

Beyond Formal Channels: A Stakeholder-Driven Closed-Loop Supply Chain Framework for Diagnosing Effectiveness Gaps in India's E-Waste Management System



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Abstract

The government data in FY2024-25 indicates that the officially reported amount of e-waste collected, dismantled and recycled or disposed has increased to 70.71 per cent from 61.94 per cent in FY2023-24, according to the Central Pollution Control Board (CPCB) (Ministry of Environment, Forest and Climate Change, 2025). India is considered as third largest E-waste producer in the world after China and United States. Even taking CPCB's own optimistic figures at face value, close to 30 percent of officially estimated generation remains outside documented formal channels in the most recent reporting year, and because CPCB's generation estimates are themselves modelled from producer sales data and average product life rather than measured directly, independent field-based research on India's informal e-waste sector suggests this gap understates the true scale of informal absorption. This gap between regulatory design and documented operational outcomes motivates the present paper. Drawing on Stakeholder Theory (Freeman, 1984) and the Triple Bottom Line (TBL) framework (Elkington, 1997), this paper develops a conceptual model in which Government Policy Support, Consumer Awareness, Technology Readiness, and Infrastructure Availability act as stakeholder-driven antecedents of the Effectiveness of E-Waste Management, which in turn mediates the achievement of a Sustainable E-Waste Solution. Departing from prior applications of this model class, the paper reframes the mediating construct as a diagnostic "leakage point" at which stakeholder inputs are only partly converted into documented formal-channel outcomes, and it operationalises the TBL economic pillar through the concept of urban-mining value capture. The analysis draws on verified primary and official secondary data, including CPCB and Ministry of Environment, Forest and Climate Change reporting to Parliament, National Green Tribunal filings, the Global E-waste Monitor 2024 (UNITAR/ITU), and peer-reviewed literature, to illustrate the framework's plausibility and to generate testable propositions for future primary research. The paper concludes with policy implications for EPR enforcement, informal-sector integration, and infrastructure planning in the Indian context.

Keywords: e-waste management; closed-loop supply chain; stakeholder theory; triple bottom line; extended producer responsibility; India

1. Introduction

Electronic waste is one of the fastest-growing waste streams in the world, due to the short life cycles of electrical and electronic equipment (EEE). The global volume of e-waste is also increasing at a quick pace and has reached a record 62 million tonnes in 2022, up 82 percent from 2010, and is expected to grow to 82 million tonnes by 2030 (Baldé et al., 2024). Of this, only 22.3 percent was formally collected and recycled in an environmentally sound way, while estimated US\$62 billion worth of recoverable material has not been collected or recycled at all, is leaked into the environment, or is collected and recycled in ways that create environmental and health risks (Baldé et al., 2024). Although the volume of e-waste generated in Asia is close to half of the global total (around 30 million tonnes), few Asian countries have set binding targets or laws for e-waste collection or regulation. (Baldé et al., 2024)

considered as the third-largest number of e-waste generators in the world, only after China and the United States (Baldé et al., 2024). The Ministry of Environment, Forest and Climate Change reported that for FY 2020-21, 1346496.31 tonnes of e-waste was generated nationally, increasing to 1601155.36 tonnes in FY 2021-22, 1254286.55 tonnes in FY 2023-24 and 1397955.59 tonnes in FY 2024-25 as per revised E-Waste (Management) Rules, 2022 reporting framework (Ministry of Environment, Forest and Climate Change, 2025; Press Information Bureau, 2022). This figure is not a physical figure of the waste generated but an estimated figure based on the countrywide producer sales information and an average notified life of electrical and electronic equipment (Refer CPCB's Explicit Statement in ministry of Environment, Forest and Climate Change in 2025).

This place of India is especially significant. India is

Regulatory environment has come a long way in India

over the decade. The E-Waste (Management) Rules, 2016 have superseded the earlier rules, 2011, and introduced the concept of a Producer Responsibility Organization and the E-Waste (Management) Rules, 2022, which will be effective from 1st April 2023, have ushered in a digital Extended Producer Responsibility (EPR) regime for 106 categories of electrical and electronic equipment, with increasing collection targets (Ministry of Environment, Forest and Climate Change, 2022). The Central Pollution Control Board (CPCB) has implemented this regime in the form of a digital EPR portal, where producers, recyclers, refurbishers, and manufacturers have to register and report (Central Pollution Control Board, 2024).

Official data are speaking of a fast but incomplete formalisation process. As per documentation submitted by CPCB to the Rajya Sabha, the collected, dismantled and recycled or disposed e-waste from the generated e-waste has increased from 61.94 percent in FY 2023 – 24 to 70.71 percent during FY 2024 – 25 (Ministry of Environment, Forest and Climate Change, 2025). As per the information in the CPCB's filings before the National Green Tribunal, 92 per cent of EPR obligation (in terms of MT) registered to the registered producers under the EPR by them under FY 23–24 had reportedly been met till 10 December 2024 (Report by CPCB in EA No. 04 of 2024, 2024). Even if taken at face value, there is a documented gap of 29–38

percent of the estimated amount of generation each year not being collected by the authorized processors, and e-waste generation itself is a modelled sales-based estimate, not a direct measure, as are recorded plant-to-plant trade and dismantling activities in India, which are informal and unregistered (Borthakur, 2015; Dutta & Goel, 2021; Sengupta et al., 2023), so the actual share of e-waste which is not collected by the authorised processors is more likely to be even higher. It is this discrepancy between CPCB's self-reported performance on the formal channel and the informal-sector dynamics revealed in independent research that suggests there is an empirical puzzle to explain, and is the motivation of this paper.

