Article Type

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Keywords

E-waste Management, Emerging Economies, Developed Countries, Comparative Analysis, Sustainable Solutions, Informal Recycling Sector, Extended Producer Responsibility (EPR), Circular Economy, Digital Waste Growth, Environmental Impact, Public Health, Policy Intervention, Statistical Analysis, Predictive Modelling, Electronic Waste Generation, Waste-to-GDP Ratio, Recycling Infrastructure, Decoupling of GDP and Waste, United Nations SDGs, India E-waste Case Study

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Comparative Analysis and Sustainable Solutions for E-Waste Management in Emerging and Developed Economic Countries

Abstract

The global rise in electronic waste is a primary reason for environmental and public health issues, driven by rapid advancements in technology, innovations, shorter product life cycles, and consumer demand. As digitalization continues to transform economies, the quantity of e-waste increases, and the environmental and health implications of improper e-waste disposal have intensified, especially in those regions where there is an inadequate disposal infrastructure and informal recycling practices. Particularly in Asia, there are unstructured policies and recycling practices. This research paper provides a comparative study as well as analysis of e-waste generating patterns, causing countries involved, comparison among the management strategies between emerging and developed economic countries. Analysis is done using multidimensional data from 2017 to 2024 across ten selected nations.

Developed countries such as Germany, Sweden, Japan, and Switzerland demonstrate absolute decoupling, reducing e-waste levels even as GDP rises through advanced recycling infrastructure, strong legislation, and successful circular economy models. In contrast, emerging economies, including Indonesia, China, and India, are the ones that have an exponential rise in e-waste volumes, overtaking GDP growth (3-5x) and leading to elevated e-waste-to-GDP ratios. These trends help to expose systemic issues in the proper management of countries, such as dependence on informal recycling sectors, weak regulatory enforcement, weak strictness in punishment, and low public awareness.

An analysis of all the strengths and weaknesses of countries, a focused case study on India is conducted to reveal challenges. Some of the challenges are e-waste imports, the supremacy of informal processing, and industrial contributions. Analytical strategies are made by understanding the management skills of well-managed nations, so that our country can reach that level. Opportunities through Extended Producer Responsibility (EPR) policies and formalization efforts. Predictive modeling forecasts severe increases in e-waste for high-growth nations if policy interventions are not urgently applied.

The research aligns with several United Nations Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being), SDG 6 (Clean Water and Sanitation), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). These findings underscore the necessity for coordinated international efforts, including technology sharing, public-private partnerships, and sustainable product design incentives, to bridge the global e-waste management gap. The study provides actionable strategies for governments and stakeholders aiming to balance economic growth with environmental sustainability.

1. Introduction

1.1 The Growing E-Waste Emergency: A Global Environmental Threat

Our world is continuously advancing in technology and providing comfort to citizens in various tasks. The launch of a new product creates a sense of greed in people's minds, leading them to purchase the latest item while leaving older products unused quickly. This practice increases the number of unused products as well as waste. Shorter product lifecycles, growing consumerism, and lower management have resulted in a remarkable rise in e-waste generation worldwide. From a small pen drive to large-scale industrial electronics, outdated and discarded devices are accumulating at an alarming rate. Have you ever read about the CRT? A cathode ray tube is a glass video display component of an electronic device like a television. It has toxic materials like lead, cadmium, barium, etc, which can be released if not recycled properly. Like this, many such devices in the world are harmful to nature as well as to us. In 2022, an estimated 62 million tonnes of e-waste were produced globally. Only 22.3% was documented as formally collected and recycled. Common items in e-waste include computers, mobile phones, large household appliances, medical equipment, etc. But the problem was that millions of tonnes of e-waste are recycled using unsound or improper activities, as well as being stored in homes, warehouses and dumped or illegally exported. By these practices, landfill area is increasing by and pollution caused by landfills is 14.4 percent. [2][3]

Negative impacts of e-waste:

- Releases toxic chemicals when burned (like dioxins).
- Causes air pollution that can spread for miles.
- Causes air pollution that can spread for miles.
- Increases risk of breathing problems, cancer, and other diseases.
- Harms animals and ecosystems by polluting the air.
- Toxic metals and chemicals leak into soil.
- Crops grown in polluted soil can be unsafe to eat.
- Soil becomes less fertile and productive.
- Harms small organisms living in the soil.
- Toxins from e-waste leak into groundwater.
- Pollutes rivers, lakes, and drinking water.
- Kills fish and other aquatic life.
- Damages entire water ecosystems.

Impacts on Humans:

- Exposure can damage the brain, heart, liver, and kidneys.
- Affects the nervous and reproductive systems.
- Can cause serious diseases and birth defects.
- Especially dangerous for workers handling e-waste without protection. [4]

The global movement of e-waste underscores the cross-border nature of this issue. Wealthy countries frequently send their electronic waste to poorer regions, where regulatory measures may be less stringent and recycling methods tend to be informal and dangerous. Figure 1.1 illustrates the yearly increase in e-waste, while Figure 1.2 below depicts global e-waste export patterns, highlighting major collection hubs and their corresponding export destinations. These visuals reveal the environmental inequity tied to e-waste distribution, as developing nations endure the consequences of hazardous waste disposal despite not generating or consuming a similar amount.

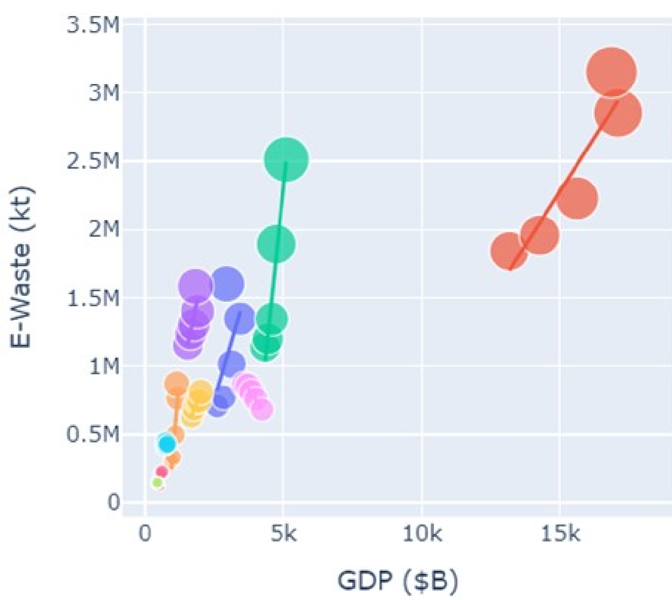

Figure 1. GDP vs E-waste (Click to open interactive flow)

Figure 2. Collection and Export Destinations (Click to open interactive flow)

1.2 Understanding E-Waste: Definition and Categories

What is E-waste? E-waste refers to old, end-of-life, discarded electronic equipment that is no longer useful to its owner or no longer serves its best services and original purpose. This includes white goods (like microwaves, washing machines, refrigerators, etc) and brown goods (like televisions, radios, cell phones, etc). [5] These items may contain hazardous materials like lead, cadmium, mercury, arsenic, chromium VI, brominated flame retardants, polychlorinated biphenyls, beryllium, etc. If they are not properly treated, then they can cause problems to the environment and human health. Common types of e-waste include:

- **Large Household Appliances:** Refrigerators, washing machines, microwaves.
- **Small Household Appliances:** Toasters, Irons, Hair dryers, Electric kettles.
- **Consumer Electronics:** TVs, smartphones, tablets, cameras
- **IT and Telecommunications Equipment:** Servers, routers, cables
- **Electrical & Electronic Tools:** Drills, Saws, Sewing machine
- **Electrical & Electronic Tools:** Drills, Saws, Sewing machine
- **Lighting Devices:** Fluorescent lamps, LED lights
- **Medical Equipment:** Monitors, diagnostic machines
- **Industrial Tools:** Control panels, electric tools, automation systems [6]

Figure 3. Categories of E-Waste.

E-waste is also categorized under 3Rs, Recyclability, Reusability, and potential for Recovery of valuable materials.

1.3 Spanning the Global Boundary: Why a Comparative Analysis Matters

E-waste is not an issue of just one country, it is a worldwide concern. Talking about worldwide waste management, some countries are good at managing e-waste, but some are not. A study tells that e-waste is not merely a waste management issue; it reflects deeper socio-economic and technological disparities between nations. Earlier, developed countries used to export their e-waste to the least developed countries, and this led to toxic impacts on their surroundings. But now, after the Basel Convention came into effect, this practice has been stopped.

Developed economies like Germany and Japan have made significant progress in implementing circular economy models, strict regulations, and high public awareness. In conflict, emerging economies such as India, Indonesia, and China struggle with informal recycling, weak enforcement, and insufficient policy frameworks. This study aims to bridge that gap by offering a comparative analysis of e-waste trends, policies, and management strategies across both developed and emerging nations. This analysis will help to make further policies for e-waste management for all emerging nations.

Figure 4. Circular Economy [8]

1.4 Sustainable Development Goals (SDGs)

SDGs are the 17 sustainable development goals, with the aim of "peace and prosperity for people and the planet". And three core elements: economic growth, social inclusion, and environmental protection. [7] Here is how the SDGs are related to this topic:
SDG 12 (Responsible Consumption): Targets sustainable waste reduction and circular practices.
SDG 3 (Health): Mitigates toxic exposure from informal recycling.
SDG 8 (Decent Work): Formalizing recycling aligns with inclusive labor policies.
SDG 13 (Climate Action): Proper e-waste handling reduces GHG emissions (e.g., avoided CFC leaks).

Figure 5. SDG Goals [9]

1.5 India in Focus: Challenges, Contradictions, and Possibilities

India is also a prime interest of this research as it embodies the challenges and prospects of e-waste management in rapidly developing economies. With rising mobile phone usage, electronics consumption, and product lifespan reduction, India produces 3.2 million metric tons of e-waste annually—one of the largest amounts worldwide. Yet, 90% of the waste is dealt with by the unorganized sector, resulting in significant health, environmental, and economic issues.

1.5.1 Policy Gaps: Strong Rules vs. Weaker Enforcement in Developed Countries

India has legislated laws such as the E-Waste Management Rules (2022) requiring proper recycling and Extended Producer Responsibility (EPR). But enforcement continues to be weak owing to corruption, poor monitoring, and inadequate recycling facilities.
The European Union's WEEE Directive, on the other hand, involves stringent recycling targets, penalties for non-compliance, and well-funded collection systems. The contrast illuminates how policy implementation, not legislation alone, assures success.

1.5.2 Informal Sector: A Double-Edged Sword

Health & Environmental Risks: In places like Delhi's Mandoli recycling hub, workers (including children) manually dismantle electronics without safety gear, exposing themselves to toxic metals (lead, mercury) and burning cables in open pits, releasing carcinogenic fumes.
Economic Reality: The informal sector thrives because it offers quick cash for discarded electronics, while formal recycling centres are scarce and less profitable for waste collectors.

1.5.3 Opportunities for Improvement

1.5.3.1 Tech Transfer: Rich countries can transfer sophisticated recycling technologies (such as automated dismantling) to wean India from risk-prone manual techniques.

