, M., Chidambaram, R., 2014. Electronic waste – an emerging threat to the environment of urban India. J Environ Health Sci Engineer 12, 36. https://doi.org/10.1186/2052-336X-12-36.

NITI Aayog, 2021. SDG Index 2020-21. https://www.niti.gov.in/writereaddata/filesSDG_3.0_Final_04.03.2021_Web_Spreads.pdf.

PACE, 2021. Platform for Accelerating the Circular Economy (PACE) Circular Economy Action Agenda Electronics. 1-56. https://pacecircular.org/sites/default/files/2021-02/action-agenda-electronics- feb2021_FINAL.pdf.

Parajuly, K., Kuehr, R., Awasthi, A.K., Fitzpatrick, C., Lepawsky, J., Smith, E., Widmer, R., Zeng, X. 2019. Future E-waste Scenarios; StEP (Bonn), UNU ViE-SCYCLE (Bonn) & UNEP IETC (Osaka).

Parthsarathy, P., Bulbule, K.A., 2017. E-waste recycling best option for mineral substitution and environmental protection. Journal of the Geological Society of India 89, 221. https://doi.org/10.1007/s12594-017-0589-8.

Rajesh, R., Kanakadhurga, D., Prabaharan, N., 2022. Electronic waste: A critical assessment on the unimaginable growing pollutant, legislations and environmental impacts. Environmental Challenges 7, 100507. https://doi.org/10.1016/j.envc.2022.100507.

Ramanayaka, S., Keerthanan, S., Vithanage, M., 2020. Urban mining of E-waste: treasure hunting for precious nanometals, in: Handbook of Electronic Waste Management. Elsevier, pp. 19–54. https://doi.org/10.1016/B978-0-12-817030-4.00023-1.

Rashmi, G., Sathish Kumar, K., 2022. Cloud based Forecast of Municipal Solid Waste Growth using AutoRegressive Integrated Moving Average Model: A Case Study for Bengaluru. International Journal of Advanced Computer Science and Applications 13.

Sahajwalla, V., Hossain, R., 2023. Rethinking circular economy for electronics, energy storage, and solar photovoltaics with long product life cycles. MRS Bulletin 48, 375–385. https://doi.org/10.1557/s43577-023-00519-2.

sdgindex, 2021. Sustainable Development Report 2021. https://dashboards.sdgindex.org/static/profiles/pdfs/SDR-2021-india.pdf.

Yang, M., Chen, L., Wang, J., Msigwa, G., Osman, A.I., Fawzy, S., Rooney, D.W., Yap, P.-S., 2023. Circular economy strategies for combating climate change and other environmental issues. Environmental Chemistry Letters 21, 55–80. https://doi.org/10.1007/s10311-022-01499-6.

Yang Yang, Jian Zhang, Weizhe Feng, 2010. A prediction on electronic waste resource with time series model, in: 2010 International Conference on Computer Application and System Modeling (ICCASM 2010). Presented at the 2010 International Conference on Computer Application and System Modeling (ICCASM 2010), IEEE, Taiyuan, China, pp. V2-551-V2-555. https://doi.org/10.1109/ICCASM.2010.5620680.

Zhang, K., Schnoor, J.L., Zeng, E.Y., 2012. E-Waste Recycling: Where Does It Go from Here? Environmental Science & Technology 46, 10861–10867. https://doi.org/10.1021/es303166s.