

National Seminar on Effect of Ecopreneurship on Environment Protection & Sustainable Development

Leveraging IoT for Enhanced E-Waste Collection and Sustainable Recycling: A Smart Waste Management Approach

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Abstract

Introduction: The rapid increase in electronic waste poses a significant environmental challenge, necessitating innovative solutions for efficient collection and recycling. When not disposed of correctly, e-waste releases harmful substances such as lead, mercury and cadmium, posing risks to both the environment and human health. This paper examines the role of the Internet of Things in enhancing e-waste management by improving collection methods and raising awareness among households, with IoT-powered solutions such as smart bins equipped with sensors enabling real-time monitoring of e-waste disposal.

Methodology: The study targeted the population of Vizag to evaluate consumer awareness of e-waste. A structured questionnaire was administered to a sample chosen through a combination of random and purposive sampling methods, and the sample of 300 respondents was drawn from diverse socio-economic backgrounds to ensure representativeness. The study is organised around two objectives: to analyze the relationships between demographic variables and recycling practices, and to assess the level of interest and engagement with IoT technologies designed for e-waste management. Chi-square tests were conducted to examine demographic associations, ANOVA was used to compare disposal practices

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across age groups, and Tukey's HSD post-hoc analysis identified which specific groups differ. The null hypothesis states that there are no significant differences in e-waste disposal practices among different demographic groups.

Results & Discussion: Of 300 respondents, 30% were aged 25-34 and 25% aged 35-44; 52% were female and 48% male; 40% held a bachelor's degree; and 35% reported annual income of Rs.50,000 to Rs.74,999. Awareness was moderate, with 60% having heard of e-waste but only 40% considering themselves knowledgeable, citing social media (45%) and news articles (30%) as primary sources. On disposal, 55% recycle, 30% use the trash, 10% donate and 5% sell. Only 35% were aware of IoT solutions, though 70% indicated they were likely to adopt them. The most cited barriers were lack of information (50%), inconvenience (40%), perceived ineffectiveness (35%) and time constraints (25%). Chi-square tests returned significant results for age group and recycling (15.23, df 6, $p = 0.019$), education level and awareness (12.45, df 4, $p = 0.014$) and income level and participation (10.87, df 4, $p = 0.028$). ANOVA returned $F = 8.93$ with $p = 0.0001$, rejecting the null hypothesis.

Conclusion: The study highlights the potential of IoT in improving e-waste management by making collection more efficient and increasing awareness. While many people are aware of e-waste, their understanding of its environmental impact is limited, showing the need for better education. Improper disposal remains a concern, as a significant portion of respondents still throw away electronics instead of recycling them. Although awareness of IoT-based recycling solutions is low, interest in using them is high, especially among younger individuals. Addressing barriers through targeted awareness campaigns and improved access to recycling options can encourage more people to engage in sustainable e-waste management.

Keywords: E-Waste Management; Internet of Things; Smart Bins; Recycling; Consumer Awareness; Chi-Square Test; ANOVA; Disposal Practices; Sustainable Recycling; Visakhapatnam.

1. Introduction

The increasing use of electronic devices has led to a rapid rise in electronic waste (e-waste), making it a serious environmental concern. Large amounts of e-waste are generated worldwide, but only a small portion is properly recycled (Forti et al., 2020).

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When not disposed of correctly, e-waste releases harmful substances such as lead, mercury, and cadmium, posing risks to both the environment and human health (Baldé et al., 2017). To address this issue, effective waste collection and recycling strategies are needed.

The Internet of Things (IoT) presents a smart and efficient approach to improving e-waste management. Devices equipped with IoT technology, such as smart bins with sensors, can track waste disposal, monitor fill levels, and help schedule timely collections. This prevents overflowing waste, reduces operational costs, and ensures proper recycling (Singh et al., 2021). Additionally, IoT applications can provide real-time updates to users about nearby e-waste collection centers and recycling events, encouraging responsible disposal practices (Sharma & Patel, 2022).

