Institutional, Infrastructural, and Behavioural Constraints to Formal E-Waste Recycling: A Systems-Level Stakeholder Analysis in Bhavnagar

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DOI: https://doi.org/10.51244/IJRSI.2025.120700084

Received: 07 July 2025; Accepted: 11 July 2025; Published: 02 August 2025

ABSTRACT

The study examines the institutional, infrastructural, and behavioural barriers to formalising e-waste recycling in the Indian city of Bhavnagar at a systems level, involving stakeholders. They also employed a mixed-methods study, which comprised surveys of 110 respondents, seven focus group discussions, and maps of the geospatial locations of informal recycling areas. Results showed that 85% of the respondents noted the presence of weak regulatory enforcement, 80% indicated the absence of governmental support, and 75% stated the presence of significant policy lapses. Infrastructurally, 85% of them did not have a formal recycling setup, 60% lacked modern tools and technology, and 80% reported poor waste management services. The geospatial examination revealed high-density informal sites located within 100 meters of residential areas, characterised by hazardous levels of lead and mercury pollution. Behaviourally, although 90% admitted to health hazards, 55% opposed formalisation due to the low level of profitability and economic reliance, with only 50% willing to switch. Other checklists provided information, including 89% of sites did not have safety equipment, 88% had open burning, and 69% did not have child labour. According to the local government, NGOs and private recyclers were identified as essential stakeholders after an analysis of stakeholders. Their study suggests policy reform, targeted incentives, investment in infrastructure, and behavioural reorientation to ensure that the e-waste recycling systems in Bhavnagar are safe, inclusive, and sustainable.

Keywords: e-waste recycling, Bhavnagar, institutional constraints, behavioural barriers, environmental impact

INTRODUCTION

It is known that the informal e-waste recycling branch has been an ever more important problem in the world because of the increasing amounts of e-waste that are produced. E-waste is a waste consisting of used electronic gadgets and electrical products such as mobile phones, computers, and televisions, which in most cases comprise toxic materials such as lead, mercury and cadmium. The formal e-waste recycling industry is promising a safe and environmentally good process of disposing of the e-waste, although informal recycling is still very common, especially in the developing world, such as India, where most informal recycling happens without any regulation. In Bhavnagar, it is an important economic process since people engage in e-waste recycling not because of the deficient formal waste recycling system but due to the non-existence of polices. One of the factors which have been seen as major determinants of the formalisation of e-waste recycling in developing regions is institutional constraints. Another important aspect, such as the non-enforcement of policy, the absence of a regulatory regime and government involvement, has been identified as a major challenge in the establishment of a formal e-waste recycling market by various studies. Misunderstood laws or a lack of funds to keep a check on the informal recycling activities result in further unsafe procedures, which are risky to both the people and the environment. For example, Kaur *et al*. (2018) begin by highlighting the issue of a lack of regulatory framework, as informal recycling persists due to the laxity of enacted policies.

The presence of infrastructural limits is also a key factor that contributes to the existence of informal recycling of e-waste. Much of the recycling activity in places such as Bhavnagar remains limited due to a lack of access

to facilities, technologies, and financial resources. As a result, informal workers often employ crude techniques to recover valuable materials, including manual dismantling, open burning, and acid baths. As certain scholars have noted, even where formal facilities are available, suitable technology to manage e-waste in an environmentally friendly manner is often lacking, even in such areas (Soni & Kumar, 2020). Additionally, the geographical location of the informal recycling sites in Bhavnagar reveals that they are also underdeveloped in terms of infrastructure, which poses even greater harm to the environment. The other significant influence on the formalization of e-waste recycling is behavioral constraints. People in poverty who have no other option but to work in the informal sector are not well informed of the health hazards of unsafe recycling processes. The eagerness of informal workers to adopt formal practices is hindered by community opposition, a lack of education, and financial constraints. As Soni and Kumar (2020) claim, ineffective public awareness and social stigma against recycling e-waste, in addition to the lack of government regulation, complicate the process of formalising the industry. Informal workers who engage in e-waste recycling often lack knowledge of safer recycling methods, making it a challenging task to modify their behavior and adopt formal recycling methods.

This study aims to investigate these institutional, infrastructural, and behavioural constraints in Bhavnagar, offering a systems-level stakeholder analysis to better comprehend the challenges to formalising e-waste recycling in the region. By examining the roles of government institutions, recycling workers, NGOs, and local businesses, this research aims to highlight the most pressing barriers and propose actionable recommendations for overcoming these constraints.

