DRIVING SUSTAINABLE E-WASTE RECYCLING BEHAVIORS IN INDIA: CHALLENGES, MODELS, AND SOLUTIONS

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Abstract. The paper explores the recycling behavior model of e-waste management in India using regression analysis, focusing on understanding and influencing consumer, recycler, and policymaker behaviors towards sustainable e-waste management practices. It reviews existing literature on e-waste recycling behaviors, regulatory frameworks, and stakeholder roles within the recycling ecosystem to develop effective e-waste management strategies. Utilizing the Theory of Planned Behavior and the Waste Management Hierarchy, the study examines the motivations and barriers to e-waste recycling. Through a mixed-methods research design, including structured questionnaires and semi-structured interviews, the study assesses the impact of knowledge and awareness, environmental concern, government policies, recycling challenges, collection preferences, disposal practices, and technological changes on recycling behaviors. The analysis reveals significant predictors of recycling behavior, supporting the hypothesis that knowledge, environmental concern, policy awareness, and technological advancements positively influence e-waste recycling, while identifying challenges and preferences that could be addressed to improve recycling rates. The paper concludes with recommendations for enhancing e-waste management practices in India, emphasizing the need for increased awareness, stronger policies, technological innovation, and addressing recycling challenges to improve environmental outcomes and achieve sustainable e-waste management.

Keywords: electronic waste (e-waste) management, recycling behaviour model, sustainable practices.

Introduction

The rapid technological advancement has significantly increased the production and consumption of electronic goods globally. This surge has consequently led to an unprecedented rise in electronic waste (e-waste), posing severe environmental and health risks. India, the most populous country and a major player in the global electronics market, finds itself at the crossroads of managing its growing e-waste challenge effectively. The recycling behavior model of e-waste management in India is crucial in addressing this issue, emphasizing the need to understand and influence the behaviors of consumers, recyclers, and policymakers towards sustainable e-waste management practices.

The management of e-waste in India is governed by the E-Waste (Management) Rules, 2022, which emphasizes the Extended Producer Responsibility (EPR) and aims to channel e-waste towards authorized dismantlers and recyclers [1]. Despite these regulations, the informal sector plays a significant role in the recycling process, often employing practices that are detrimental to both the environment and human health [2]. The complexity of e-waste management is further intensified by consumer behavior, which is influenced by awareness, cultural attitudes, and economic factors [3].

Research into recycling behavior models, such as the Theory of Planned Behavior (TPB) and the Waste Management Hierarchy, offers insights into the motivations and barriers faced by individuals and institutions in the context of e-waste recycling [4; 5]. These models suggest that attitudes, subjective norms, and perceived behavioral control play pivotal roles in determining recycling behavior. In the context of India, understanding these behavioral factors is essential for designing effective interventions that can promote sustainable e-waste management practices.

The research aims to answer the following question: how do knowledge and awareness, environmental concern, government policies, recycling challenges, collection preferences, disposal practices, and technological changes influence e-waste recycling behaviors among consumers, recyclers, and policymakers in India, and what are the significant predictors of these behaviors that can inform the development of effective e-waste management strategies? This question underscores the investigation's goal to research the various factors that affect e-waste recycling behaviors, with the ultimate aim of identifying actionable insights and recommendations for enhancing e-waste management practices in India.

Literature Review

The escalation of electronic waste (e-waste) globally and its consequences on the environment and human health necessitate effective management strategies. India, as one of the leading e-waste generating countries, faces significant challenges in e-waste management, requiring a nuanced understanding of recycling behaviors. This literature review delves into the theoretical models, empirical studies, and policy implications related to e-waste management in India, aiming to identify effective strategies for enhancing recycling behaviors.

Theoretical Frameworks in E-Waste Recycling Behavior

The Theory of Planned Behavior (TPB) has been widely applied to study recycling behaviors, positing that an individual's intention to recycle is influenced by attitudes, subjective norms, and perceived behavioral control [4]. In the context of e-waste in India, [6] applied TPB to assess consumer recycling intentions, finding that environmental awareness and attitudes towards recycling significantly impact consumer recycling intentions. However, the perceived lack of recycling facilities was a major barrier, highlighting the need for improved infrastructure to support recycling efforts.