1.5.3.2 Formalizing the Informal Sector: Rather than prohibit informal recyclers, India can formalize their operations with training, safety practices, and decent wages.

1.5.3.3 Urban Mining: Electronics waste holds gold, silver, and rare earth elements. Proper recycling can commodify waste, lessening India's raw material import dependence.

1.5.4 Why This Is Important for India & Other Similar Economies

India's experience with e-waste is reflective of issues in other emerging markets (Nigeria, Indonesia, Brazil). Through a better understanding of India's shortcomings and how to address them, this research offers a guidebook for responsible e-waste management in countries undergoing digital growth but not yet having robust regulatory frameworks.

1.6 Research Aim and Guiding Questions

This study aims to conduct a comparative study on the e-waste status among the two categories of countries. Categories are like developed and emerging economies. Taking this country, visual analysis as well as the mathematical analysis is there for a better understanding. The focus is on identifying the trends to suggest solutions by filling the gaps.
The questions that this paper answers are:

1. Does the status mean GDP of the nation impacts the e-waste growth?
2. What will be the future growth in e-waste, if the situation of nations remains the same as today?
3. Can circular economy models from developed nations be adapted to emerging contexts?
4. How do policy frameworks like EPR, PRO, etc. differ in effectiveness between developed and emerging countries?
5. Which factors most impact the recycling price of e-waste?
6. How does the carbon footprint differ across different recycling methods?
7. Can we predict which items will contain toxic components based on their specifications?
8. What are the spatial patterns in e-waste generation and recycling facility distribution?
9. Which country can be ideal for all in terms of e-waste management?

2. Related Works

The growing concern around electronic waste (E-waste) has led to a surge in research addressing its generation, management, and environmental impact. One prominent study emphasizes the rapid global increase in E-waste due to technological advancements and consumer culture, stressing the need for comprehensive management strategies to prevent long-term ecological damage[77].

A review focusing on recycling techniques highlights the challenges posed by rapid obsolescence of electronics and the growing volume of waste, pointing out that although numerous methods exist, many are still inefficient, especially in the context of emerging economies[75].

Comparative analyses of developed and developing countries underline stark disparities in handling E-waste. While developed nations benefit from structured policies and advanced recycling systems, developing countries often depend on informal sectors, leading to environmental contamination and health hazards[76].

Toxicological assessments of E-waste treatment have drawn attention to the harmful chemical exposures associated with informal recycling methods. Research in this area highlights the urgent need to adopt safer and less hazardous practices to protect workers and nearby populations[83].

Several studies have further enriched the discourse on E-waste by addressing emerging trends and innovative solutions. A comprehensive analysis of E-waste in India outlines both current practices and future prospects, emphasizing the urgent need for infrastructure improvements and increased public participation[80].

Digital technologies are being recognized as pivotal tools in enhancing regulatory compliance and monitoring. Research in this area suggests that technologies like blockchain, IoT, and AI can improve traceability, transparency, and enforcement in E-waste management[79].

Artificial intelligence has also been proposed for regulatory support, with studies advocating AI-driven frameworks for better implementation of compliance and auditing systems to ensure adherence to E-waste guidelines[82].

From a broader perspective, investigations into the global generation, treatment, and end-of-life practices of E-waste call for harmonized policies and sustainable models that integrate economic, environmental, and social dimensions[81].

Extended Producer Responsibility (EPR) remains a cornerstone of sustainable E-waste management. Some studies analyse its implementation challenges in developing countries, stressing the importance of institutional support, stakeholder awareness, and clear accountability mechanisms[78].

In terms of long-term planning, some studies have proposed structured roadmaps aimed at building sustainable E-waste management systems. These include strategies such as implementing extended producer responsibility (EPR), strengthening public awareness campaigns, and promoting the circular economy to reduce environmental burden[74].

Collectively, this body of work underscores a multidisciplinary approach involving policy reform, scientific research, and technological innovation. It also reflects the growing consensus on the need for global cooperation to help countries—particularly those in the Global South—develop resilient, inclusive, and environmentally sound E-waste management frameworks.

3. Methodology

3.1 Research Design and Approach

This study emphasizes a comparative, data-driven approach and an analytical approach to examine the disparities in e-waste management in emerging and developed economies. This research is designed in such a way that it integrates quantitative and qualitative statistical analysis, predictive modelling, and policy evaluation. This ensures a multidimensional understanding of the e-waste challenges in different nations.
Now, the thing is, what we are doing:

1. Global Comparison
2. Comparison of E-waste Vs GDP
3. India Specific Analysis
4. Overall conclusions with possible solutions

3.2 Selection of Countries (Datasets 1 & 2)

How have the countries been selected? For the analysis, we have taken 10 countries.
5 countries are selected from that category where countries are well-managing their e-waste. And have proper rules and regulations.
The other 5 countries are Asian countries, which are not good at managing as well as in policy backgrounds.
Dataset 1: E-waste generation data of all these 10 countries are taken for analysis. And the data is for 8 years, i.e., 2017 to 2024.
Dataset 2: GDP of all 10 countries is also taken along with the e-waste generation data of 10 countries. The data is for 8 years, i.e., 2017 to 2024.

Highly Managing E-waste	Low management
Switzerland	India
Sweden	China
Norway	Japan
Germany	Korea
Canada	Indonesia

Table 1. Selected Countries for Analysis

3.3 Dataset 3: Analysing trends in India

Time Series Forecasting
This analysis is done from a time series forecasting approach using Prophet, a forecasting tool developed by Facebook.

- **Prophet Model:** It is designed for forecasting time series data with strong seasonal patterns and missing data. It is particularly good at handling daily, weekly, and yearly seasonality.
- **Automatic Handling of Seasonality and Trends:** Prophet automatically decomposes the time series into components (trend, seasonality) and allows for easy integration of holidays or special events.
- **Forecasting and Visualization:** After forecasting, the actual and predicted values are visualized together, allowing for easy comparison and trend analysis

3.4 Data sources

The datasets used in this research were collected from:

- **Global E-Waste Monitor** reports (2017–2024)
- **UNU (United Nations University)** statistics on e-waste
- **World Bank** and **IMF** databases for GDP and development indicators
- National environmental and recycling agencies for country-specific data
- **International Monetary Funds** - climate change indicators
- **Green Government MeitY:** E-waste

3.5 Analytical Tools and Techniques

To analyse the relationships and patterns in the data, the following tools and techniques were used:

- **Statistical Correlation Analysis:** Pearson's correlation coefficient was used to analyze the relationship between GDP and e-waste generation. Through this, it is determined that, Whether the GDP is related to e-waste generation or not?
- **Significance Testing:** p-values were calculated (with $p<0.05$ considered statistically significant) to validate findings with our understanding.
- **Ratio Analysis:** E-waste per capita and e-waste-to-GDP ratios were calculated for innate insights.
- **Predictive Modeling:** For the prediction of the next 10 years, Time-series forecasting using Polynomial Regression was used to project future e-waste generation trends up to 2030 in those countries.
- **Comparative Visualization:** Bar graphs, trend lines, and scatter plots were used to visualize differences among countries.
- **Time Series Forecasting:** The Prophet model was employed to forecast future trends in e-waste collection, carbon footprint, and recycled price in India. By utilizing historical data, it predicts future values, such as the e-waste collected (in kg) over the next several months.
- **Data Aggregation and Visualization:** A **pivot table** was used to calculate the **average lifespan** of products based on **purchase year** and **brand**. This aggregation was then visualized through a **heatmap**, which helps to identify patterns in the lifespan across different years and brands. Additionally, a **pie chart** was used to visualize **state-wise e-waste generation** in India, showcasing the proportion of e-waste generated by each state. These visualizations offer both detailed insights into product lifespan and an overview of regional contributions to e-waste.

3.6 Focused Case Study on India

A detailed case study was conducted on India due to its unique position. India is at the position of a high e-waste producer and a developing country in terms of its GDP. India's GDP is growing at a good %rate. So, India will be a good choice to study. This study involves:

- Impacts of different sectors on waste generation.
- Analysis of informal recycling data.
- Policy understandings, other factors.

4. DATA ANALYSIS & RESULTS

This section covers all the comprehensive studies or analyses of the three datasets used for the analysis. This covers both descriptive and inferential statistics. For a better understanding of the results, visualizations are used. Each dataset is analyzed separately to extract its trends, identify discrepancies, and provide valuable information.

4.1 Dataset A: Comparative Analysis of GDP vs E-waste Growth (2017-2022)

Country	2017	2018	2019	2020	2021
Canada	1682.37	1773.80	1860.06	1958.15	2015.98
China	13173.59	14272.35	15620.71	17100.06	16862.98
Germany	3595.41	3721.37	3846.70	4004.94	4230.17
India	2607.41	2846.16	3131.95	3443.60	2946.06
Indonesia	950.44	1021.23	1103.29	1193.91	1150.25
Japan	4342.16	4446.33	4590.91	4746.88	5103.11
Korea	1545.81	1649.08	1763.36	1898.76	1823.85
Norway	415.19	436.47	453.44	470.99	445.51
Sweden	519.64	541.47	562.12	585.74	622.37
Switzerland	707.53	727.23	746.28	770.93	810.83

Table 2. Country GDP data from 2017 to 2021 (in billions USD)

Country	2017	2018	2019	2020	2021
India	708445	771215	1014961	1346496	1601155
China	1842120	1958000	2228421	2853610	3153228
Japan	1139000	1200000	1345218	1893041	2512743
Korea	1152807	1236793	1303679	1400340	1583409
Indonesia	305645	332465	496536	765487	869087
Switzerland	410000	430000	450000	418113	430000
Sweden	138610	123220	211000	215000	228000
Norway	143600	145000	146500	147800	148600
Germany	863412	853124	810203	756321	682300
Canada	625132	685810	740532	745732	810321

Table 3. E-waste Generation data from 2017 to 2021 (in tonnes)

4.1.1 Data Pre-processing

In terms of the dataset, we have e-waste generation data and GDP data for 10 countries. To ensure consistency of the data, the data is pre-processed in terms of:

- GDP and E-waste generation values were cleaned of commas, whitespaces, and converted to numerical data.
- It has been ensured that the first column shows the countries, and then the dataset is distributed by years in their respective columns.
- E- data was standardized to kilo-tonnes (kt), and GDP is in ($B)
- The datasets were reshaped into the long format for quick analysis, and merged on 'Country' and 'Year'.
- To assess the waste efficiency, a normalized metric, E-waste per $1B GDP was calculated.

4.1.1.1 Analytical Techniques The following analytical methods were employed:

Techniques	Uses
Descriptive Statistics	Summarizes central tendencies and variability
Scatter Plots & line charts	Observe relationships and trends
Linear Regression	Measure e-waste change with GDP
Pearson correlation analysis	Relationship between e-waste, GDP, and efficiency
Boxplots and Two sample t-tests	Compares waste efficiency by development status
Growth rate comparisons	Change in GDP and e-waste over five years

Table 4. Analytical Techniques with their uses

Python Libraries used: matplotlib, seaborn, pandas and statsmodels.