METHODOLOGIES

The study adopted a mixed-methods approach, including qualitative and quantitative research methods, to address the institutional, infrastructural and behavioural bottlenecks to the formalisation process of e-waste recycling in Bhavnagar, India. A structured survey involving 110 respondents (informal e-waste workers, non-governmental organisations and local business companies) was conducted, where data were collected. Seven focus group discussions (FGDs) of informal workers were conducted in order to discuss their behavioural attitudes, knowledge of formal recycling practices, social, and economic barriers. The focus groups also provided insights into health risks, cultural perceptions, and readiness to transition to formal systems. Additionally, geospatial data were collected using a Geographic Information System (GIS) to identify informal e-waste processing sites and assess their environmental impact. To identify key stakeholders and determine their roles and influence in the e-waste recycling industry, a stakeholder analysis was conducted using the power-interest matrix.

Various methods of data analysis were employed to provide comprehensive information. Thematic analysis was used to analyse the qualitative data, with code being run using NVivo software to arrive at common themes that included policy gaps, absence of infrastructure and worker resistance. Descriptive statistics were applied to summarise information about income, working conditions, and awareness of formal recycling, as this approach is referred to as quantitative analysis. The multiple regression analysis and chi-square tests were used to examine the associations among variables such as education, income, and the adoption of formal recycling. Factor analysis was applied to determine hidden factors that were affecting the transition to formal systems. Lastly, geo-spatial analysis was used to identify high-risk areas of e-waste processing, which contributed to determining the levels and priorities of contaminated areas to inform policy implementation. The approach yields a comprehensive systems-level understanding of the obstacles to local formalisation of e-waste recycling in Bhavnagar, guiding the direction of future policy-making.

RESULTS

Table 1: Demographic Profile of Respondents

Variable	Frequency (n)	Percentage (%)
Gender		
Female	66	60%
Male	44	40%

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VII July 2025

Age Group		
25-40 years	71	65%
Other (under 25 and over 40)	39	35%
Educational Level		
Secondary education	44	40%
Primary education	33	30%
Graduate	11	10%
Income Level		
₹5,000–₹10,000	55	50%
Less than ₹5,000	45	40%
Formal Employment		
No	55	50%
Yes	55	50%
Involvement in E-Waste Recycling		
Yes	88	80%
No	22	20%

Table 2: Institutional Constraints

Institutional Challenge	Frequency (n)	Percentage (%)
Policy Gaps	83	75%
Government Support	88	80%
Regulatory Enforcement	94	85%
Awareness of Formal Regulations	77	70%

Table 3: Infrastructural Constraints

Infrastructural Issue	Frequency (n)	Percentage (%)
Formal Recycling Facilities	94	85%
Recycling Tools & Technology	66	60%
Waste Management Services	88	80%

Table 4: Behavioural Constraints

Behavioural Challenge	Frequency (n)	Percentage (%)
Awareness of Health Risks	99	90%
Willingness to Adopt Formal Recycling	55	50%
Resistance to Formalization	61	55%

Table 5: Geospatial Analysis Results

Geospatial Factor	Finding
Informal Recycling Sites Density	High density in low-income areas
Proximity to Residential Areas	Many sites located within 100 meters of residential areas
Toxic Contamination Levels	High lead and mercury levels near processing sites

Table 6: Checklist Validation Results

Checklist Item	Percentage (%)
The work location is a dumpsite.	85%
Presence of hazardous materials (e.g., lead, CRT)	86%
Burns, cuts, or visible injury observed	80%
No safety gear in use	89%
Children seen working	69%

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VII July 2025

The site lacks waste bins or storage.	83%
Materials are being openly burned.	88%
Recyclables are mixed with hazardous waste.	77%
Respondent appears fatigued	82%
Area has strong odour or fumes	85%

Table 7: FGD Findings (Institutional, Infrastructural, and Behavioural Constraints)

Category	Key Findings	Percentage (%)
Institutional Constraints	Lack of Government Support: 85% of participants reported no government involvement.	85%
	Awareness of Policies: 70% were unaware of formal recycling regulations.	70%
	Policy Gaps: 75% noted significant gaps in policy enforcement and government action.	75%
Infrastructural Constraints	Lack of Formal Recycling Facilities: 90% of workers lacked access to formal facilities.	90%
	Recycling Tools & Technology: 60% of workers had no access to proper tools or modern tech.	60%
	Waste Management Services: 80% reported inadequate waste management services.	80%
Behavioural Constraints	Awareness of Health Risks: 90% of workers were aware of the health risks of informal recycling.	90%
	Willingness to Adopt Formal Recycling: 50% expressed willingness to transition to formal systems.	50%
	Resistance to Formalization: 55% of workers were resistant to formalization due to low profitability and economic concerns.	55%
Social and Economic Barriers	Child Labor: 69% of sites observed had children involved in e-waste processing.	69%
	Social Stigma: 60% of workers felt social stigma related to e-waste work.	60%
	Economic Pressures: 75% indicated that informal recycling was their only means of survival.	75%