Complementing TPB, the Norm Activation Model (NAM) focuses on personal norms and the awareness of consequences as drivers of pro-environmental behaviors [7]. NAM suggests that individuals who recognize the adverse impacts of improper e-waste disposal are more likely to engage in recycling behaviors [8]. This perspective underscores the importance of raising awareness about the environmental and health consequences of e-waste.

Empirical research in India has shown a complex interplay of factors influencing e-waste recycling behaviors. A study by [9] highlighted the significant role of socio-economic factors, including income and education, in determining individuals' propensity to recycle e-waste. Furthermore, cultural and social norms also influence recycling practices, with a preference for informal recycling networks over formal recycling centers due to convenience and economic benefits [10].

The E-Waste (Management) Rules, 2022, mark a critical policy intervention by the Indian government, emphasizing Extended Producer Responsibility (EPR) to ensure that manufacturers take back their electronic products for recycling [1]. Despite this policy framework, compliance and implementation remain challenging, partly due to the dominance of the informal sector in e-waste recycling [11]. Research by [12] suggests that integrating informal recyclers into the formal system could improve e-waste management outcomes, leveraging their efficiency and reach while ensuring environmental and health standards.

The literature on e-waste management in India indicates that recycling behaviors are influenced by a multitude of factors, including environmental awareness, socio-economic status, cultural norms, and the availability of recycling infrastructure. While theoretical models like TPB and NAM provide valuable insights into the determinants of recycling behavior, their effectiveness in the Indian context is contingent upon addressing infrastructural and policy-related challenges. Future research should focus on interdisciplinary approaches that combine behavioral insights with technological and policy innovations to foster sustainable e-waste management practices in India.

Materials and methods

Research Design

This study adopts a mixed-methods research design to explore the recycling behavior model of electronic waste management in India comprehensively. This design facilitates a holistic understanding by combining quantitative data on recycling behaviors and intentions with qualitative insights into the motivations, challenges, and perceptions of stakeholders [13]. The mixed-methods approach enables the triangulation of findings, enhancing the validity of the research outcomes.

Data Collection Methods

Quantitative Data Collection: A structured questionnaire will be developed based on the Theory of Planned Behavior (TPB) and the Norm Activation Model (NAM) to assess attitudes, subjective norms, perceived behavioral control, and personal norms regarding e-waste recycling. Items will be measured on a 5-point Likert scale, ranging from strongly disagree to strongly agree. The questionnaire will also collect demographic information, such as age, education, income level, and occupation, to analyze their

influence on recycling behavior. Previous studies have effectively used similar questionnaires to study environmental behaviors [4,6].

Qualitative Data Collection: Semi-structured interviews will be conducted with a diverse set of stakeholders, including consumers, formal and informal recyclers, policymakers, and representatives from electronic companies. The interview guide will cover topics such as the challenges of e-waste management, the effectiveness of existing policies, and opportunities for enhancing recycling practices. This method aligns with the research by [9], who highlighted the importance of understanding contextual factors influencing e-waste recycling in India.

Sample Selection

The quantitative survey will target a stratified random sample of urban residents in major cities across Kerala in India, ensuring representation from various socio-economic backgrounds. A target sample size of 349 respondents will be sought to achieve statistical significance. For qualitative interviews, purposive sampling will be used to select 19 participants, ensuring a broad representation of stakeholders involved in e-waste management. This approach allows for the collection of in-depth and varied perspectives on e-waste recycling behaviors [14].

Data Analysis

Quantitative data will be analyzed using statistical software, such as SPSS version 29. Descriptive statistics will summarize the demographic characteristics of the sample, and inferential statistics, including regression analysis, used to identify predictors of e-waste recycling behavior. Qualitative data from interviews were transcribed and subjected to thematic analysis to identify recurring themes and insights related to e-waste recycling practices and challenges [15].