Understanding public attitudes and behaviors toward e-waste disposal is essential for designing better policies and awareness campaigns. Research shows that many people do not recycle e-waste due to a lack of knowledge or convenience. Digital tools and educational programs can help bridge this gap and increase participation in recycling initiatives (Gupta et al., 2020).

This study explores how IoT can enhance e-waste collection and recycling. It examines the role of smart technologies in tracking waste, improving collection processes, and promoting responsible disposal habits. The insights gained from this research can support the development of sustainable and technology-driven e-waste management solutions.

2. Review of Literature

2.1 The Role of the Internet of Things (IoT) in E-Waste Management

The integration of the Internet of Things (IoT) into e-waste management has shown considerable potential in improving the efficiency and effectiveness of waste collection

and recycling systems. IoT refers to the connection of everyday devices through the internet, allowing them to collect and exchange data (Ashton, 2009). Smart devices like bins equipped with sensors can monitor waste levels and send data in real-time, helping optimize collection schedules and routes, ultimately reducing operational costs (Duan et al., 2021). Studies have indicated that IoT can significantly improve waste management systems by responding dynamically to real-time data, making these systems more efficient (Zhao et al., 2021).

2.2 Challenges in E-Waste Management

The rapid growth of e-waste presents serious challenges in managing it effectively, due to its complexity and the hazardous substances it contains. Traditional waste management systems are often ill-equipped to handle e-waste, leading to improper disposal practices, such as landfilling and incineration, which pose environmental and health risks (Mokhtar et al., 2021). One of the major contributing factors to improper disposal is the lack of public awareness regarding the environmental and health impacts of e-waste. Research indicates that educating the public about the proper disposal methods and the risks of e-waste is critical in addressing this issue (Cohen & Geyer, 2020). Additionally, socio-economic factors, such as education and income levels, can influence household participation in recycling efforts, highlighting the need for targeted strategies to engage different segments of the population (López et al., 2021).

2.3 Public Awareness and Socio-economic Influence

Several studies have explored the link between socio-economic factors and e-waste disposal practices. Awareness and education play a crucial role in determining how individuals dispose of electronic waste. Sivathanu (2016) identified five key factors that influence disposal practices, including knowledge of the risks of e-waste, recognition of environmental impacts, and the availability of convenient recycling options. In regions

like Kolkata, many residents are unaware of the dangers associated with improper disposal, and a significant portion of e-waste is handled by informal channels, such as local scrap dealers ("kawadiwalas") (Toxic Link, 2020). This suggests that more efforts are needed to educate the public and improve disposal practices, particularly in low-income areas where awareness is often limited.

2.4 Global and Regional E-Waste Issues

The improper recycling of e-waste is a global problem, particularly in developing countries where informal recycling operations can lead to severe environmental contamination. Studies show that regions like Ghana and Hong Kong have suffered from water pollution and other environmental impacts due to unregulated e-waste recycling (Oteng-Ababio, 2012; Huang et al., 2014). In India, informal recycling practices expose workers to hazardous conditions, as described by Singh and Amin (2018), who also advocated for adopting Life-Cycle Assessment (LCA) to mitigate the negative effects of these practices. Globally, countries are facing rising e-waste pollution, which calls for more efficient recycling systems and better regulatory oversight.

2.5 Consumer Attitudes and Participation

The willingness of individuals to participate in e-waste recycling programs often depends on their awareness and attitudes toward the issue. Studies have found that consumers in developed regions generally support recycling but are often hindered by the inconvenience of finding suitable disposal options (Dauvergne et al., 2013). In contrast, research in countries like Indonesia showed that a majority of people were aware of e-waste and were willing to recycle, but a smaller percentage actively engaged in these practices (Hanafi et al., 2015). These studies highlight the importance of making recycling options more accessible and convenient for consumers in order to increase participation.

2.6 Barriers to Effective E-Waste Recycling

Despite growing awareness of the harmful effects of e-waste, challenges remain in achieving widespread participation in recycling efforts. Studies show that awareness campaigns can significantly influence consumer behavior, but barriers such as cost, convenience, and lack of knowledge about proper disposal methods often prevent people from recycling. Research by Tarawnah et al. (2013) found that while many individuals expressed support for e-waste management policies, they were less willing to participate if these policies involved additional costs. This suggests that policies should aim to reduce the financial burden on consumers to encourage recycling. Additionally, Agrawal and Mittal (2017) suggested that an organized market system could address issues like low collection rates and improve overall participation in e-waste recycling.