4.1.2 Descriptive Statistics

Across 45 observations:

Sr. No.	Metric	E-waste (kt)	GDP($B)	E-Waste/ GDP (kt/$B)
1	Mean	8.8211	3514.62	352.27
2	Std Dev	7.5365	4522.62	145.44
3	Max	3.1532	17100.06	755.56
4	Min	1.232	415.190	137.188

Table 5. Descriptive Statistics

4.1.3 Correlation Analysis

The correlation heatmap highlights how E-waste, GDP, and E-waste per $B GDP are related.

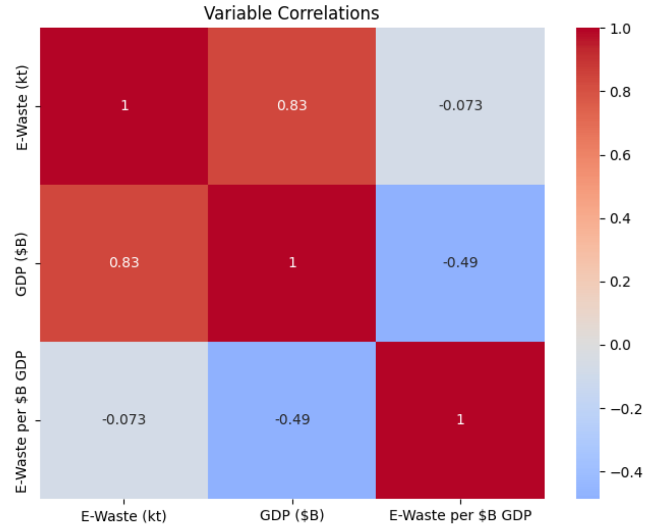

Figure 6. Pearson's Correlation Heatmap

Variables	Pearson's r	Interpretations
E-waste vs GDP	0.88	Strong positive relation – higher GDP, more e-waste generation
GDP vs E-waste per $B GDP	-0.55	Moderate negative – richer countries more efficient
E-waste vs E-waste per $B GDP	-0.28	Weak negative relationship

Table 6. Pearson Correlation Analysis

However, Moderate to weak correlations of waste per GDP indicate that economic strength alone doesn't guarantee that countries have better waste practices.
Country Level Correlation Matrix:

Sr. No.	Country	Correlation (r)	P-value	Interpretation
1	Japan	0.983	0.0028	Strong & statistically significant positive relation – GDP more, more e-waste generation
2	Canada	0.969	0.0067	Strong & statistically significant positive relation – GDP more, more e-waste generation
3	China	0.929	0.0223	Strong & statistically significant positive relation – GDP more, more e-waste generation
4	Indonesia	0.902	0.0361	Strong & statistically significant positive relation – GDP more, more e-waste generation
5	Sweden	0.854	0.0652	Strong but marginally insignificant correlation.
6	Norway	0.794	0.1089	Moderate positive correlation, insignificant – possible trend with uncertainty

Sr. No.	Country	Correlation (r)	P-value	Interpretation
7	India	0.575	0.3105	Weak to moderate correlation
8	Switzerland	0.230	0.7103	Very weak and insignificant correlation – GDP impacts less on e-waste generation
9	Germany	-0.990	0.0013	Very strong negative and statistically significant correlation – GDP increases, e-waste decreases
10	Korea	0.805	0.1006	Moderate positive correlation, insignificant – possible trend with uncertainty

Table 7. Country Level Correlation Matrix

Significant correlations, i.e., $p<0.05$, were observed for 5 of the nations – Germany, Japan, Canada, China, and Indonesia.
India's correlation, i.e., r=0.575 and p=0.3105, stats that there is an inconsistency in e-waste growth relative to GDP.

4.1.4 Waste Generation Efficiency (2017-2021)

This section states how nations are managing the balance between economic development and e-waste management. Are they focusing on environmental sustainability?
Through analysis, we got some data:

Country	E-Waste Growth (%)	GDP Growth (%)	Growth Ratio
Indonesia	184.35	21.02	8.77
India	126.01	12.99	9.70
Japan	120.61	17.52	6.88
China	71.17	28.01	2.54
Sweden	64.49	19.77	3.26
Korea	37.35	17.99	2.08
Canada	29.62	19.83	1.49
Switzerland	4.88	14.60	0.33
Norway	3.48	7.30	0.48
Germany	-20.98	17.65	-1.19

Table 8. Growth Rates (2017-2024)

From the table,

- Concerning Nations – India, Indonesia, Japan – High e-waste with respect to their GDP and Growth Ratio – Weak Infrastructure for E-waste management.
- Moderate / Manageable – Sweden, China, Korea, Canada – Here, monitoring of management is needed
- Positive trends – Norway, Switzerland, Germany – Strong e-waste regulations, in balanced condition.

4.1.5 Regression Analysis

Regression analysis helps to uncover the trends over time, i.e. 2017-2021, and tell how strongly and at what rate e-waste is growing annually.

Rank	Country	Slope	R-squared	P-value
1	Indonesia	2332.644777	0.814290	0.036073
2	Japan	1921.193463	0.965386	0.002762
3	Sweden	1039.66194	0.730008	0.065213
4	Korea	950.478390	0.647422	0.100573
5	India	696.875829	0.330602	0.310534
6	Canada	499.512686	0.937997	0.006679
7	China	316.207690	0.863789	0.022277
8	Switzerland	86.418985	0.052692	0.710318
9	Norway	78.200286	0.630007	0.108911
10	Germany	-299.378930	0.979279	0.001274

Table 9. Country-wise Regression Analysis

4.1.5.1 Slope (β1) Slope states how much E-waste increases per increase in GDP.

$$\beta_1 = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sum(x_i - \bar{x})^2} \quad (1)$$

- x_i = GDP value
- y_i = E-waste value
- $\bar{x}$ = Mean of GDP
- $\bar{y}$ = Mean of E-waste

Cases – 1: High Slope = More E-waste per GDP ()
Case – 2: Low Slope = More efficiency
Case – 3: Negative Slope = E-waste decreases when GDP increases.

4.1.5.2 R-Squared (R2) R-Squared (R2) tells about the proportion of variation in E-waste explained by GDP
Its Values range from 0 to 1:
Case – 1: Closer to 1 = better fit model
Case – 2: Closer to 0 = weak relationship

4.1.5.3 Statistical Significance (P-value)

1. P < 0.05 – Shows statistically significant trends
2. P (0.05 – 0.10) – Marginally significant trends
3. P > 0.10 – Not statistically significant

4.1.5.4 Final Analysis: Country by Country .

Country	Slope	R^2	P-value	Interpretation
Indonesia	2332.64	0.814	0.036	Significant. Strong relationship. High E-waste per GDP.
Japan	1921.19	0.965	0.003	Highly significant. Strong relationship.
Sweden	1039.66	0.730	0.065	Marginally significant. The relationship was likely but borderline.
Korea	950.48	0.647	0.101	Not significant. Somewhat weak evidence.
India	696.88	0.331	0.311	Not significant. Low R^2. Weak or no relationship.
Canada	499.51	0.938	0.007	Significant. Strong fit despite moderate slope.

Country	Slope	R^2	P-value	Interpretation
China	316.21	0.864	0.022	Significant. Lower slope, but GDP is still a good predictor.
Switzerland	86.42	0.053	0.710	Not significant. GDP is not a good predictor.
Norway	78.20	0.630	0.109	Not significant.
Germany	-299.38	0.979	0.001	Significant. Negative trend — notable and rare case.

Table 10. Regression Results: E-waste vs GDP

4.1.6 Conclusion

From the analysis, it has been concluded that GDP growth strongly directs E-waste growth. Indirectly or directly, GDP growth supports more E-waste in the nations. Most countries, like Japan, China, and India, show a positive relationship between GDP growth and e-waste growth. Here, Germany is the only nation that came as an exception despite 18% growth in GDP, Germany is receiving a 21% reduction in e-waste generation in the nation. This can be simply seen in the graph below. And the top 4 nations, China, India,

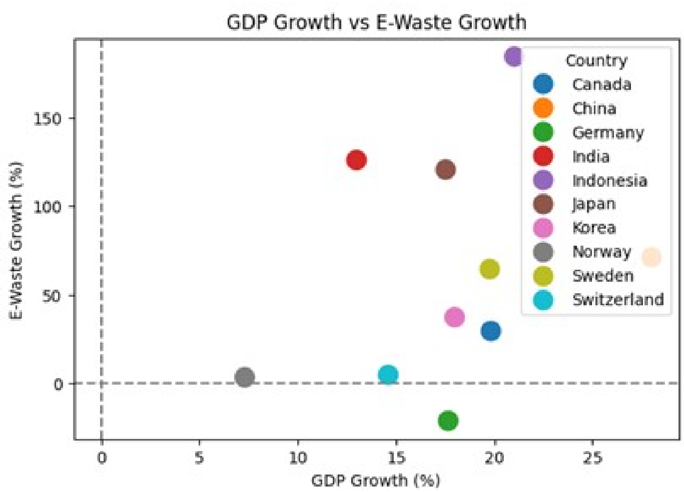

Figure 7. GDP growth vs E-Waste growth

Germany, and Japan, are taken to show the trends. Here, China and India show upward trends. Japan shows a slight upward but then after 2020, it may have a flatter trend. And Germany, reflecting the mature market, has better recycling outcomes, with waste generation declining.

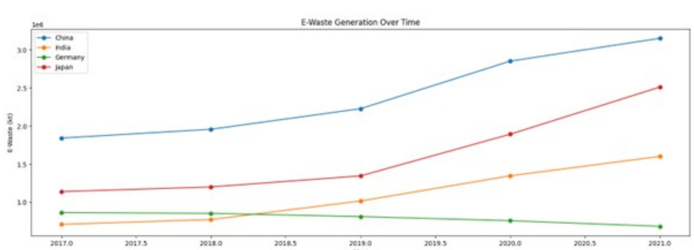

Figure 8. E-waste Generation over time

4.2 Dataset B: Comparative Analysis of Developed vs Emerging countries (2017-2024)

4.2.1 Annual E-waste trends (2017 - 2024)

Line graph is used to visualize the annual e-waste growth from 2017 to 2014. What this data shows? It shows exponential growth in emerging economies, especially in Indonesia and china. On the side, developed countries exhibit negative growth. This is may be because of their e-waste management practices, awareness among their citizens, etc.

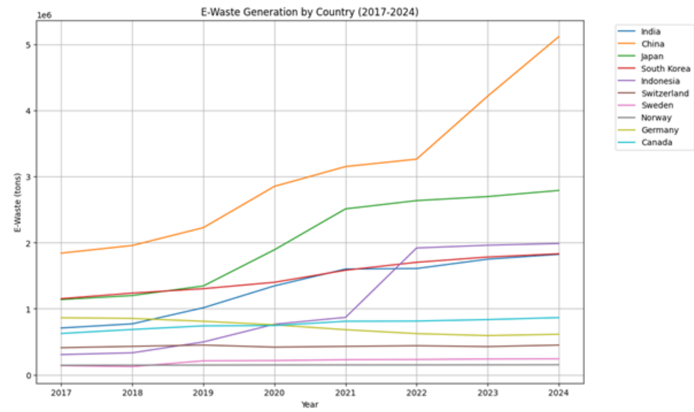

Figure 9. E-waste Generation by Country

This also helps to identify that is there are any decoupling trends. Countries like Germany and Sweden show their stabilization in the e-waste growth, indicating decoupling success.