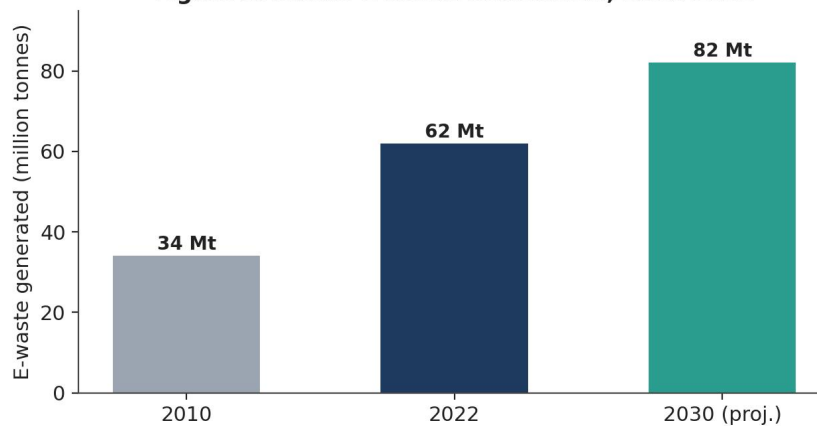
Reported compliance under the EPR-certificate mechanism does not necessarily indicate that a proportionate share of physical e-waste has been diverted from informal channels, because producers can discharge recycling obligations by purchasing EPR certificates from registered recyclers rather than by directly verifying the provenance of collected material (Central Pollution Control Board, 2024; Report by CPCB in EA No. 04 of 2024, 2024). This structural feature of the certificate-trading mechanism is a plausible contributor to the gap between reported target achievement and the residual shortfall in CPCB's own generation-versus-collection figures, and it is a theme this paper returns to in the discussion.

Table 1. Summary of Verified Official Statistics on India's E-Waste Generation and Management, FY 2020-21 to FY 2024-25

Indicator	Value	Source
India's global e-waste rank	3rd largest generator (after China, USA)	Baldé et al. (2024)
India e-waste generation, FY 2021-22	1,601,155.36 tonnes	MoEFCC (2025); PIB (2022)
India e-waste generation, FY 2023-24	1,254,286.55 tonnes	MoEFCC (2025)
India e-waste generation, FY 2024-25	1,397,955.59 tonnes	MoEFCC (2025)
Documented collection/dismantling/recycling share, FY 2023-24	61.94%	MoEFCC (2025)
Documented collection/dismantling/recycling share, FY 2024-25	70.71%	MoEFCC (2025)
CPCB-registered recyclers nationally, Dec 2024	295 (across 19 states)	NGT/CPCB filing (2024); MoEFCC (2025)
CPCB-registered producers, Dec 2024	7,226	NGT/CPCB filing (2024)

Indicator	Value	Source
FY 2023-24 EPR recycling target achieved	92% (254,304 of 275,971 MT)	NGT/CPCB filing (2024)
Global recoverable value in e-waste, 2022	~US\$62 billion	Baldé et al. (2024)

Figure 1. Global E-Waste Generation, 2010-2030



Source: International Telecommunication Union & United Nations Institute for Training and Research (ITU/UNITAR), Global E-waste Monitor 2024 (Baldé et al., 2024).

Figure 1. Global E-Waste Generation, 2010-2030

1.1 Problem Statement

India's e-waste volume continues to grow, and while CPCB's own documented collection and processing share has improved markedly in official reporting, a residual gap of roughly 29-38 percent of estimated generation remains outside documented formal channels even in the most recent reporting year (Ministry of Environment, Forest and Climate Change, 2025). Peer-reviewed field research indicates that informal collectors and dismantlers continue to play a substantial role in Indian e-waste flows, particularly at the household collection stage (Sengupta et al., 2023), and that formal and informal systems remain poorly integrated (Dutta & Goel, 2021). Existing scholarship suggests that weak coordination among producers, third-party collectors, and recyclers continues to constrain the effectiveness of closed-loop supply-chain efforts in India, and that policy reforms and EPR rules, although present, have limited practical effect where consumer awareness, digital tracking, and infrastructure remain uneven (Dwivedy & Mittal, 2012; Kosarkar & Barthwal, 2025).

1.2 Aim and Objectives

This paper aims to develop and illustrate a stakeholder-driven conceptual model of closed-loop e-waste management effectiveness in India, and to reframe the model's mediating construct as a diagnostic device for locating where stakeholder inputs fail to convert into documented sustainable outcomes. The specific objectives are to: (a) synthesise

verified official and peer-reviewed data on India's formal e-waste reporting and its residual gaps; (b) integrate Stakeholder Theory and the Triple Bottom Line framework into a model linking Government Policy Support, Consumer Awareness, Technology Readiness, and Infrastructure Availability to the Effectiveness of E-Waste Management and, through it, to a Sustainable E-Waste Solution; (c) operationalise the TBL economic pillar through the concept of urban-mining value capture; and (d) derive policy-relevant propositions regarding where interventions are most likely to reduce the documented reporting-to-recovery gap.

1.3 Significance of the Study

The paper contributes to the literature in three ways. First, it consolidates verified official statistics from CPCB, the Ministry of Environment, Forest and Climate Change, Parliamentary responses, and the UNITAR/ITU Global E-waste Monitor into a single evidentiary base for India-specific CLSC research, deliberately excluding unverified secondary aggregation. Second, it reflects a theoretical development from treating the mediating variable as simply an intermediary step to taking the step of incorporating the mediation variable as a point where the model may be used for diagnosis of the discrepancy between the documented formal performance and the informal but residual performance. Thirdly, it provides an avenue for the

identification by producers, recyclers and regulators of the stakeholder domain that offers greater potential returns for additional investment, which has direct applicability to India's EPR compliance environment.

2. Theoretical Framework

2.1 Stakeholder Theory

Stakeholder Theory (Freeman, 1984) proposes that organisations are part of a network of relationships with groups that influence, or are influenced by, organizational behavior. In the context of supply chains, the theory also holds responsibility for supply chain members beyond the suppliers and the buyers, including the regulator, consumers, employees and local communities (Freeman & McVea, 2001). In waste management, stakeholders consist of the producers, collectors, recyclers, residents and the government, by each creating waste or delivering services or exercising oversight (Koiwanit & Filimonau, 2023). Borthakur and Sinha (2013) characterize the Indian e-waste system as a system of interdependent actors where the efficiency and safety of the entire system depend upon the cooperation of these actors; in the absence of coordinated actions, the informal collectors and recycled unregistered businesses result in a less efficient and safe e-waste system.