Table 8: Stakeholder Analysis for Formalizing E-Waste Recycling

Stakeholder	Interest	Influence/ Power	Role in the Formalization Process	Engagement Strategy
Government (Local/State)	Enforce regulations, develop policies, provide funding and support for formal systems, and improve public health.	High	Regulatory body, policy maker, and enforcer of e-waste laws.	Engage through policy development, public awareness campaigns, and funding initiatives.
Informal E-Waste Workers	Economic survival, safe working conditions, fair wages, and better job opportunities.	Medium	Primary workers in the e-waste sector.	Training for safer recycling practices, economic incentives, and health awareness.
NGOs/ Environmental Groups	Advocate for environmental protection, worker safety, and better waste management practices.	Medium	Provide education and support through awareness campaigns.	Partnerships for awareness campaigns, worker health advocacy, and policy lobbying.
Local Businesses/Dealers	Profit from buying and selling e-waste materials,	Medium	Act as intermediaries between workers and	Collaborate with businesses to establish

	and access to safe and profitable recycling practices.		formal systems.	partnerships in formal recycling chains and promote ethical sourcing practices.
Residents in Informal Recycling Zones	Health and environmental quality, as well as safety from pollution.	Low	Affected by informal e-waste processing activities.	Engage through community awareness programs, health monitoring, and environmental protection efforts.
Academic/Research Institutions	Research on e-waste recycling, environmental and health impacts, and technological solutions.	Medium	Conduct studies, develop technologies, and provide data.	Collaborate on research, technology development, and policy recommendations.
Private Recycling Companies	Commercial profit, access to raw materials (e.g., metals), and improved supply chain management.	High	Key players in the formal e-waste recycling sector.	Promote public-private partnerships and investment in infrastructure for formal recycling.
Workers' Unions	Improve working conditions, ensure fair wages, and protect worker rights in the transition to formalization.	High	Represent informal workers' rights and interests.	Form alliances with NGOs and the government to advocate for worker rights and support formalization.

DISCUSSION

Demographic and Socio-Economic Profile of Respondents

The demographics of the surey in this study emphasized the susceptibility of the populations involved in the informal recycling of e-waste in Bhavnagar. The high rate of women's involvement (60%) is an anomaly to traditional gender patterns observed in the informal recycling industries of South Asia, where men typically dominate (Sthiannopkao & Wong, 2013). This male-to-female role inversion can be attributed to regional labour relations or socio-cultural responses to economic inequality. The dominant age category (25-40 years) and the high proportion of low educational attainment level (70% with primary or secondary education level) are similar to those of Chi *et al.* (2014), Isangadighi & Udeh (2023) and Wilson *et al.* (2006), who specify the informal waste sector to be more attractive to the population with poor access to formal employment because of education deficiency and lack of skills training. The level of income that 90% of the population has earned is less than 10,000 rupees per month, and half of the rate of unofficial employment adds more argument that informal recycling is a subsistence approach created based on account of being excluded economically and the lack of progress in the economic ladder (Medina, 2007).

Institutional Constraints

The research identified that there exist significant institutional barriers to the formalization of the e-waste sector. 85% of the respondents viewed the legal enforcement as low, eighty percent lacked government support, and three-quarters of them evoked the policy gap. Such findings are consistent with previous research by Manomaivibool (2009) and Widmer *et al.* (2005), who explain that e-waste regulations in developing countries tend to fail due to disorganised policies, insufficient enforcement capabilities, and inadequate state involvement. The necessary systemic institutional inertia was also revealed through Focus Group Discussions (FGDs), where 85% of the participants reported that the government presence was completely absent at the operational level. This supports the idea of having a policy-practice disconnect, as rules are written but not implemented in a formal process or a way of engaging the stakeholders (Akenji *et al.*, 2015 & Islam, 2021).

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VII July 2025

Infrastructural Constraints

The major impediments to the switch from informal to formal recycling systems were infrastructural deficits. About 85% of the respondents reported the absence of formal recycling facilities, 80% noted the absence of waste management services, and 60% reported the lack of modern recycling tools and technologies. These results are congruent with those of Julander (2014) and Müller *et al*. (2009), who previously underscore that the physical access of poor infrastructure is a severe limitation to the potential of sustainable waste management within low-resource urban contexts. Increased geospatial analyses also revealed that the densities of informal recycling sites were concentrated in low-income neighbourhoods and locations too close to residential living quarters, in some cases, less than 100 meters apart. Such spatial arrangements increase the possibility of exposure to toxic waste products, such as lead and mercury, supporting the claims by Chatterjee (2010), Isangadighi et al. (2025), and Pradhan and Kumar (2014) that environmental injustice is deeply rooted in the spatial politics of e-waste disposal management in India.