4.2.2 Statistical Insights

From the previous analysis of Dataset A.

4.2.2.1 Correlation Analysis .

A moderate positive correlation was found between the GDP and e-waste generation, i.e., a r ≈ of 0.88. This shows that as GDP rises, it will have a positive impact on e-waste generation.

4.2.2.2 Country Comparisons

- Emerging nations that have a higher e-waste/GDP ratio show inefficient recycling or management systems.
- Developed countries had stable and some have declining e-waste growth, which suggests effective waste management.

4.2.2.3 Significance Testing .

From our observations, the value is $p < 0.05$ for the differences in growth trends between developed and emerging countries, statistically significant.

4.2.3 Predictive Analysis

For the predictive analysis, linear and polynomial regression are both used. According to the data within each country our model will fit over it. Comparing R2 will help to choose the best-fitting model. If the polynomial model gives a better fit by 1% or more, we will choose this, otherwise, we stick to the simpler linear model.

The model was trained over the dataset from 2017 – 2024. Each country's prediction analysis includes:

- Best fit model details

- R2 Score (model accuracy)
- Average Annual Growth Rates
- Standard deviation
- Forecasted Values (2025 - 2034)

4.2.3.1 Country-wise Prediction Analysis .

How much e-waste is expected to grow in each country from 2024 to 2034?

Country	Model	2024	2034	% Growth (2024–34)
Indonesia	Polynomial	1987960	8067946	305.84%
China	Polynomial	5120804	17986446	251.24%
Korea	Linear	1832307	2925357	59.65%
Japan	Polynomial	2791867	3113537	11.52%
Norway	Linear	151700	162425	7.07%
Switzerland	Linear	449600	470485	4.65%
Canada	Polynomial	865673	691402	-20.13%
India	Polynomial	1823690	1207888	-33.77%
Germany	Linear	613280	131951	-78.48%
Sweden	Polynomial	241200	-124410	-151.58%

Table 11. E-waste Projections for 2034 Using Regression Models

4.2.3.1.1 Indonesia

Best Model Used: Polynomial Regression (deg=2)
R² Score: 0.9024
Average Annual Growth (2017–2024): 240331 tons
Standard Deviation: 751327
Projected Average Growth (2025–2034): 602768 tons

Figure 10. E-waste Growth in Indonesia (2017–2034)

4.2.3.1.2 China

Best Model Used: Polynomial Regression (deg=2)
R² Score: 0.9775
Average Annual Growth (2017–2024): 468383 tons
Standard Deviation: 1138500
Projected Average Growth (2025–2034): 1348627 tons

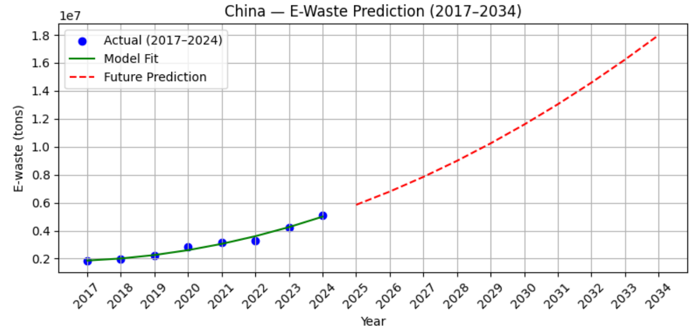

Figure 11. E-waste Growth in China (2017–2034)

4.2.3.1.3 South Korea

Best Model Used: Linear Regression
R² Score: 0.9814
Average Annual Growth (2017–2024): 97071 tons
Standard Deviation: 261145
Projected Average Growth (2025–2034): 105618 tons

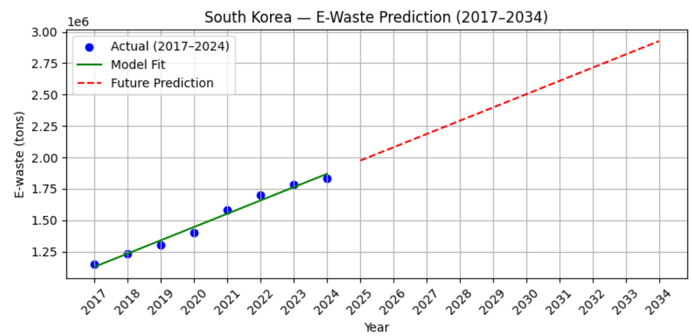

Figure 12. E-waste Growth in South Korea (2017–2034)

4.2.3.1.4 Japan

Best Model Used: Polynomial Regression (deg=2)
R² Score: 0.9286
Average Annual Growth (2017–2024): 236124 tons
Standard Deviation: 717254
Projected Average Growth (2025–2034): 5859 tons

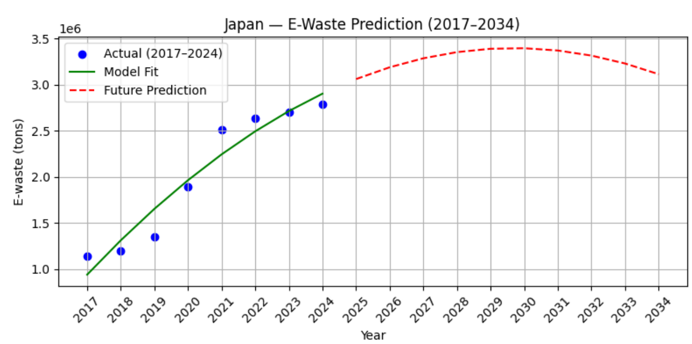

Figure 13. E-waste Growth in Japan (2017–2034)

4.2.3.1.5 Norway

Best Model Used: Linear Regression
R^2 Score: 0.9861
Average Annual Growth (2017–2024): 1157 tons
Standard Deviation: 2678
Projected Average Growth (2025–2034): 1083 tons

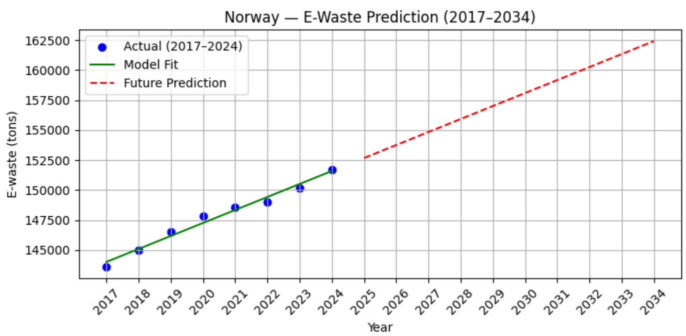

Figure 14. E-waste Growth in Norway (2017–2034)

4.2.3.1.6 Switzerland

Best Model Used: Linear Regression
R^2 Score: 0.2519
Average Annual Growth (2017–2024): 5657 tons
Standard Deviation: 14154
Projected Average Growth (2025–2034): 2870 tons

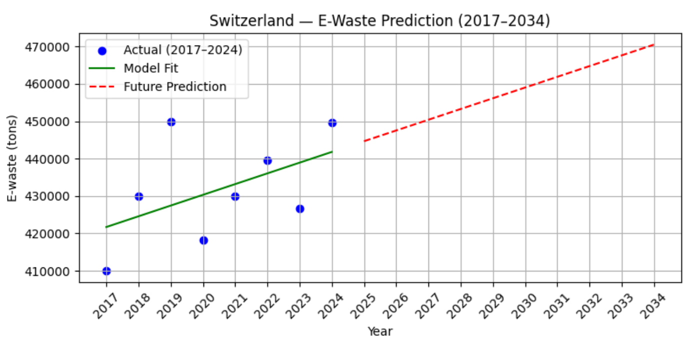

Figure 15. E-waste Growth in Switzerland (2017–2034)

4.2.3.1.7 Canada

Best Model Used: Polynomial Regression (deg=2)
R^2 Score: 0.9781
Average Annual Growth (2017–2024): 34363 tons
Standard Deviation: 81355
Projected Average Growth (2025–2034): -19571 tons

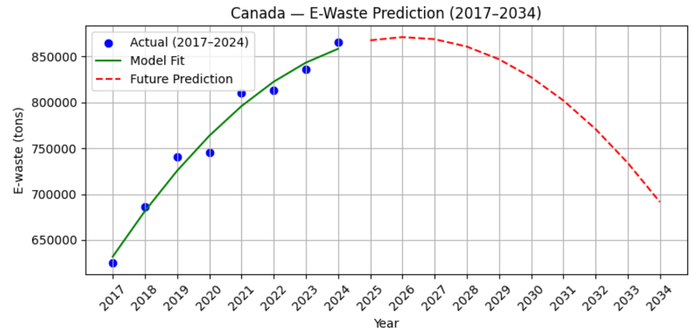

Figure 16. E-waste Growth in Canada (2017–2034)

4.2.3.1.8 India

Best Model Used: Polynomial Regression (deg=2)
R^2 Score: 0.9683
Average Annual Growth (2017–2024): 159321 tons
Standard Deviation: 442485
Projected Average Growth (2025–2034): -77689 tons

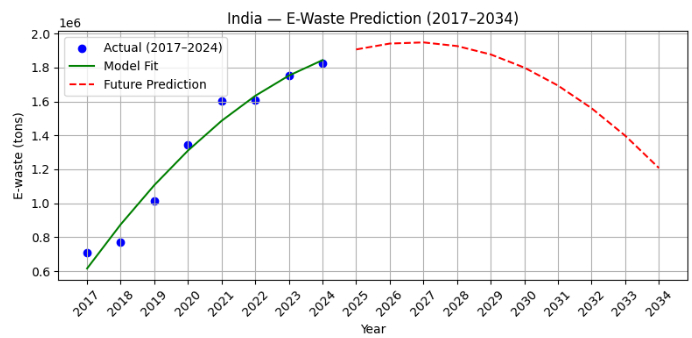

Figure 17. E-waste Growth in India (2017–2034)

4.2.3.1.9 Germany

Best Model Used: Linear Regression
R^2 Score: 0.9475
Average Annual Growth (2017–2024): -35733 tons
Standard Deviation: 110767
Projected Average Growth (2025–2034): -43882 tons

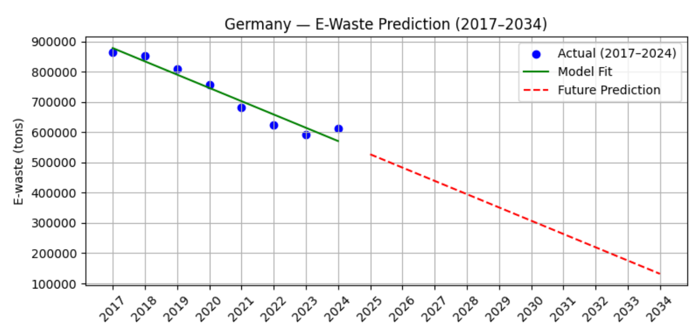

Figure 18. E-waste Growth in Germany (2017–2034)