Stakeholder Theory proposes that the independent constructs of the model include Government Policy Support, Consumer Awareness, Technology Readiness and Infrastructure Availability. All have dedicated stakeholder groups: government provides regulation and enforcement, producers and recyclers are responsible for technology and infrastructure, and consumers decide, in the first instance, where their discarded products end up, whether formally or

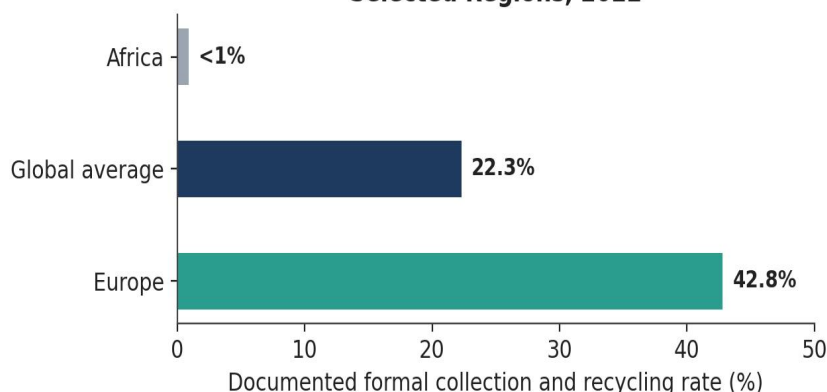
informally. The theory suggests that advancing a portion of the domains is unlikely to lead to a more effective system until advancement is made across the other domains, such as expanding producer registration under EPR.

2.2 The Triple Bottom Line and Urban-Mining Value Capture

The Triple Bottom Line (TBL) framework (Elkington, 1997) assesses the triple bottom line of organisations and systems: economic, environmental integrity and social equity. In closed-loop e-waste research the environmental and social aspects have been of more focus than the economic side that is often cited as a "cost efficiency" or "profitability. It is contended in this paper that within India's setting the economic component should be better defined as urban mining which is defined as the extraction of precious and base metals from discarded electronic waste as an alternate source of these metals instead of primary sources.

This operationalisation has empirical grounding. The Global E-waste Monitor 2024 estimates that the 62 million tonnes of e-waste generated worldwide in 2022 contained recoverable metals and other materials collectively worth approximately US\$62 billion (Baldé et al., 2024). Because secondary metal recovery from e-waste is generally less energy- and capital-intensive than primary ore mining, the economic case for formal recycling infrastructure in India can be stated in concrete, quantifiable terms rather than as a general appeal to cost-efficiency. Framing the economic pillar as urban-mining value capture therefore gives TBL analysis a measurable anchor that is specific to the e-waste context, distinguishing it from generic profitability measures used in other closed-loop supply chain domains.

Figure 2. Documented Formal E-Waste Collection Rate, Selected Regions, 2022



Source: ITU/UNITAR, Global E-waste Monitor 2024 (Baldé et al., 2024). No separate documented collection rate for Asia/India is published in the report; Asia's contribution to global generation volume (~50%, or 30 Mt) is discussed narratively rather than as a collection rate.

Figure 2. Documented Formal E-Waste Collection Rate, Selected Regions, 2022

2.3 Reconceptualising the Mediator: Effectiveness of E-Waste Management as a Leakage Diagnostic

Prior stakeholder-TBL applications to closed-loop supply chains typically model an intermediate "effectiveness" or "performance" construct as a simple pass-through mediator: stakeholder inputs raise effectiveness, and effectiveness raises sustainability outcomes. This paper proposes a reframing that is more consistent with the verified evidence reviewed in Section 1. Because CPCB's own documented figures leave 29-38 percent of estimated annual generation outside formally reported collection and processing even in the most recent reporting years (Ministry of Environment, Forest and Climate Change, 2025), and because independent field research indicates that informal collection continues to compete effectively with formal channels at the household level (Sengupta et al., 2023), a simple linear mediation model risks concealing where, specifically, stakeholder effort fails to convert into recovered material.

In this perspective, the present paper suggests that the leakage-diagnostic mediator is the construct "Effectiveness of E-Waste Management" (EWM) in which the sub-dimensions of this construct (such as resource efficiency, recycling rates etc.) can be analysed both in absolute numeric terms as well as in the term of the remaining gap between the document led generation quantity and the document led quantity collected/processed by CPCB. This reframing is not a null finding, but an alternative interpretation of a weak or statistically insignificant path from a stakeholder construct to EWM, as a candidate site of leakage to an undocumented or informal absorption of the stakeholder domain. This reframing of the diagnosis occurs in the absence of any structural changes of the model, only interpretations of null or weak paths which are reframed as being substantively informative, rather than as evidence of a poorly specified model.

2.4 Conceptual Model and Propositions

The conceptual model presented in Sections 2.1-2.3 links four stakeholder-driven antecedents — Government Policy Support (GP), Consumer Awareness (CA), Technology Readiness (TR), and Infrastructure Availability (IA) — to the mediating construct of Effectiveness of E-Waste Management (EWM), which in turn is proposed to influence the outcome of a Sustainable E-Waste Solution (SWS). Consistent with the leakage-diagnostic reframing set out in Section 2.3, each antecedent is discussed below together with its supporting rationale, immediately followed by the corresponding testable proposition.

Government Policy Support (GP) refers to the regulatory architecture governing e-waste in India, most directly the digital Extended Producer Responsibility (EPR) regime established under the E-Waste (Management) Rules, 2022, through which producers discharge collection and recycling

obligations either directly or by purchasing EPR certificates from registered recyclers (Central Pollution Control Board, 2024).

The rationale for treating this relationship as only partially effective is that certificate-based compliance verifies obligation discharge rather than physical material provenance: a producer can meet its reported target by purchasing certificates without the recycler having verifiably processed a proportional quantity of that producer's own waste stream (Central Pollution Control Board, 2024; Report by CPCB in EA No. 04 of 2024, 2024). This structural feature of the certificate-trading mechanism means that improvements in policy-driven compliance metrics need not translate one-to-one into increased physical diversion of e-waste from informal channels.