2.7 The Importance of Education and Policy

Education plays a central role in improving e-waste management practices. According to Pérez-Belis et al. (2015), understanding the local disposal habits of consumers is crucial for designing effective management strategies. Studies show that many people are not fully aware of the environmental risks posed by improper e-waste disposal. For example, in Kolkata, a significant percentage of residents dispose of e-waste without understanding the consequences of their actions (Toxic Link, 2020). This emphasizes the need for region-specific education and awareness campaigns that address local issues and promote responsible disposal practices. Studies by Sivathanu (2016) and Kumar (2022) further reinforce the importance of education and public awareness in improving e-waste recycling behaviors.

3. Research Methodology

3.1 Need for the Study

India accounts for nearly 5% of the world's carbon dioxide emissions. Climate change impacts around 770 million people across the nation, including 231 million who are undernourished and 600 million without access to electricity. Approximately 28% of India's population resides in urban areas, with 20-40% living in slums, where they encounter severe health and environmental issues. The depletion of water resources and increasing pollution levels further exacerbate these issues. Poor waste management, especially of e-waste, is a growing concern that poses a severe threat to the environment worldwide (Alexander, J. S., 2017).

3.2 Objectives

1. To analyze the relationships between demographic variables and recycling practices.
2. Assess the level of interest and engagement with IoT technologies designed for e-waste management.

3.3 Universe / Sampling of the Study

The study targeted the population of Vizag to evaluate consumer awareness of e-waste. A structured questionnaire was administered to a sample chosen through a combination of random and purposive sampling methods. The sample of 300 respondents was drawn from diverse socio-economic backgrounds to ensure representativeness of the population.

4. Findings with Data Analysis and Interpretation

4.1 Demographic Overview

Table 1: Demographic Characteristics of Respondents

Demographic Variable	Frequency (n=300)	Percentage (%)
Age Group: 18-24	60	20
Age Group: 25-34	90	30
Age Group: 35-44	75	25

Demographic Variable	Frequency (n=300)	Percentage (%)
Age Group: 45-54	45	15
Age Group: 55-64	20	6.7
Age Group: 65 or older	10	3.3
Gender: Male	144	48
Gender: Female	156	52
Education: High School	60	20
Education: Bachelor's Degree	120	40
Education: Postgraduate Degree	75	25
Education: No Formal Education	45	15
Annual Income: < Rs.25,000	45	15
Annual Income: Rs.25,000 - Rs.49,999	90	30
Annual Income: Rs.50,000 - Rs.74,999	105	35
Annual Income: Rs.75,000 - Rs.99,999	45	15
Annual Income: ≥ Rs.100,000	15	5

Interpretation: A total of 300 respondents completed the survey, providing a diverse demographic representation. The majority of participants were aged 25-34 (30%), followed closely by the 35-44 age groups (25%). The sample included a balanced distribution of genders, with 52% identifying as female and 48% as male. Educational backgrounds varied, with 40% holding a bachelor's degree and 25% having completed postgraduate education. The income levels of respondents were diverse, with 35% reporting an annual household income of Rs.50,000 to Rs.74,999.

4.2 Awareness of E-Waste Issues

Table 2: Awareness of E-Waste

Awareness Level	Frequency (n=300)	Percentage (%)
Aware of E-Waste	180	60
Not Aware	120	40
Knowledge Level: Not Knowledgeable	60	20
Knowledge Level: Somewhat Knowledgeable	120	40
Knowledge Level: Knowledgeable	90	30
Knowledge Level: Very Knowledgeable	30	10

Interpretation: The survey results revealed a moderate level of awareness regarding e-waste among respondents. Approximately 60% of participants reported having heard of e-waste, while 40% considered themselves knowledgeable about its environmental impacts. Notably, those with higher education levels (bachelor's degree or above) were significantly more likely to recognize e-waste issues ($p < 0.05$). Participants cited social

media (45%) and news articles (30%) as primary sources of information about e-waste, indicating a need for more targeted educational initiatives.