4.2.3.1.10 Sweden

Best Model Used: Polynomial Regression (deg=2)
R^2 Score: 0.8589
Average Annual Growth (2017–2024): 14656 tons
Standard Deviation: 46109
Projected Average Growth (2025–2034): -39416 tons

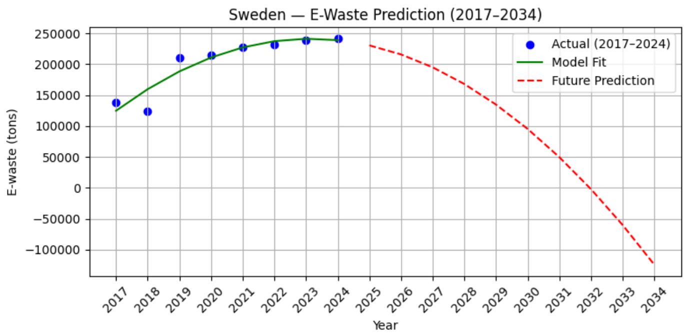

Figure 19. E-waste Growth in Sweden (2017–2034)

4.2.4 Overall Conclusion from the analysis

From the above analysis of e-waste growth and prediction in upcoming years, it has been found that two broad classifications exist among the countries.
Countries with an increase in E-waste: Indonesia, China, South Korea, Japan, Norway, Switzerland
Countries with a decrease in E-waste: Sweden, Germany, India, Canada
Countries falling in category 1 have having highest projected growth, which means these countries need urgent action for better recycling or e-waste management systems. And in similar cases, countries falling in category 2 are with declining trends, and this trend is predicted significantly. These countries indicate effective waste management practices that they are following. From this category, 2 of the 4 countries, i.e., Germany and Sweden, are those that can become the ideal country that can help in shaping the global e-waste strategies. Taking these as ideal, we can extract their practices that can be best fitted to our countries.
Talking about the modeling, polynomial regression is the one that gives better predictions for the given data due to data fluctuations.

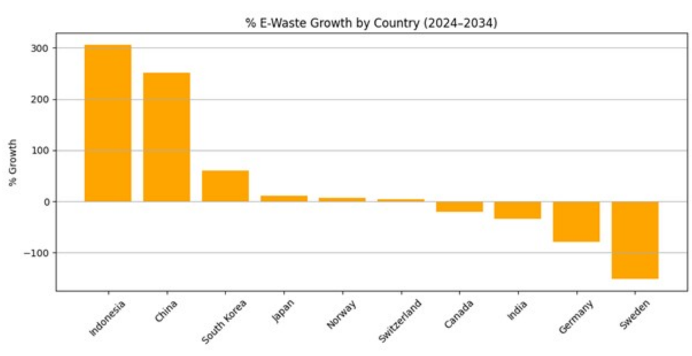

Figure 20. % E-waste Growth by Country

4.3 Dataset C: Analysing E-Waste Trends and Product Lifespan in India

As the world grows and urbanizes at an incredible pace, India is growing right alongside it. With more and more people using smartphones, laptops, and other electronic devices in their daily lives, the amount of electronic waste or e-waste is increasing rapidly. In the sections that follow, we take a closer look at how e-waste is shaping up in India and what the current trends reveal.

4.3.1 Analysing E-waste generation in India

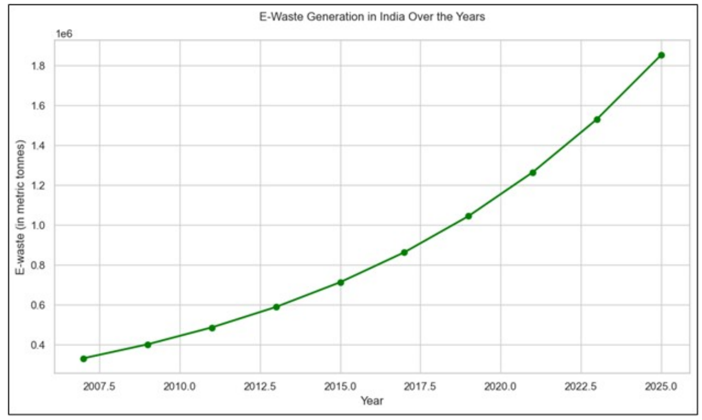

Figure 21. E-waste Generation in India

Year	E-waste Generation (Metric Tonnes)
2007	332,979
2009	402,905
2011	487,515
2013	589,893
2015	713,770
2017	863,662
2019	1,045,031
2021	1,264,488
2023	1,530,030

Table 12. E-waste Generation Trends from 2007 to 2023

According to this graph, India's production of e-waste increased significantly between 2007 and 2023. The amount of e-waste has grown from about 330,000 to over 1.53 million metric tonnes. It has also predicted that this value will rise to 1.85 million metric tonnes, demonstrating the quick development of digital technology and the pressing need for improved e-waste treatment.

Looking into a deeper picture of India, state-wise data reveals that the E-waste generation in India isn't uniform—it varies widely from state to state, largely depending on factors like population size, urbanization, and industrial activity. Some states, especially those with major cities and tech hubs, produce significantly more e-waste each year compared to others. The data below offers a state-wise breakdown of e-waste generation (in tonnes per year), helping us understand where the highest volumes are coming from and highlighting regional patterns in electronic consumption and disposal.

The pie chart illustrates the top 9 state-by-state contribution to e-waste (in tonnes annually), with respect to the upward trend for e-waste generation in India.

- Maharashtra is in first place with 19.8%, followed by Andhra Pradesh (12.5%) and Tamil Nadu (13.1%).
- States that contribute significantly (about 9–10% each) include Uttar Pradesh, West Bengal, Delhi, and Karnataka.
- At 7.6%, Madhya Pradesh has the lowest share of all the states on the list.

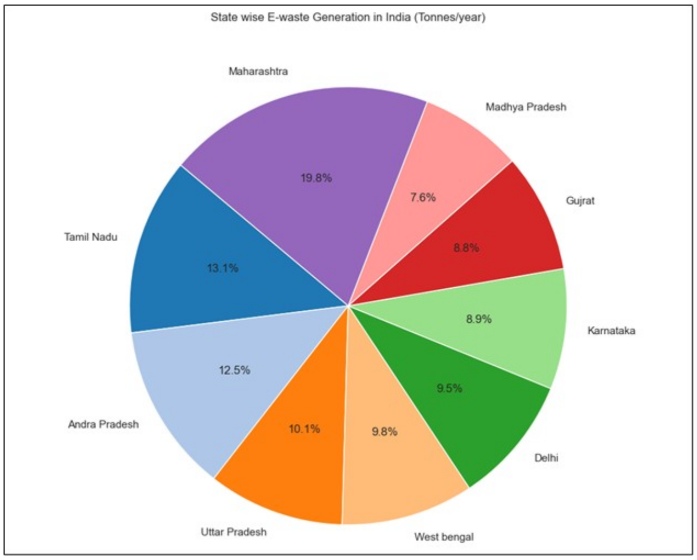

Figure 22. State wise E-Waste Generation in India (Tonnes/year)

This suggests that states that are industrialized and urbanized are the main producers of e-waste, highlighting the necessity of focused recycling and education initiatives in these areas.

4.3.2 Trends and Forecasts: E-Waste Collection, Carbon Footprint & Recycled Price (2023–2028)

E-waste management in India involves more than just disposal - it's closely tied to how much is collected, the environmental impact it leaves behind, and the value recovered through recycling.

India's e-waste sector is expected to grow rapidly between 2023 and 2028, driven by increasing use of electronic devices and stricter recycling regulations. At the same time, there's a stronger push toward reducing the carbon footprint associated with electronics manufacturing and recycling. As sustainability becomes a national and global priority, circular economy practices - focused on reuse, recovery, and reducing emissions are gaining traction. The pricing of recycled materials, especially valuable metals like copper and gold, is likely to remain volatile. However, as industries begin to rely more on recycled inputs, market demand could drive prices upward.

This section focuses on key aspects such as e-waste collection, the carbon footprint it generates, and the pricing of recycled materials, offering a snapshot of how these elements are shaping up between 2023 and 2028.

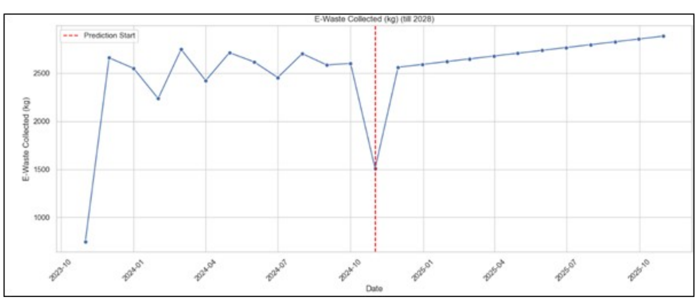

Figure 23. E-Waste Collection Trend and Prediction (2023–2028)

The graph shows monthly e-waste collection (in kg) from October 2023 to October 2025, with future predictions starting November 2024 (marked by the red dashed line). After a sharp initial rise, values fluctuate but mostly stay above 2500 kg, except for a sudden dip before the prediction point. In India, October often coincides with major festivals like Diwali, which could temporarily slow down collection due to staff unavailability, shifted public focus, or disruptions in normal services which resulted in a sharp dip. Post-prediction, a steady upward trend is projected, indicating improved or consistent collection efforts in the future.

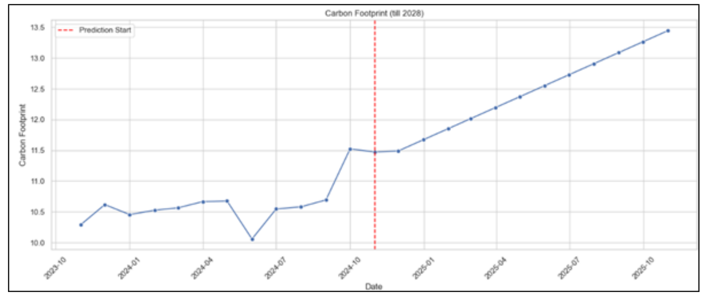

Figure 24. Carbon footprint due to E-Waste in India

The graph shows India's carbon footprint from October 2023 to October 2025, with future projections starting in November 2024. Initially, emissions remained relatively stable with minor ups and downs, suggesting controlled activity or effective policies. However, around October 2024, there's a noticeable spike, likely due to increased industrial or energy activity. After this point, the prediction shows a steady rise, indicating a consistent increase in emissions over time—possibly driven by economic growth, urban expansion, or limited adoption of greener technologies.