P1: The Effectiveness of E-Waste Management is positively associated with Government Policy Support, but this relationship is diluted when EPR-certificate trading allows producers to discharge their obligation without a proportional increase in physically diverted material (Central Pollution Control Board, 2024).

Consumer Awareness (CA) refers to the extent to which households recognise the environmental and safety implications of e-waste and are willing to route discarded electronics through formal collection channels rather than informal collectors (kabadiwalas).

The rationale here is that awareness alone does not determine channel choice: informal collectors typically offer greater convenience, immediacy, and often better prices than formal collection points, so even environmentally conscious consumers continue to use informal channels where these structural advantages persist (Sengupta et al., 2023). Consistent with this, prior research finds only limited movement of e-waste volumes from informal to formal registration over time, suggesting that consumer-facing awareness campaigns alone are unlikely to close the reporting-to-recovery gap identified in Section 1 (Dutta & Goel, 2021).

P2: Consumer Awareness is positively related to formal-channel participation, but the strength of this relationship is contingent on the relative availability and convenience of formal collection points compared with established informal recyclers (Sengupta et al., 2023).

Technology Readiness (TR) refers to the digital infrastructure available to stakeholders for registering, tracking, and reporting e-waste flows, most notably CPCB's EPR portal, on which producers, recyclers, and refurbishers register and report (Central Pollution Control Board, 2024).

The rationale for treating TR's contribution as

reporting-focused rather than volume-generating is that the portal's core function is to formalise and track obligations for actors who are already registered; it does not, by itself, bring unregistered or informal-sector volume into the formal system. Its value therefore lies primarily in strengthening the traceability and auditability of EWM rather than in directly expanding the physical quantity of e-waste collected.

P3: Technology Readiness is positively associated with Effectiveness of E-Waste Management, but its contribution operates mainly through improved monitoring, traceability, and reporting via tools such as the CPCB EPR portal rather than through an increase in the physical volume of e-waste collected.

Infrastructure Availability (IA) refers to the geographic distribution of authorised collection, dismantling, and recycling facilities relative to the distribution of e-waste generation across India's states.

The rationale for proposing a moderating geographic effect is that CPCB's own state-wise registration and processing data show authorised capacity concentrated in a small number of states, while e-waste generation is spread more broadly across the country in proportion to population and consumption (Ministry of Environment, Forest and Climate Change, 2025). Where authorised facilities are geographically distant from generation points, the practical accessibility of the formal channel is reduced regardless of how much policy support or consumer willingness exists.

P4: Infrastructure Availability is positively associated with Effectiveness of E-Waste Management, and this relationship is moderated by the geographic distribution of authorised facilities, given that CPCB's own state-wise data show recycling activity concentrated in a small number of states (Ministry of Environment, Forest and Climate Change, 2025).

Effectiveness of E-Waste Management (EWM), reframed in Section 2.3 as a leakage diagnostic rather than a simple pass-through mediator, is proposed to shape the achievement of a Sustainable E-Waste Solution (SWS), operationalised through the three TBL pillars set out in Section 2.2: environmental integrity, social equity, and — specific to this paper's contribution — the economic pillar of urban-mining value capture.

The rationale for this outcome linkage is that each pillar has a concrete, measurable referent in the Indian context: environmental outcomes can be tied to documented pollution and health-risk reduction, social outcomes to the safe transition of informal workers into regulated employment, and economic outcomes to the recoverable material value that the Global E-waste Monitor estimates at approximately US\$62 billion worldwide, which is generally cheaper to recover than to extract from primary ore (Baldé et al., 2024). Because EWM is measured against CPCB's own documented collection and processing figures, higher EWM should, in principle, correspond to greater realised value across all three pillars.

P5: Effectiveness of E-Waste Management is positively associated with the Sustainable E-Waste Solution, operationalised across environmental (pollution reduction), economic (urban-mining value capture), and social (safe informal-worker transition) dimensions.

Finally, the leakage-diagnostic reframing of EWM implies a specific empirical pattern in the residual gap between CPCB's modelled generation estimate and its documented collection/processing figure, which stood at 29-38 percent of estimated annual generation even in the most recent reporting year (Ministry of Environment, Forest and Climate Change, 2025).

The rationale is that this gap should not be uniform: it should be largest precisely where informal collectors are most competitive with the formal channel, since informal actors intercept material before it reaches any point of official measurement, and independent field research indicates this dynamic is strongest at the household collection stage (Borthakur, 2015; Dutta & Goel, 2021; Sengupta et al., 2023). If the gap instead proved uniform across regions and stakeholder conditions, this would weaken the leakage-diagnostic interpretation relative to a simpler measurement-error explanation.

P6: The residual gap between CPCB's documented generation estimate and its documented collection/processing figure is largest where informal-sector competitiveness is highest, consistent with the leakage-diagnostic reframing proposed in Section 2.3.

Taken together, Propositions 1-6 and their supporting rationale are synthesised in the integrated conceptual model shown in Figure 3.