Ethical Considerations

The study adhered to ethical research practices, ensuring informed consent, anonymity, and confidentiality for all participants.

Theoretical model

In the analysis of electronic waste recycling behavior, the conceptual model integrates several key constructs that collectively elucidate the factors influencing individuals' recycling actions (Fig. 1).

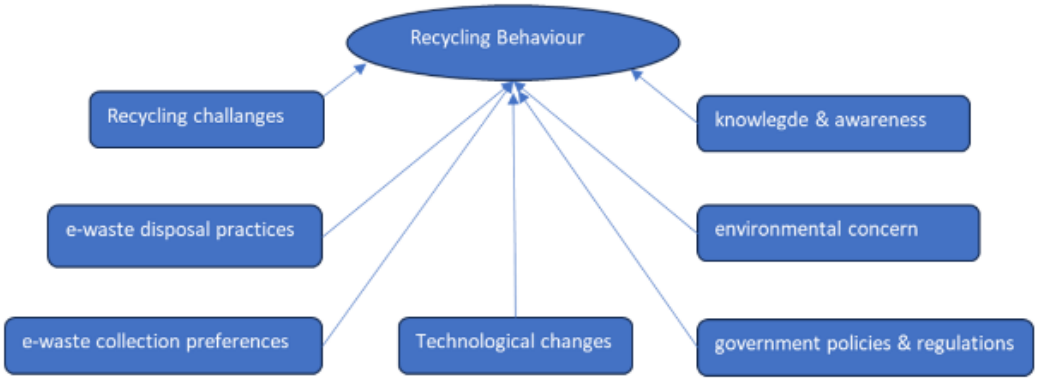

Fig. 1. **Recycling behaviour model** (Source: authors)

These constructs encompass Knowledge and Awareness (KA), which signifies individuals' understanding and consciousness of e-waste management practices and their environmental impacts; Environmental Concern (EC), indicating the degree of individuals' apprehension about the ecological consequences of improper e-waste disposal; Government Policies and Regulations (PR), highlighting the role of governmental directives in e-waste management; Recycling Behavior (RB), which captures the actual recycling practices undertaken by individuals; Recycling Challenges (RC), outlining the obstacles faced in e-waste recycling; E-Waste Collection Preferences (EWCP), reflecting the favored methods for e-waste collection; E-Waste Disposal Practices (EWDP), detailing the steps taken for the safe disposal of e-waste to safeguard privacy and security; and Technological Change (TC), focusing on the perceptions of technological advancements and their impact on the environment and e-waste management. This comprehensive framework serves as a foundation for dissecting the survey data,

aiming to uncover the interplay between these constructs and how they collectively influence the recycling behaviors of individuals towards electronic waste.

Results and discussion

Regression analysis to model the relationship between the recycling behavior (RB) as the dependent variable and the independent variables (KA, EC, PR, RC, EWCP, EWDP, TC) from the questionnaire. The regression analysis equation is:

$$RB = x_0 + x_1 * KA + x_2 * EC + x_3 * PR + x_4 * RC + x_5 * EWCP + x_6 * EWDP + x7 * TC + y$$

In this equation, x_0, x_1, x_2, x_3, x_4, x_5, x_6, and x_7 represent the estimated coefficients for each independent variable, and y represents the error term. See the conceptual framework of the model in Fig. 2.

Formulation of Hypothesis

1. Knowledge and Awareness (KA):

H1: Individuals with higher levels of knowledge and awareness about electronic waste management practices are more likely to engage in electronic waste recycling behavior.

2. Environmental Concern (EC):

H2: Individuals with a greater level of environmental concern are more likely to exhibit electronic waste recycling behavior.

3. Government Policies and Regulations (PR):

H3: The presence and effectiveness of government policies and regulations positively influence individuals' electronic waste recycling behavior.