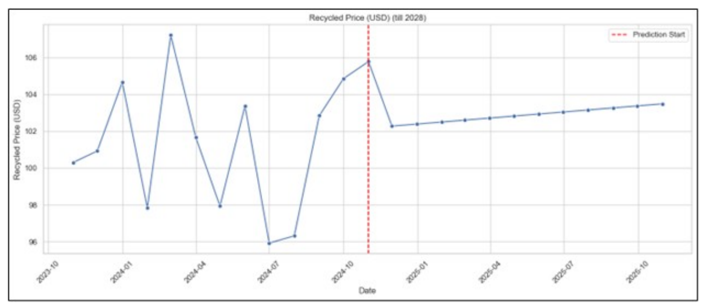

Figure 25. Recycled Price (USD) in India

This graph shows recycled material prices from **October 2023 to October 2025**, with predictions starting **November 2024** (marked by the red dashed line). Prices fluctuated significantly before prediction, with peaks and dips. After prediction starts, prices stabilize and show a **gradual upward trend**, indicating a steady rise in recycled material value over time.

4.3.3 Recycling Method Trends (2023–2024)

Recycling in India involves several methods, including automated, manual, and hybrid approaches.

- **Automated Recycling:** This method uses machines, sensors, and robotics to sort and process materials more efficiently. It is commonly used in large-scale recycling plants where the volume of waste is high, and fast, accurate sorting is required.
- **Manual Recycling:** In this method, workers manually sort through waste materials to separate recyclables from non-recyclables. It is still widely used in smaller or informal recycling sectors, where automation is not yet fully integrated.
- **Hybrid Recycling:** A combination of automated and manual methods, where machines handle the bulk of sorting, and workers do the more detailed or specialized tasks. This method helps to maximize efficiency while addressing the limitations of automated systems in handling certain types of waste.

These methods are used to recycle various materials, including plastics, metals, paper, and electronic waste, aiming to reduce landfill waste and conserve resources.
This section focuses on analyzing the evolving trends in recycling methods used in India between 2023 and 2024.

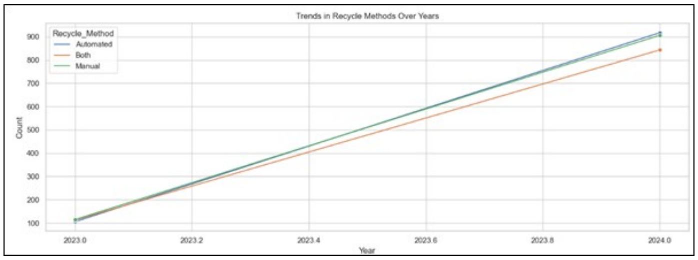

Figure 26. Trends in Recycle Methods Over Years in India

From 2023 to 2024, the graph indicates a consistent rise in the three types of recycling: automated, manual, and both. The combined approach reached about 850 numbers, while the manual and automated procedures grew the fastest, each reaching about 900 counts. This suggests a well-rounded use of both human and technological methods to enhance recycling initiatives.

4.3.3.1 Product Life Span Analysis .

India is home to numerous companies and consumers of electrical and electronic appliances, ranging from mobile phones and laptops to household gadgets and industrial equipment. With rapid technological advancements and growing consumer demand, products are often discarded well before the end of their functional life, leading to increasing volumes of e-waste. This section focuses on the product life cycles and e-waste trends associated with top-selling companies like Apple, Dell, HP, LG, Panasonic, Samsung, Xiaomi, and Sony.

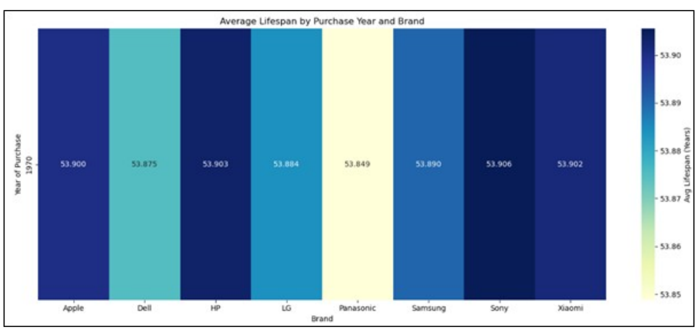

Figure 27. Average Lifespan by Purchase Year and Brand

This image is a heatmap showing the **average lifespan** of products from different brands in the year **1970**.

- Each coloured box shows how many years, on average, a product from that brand lasted.
- The **darker the colour, the longer the lifespan**.
- The numbers inside the boxes are the exact average lifespan in years.

Observations:

- **Sony** and **HP** products lasted the longest (around **53.9 years**).
- **Panasonic** products had the shortest lifespan (about **53.8 years**).
- All brands have very similar lifespans, with only small differences.

In India, once the lifespan of these electronic products ends, these electronic wastes are simply thrown away - dumped in landfills or handed over to informal recyclers. But what many don't realize is that these devices are packed with harmful substances like lead, mercury, and cadmium. These toxins don't just disappear - they seep into the soil, pollute our water, and even get released into the air if the waste is burned. This isn't just bad for the planet; it's harmful to people too. The workers handling this waste, often without protection, and communities living nearby are directly exposed to these dangerous chemicals. In fact, most of the toxic threat from e-waste comes from just a few of these substances. That's why it's so important to dispose of electronics the right way - and to build systems that make it easy and safe for everyone to do so.

Below is the analysis of top three toxic components most commonly found in e-waste generated in India, based on discarded electronics from leading companies.

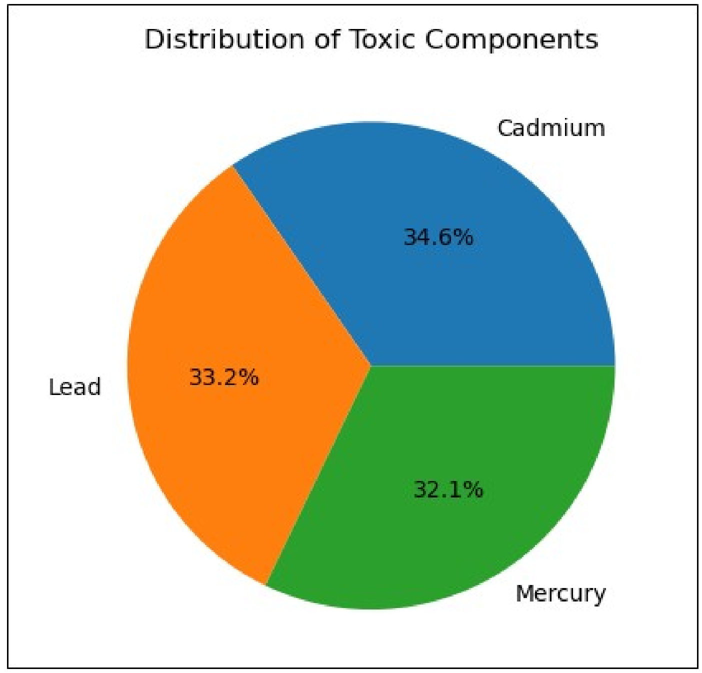

Figure 28. Distribution of Toxic Components in India

This pie chart shows the **distribution of major toxic components** found in **e-waste generated in India**, coming from **electronics made by various companies**.

- All three toxic components are present in **almost equal amounts**.
- **Cadmium** is slightly more than the others.
- **Mercury** is the least, but only by a small margin.

4.3.4 Overall Conclusion

This section presents a detailed analysis of **e-waste generation, trends, recycling methods, and product lifespan in India**, highlighting the rapid digital growth and the environmental challenges it brings.

The analysis of e-waste trends and product lifespan in India highlights a growing environmental challenge driven by the rapid expansion of electronic consumption. From 2007 to 2024, India's e-waste generation has surged from approximately **330,000** to over **1.85 million metric tonnes**, underscoring the urgent need for efficient and sustainable e-waste management systems.

Urbanized and industrial states like **Maharashtra, Tamil Nadu, and Andhra Pradesh** contribute the most to this waste, indicating the importance of focusing recycling efforts and awareness programs in these regions.

Forecasting models predict that between **2023 and 2028**, e-waste collection will improve steadily, while **carbon emissions** from e-waste processing are also expected to rise, signaling the need for cleaner recycling technologies. At the same time, the **value of recycled materials** such as metals is anticipated to increase, encouraging economic incentives for recycling.

India currently uses a **combination of manual, automated, and hybrid recycling methods**, all of which are expanding, reflecting a balanced approach that leverages both human labor and technology to manage the growing waste.

The **product lifespan analysis** shows only minor differences between brands, suggesting that while product durability is relatively consistent, the accumulation of waste is more related to consumer habits and disposal practices than product failure.

Finally, the **presence of toxic components** like **cadmium, lead, and mercury**—in nearly equal proportions—highlights serious environmental and health risks. Proper handling and regulation of these materials are crucial to mitigate harm.

Overall, the findings emphasize the need for:

- **Stronger policies and infrastructure** for collection and recycling,
- **Wider adoption of sustainable and clean technologies,**
- **Public education** on responsible e-waste disposal,
- And a shift toward a **circular economy** where reuse and recycling are prioritized.

By combining **data analysis, forecasting, and technological advancement**, India can move toward a safer and more sustainable future in managing its electronic waste.

5. DISCUSSION

5.1 Role of Industry Players in E-Waste Recycling

The efficacy of sustainable e-waste management in India greatly relies on participation from certified recyclers, private companies, and community organizations. These stakeholders in the industry support the collection, transportation, segregation, and processing of e-waste while keeping environmental standards and Extended Producer Responsibility (EPR) regulations intact. Many e-waste management companies are operating in India, providing new models like doorstep collection, digital scrap valuation, community-based recycling programs, and circular economy integrations. There exists a varied ecosystem that includes large-scale e-waste recyclers like Eco Recycling Ltd, EMS Ltd, and Namo eWaste Management Ltd as well as new-age startups like Scrapuncle, Trashfix, and Recircle. Their activities minimize the environmental impact and generate employment and awareness in waste management industries. A comprehensive list of more than 50+ operational companies handling e-waste recycling is cited at the end of this paper (see References section).