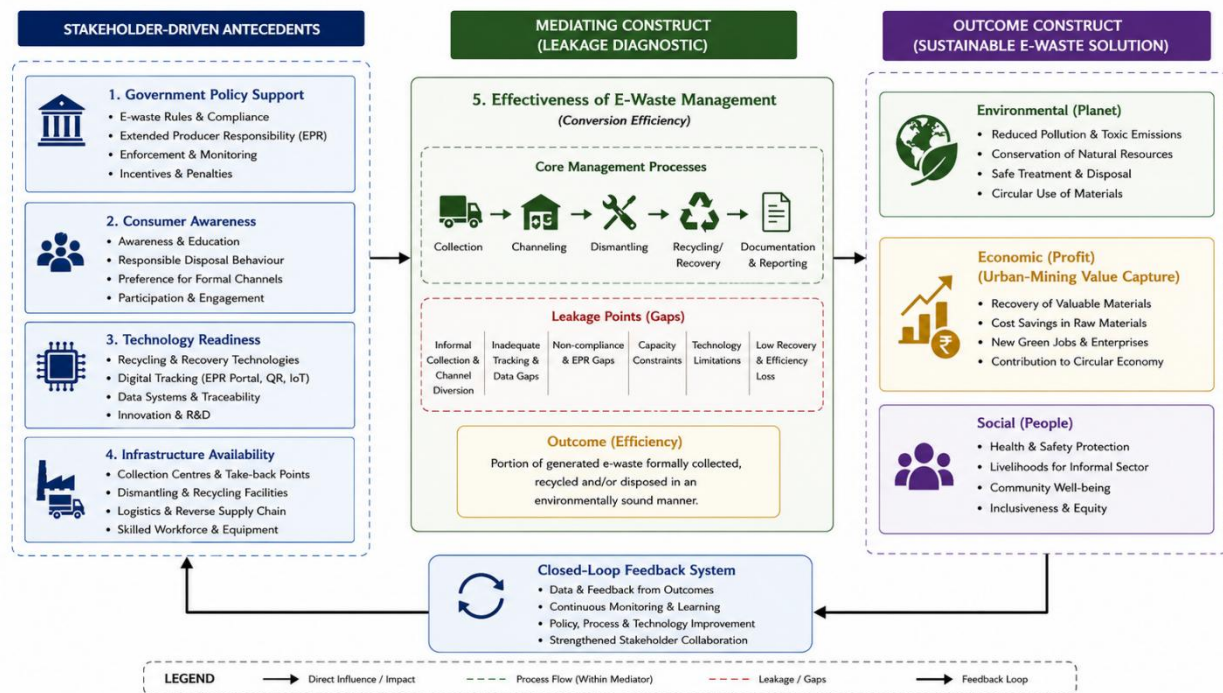


Figure 3. Proposed Stakeholder-Driven Closed-Loop E-Waste Management Framework

3. Methodology

This paper adopts a verified secondary-data, framework-development approach rather than primary survey or interview data collection. The rationale for this design is twofold. First, the conceptual reframing proposed in Section 2, treating the mediating construct as a leakage diagnostic and the TBL economic pillar as urban-mining value capture, is a theoretical contribution that can be motivated and illustrated using existing verified statistics before it is subjected to primary hypothesis testing. Second, official data currently available from CPCB, Parliamentary responses, and the UNITAR/ITU Global E-waste Monitor already provide indicative evidence of a documented reporting-to-recovery gap that the model is designed to explain, making a verified secondary-data illustration a reasonable first step ahead of a fully powered primary study.

3.1 Data Sources

Data were drawn exclusively from primary official and peer-reviewed sources, deliberately excluding unverified secondary aggregators such as commercial market-research summaries or exam-preparation websites. First, official government documents, such as the CPCB's E-waste Management EPR portal, and Written replies submitted to the Rajya Sabha and Lok Sabha by the Ministry of Environment, Forest and Climate Change (MoEF&CC) to the Parliament in the form of Press Information Bureau (PIB) documents regarding the production, collection and recycling of e-waste (Central Pollution Control Board, 2024; Ministry of Environment, Forest and Climate change, 2022, 2025; Press Information Bureau, 2022). The second

source facilitating the monitoring of e-waste are International monitoring data, in particular the Global E-waste Monitor 2024, which is a collaborative effort by the United Nations Institute for Training and Research (UNITAR), the International Telecommunication Union (ITU) and the Fondation Carmignac (Baldé et al., 2024). Third, Tribunal and Regulatory Filings; in this regard, National Green Tribunal (NGT) directed CPCB to submit a compliance report to it regarding the report on EPR compliance (CPCB's Report in EA No. 04 of 2024, 2024). Fourthly, peer-reviewed academic studies related to e-waste stakeholders, informal recycling, and closed loop supply chain (Borthakur, 2015; Dutta & Goel, 2021; Dwivedy & Mittal, 2012; Kosarkar & Barthwal, 2025; Sengupta et al., 2023).

3.2 Analytical Approach

Instead of using statistical hypothesis testing, a structured narrative synthesis is used: the statistics from each of the sources validated are categorized and mapped in relation to the four constructs in the antecedent (GP, CA, TR, IA) and two in the outcome (EWM, SWS) and compared with the propositions in Section 2.4. The paper does not attempt to replace a point estimate for leakages with an unverified estimate of the leakages, as official generation estimates by CPCB are already model-based and it is difficult to argue that it would not have been a conservative estimate of leakage, even if it is not a true measurement of the gap.

This method is clearly stated to be a tool that can be

used as a pretest for primary data collection. A detailed design for the survey and interview needed to test the propositions of Section 2.4 is presented in Section 6.

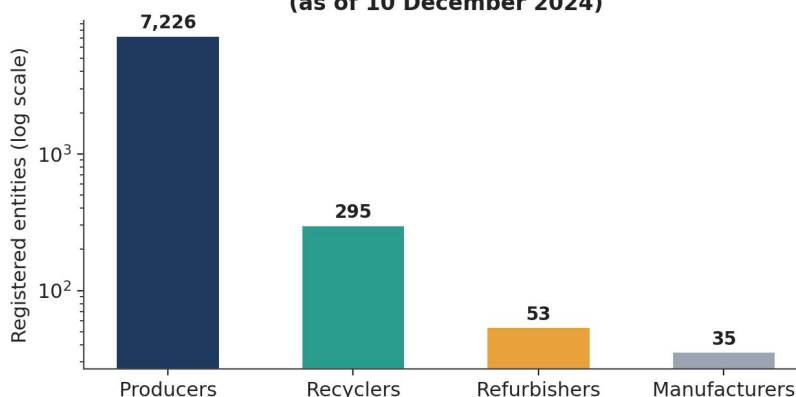
4. Findings and Discussion

4.1 Government Policy Support: Reported Compliance Versus Physical Diversion

Proposition 1 is consistent with mixed evidence on Government Policy Support. On the other hand, formal compliance indicators have shown significant improvement: 7,226 producers, 295 recyclers, 35 manufacturers and 53 refurbishers were registered on

the EPR portal of CPCB as of 10th December 2024, and 92% of the recycling targets (254,304 MT in obligation terms) achieved during FY 2023-24 (Report by CPCB in EA No. 04 of 2024, 2024). However, this obligation discharge value is reported with EPR certificates that are bought by the producers from recyclers, instead of using separate, independently established tracking of physical material from the consumer waste site to the recycler (Central Pollution Control Board, 2024). This structural characteristic supports the potential that reported compliance rate overstates the actual diversion from the informal sector of physical e-waste, thereby giving some indicative support to Proposition 1's diminution clause.