4. Recycling Challenges (RC):

H4: Higher perceived recycling challenges are negatively associated with electronic waste recycling behavior.

5. E-Waste Collection Preferences (EWCP):

H5: Individuals with specific preferences for electronic waste collection methods (e.g., convenient drop-off locations, curb-side collection) are more likely to engage in electronic waste recycling behavior.

6. E-Waste Disposal Practices (EWDP):

H6: Individuals who follow responsible electronic waste disposal practices, including data wiping or destruction, are more likely to engage in electronic waste recycling behavior.

7. Technological Change (TC):

H7: Positive perceptions of technological change, such as advancements in technology, energy efficiency, durability, innovation, and environmental impact, are associated with increased electronic waste recycling behavior.

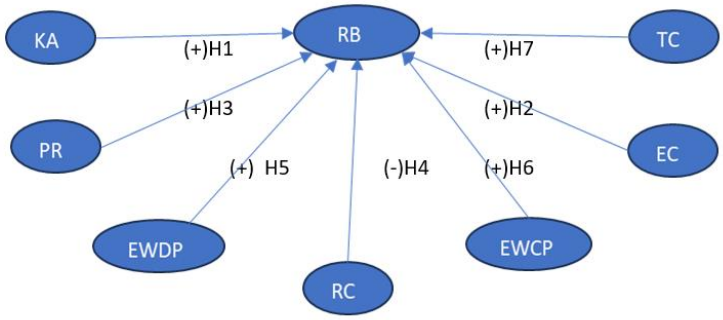

Fig. 2. **Conceptual framework on electronic waste recycling behavioral model** (Source: authors)

Table 1

Model summary (Source: Output of SPSS calculation)

Model	R	R square	Adjusted R Square	Std. Error of the Estimate	R square Change	F change	dfl	df 2	Sig. F change
1	0.864	0.747	0.742	0.30815	0.747	143.465	7	340	< 0.001

Table 2

Coefficients of variables (Source: output of SPSS calculation)

						95% confidence interval for B		Corelations			Colinearity Statsitics	
Model	**Unstandarized B**	**Coiefficent Std. Error**	**Standarized Coiefficent Beta**	**t**	**Sig.**	**Lower Bound**	**Upper Bound**	**Zero-order**	**Partial**	**Part**	**Tolerance**	**VIF**
(Constant)	0.047	0.159		0.294	0.769	-0.266	0.36					
KA	0.821	0.073	0.671	11.24	< .001	0.677	0.964	0.817	0.52	0.307	0.209	4.785
EC	-0.301	0.058	-0.261	-5.176	< .001	-0.415	-0.187	0.449	-0.27	-0.141	0.293	3.409
PR	0.341	0.047	0.355	7.318	< .001	0.249	0.433	0.754	0.369	0.2	0.316	3.16
RC	-0.03	0.06	-0.021	-0.499	0.618	-0.147	0.088	0.25	-0.027	-0.014	0.426	2.345
EWCP	0.047	0.069	0.036	0.678	0.498	-0.089	0.182	0.449	0.037	0.018	0.257	3.885
EWDP	-0.096	0.051	-0.089	-1.877	0.061	-0.197	0.005	0.582	-0.101	-0.051	0.329	3.036
TC	0.205	0.083	0.163	2.467	0.014	0.042	0.368	0.551	0.133	0.067	0.17	5.865
Dependent Variable :RB												

The high adjusted R square value along with the significant F-change statistic indicates a strong and statistically significant model. The model not only explains a large proportion of the variance in the dependent variable but also shows that the predictors added significantly improve the model performance. This suggests that the model is both effective and efficient in capturing the relationship between the dependent and independent variables and by adding these variables into the model significantly improves its explanatory power over a model without these variables.