Behavioural Constraints and Risk Perceptions

Although awareness of the health threat is high (90%), only 50% of respondents were willing to switch to formal systems, whereas 55% were opposed to such formalisation. This opposition was mainly explained by the aspects of diminishing profitability, intransigent bureaucracy, and the fear of being edged out of deriving income, which was reflected in Medina (2007) and Awasthi *et al*. (2016) and Isangadighi and Ukudo (2025), who had found similar dynamics in Delhi and Lagos where formal recyclers were experiencing formalization as a source of economic losses. The irony of risk awareness and the refusal to formalize it allows for the expression of heavily worn livelihood strategies, in which informal people are willing to sacrifice their futures and the future of their living environment in the name of immediate economic survival. Such dissonance in behaviour confirms the findings of Velis and Wilson (2015) that interventions aimed at changing behaviour should be both economically rewarded and socially situated.

Occupational Hazards and Site Conditions

Observation of data on the checklist showed that the issue of health and safety was serious. Nearly 90% of workers lacked any personal protective equipment (PPE), 88% of workplaces had open firing terms, and 86% of employees were exposed to hazardous substances, including cathode ray tubes (CRTs) and lead compounds. These working conditions resemble those established by Sepulveda and colleagues in a 2010 study, where, according to them, physical injuries were common among informal recyclers, including severe and continuous exposure to chemicals and general fatigue. The percentage of child labour existing in places where children were discovered remained high at 69%, meaning that the problem of child labour persists in even the places where the ILO has classified some places as being hazardous to international labour laws (ILO, 2013). Furthermore, the direct effects of uncontrolled recycling activities on humans are indicated by fatigue (82%) and exposure to high odours and fumes (85%).

Social and Economic Barriers

Social stigma (experienced by 60% of the workers) and economic dependency (with 75% of workers relying solely on informal recycling for their livelihood) became two significant limiting factors. The e-waste labour is also stigmatised, even though it is a new ecological necessity, which is a symptom of socio-cultural undervaluation of waste labour, a phenomenon addressed at length by Baud & Karin (2001). In the meantime, the economic drivers behind opposition to any form of formalisation once again confirm Chaturvedi et al. (2012), who argue that a formalisation plan should include social security, trustworthy income provision, and support for generational transfer among informal employees.

Stakeholder Roles in Formalisation

Stakeholders' analysis revealed a significant disparity between power and participation. Government agencies and recycling companies, whether owned by individuals or the private sector, have a significant influence, while informal workers, although they are the main stakeholders, have a moderate influence. It aligns with Velis and Wilson (2015), who assess the exclusionary measures concentrated in the formal waste management

structure that tend to sideline the most vulnerable populations. The proposals to involve stakeholders, including capacity building, economic incentives, and participatory governance, reiterate the world's best practice as stipulated by UN-Habitat (2010) and Balestra & Tonkin (2018) in the approximately inclusive waste governance system.

CONCLUSION

This study incorporates a system-level perception, that is, a subtle insight into the restraints of formal e-waste recycling in Bhavnagar. The results evince that institutional immobility, infrastructural lassitude, and behavioural immobility have an overall impeding influence on formalisation. As the literature suggests, research emphasises the need to create integrated and stakeholder-friendly models that address both the structural and psychosocial aspects of informality. Formalisation that should be feasible and fair must be economically calculated, technology-driven, and socially acceptable.

RECOMMENDATIONS

Based on the results of this study, it is recommended that a multidimensional approach be adopted to understand the concerns of stakeholders and formalise e-waste recycling in Bhavnagar. The government needs to focus more on developing and implementing consistent regulatory schemes, as well as expanding recycling infrastructure, such as establishing properly equipped official recycling plants and enhancing waste management capacities in underdeveloped regions. At the same time, there should be special awareness-raising and behaviour change initiatives to counter disinformation and address the concerns of informal recyclers, focusing on the long-term health, safety, and economic benefits of formalisation. Monetary rewards, training, and transitional assistance should be provided to encourage informal workers to join the formal system voluntarily. Additionally, the development of the cooperation between NGOs, private recycling firms, academic institutions, and worker unions will encourage policy enforcement, technological embrace, and the representation of marginalised e-waste workers in the decision-making process.

Originality Declaration

This paper has not been previously published in any Journal or is being considered for publication anywhere else.

Conflict of interest

The author states that no conflict of interest exists as far as the publishing of this article is concerned.

ACKNOWLEDGEMENTS

The authors appreciate the contribution of JessieGie Research Associates in methodological guidance and academic feedback to the research study. All Scholars whose works contributed to the success of this study are greatly appreciated and acknowledged.

Funding

The conduct of this research was funded by no particular grant from agencies in the public, commercial, or not-for-profit sectors.

Data Availability

The data generated in the course and/or analysed in this study shall be made available upon request to the corresponding author.

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