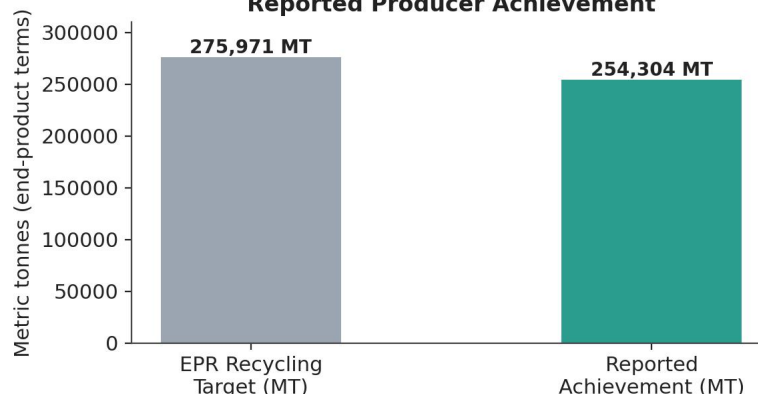
Figure 4. CPCB EPR Portal Registrations by Actor Type (as of 10 December 2024)



Source: Report by CPCB in EA No. 04 of 2024, IN OA No. 512 of 2018, National Green Tribunal (2024).

Figure 4. CPCB EPR Portal Registrations by Actor Type (as of 10 December 2024)

Figure 5. FY 2023-24 EPR Recycling Target vs. Reported Producer Achievement



Source: Report by CPCB in EA No. 04 of 2024, National Green Tribunal (2024). Achievement is measured via EPR-certificate discharge, not independently verified physical collection.

Figure 5. FY 2023-24 EPR Recycling Target vs. Reported Producer Achievement

4.2 Consumer Awareness and the Persistence of Informal Collection

As detailed in Proposition 2, consumer awareness is unlikely to alter the informal disposal habits of consumers where informal collectors are more available than formal collectors, and maybe even more

profitable. Kosarkar and Barthwal (2025) found that while Indian consumers are often "environmentally conscious," they do not seem to be "environmental actors" as they usually experience structural barriers to their involvement in formal waste collection activities. Sengupta et al. (2023) record the persistent

importance of kabadiwalas (informal waste collectors) in the disposal of household e-waste in India, arguing that the informal sector is not just an under-researched and neglected part of the e-waste system, where consumers remain oblivious to its operations, but also a part that provides convenience and immediacy in transactions. The results of Dutta and Goel (2021) also show that there has been minimal change over time in the number of recyclers moving from informal to formal registration, which suggests that awareness campaigns alone are unlikely to bridge the reporting-to-recovery gap, as outlined in Section 1.

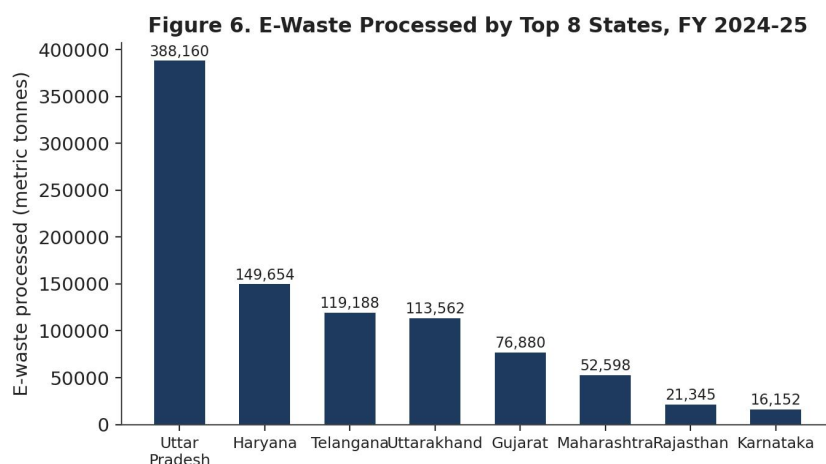
4.3 Technology Readiness And Limits Of Digital Traceability

The introduction of the CPCB's digital EPR portal is a significant technological investment on the side of the regulator with producers and recyclers being able to register and submit details of collection and recycling (Central Pollution Control Board, 2024). But, as described in Proposition 3, the key function of the portal so far has been to facilitate reporting and tracking of obligations for pre-registered formal actors: The CPCB's own data shows that as of FY 2024-25, 295 registered actors for recyclables exist across the

country, most of which are concentrated in 19 states with Uttar Pradesh alone having 125 registered actors nationwide (Ministry of Environment, Forest and Climate Change, 2025). This indicates technology readiness to an extent has greatly increased at the reporting level, but there is not an even spatial distribution of translation to real collection capacity.

4.4 Infrastructure Availability And Geographic Concentration

Data about infrastructure support the hope of Proposition 4's moderation clause. As per the processing data of CPCB for the year 2024-25, the processing volume is highly concentrated with Uttar Pradesh processing 388,160 metric tonnes (MT) followed by Haryana (149,654 MT) and Telangana (119,188 MT) with negligible volumes processed in several other states such as Assam and Bihar (Ministry of Environment, Forest and Climate Change, 2025). This clumping of authorised processing capacity in a few states and the spread of e-waste production across the country is a potential structural cause of differential access to the formal sector, in addition to varying willingness of consumers and compliance of producers.



Source: Ministry of Environment, Forest and Climate Change, written reply to Rajya Sabha, Press Information Bureau (2025), based on annual reports of registered e-waste recyclers.