E-Waste Recycling Companies

Sr. No.	Company Name	Known Focus Areas
1	5rcycle [18]	E-waste, Plastic
2	Ayya Waste Management [19]	General waste, E-waste
3	Cosmos Recycling [20]	E-waste, Industrial scrap
4	Crapbin / Bintix [21]	General scrap, Plastic, E-waste
5	Dumpit India [22]	E-waste, Batteries, Plastic
6	Econscious India [23]	E-waste, Plastic, Textiles
7	Ecocrew [24]	E-waste, Plastic, Home pickup
8	ECOVERVA E Waste Recycler [25]	E-waste
9	Eco Recycling Ltd [26]	Certified E-waste Recycler (electronics, batteries, etc.)
10	Ecotroop Foundation [27]	Environmental awareness, Plastic
11	Epr Recycler [28]	E-waste, EPR services
12	Garbage Free India [29]	Plastic, recycling awareness
13	Ganesha Ecosphere [30]	PET recycling, plastic fibers
14	Goodee.bag [31]	Plastic alternatives (bags), sustainability
15	Gravita India [32]	Lead-acid batteries, Metals recycling
16	Green IT Recycling Center [33]	E-waste, IT assets, secure destruction
17	Gujarat Green Recycling [34]	E-waste, large industrial units
18	Hulladek Recycling [35]	E-waste, Batteries
19	IndiaWasted [36]	E-waste, awareness, community collection
20	Ion Exchange (India) Ltd [37]	Water treatment, Industrial waste
21	ItsRecycleMart [38]	E-waste marketplace, B2B
22	Iyfsorg [39]	NGO, focus unknown
23	Jagruthtech [40]	E-waste and awareness campaigns
24	Namo E-Waste Management Ltd [41]	Certified E-waste recycling, large-scale operations
25	Officialipca [42]	NGO, likely plastic/E-waste
26	Onestep Greener [43]	Plastic, E-waste, Upcycling
27	Rajputana Industries [44]	Metal, Rubber, Industrial scrap
28	ReCircle [45]	Plastic, E-waste, waste-to-value models
29	Recycle Green [46]	E-waste, batteries, B2C model
30	Recycle One (Hyd) [47]	Regional e-waste recycler
31	RecycleMart [48]	Marketplace for recyclables (E-waste, plastic, etc.)
32	Recycle_Pay [49]	Payment-based recycling, likely plastics/E-waste
33	Recycling Villa [50]	E-waste, household electronics
34	Saahas Zero Waste [51]	Solid waste, plastic, food waste
35	Scrapbag [52]	E-waste and paper (likely) – not fully verified
36	Scrapmitra [53]	E-waste, industrial scrap
37	ScrapQ [54]	E-waste, plastic, collection service
38	Scrapuncle [55]	E-waste, doorstep collection
39	Skrap [56]	Zero waste events, plastic, e-waste
40	Sparkliv [57]	IT asset recovery, E-waste
41	Spreco Recycling [58]	E-waste, large appliances
42	Suzlon Energy [59]	Wind turbine recycling (composite materials)
43	Swachcoop [60]	Plastic, Solid Waste, Composting
44	TES-AMM Group [61]	Global e-waste management, data destruction

Sr. No.	Company Name	Known Focus Areas
45	Thekabadiwala [62]	E-waste, paper, plastic collection
46	TheMidwayJourney [63]	Recycling education, NGO initiatives
47	Therecycledearth [64]	Unknown
48	Tinna Rubber & Infrastructure [65]	Rubber, Tyre waste
49	Trash N Cash [66]	Plastic and dry recyclable collection
50	Trashman GreenTech [67]	General recyclables, smart bin tech
51	Trashtocash.co.in [68]	E-waste and general recyclables
52	Urban Enviro Waste Mgmt Ltd [68]	Municipal solid waste, plastic
53	Vedanta [71]	Industrial waste, metals recovery
54	Vitalwaste [72]	E-waste, home pickup
55	Waste Warriors [73]	Solid waste, plastic awareness campaigns
56	Wastewow India [74]	General waste, recycling events

Table 13. Selected Countries for Analysis

5.2 Research Outcomes

5.2.1 Does the status mean GDP of the nation impacts the e-waste growth?

Yes, the comparative analysis from Dataset A (GDP vs E-waste growth, 2017–2022) indicates a strong positive correlation between GDP and e-waste generation. High-GDP nations tend to consume more electronic products and replace them frequently, resulting in greater per capita e-waste. However, in emerging economies like India, rising GDP also correlates with increasing e-waste, although the collection and recycling infrastructure often lags. Additionally, there are countries like Sweden and Germany that are effectively managing e-waste. Nations tend to consume fewer electronic products and manage them properly.

5.2.2. What will be the future growth in e-waste if the situation of nations remains the same as today?

Predictive analysis from Datasets B reveals that if the current consumption and disposal patterns continue, global e-waste will rise significantly by 2034, especially in emerging economies due to urbanization and digital penetration. People living there consume more electronic products, and due to a lack of management facilities, the discarded products will significantly rise. Without improvements in regulation, awareness, and recycling infrastructure, this growth will make worse environmental and health hazards.

5.3.3. Can circular economy models from developed nations be adapted to emerging contexts?

Yes, but with necessary adjustments. Developed countries follow circular economy models that focus on repairing, reusing, and recycling electronic products efficiently. Emerging economies like India can adopt similar approaches, but challenges such as informal recycling practices, low public awareness, and weak policy enforcement must be addressed. In these regions, local models that involve both government and private sectors, along with community participation, are more practical and effective. Moreover, integrating these models with digital tracking and incentives can improve compliance and help bridge the gap between policy and practice. This adaptation supports sustainable development and promotes responsible e-waste management.

5.3.4. How do policy frameworks like EPR, PRO, etc., differ in effectiveness between developed and emerging countries?

In developed countries, EPR (Extended Producer Responsibility) and PRO (Producer Responsibility Organization) models are strictly enforced with high compliance and clear reporting mechanisms. In contrast, emerging economies like India face implementation gaps due to regulatory loopholes, informal sector dominance, and lack of monitoring. As a result, while policies exist, their real-world effectiveness is often diluted. So, in countries like India, frameworks like EPR, PRO, etc, must be effectively applied. Under this, producers have to ensure that, after the use of their manufactured products, the user returns to the company itself. For this, shopkeepers, retailers, distributors, etc., have to run such schemes. And make this process easier for every user kind. So that they can easily return their used products.

5.3.5. Which factors most impact the recycling price of e-waste?

Key factors include the type and quantity of recoverable metals (e.g., gold, copper, rare earth elements), labor costs, transportation logistics, and the level of automation in recycling plants. Regulatory compliance costs and material contamination levels also influence the final recycling price significantly.

5.3.6. How does the carbon footprint differ across different recycling methods?

Carbon footprint varies widely: informal methods like open burning and acid leaching have extremely high emissions and toxic output. In contrast, formal recycling using mechanized shredders, closed-loop chemical treatments, and controlled smelting processes significantly reduces emissions. Companies using advanced, certified methods demonstrate 30–70% lower carbon output compared to informal or semi-formal systems.

5.3.7. Can we predict which items will contain toxic components based on their specifications?

Yes. Analysis executed on datasets (like Dataset C) can identify patterns based on device type, year of manufacture, and brand. Older electronics, CRTs, and certain batteries have higher probabilities of containing lead, mercury, or cadmium. Specification-based classification can assist in pre-sorting items before processing.

From the analysis, we found that the most common toxic components are Cadmium, lead and mercury.

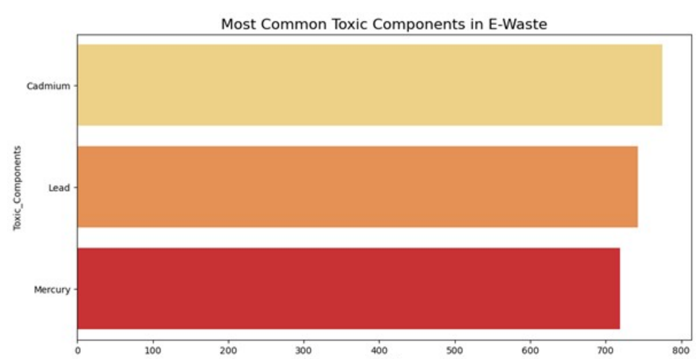

Figure 29. Most common toxic components in E-Waste

5.3.8. What are the spatial patterns in e-waste generation and recycling facility distribution?

Urban clusters exhibit high e-waste generation due to population density and tech adoption. However, recycling facilities are unevenly distributed, often concentrated in specific industrial zones. Spatial analysis shows that many Tier 2 and Tier 3 cities lack adequate recycling infrastructure, indicating a need for geographically balanced facility deployment.

5.3.9. Which country can be ideal for all in terms of e-waste management?

Germany and Sweden

6. POLICY RECOMMENDATION

Our analysis highlights a worrying trend—the production of e-waste is rising at an increasingly fast rate, both in India and globally. If left unchecked, this can lead to serious consequences for our environment and public health. To help address this, we've outlined a set of thoughtful and practical policy recommendations. These aim to slow down the exponential growth of e-waste by encouraging responsible use, easier recycling, repair, and greater awareness among consumers and industries alike. The goal is simple: create a future where technology and sustainability go hand in hand.

1. **Digital E-Waste Passport for Every Device:** Mandate that all electronic devices have a unique "e-waste passport" embedded in a QR code or RFID chip, containing detailed data about components, repairability, recyclability, and disposal instructions—trackable from production to end-of-life.
2. **E-Waste Collection by E-Commerce Platforms:** Make it compulsory for e-commerce giants (like Amazon, Flipkart, etc.) to collect old devices during delivery of new ones, especially for electronics—ensuring doorstep e-waste pickup and safe channelling to certified recyclers.
3. **Green Deposit Refund System:** Introduce a small "green deposit" fee on every new electronic purchase, refundable when users return the old product for recycling—similar to bottle-deposit systems in some countries.
4. **Urban Mining Incentive Policy:** Launch a scheme to promote "urban mining" by offering tax breaks or subsidies to startups and companies that recover precious metals from e-waste through eco-friendly methods.
5. **E-Waste Literacy in Schools and Colleges:** Make e-waste awareness and responsible digital consumption a part of school and college curricula, creating a generation that understands environmental responsibility from an early age.
6. **Community E-Waste Libraries/Donation Banks:** Establish government-funded centres where people can donate working old devices (laptops, phones, etc.) for reuse by schools, NGOs, or underprivileged communities—reducing disposal and encouraging reuse.
7. **Repair First Law:** Legally mandate that companies must provide access to spare parts, repair manuals, and service options for at least 10 years after product launch—empowering consumers and repair shops to fix rather than throw away devices.
8. **Carbon Labelling on Electronic Products:** Require electronics to display carbon footprint labels (like food nutrition labels), showing emissions from production to disposal—helping consumers make eco-conscious choices.

7. CONCLUSION

This analysis investigates the growth of e-waste in relation to GDP increases across various countries from 2017 to 2021, a timeframe that enables insightful conclusions. Section 4.1 establishes a strong link between GDP growth and e-waste generation; as a country's GDP rises, its e-waste generation tends to increase correspondingly. Notably, Germany stands out as an exception—despite an 18% GDP growth, e-waste generation in the country has decreased by 21%. This reflects Germany's status as a mature market, which has achieved improved recycling results and a reduction in waste production.

Section 4.2 analyzes future e-waste growth predictions over the next decade. If countries continue on their current trajectories, growth will likely remain positive, which is not the desired outcome. Two broad categories emerge: countries experiencing an uptick in e-waste include Indonesia, China, South Korea, Japan, Norway, and Switzerland, while those seeing a decline are Sweden, Germany, India, and Canada. The data indicates that nations with rising e-waste levels typically exhibit ineffective management practices. Germany and Sweden serve as exemplary models for shaping global e-waste strategies, from which best practices can be drawn.