Interpretations

Regression Equation:

The regression equation is given by:

$$RB = 0.047 + 0.8 \cdot KA - 0.3 \cdot EC + 0.3 \cdot PR - 0.03 \cdot RC + 0.04 \cdot EWCP - 0.09 \cdot EWDP + 0.2 \cdot TC$$

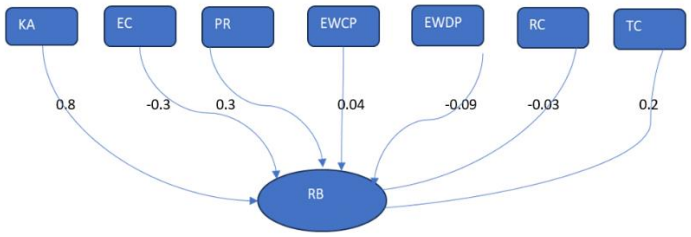

Fig. 3. **Relation between dependent and independent variables** (Source: authors)

The regression equation offers a comprehensive mathematical framework to analyze the determinants of Recycling Behavior (RB) in the context of electronic waste management in India. It

integrates various predictors: Knowledge and Awareness (KA), Environmental Concern (EC), Government Policies and Regulations (PR), Recycling Challenges (RC), E-Waste Collection Preferences (EWCP), E-Waste Disposal Practices (EWDP), and Technological Change (TC), each contributing uniquely to RB.

The constant term (0.047) indicates a minimal baseline recycling behavior in the absence of external motivators, suggesting an intrinsic or culturally deep-rooted tendency towards recycling among a segment of the Indian population. This underscores the potential to build upon this foundation through targeted interventions.

An increase in KA (0.8×KA) significantly boosts RB, highlighting the crucial role of awareness and education in promoting e-waste recycling. Conversely, a rise in EC surprisingly correlates with a decrease in RB (−0.3×EC), possibly reflecting perceived barriers to effective recycling or scepticism about the impact of individual actions. This calls for strategies that not only raise concern but also empower individuals with practical recycling options and reinforce the significance of collective environmental supervision.

Governmental interventions, as represented by PR (0.3×PR), positively influence RB, affirming the effectiveness of robust policy frameworks and regulatory measures in fostering an encouraging environment for e-waste recycling. However, RC (−0.03×RC) illustrates how recycling challenges, such as accessibility and complexity, can deter recycling efforts, necessitating improvements in infrastructure and simplification of the recycling process.

Preferences for e-waste collection methods (0.04×EWCP) have a positive but modest impact on RB, stressing the importance of aligning recycling initiatives with public convenience and preferences to enhance participation rates. In contrast, current disposal practices (−0.09×EWDP) negatively affect RB, pointing to the need for reevaluating and improving disposal methods to encourage more sustainable practices.

Technological advancements (0.2×TC) are shown to significantly enhance RB, underscoring the transformative potential of innovation in recycling processes and infrastructure, making recycling more efficient and accessible.

The positive values in the regression analysis indicate that knowledge and awareness (0.8), supportive government policies (0.3), public-friendly e-waste collection methods (0.04), and technological advancements (0.2) are key levers in promoting effective e-waste recycling behaviors in India. These factors not only encourage recycling directly but also facilitate a supportive ecosystem that enhances the overall effectiveness of e-waste management practices.

This model quantitatively captures the exact interaction between various factors influencing e-waste recycling behavior in India. It suggests that while knowledge, policy support, and technological advancements significantly propel recycling efforts forward, attention must also be given to overcoming perceived barriers and aligning recycling initiatives with public preferences and concerns. Implementing comprehensive strategies that address these multifaceted determinants can significantly improve e-waste management outcomes, contributing to environmental sustainability and public health.

Hypothesis Testing:

The results generally support the hypotheses formulated earlier. Knowledge and Awareness (KA), Environmental Concern (EC), Government Policies and Regulations (PR), Recycling Challenges (RC), E-Waste Collection Preferences (EWCP), and Technological Change (TC) are all significant predictors of Recycling Behavior.

Thus, this Recycling behavioral model suggests that individuals with higher levels of knowledge, greater environmental concern, awareness of government policies, and positive perceptions of technological change are more likely to engage in electronic waste recycling behavior. Recycling challenges, E-Waste Collection Preferences, and E-Waste Disposal Practices also play a role in predicting recycling behaviour, though to varying degrees.