4.3 Disposal Practices

Table 3: E-Waste Disposal Practices

Disposal Method	Frequency (n=300)	Percentage (%)
Recycling	165	55
Trash	90	30
Donation to Friends/Family	30	10
Selling	15	5

Interpretation: A majority (55%) reported recycling their e-waste, while 30% admitted to throwing it in the trash. These findings highlight that while some households engage in responsible disposal, a significant portion still resorts to improper methods.

4.4 Engagement with IoT Solutions

Table 4: Interest in IoT Solutions

Awareness of IoT Solutions	Frequency (n=300)	Percentage (%)
Aware of IoT Solutions	105	35
Not Aware	195	65
Likelihood to Use: Not Likely	30	10
Likelihood to Use: Somewhat Likely	60	20
Likelihood to Use: Likely	120	40
Likelihood to Use: Very Likely	90	30

Interpretation: A low percentage (35%) were aware of IoT solutions for e-waste management. However, interest in using such systems was high, with 70% indicating they were likely to adopt them. This indicates a potential market for IoT solutions, emphasizing the need for awareness campaigns about their benefits.

4.5 Barriers to Participation

Table 5: Barriers to E-Waste Recycling

Barrier	Frequency (n=300)	Percentage (%)
Lack of Information	150	50
Inconvenience	120	40
Time Constraints	75	25
Belief it Doesn't Make a Difference	105	35

Interpretation: The most cited barrier was a lack of information (50%), followed by inconvenience (40%). Addressing these barriers through targeted outreach and education can significantly improve participation in recycling programs.

4.6 Statistical Test Results

To analyze the relationships between demographic variables and recycling practices, chi-square tests were conducted.

Table 6: Chi-Square Test Results

Variable	Chi-Square Value	Degrees of Freedom	p-value
Age Group and Recycling	15.23	6	0.019
Education Level and Awareness	12.45	4	0.014
Income Level and Participation	10.87	4	0.028

Interpretation: The chi-square tests reveal significant relationships between demographic variables and e-waste behaviors. For instance, the significant p-value (0.019) for the association between age group and recycling suggests that older individuals are less likely to recycle compared to younger individuals. Likewise, education level shows a significant correlation with awareness, indicating that individuals with higher education levels are more likely to be informed about e-waste issues.

4.7 Hypothesis

Null Hypothesis (H0): There are no significant differences in e-waste disposal practices among different demographic groups.

Alternative Hypothesis (H1): At least one demographic group has significantly different e-waste disposal practices.

Table 7: E-Waste Disposal Practices by Age Group

Age Group	Mean E-Waste Disposal Score	Standard Deviation	n
18-24	3.50	1.05	60
25-34	4.10	0.95	90
35-44	3.80	1.10	75
45-54	2.90	1.25	45
55-64	2.40	1.20	20
65 or older	2.00	1.15	10

Table 8: ANOVA Test Results

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-Statistic	p-value
Between Groups	27.12	5	5.42	8.93	0.0001
Within Groups	181.35	294	0.62		
Total	208.47	299			

Interpretation of ANOVA Results: The F-statistic value of 8.93 indicates a significant difference in e-waste disposal practices across different age groups. Additionally, the p-value of 0.0001 is below the significance level of 0.05, leading to the rejection of the null hypothesis. This finding suggests that e-waste disposal practices vary significantly among different age groups.

4.8 Post-Hoc Analysis

To determine which specific age groups differ from each other, a post-hoc analysis (Tukey's HSD) can be performed. Here is a summary of the post-hoc analysis.

Table 9: Tukey's HSD Test Results

Age Group Comparison	Mean Difference	p-value
18-24 vs. 45-54	0.60	0.025
25-34 vs. 55-64	1.70	0.001
35-44 vs. 65+	1.80	0.005
45-54 vs. 25-34	-1.20	0.045
25-34 vs. 18-24	0.60	0.040

Interpretation of Post-Hoc Results: Significant differences in e-waste disposal practices were observed across age groups. Participants aged 25-34 demonstrated significantly higher disposal scores compared to those aged 55-64 and 65 and older, indicating that younger individuals are more engaged in responsible e-waste disposal. Additionally, older age groups (45-54, 55-64, and 65 or older) exhibited lower disposal scores, highlighting the need for targeted educational initiatives to raise awareness and promote better disposal practices among these demographics.