According to section 4.3, India's rapidly growing digital economy has generated a significant surge in e-waste, totaling 1.85 million metric tons, primarily from urban regions. Although recycling initiatives are expanding—both through large enterprises and grassroots efforts—challenges persist, including the handling of toxic materials, inconsistent infrastructure, and inadequate public knowledge. To establish a sustainable e-waste management system, India must:

* Strengthen recycling infrastructure and policies
* Promote cleaner technologies and circular economy principles
* Enhance public awareness and industry collaboration

A coordinated approach that integrates policy, technology, and community engagement is essential for an effective and environmentally sustainable recycling process. Analysis of various recycling companies in India reveals an evolving but fragmented landscape addressing various types of waste, including e-waste, plastics, metals, and municipal waste. While several large certified recyclers, such as Gravita India, TES-AMM, Eco Recycling Ltd, and Namo E-Waste, have developed robust systems for managing industrial and electronic waste, numerous grassroots organizations and startups—like Scrapuncle, ReCircle, and Skrap—contribute significantly to community collection efforts and eco-friendly practices. Many organizations are broadening their focus to encompass both recycling businesses and public outreach or Extended Producer Responsibility (EPR) compliance. However, challenges remain in terms of central coordination, awareness, and consistent infrastructure availability in different regions. This scenario highlights the need for strong policy support, integration of technologies, and improved collaboration among stakeholders to create a unified and efficient recycling system for India.

8. REFERENCES

1. Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M. and Böni, H., 2005. Global perspectives on e-waste. Environmental impact assessment review, 25(5), pp.436-458. Link
2. World Health Organization (WHO), 2023. Electronic waste (e-waste). [online] World Health Organization. Link
3. edie.net, 2022. In numbers: How much waste is produced in the UK – and how much is recycled? [online] edie. Link
4. Elytus, n.d. E-Waste its Negative Effects on the Environment. Link
5. Encyclopædia Britannica, 2024. Sustainability. [online] Encyclopædia Britannica. Link
6. GreenIT, n.d. Types of e-waste. [online] Link
7. United Nations, n.d. The 17 Goals. Link
8. Trends Research and Advisory, 2023. From Technology to Circular Economy: Lessons Learned for Sustainable Development. Link
9. Halim, L. and Suharyanti, Y.O.S.E.P.H.I.N.E., 2019. E-waste: current research and future perspective on developing countries. International Journal of Industrial Engineering and Engineering Management, 1(2), pp.25-42. Link
10. ABHIYAN, S.B., E-WASTE MANAGEMENT IN INDIA: OPPORTUNITIES AND PREDICAMENTS UNDER. Link
11. Kaushik, P.R. and Herat, S., 2020. Current state of e-waste management in India. International Journal of Environment and Waste Management, 25(3), pp.322-339. Link
12. Bagwan, W.A., 2024. Electronic waste (E-waste) generation and management scenario of India, and ARIMA forecasting of E-waste processing capacity of Maharashtra state till 2030. Waste Management Bulletin, 1(4), pp.41-51. Link
13. Office of the Principal Scientific Adviser to the Government of India, n.d. Initiatives For E-Waste Management. Link
14. Chatterjee, S., n.d. Electronic Waste and India. [pdf] New Delhi: Department of Information Technology, Ministry of Electronics and Information Technology. Link
15. Sabha, R., 2011. E-waste in India, research unit (Larrdis), Rajya Sabha secretariat, New Delhi. Link
16. Press Information Bureau, 2023. e-Waste Management. [online] PIB Delhi. Link
17. Dataful, n.d. Electronic Waste: Year- and State-wise Quantity of E-Waste Collected and Processed. Link
18. 5Rcycle, n.d. 5Rcycle – E-waste recycling initiative. Link
19. Attero Waste Management, n.d. Attero – E-Waste Recycling and Management Company. Link
20. Cosmos Recycling, n.d. Cosmos Recycling – E-Waste Management Services. Link
21. Crapbin Recycling Private Limited, n.d. Crapbin – Scrap and E-Waste Buyers in Hyderabad. Link
22. Dumpit India, n.d. Dumpit India – The Best Online Kabadiwala in Delhi NCR. Link
23. Ecoconsious, n.d. Ecoconsious – Sustainable Living Marketplace. Link
24. Ecocrew, n.d. Ecocrew – Rewarding you for being eco-friendly. Link
25. Ecoverva, n.d. E-waste Recyclers in Gurgaon. Link
26. Eco Recycling Ltd, n.d. E-waste Recycling. Link
27. Ecotroop Foundation, n.d. Ecotroop Foundation. Link
28. EPR Recycler, n.d. EPR Recycler. Link
29. Garbage Free India, n.d. Garbage Free India. Link
30. Ganesha Ecosphere, n.d. Ganesha Ecosphere. Link
31. Goodeebag, n.d. Goodeebag – Rewarding you for being eco-friendly. Link Link
32. Gravita India, n.d. Gravita India – Leading Recycling Company Across The World. Link
33. Green IT Recycling Center Pvt Ltd, n.d. Green IT Recycling Center Pvt Ltd – E-waste Recycling Service Provider Pune. Link
34. RecycleInMe, n.d. Gujarat Green Recycling – RecycleInMe. Link
35. Hulladek Recycling, n.d. Hulladek Recycling – Your Waste Management Partner. Link
36. India Wasted, n.d. India Wasted – Sustainable Products and Solutions. Link
37. Ion Exchange Global, n.d. Ion Exchange – Total Water Environment Management Solution. Link
38. Recyclekart, n.d. Recyclekart – Buy Refurbished Electronics Online. Link
39. India Youth For Society (IYFS), n.d. IYFS – Empowering Youth for Climate Action and Volunteering. Link
40. Jagruth Tech, n.d. Jagruth Tech – Sustainable Technology Solutions. Link
41. Namo E-Waste, n.d. Namo E-Waste – E-Waste Recycling Services. Link
42. IPCA, n.d. Official IPCA. Link
43. One Step Greener, n.d. One Step Greener – Sustainable Living Solutions. Link
44. Rajputana Industries, n.d. Rajputana Industries – Industrial Solutions. Link
45. Recircle, n.d. Recircle – Sustainable Rubber Solutions. Link
46. Recycle.Green, n.d. Recycle.Green – Sustainable Products Marketplace. Link
47. RecycleOne, n.d. RecycleOne – Scrap Buyers in Hyderabad Secunderabad. Link
48. Recycle Mart, n.d. Recycle Mart – E-Waste Recycling Services. Link
49. Recycle Pay, n.d. Recycle Pay – Dry Waste Collection Service. Link
50. Recycling Villa, n.d. Recycling Villa – E-Waste Recycling Services. Link
51. Saahas Zero Waste, n.d. Saahas Zero Waste – Professional Waste Management for Corporates. Link
52. ScrapBags, n.d. ScrapBags – Handmade, Repurposed Totes, Messenger Bags and Backpacks. Link
53. Scrap Mitra, n.d. Scrap Mitra – Online Doorstep Scrap Pickup. Link Link Link
54. ScrapQ, n.d. ScrapQ – Recycling is Divine. Link Link
55. ScrapUncle, n.d. ScrapUncle – Recycling Made Easy. Link
56. Skrap, n.d. Skrap – Comic Book. Link
57. SparkLiv, n.d. SparkLiv – A Step Towards Sustainable Future. Link
58. Spreco Recycling (OPC) Pvt Ltd, n.d. Spreco Recycling – Waste Management Services. Link
59. Suzlon Energy Ltd, n.d. Suzlon Energy Ltd – Wind Energy Solutions. Link
60. SWaCH, n.d. SWaCH – Solid Waste Collection and Handling. Link
61. TES, n.d. TES – Global Leader in IT Asset Disposition and E-Waste Recycling. Link
62. The Kabadiwala, n.d. The Kabadiwala – Sell Scrap Online in India. Link

63. The Midway Journey, n.d. The Midway Journey – Environmental Awareness Initiative. Link
64. The Recycled Earth, n.d. The Recycled Earth – Sustainable Living Solutions. Link
65. Tinna Rubber and Infrastructure Ltd, n.d. Tinna Rubber and Infrastructure Ltd – Rubber Recycling Company. Link
66. Trash to Cash, n.d. Trash to Cash – E-Waste and Plastic Recycling Services in Bangalore. Link
67. Trashman GreenTech, n.d. Trashman GreenTech – Waste Management Solutions. Link
68. Unplastik India, n.d. Unplastik India – Plastic Waste Management Services. Link
69. Urban Enviro Waste Management Ltd, n.d. Urban Enviro Waste Management Ltd – Waste Management Services. Link
70. Vedanta Resources, n.d. Vedanta Resources – Global Natural Resources Company. Link
71. Vital Waste, n.d. Vital Waste – E-Waste and Waste Management Services in Kolkata. Link
72. Waste Warriors Society, n.d. Waste Warriors – Nonprofit Organisation for Waste Management in the Indian Himalayan Region. Link
73. Waste WoW India, n.d. Waste WoW India – Plastic Packaging Recycling Initiative. Link
74. Wath, S.B., Vaidya, A.N., Dutt, P.S. and Chakrabarti, T., 2010. A roadmap for development of sustainable E-waste management system in India. Science of the Total Environment, 409(1), pp.19-32. Link
75. Gupta, S., Modi, G., Saini, R. and Agarwala, V., 2014. A review on various electronic waste recycling techniques and hazards due to its improper handling. International Refereed Journal of Engineering and Science (IRJES), 3(5), pp.05-17. Link
76. Sthiannopkao, S. and Wong, M.H., 2013. Handling e-waste in developed and developing countries: Initiatives, practices, and consequences. Science of the Total Environment, 463, pp.1147-1153. Link
77. Bagwan, W.A., 2024. Electronic waste (E-waste) generation and management scenario of India, and ARIMA forecasting of E-waste processing capacity of Maharashtra state till 2030. Waste Management Bulletin, 1(4), pp.41-51. Link
78. Faibil, D., Asante, R., Agyemang, M., Addaney, M. and Baah, C., 2023. Extended producer responsibility in developing economies: Assessment of promoting factors through retail electronic firms for sustainable e-waste management. Waste Management Research. Link
79. Isarin, N., Barteková, E., Brown, A. and Börkey, P., 2024. Digital Technologies for Better Enforcement of Waste Regulation and Elimination of Waste Crime. OECD Environment Working Papers. Link
80. Arya, S. and Kumar, S., 2020. E-waste in India at a glance: Current trends, regulations, challenges and management strategies. Journal of Cleaner Production, 271, p.122707. Link
81. Mmereki, D., Li, B., Baldwin, A. and Hong, L., 2016. The generation, composition, collection, treatment and disposal system, and impact of E-waste. E-waste in Transition-from Pollution to Resource, 10, p.61332. Link
82. Wall, A.M., 2021. Guidelines for artificial intelligence-driven enterprise compliance management systems (Doctoral dissertation). Link
83. Tsydenova, O. and Bengtsson, M., 2011. Chemical hazards associated with treatment of waste electrical and electronic equipment. Waste management, 31(1), pp.45-58. Link

9. APPENDIX

i) Github Repo
https://github.com/harshita-0717/E-waste$_{r}esearch_{p}aper_{a}nalysis$