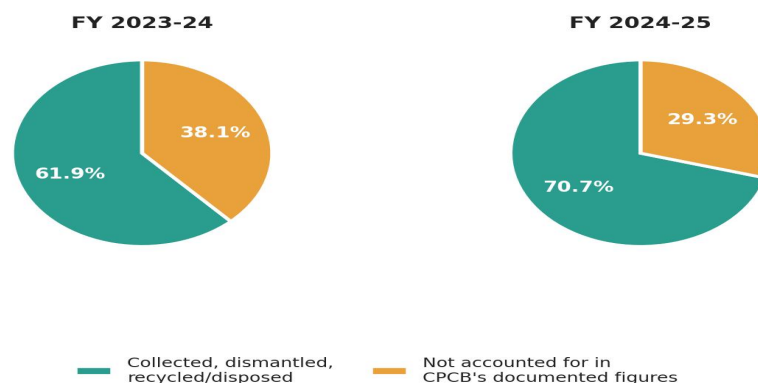
Figure 6. E-Waste Processed by Top 8 States, FY 2024-25

4.5 Effectiveness of E-Waste Management as a Site of Leakage

Taken together, Sections 4.1-4.4 illustrate the leakage-diagnostic reframing proposed in Section 2.3. Reported formal-sector recycling performance has improved substantially by CPCB's own obligation-based and collection-based metrics, rising from 61.94 percent documented collection/processing in FY 2023-24 to 70.71 percent in FY 2024-25 (Ministry of Environment, Forest and Climate Change, 2025). Yet

this still leaves a documented residual gap of 29-38 percent of estimated annual generation outside formally reported channels, and peer-reviewed field research on Indian e-waste flows suggests this official gap likely understates true informal-sector absorption, since CPCB's generation figure is a sales-based model rather than a directly measured quantity, and informal collectors are known to intercept material before it reaches any point of official measurement (Borthakur, 2015; Dutta & Goel, 2021; Sengupta et al., 2023).

Figure 3. CPCB-Reported Share of E-Waste Collected, Dismantled, and Recycled/Disposed, India, FY 2023-24 and FY 2024-25



Source: Ministry of Environment, Forest and Climate Change, written reply to Rajya Sabha, Press Information Bureau (2025). Figures are CPCB's official documented percentages; generation itself is a modelled estimate based on producer sales data and average product life, not a direct physical measurement, so the "not accounted for" share is a lower-bound estimate of material outside documented formal channels.

Figure 3. CPCB-Reported Share of E-Waste Collected, Dismantled, and Recycled/Disposed, India, FY 2023-24 and FY 2024-25

Table 2. Leakage-Diagnostic Comparison Across Stakeholder Constructs, Using CPCB's Own Documented Figures

Construct	CPCB/Official Indicator	Qualifying Evidence	Assessed Gap
Government Policy Support (EPR)	92% of FY23-24 obligation discharged via certificates	Certificates need not track physical material provenance (Central Pollution Control Board, 2024)	Potentially large
Infrastructure Availability	295 recyclers registered across 19 states	Processing highly concentrated in a few states (Ministry of Environment, Forest and Climate Change, 2025)	Moderate
Technology Readiness	Full EPR portal coverage for registered actors	No documented link to unregistered/informal volume reduction	Undetermined
Consumer Awareness	Awareness obligations under EPR rules	Informal collectors remain dominant at household level (Sengupta et al., 2023)	Moderate-Large
Overall EWM (generation vs. documented processing)	70.71% documented processed, FY24-25	29.29% of modelled generation outside documented channels; likely understated per field research	29% (lower bound)

4.6 Sustainable E-Waste Solution: Economic, Environmental, and Social Readings

On the economic pillar, the urban-mining value-capture framing proposed in Section 2.2 is supported by the scale of recoverable value estimated in e-waste globally, approximately US\$62 billion in 2022 (Baldé et al., 2024), a figure that provides a concrete economic rationale for closing the infrastructure and technology gaps identified above. On the environmental pillar, informal e-waste processing in India, including open burning and acid leaching to recover metals, is documented in field studies to expose workers and surrounding communities to hazardous substances including lead and mercury (Sengupta et al., 2023). On the social pillar, a cross-sectional occupational health study of 220 informal e-waste workers across three Delhi recycling sites found that personal protective equipment was used by only 12 percent of workers, and that knowledge of e-waste-related health risks was generally poor (Singhal et al., 2021), reinforcing the case for formalisation pathways that integrate rather than displace existing informal workers.

5. Policy and Managerial Implications

The leakage-diagnostic framework developed in this paper points to several specific, actionable implications for regulators, producers, and recyclers operating in India's e-waste system.

First, CPCB and the Ministry of Environment, Forest and Climate Change could strengthen the EPR-certificate mechanism by pairing obligation-discharge reporting with independently audited physical-collection verification, narrowing the gap between reported compliance and the residual shortfall identified in Section 4.1. Second, given the finding in Section 4.4 that authorised recycling capacity is heavily concentrated in a small number of states, for example Uttar Pradesh, Haryana, and Telangana together accounting for a large share of national processing volume (Ministry of Environment, Forest and Climate Change, 2025), infrastructure investment would plausibly yield the greatest marginal improvement in EWM if it were prioritised in states currently underrepresented in authorised processing capacity relative to their population and consumption base. Third, given the persistence of informal collection documented in Section 4.2, policies aimed at consumer awareness alone are unlikely to be sufficient; integration strategies that formally register and incentivise existing informal collectors, as suggested in prior research (Dutta & Goel, 2021; Sengupta et al., 2023), may yield faster gains than awareness campaigns targeted at end consumers in isolation. Fourth, the urban-mining value-capture framing suggests that producers and recyclers have a direct commercial incentive, not only a compliance incentive, to invest in formal collection infrastructure, since

secondary metal recovery is generally more resource-efficient than primary extraction (Baldé et al., 2024).

6. Limitations and Directions for Future Research

This paper is a conceptual and verified-secondary-data synthesis rather than a primary empirical test of the proposed model. The propositions in Section 2.4 have not been subjected to statistical testing and should be treated as hypotheses for future research rather than as established findings. Official sources also vary in scope, reporting period, and methodology: CPCB's EPR-portal and Parliamentary figures cover registered formal actors and modelled generation estimates, while the Global E-waste Monitor's global and regional estimates are derived through a different, internationally standardised methodology that does not publish a separately verified informal-sector percentage specific to India, so the figures cited in Section 4 should not be treated as directly interchangeable across sources.