5. Findings

5.1 General Findings

The largest age group among respondents was 25-34 years, indicating a younger demographic, which is essential for targeted educational initiatives. Gender representation was nearly balanced, with a slight majority of females. The majority (40%) held a bachelor's degree, suggesting that the respondents are relatively well-educated. 60% of respondents were aware of e-waste, but only 40% felt knowledgeable about its environmental impacts. This suggests a gap between awareness and understanding, emphasizing the need for educational programs that deepen knowledge.

5.2 Awareness of E-Waste Issues

The survey results revealed a moderate level of awareness regarding e-waste among respondents. Approximately 60% of participants reported having heard of e-waste, while 40% considered themselves knowledgeable about its environmental impacts. Notably, those with higher education levels (bachelor's degree or above) were significantly more likely to recognize e-waste issues ($p < 0.05$). Participants cited social media (45%) and news articles (30%) as primary sources of information about e-waste, indicating a need for more targeted educational initiatives.

5.3 Disposal Practices

The findings indicated that a significant portion of e-waste is not disposed of responsibly. While 55% of respondents reported recycling their electronic devices, 30% admitted to discarding them in the trash. Additionally, only 40% were aware of local e-waste recycling programs. Participants who regularly engage in recycling were found to have higher awareness of e-waste issues ($p < 0.01$), highlighting the link between knowledge and responsible disposal practices.

5.4 Engagement with IoT Solutions

The data revealed that awareness of IoT-enabled recycling initiatives was relatively low, with only 35% of respondents familiar with such technologies. However, interest in

utilizing IoT solutions was high; 65% expressed willingness to use an IoT-enabled system for e-waste disposal, particularly if it offered features such as notifications for collection events and easy access to drop-off locations. Notably, respondents in the younger age group (18-24) showed greater enthusiasm for adopting IoT solutions compared to older participants.

5.5 Barriers to Participation

When asked about barriers to participation in e-waste recycling programs, respondents identified several key factors:

- **Lack of Information (50%):** Many participants indicated that they were unaware of available recycling options.
- **Inconvenience (40%):** Respondents cited the distance to drop-off locations and time constraints as significant deterrents.
- **Perceived Ineffectiveness (35%):** Some participants expressed skepticism about the impact of recycling efforts on reducing environmental harm.

6. Suggestions

- **Enhance Awareness:** Use social media, news articles, and educational campaigns to improve understanding of e-waste and its impact.
- **Improve Recycling Information:** Provide clear details about local e-waste recycling programs and drop-off locations.
- **Encourage Responsible Disposal:** Promote the benefits of recycling and its positive impact on the environment.
- **Promote IoT Solutions:** Increase awareness of smart recycling technologies and their convenience, especially among younger people.
- **Increase Accessibility:** Set up more collection points and introduce scheduled pickup services to make recycling easier.

- **Address Skepticism:** Highlight the effectiveness of recycling programs through real-world examples and success stories.

7. Conclusion

The study highlights the potential of IoT in improving e-waste management by making collection more efficient and increasing awareness. While many people are aware of e-waste, their understanding of its environmental impact is limited, showing the need for better education. Improper disposal remains a concern, as a significant portion of respondents still throw away electronics instead of recycling them. Those who recycle regularly tend to have higher awareness, indicating that knowledge influences responsible behavior. Although awareness of IoT-based recycling solutions is low, interest in using them is high, especially among younger individuals. However, barriers such as lack of information, inconvenience, and doubts about the effectiveness of recycling programs hinder participation. Addressing these challenges through targeted awareness campaigns and improved access to recycling options can encourage more people to engage in sustainable e-waste management. The insights from this study can help policymakers and waste management professionals design better strategies to promote responsible disposal and support environmental sustainability.

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