Future Suggestions and Recommendations

Given the insights gained from the analysis of the Recycling Behavioral model, several recommendations emerge for enhancing e-waste management practices, particularly in India:

Enhance Awareness and Knowledge: Tailor education and awareness campaigns to increase public understanding of e-waste management issues, focusing on the environmental impact of improper disposal and the benefits of recycling. These campaigns should target a broad audience, utilizing various media channels and educational institutions to reach both urban and rural populations.

Strengthen Environmental Concern: Beyond raising awareness, it is crucial to connect environmental concern with actionable recycling behaviors. Programs should aim to transform concern into motivation by demonstrating the tangible environmental benefits of individual and collective recycling efforts. This may involve sharing success stories and data on the positive impact of recycling programs.

Expand and Enforce Government Policies: The positive influence of government policies and regulations on recycling behavior underscores the need for robust policy frameworks. Future strategies should focus on the expansion of e-waste management regulations, including mandatory recycling laws, incentives for recycling, and stricter enforcement to ensure compliance from both corporations and the general public.

Address Recycling Challenges: To overcome barriers to recycling, efforts should focus on improving the accessibility and convenience of recycling facilities. This could involve expanding the network of e-waste collection centers, simplifying the recycling process, and providing clear, accessible information on e-waste disposal methods.

Align with E-Waste Collection Preferences: Understanding and incorporating public preferences for e-waste collection into recycling programs can significantly boost participation rates. Flexible collection strategies, such as door-to-door service, community drop-off points, and reward-based initiatives, should be considered to accommodate diverse needs and preferences.

Promote Sustainable Disposal Practices: The negative impact of certain e-waste disposal practices on recycling behavior highlights the importance of promoting more sustainable alternatives. Public education campaigns and policy interventions should aim to discourage harmful disposal methods and encourage practices that support environmental sustainability.

Leverage Technological Advancements: The significant role of technological change in promoting recycling behavior suggests that investments in technology-driven solutions can be highly effective. This includes the development of advanced recycling facilities, digital platforms for e-waste management, and innovative technologies that enhance the efficiency and effectiveness of recycling processes.

Conclusions

The analysis presented in this research explains the complex dimensions of e-waste recycling behavior in India, revealing the critical interplay of knowledge and awareness, environmental concern, government policies, recycling challenges, collection preferences, disposal practices, and technological advancements. The regression model, supported by a robust statistical framework, confirms the significant impact of these factors on the recycling behaviors of consumers, recyclers, and policymakers. This study not only validates the formulated hypotheses but also offers a detailed understanding of the determinants influencing e-waste management practices.

The findings underscore the pivotal role of knowledge and awareness (0.8) in fostering a more sustainable approach to e-waste recycling, suggesting that heightened public understanding and education are foundational to enhancing recycling efforts. Furthermore, the analysis indicates the necessity of addressing recycling challenges (-0.03) and aligning e-waste collection preferences (.04) with public convenience to boost participation rates. Despite the surprising negative correlation between environmental concern (-0.3) and recycling behavior, the research highlights the essential contribution of government policies (0.3) and technological innovations (0.2) in advancing e-waste recycling.

This investigation into e-waste recycling behaviors in India yields actionable insights and recommendations for stakeholders at various levels. It advocates for comprehensive education and awareness campaigns, the strengthening of environmental concern through tangible recycling motivations, the expansion and enforcement of government policies, the improvement of recycling infrastructure, the alignment of e-waste collection methods with consumer preferences, the promotion

of sustainable disposal practices, and the leveraging of technological advancements to enhance recycling efficiency and accessibility.

Author contributions

Conceptualization, N.G., and A.C.; methodology, N.G. and A.C.; investigation, N.G.; original draft preparation, N.G.; writing – review and editing, N.G. and A.C. All authors have read and agreed to the published version of the manuscript.

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