Future research should test the propositions developed here using primary data: a structured survey of stakeholders (consumers, producers, recyclers, and regulators) analysed through variance-based structural equation modelling such as PLS-SEM, paired with semi-structured interviews with industry experts to explain quantitative findings, following an explanatory sequential mixed-methods design (Creswell & Plano Clark, 2018; Ivankova et al., 2006). Particular priority should be given to operationalising EWM as a two-indicator construct, CPCB-documented processing and independently verified physical collection, as proposed in Section 4.5, so that the leakage-diagnostic function of the model can be empirically tested with primary field data rather than only illustrated through official reporting gaps.

7. Conclusion

India's e-waste challenge is not simply a matter of insufficient regulation; the E-Waste (Management) Rules, 2022 already establish an EPR framework with escalating collection targets and a functioning digital compliance portal, and CPCB's own reporting shows a genuine, substantial improvement in documented collection and processing performance between FY 2023-24 and FY 2024-25. Rather, the evidence reviewed in this paper suggests that the more consequential problem is a persistent, officially documented residual gap between modelled generation and formally reported processing, a gap that conventional stakeholder-TBL models risk obscuring if their mediating construct is treated only as a simple pass-through variable. By reframing the Effectiveness of E-Waste Management construct as a leakage diagnostic grounded in CPCB's own figures, and by anchoring the TBL economic pillar in the

concrete, quantifiable concept of urban-mining value capture, this paper offers a theoretical refinement that is directly responsive to the specific, verifiable empirical pattern documented in India's official e-waste statistics. The resulting propositions provide a clear basis for the primary survey and interview research needed to test where, specifically, stakeholder-driven interventions would most reduce the flow of India's growing e-waste volume into undocumented, informal processing.

References

- Baldé, C. P., Kuehr, R., Yamamoto, T., McDonald, R., D'Angelo, E., Althaf, S., Bel, G., Deubzer, O., Fernandez-Cubillo, E., Forti, V., Gray, V., Herat, S., Honda, S., Iattoni, G., Khatriwal, D. S., Luda di Cortemiglia, V., Lobuntsova, Y., Nnorom, I., Pralat, N., & Wagner, M. (2024). The global e-waste monitor 2024. International Telecommunication Union and United Nations Institute for Training and Research. <https://ewastemonitor.info/the-global-e-waste-monitor-2024/>
- Borthakur, A. (2015). Generation and management of electronic waste in India: An assessment from stakeholders' perspective. *Journal of Developing Societies*, 31(4), 220-248.
- Borthakur, A., & Sinha, K. (2013). Electronic waste management in India: A stakeholder's perspective. *Electronic Green Journal*, 1(36).
- Central Pollution Control Board. (2024). E-waste management system: Extended producer responsibility portal. <https://eprewaste.cpcb.gov.in/#/>
- Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). SAGE.
- Dutta, D., & Goel, S. (2021). Understanding the gap between formal and informal e-waste recycling facilities in India. *Waste Management*, 125, 163-171. <https://doi.org/10.1016/j.wasman.2021.02.032>
- Dwivedy, M., & Mittal, R. K. (2012). Estimation of future outflows of e-waste in India. *Waste Management*, 32(8), 1723-1729.
- Elkington, J. (1997). *Cannibals with forks: The triple bottom line of 21st century business*. Capstone.
- Freeman, R. E. (1984). *Strategic management: A stakeholder approach*. Pitman.
- Freeman, R. E., & McVea, J. (2001). A stakeholder approach to strategic management. In M. A. Hitt, R. E. Freeman, & J. S. Harrison (Eds.), *The Blackwell handbook of strategic management* (pp. 189-207). Blackwell.
- Ivankova, N. V., Creswell, J. W., & Stick, S. L. (2006). Using mixed-methods sequential explanatory design: From theory to practice. *Field Methods*, 18(1), 3-20. <https://doi.org/10.1177/1525822X05282260>
- Koiwanit, J., & Filimonau, V. (2023). Stakeholder engagement in waste management: A review. *Journal of Cleaner Production*, 385, Article 135732.
- Kosarkar, M., & Barthwal, S. (2025). Environmentally conscious but helpless: Consumer challenges for participation in formal e-waste collection initiatives of India. *Cleaner Waste Systems*, 12, Article 100363. <https://doi.org/10.1016/j.clwas.2025.100363>
- Ministry of Environment, Forest and Climate Change. (2022). E-waste (management) rules, 2022. *The Gazette of India: Extraordinary*. https://cpcb.nic.in/uploads/Projects/E-Waste/e-waste_rules_2022.pdf
- Ministry of Environment, Forest and Climate Change. (2025, July 24). Parliament question: E-waste processing management [Press release]. Press Information Bureau. <https://www.pib.gov.in/PressReleasePage.aspx?PRID=2147876>
- Press Information Bureau. (2022). E-waste management [Press release]. Ministry of Environment, Forest and Climate Change. <https://www.pib.gov.in/PressReleasePage.aspx?PRID=1941054>
- Report by CPCB in EA No. 04 of 2024 IN OA No. 512 of 2018 (Shailesh Singh v. State of Uttar Pradesh and Ors.). (2024). National Green Tribunal. https://www.greentribunal.gov.in/sites/default/files/news_updates/Report%20of%20CPCB%20in%20EA%20No.%2004%20of%202024%20IN%200A%20No.%20512%20of%202018.pdf
- Sengupta, D., Ilankoon, I. M. S. K., Kang, K. D., & Chong, M. N. (2023). Circular economy and household e-waste management in India. Part II: A case study on informal e-waste collectors (Kabadiwalas) in India. *Minerals Engineering*, 200, Article 108154. <https://doi.org/10.1016/j.mineng.2023.108154>
- Singhal, D., Lyngdoh, T., & Prabhakaran, P. (2021). Knowledge, attitude and practice study of health risks among e-waste recyclers in Delhi. *Journal of Health and Pollution*, 11(29), Article 210306. <https://doi.org/10.5696/2156-9614-11.29.210306>