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Strengthening U.S. Infrastructure for E-Waste Data Collection and Export Accountability: A Narrative Review

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Abstract: This review synthesizes U.S. policy and practice on electronic-waste (e-waste) data collection and export accountability, by identifying continuing gaps that enable undocumented transboundary flows and associated environmental-health and equity harms. Drawing on a narrative literature review and comparative policy analysis of sources from 2018 to 2025, the paper maps federal and state roles, existing tracking tools, such as paper and electronic manifests, and voluntary registries, and fragmented data architectures with inconsistent classifications and limited interoperability. Findings reveal regulatory and enforcement weaknesses, misclassification of used electronics, variable state permit regimes, limited customs scrutiny, and operational constraints, including funding shortfalls, uneven IT capacity, and staffing shortages that hinder surveillance and foster export loopholes. The paper proposes a targeted reform package into three actionable clusters (1) Data & Standards, a national e-waste taxonomy and harmonized reporting fields, a mandatory, machine-readable national e-manifest and export-permit system with chain-of-custody, interoperable API-based data architecture. (2) Enforcement & trade controls strengthened customs and port screening, targeted audits, clearer legal definitions to reduce misclassification, and international coordination on export documentation and destination monitoring; and (3) Financing, capacity & equity, expanded Extended Producer Responsibility (EPR) funding, grants and technical assistance for states and small processors, phased implementation with exemptions/assistance, and third-party verification with public dashboards for transparency. A phased implementation roadmap (0–2 years: taxonomy and pilots, 2–5 years: national rollout and customs integration, 5+ years: full interoperability and serialized tracking where feasible) balances traceability, cost, and equity. Limitations stem from the literature-only scope and state-level diversity. Recommended next steps include empirical pilots, rigorous cost–benefit studies for serialization or blockchain, longitudinal export monitoring, and comparative analyses with EU and Asian models to inform adaptive and equitable policy design. Collectively, these measures aim to reduce harmful exports, protect vulnerable communities, and provide actionable guidance for policymakers and practitioners.

Keywords: Electronic waste, E-waste tracking, Waste manifest, Export of used electronics, Chain of custody, Policy reforms, Data integration.

INTRODUCTION

In the United States, oversight is uniquely fragmented because federal hazardous waste law under the Resource Conservation and Recovery Act (RCRA) excludes many categories of used electronics, leaving states to adopt divergent rules and reporting systems that vary widely in scope and enforcement. According to International Telecommunication Union and United Nations Institute for Training and Research (2024), global electronic waste (e-waste) discarded electrical or electronic equipment and its components, has risen sharply, reaching an estimated 62 million metric tonnes in 2022. It is projected to continue growing, while formal collection and environmentally sound recycling remain low (Baldé, *et al.*, 2024). E-waste contains heavy metals and persistent organic pollutants that are linked to neurodevelopmental, reproductive, respiratory, and other adverse health outcomes, especially among workers and children exposed through informal recycling and uncontrolled disposal (Parvez, *et al.*, 2021). Concerns about environmental and public health harms, loss of valuable materials, and illicit transboundary flows have driven recent international and national policy actions, including the Basel Convention's 2022 e-waste amendments and new U.S. guidance responding to those changes, which raise expectations for prior informed consent, tighter export controls, and improved documentation of e-waste movements (Kuehr, *et al.*, 2022). Notwithstanding the growing attention, governance is fragmented. Sectoral definitions and reporting standards vary, chain-of-custody and tracking systems are inconsistent or incomplete, and legal and operational loopholes enable undocumented or potentially harmful exports and informal diversion. Past assessments highlight gaps in federal and state coordination and weaknesses that permit transboundary bypasses of environmental safeguards (Chaudhary, 2025). This study aims to evaluate current federal and state e-waste tracking and reporting systems, map structural and regulatory gaps that enable bypass into export streams and propose practical data-integration strategies and policy reforms to strengthen oversight, accountability, and environmental health protection. Thus, the review seeks to address the following:

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- How effective are tracking or reporting systems across sectors?
- What legal, institutional, and technical gaps permit undocumented or illegal exports? And
- Which data-integration and policy measures are feasible and have the highest impact?

METHODOLOGY

This study used a literature-only approach combining a systematic literature review with comparative policy analysis of U.S. e-waste governance and export-accountability frameworks. Systematic searches were conducted in Web of Science, Scopus, Business Source Complete, and Google Scholar, and targeted searches were performed on official websites (EPA and state environmental agencies), the Basel Convention/UN sites, the International Telecommunication Union/UNITAR Global E-waste Monitor, customs/port sources, and major NGO/industry repositories. Search queries used the terms "electronic waste," "e-waste tracking," "waste manifest," "export of used electronics," "extended producer responsibility," "state e-waste law," and "chain of custody." Inclusion criteria: U.S.-focused materials with emphasis on 2018 to 2025 for primary synthesis), peer-reviewed papers, statutory/regulatory texts, and authoritative agency, NGO, industry, and customs/port reports with direct relevance to tracking, manifests, permits, export controls, or data systems. Excluded: device-level technical recycling papers lacking system/policy relevance. Grey literature was identified via targeted website searches and reference-list mining; each grey item was appraised using an adapted AACODS checklist (Authority, Accuracy, Coverage, Objectivity, Date, Significance), and justification for inclusion. From each included item we extracted governance actors; data systems and standards; manifest/permit processes; reporting frequency and granularity; enforcement mechanisms; documented export pathways; and stakeholder roles. Analysis combined thematic coding, cross-case comparative matrices (state vs. federal models), gap analysis, schematic flow mapping, and feasibility assessment (legal, technical, cost/practicality). No primary data were collected; findings synthesize secondary literature and official documents.

FINDINGS

Thematic Summary of Findings on U.S. E-Waste Governance

Table:1 Governance-Related Themes

Theme	Details	Summary Notes
Fragmented Governance Architecture	No unified federal oversight for e-waste. EPA provides guidance and e-Manifest for hazardous waste. RCRA excludes many electronics. States lead implementation with wide variation. (Das *et al.*, 2023; Agbemabiese, 2020)	Governance is decentralized, with federal gaps and state-level inconsistencies creating a patchwork system.
Regulatory & Enforcement Gaps	Misclassification of used electronics as non-waste. Limited customs scrutiny. Divergent state permit regimes. Pathways for undocumented exports. (Rodrigue, 2020; Brewer *et al.*, 2021)	Weak enforcement and loopholes allow harmful exports and misreporting of e-waste.
Environmental & Justice Implications	Incomplete national estimates. Documented cases of undocumented exports. Environmental health and justice concerns in receiving communities. (Andeobu *et al.*, 2023)	The lack of oversight leads to real-world harm, especially in vulnerable communities affected by e-waste dumping.

Table:2 Operational-Related Themes

Theme	Details	Summary Notes
Inconsistent Tracking & Reporting Tools	Use of paper manifests, EPA's e-Manifest, voluntary registries, and self-reporting. Systems are siloed and non-interoperable. (Rendleman, 2024; Chocola, 2025)	Tracking tools vary widely and don't communicate with each other, making national data unreliable.
Fragmented Data Architecture	Trade codes and definitions vary. Classification gaps hinder comprehensive tracking. Inconsistent granularity across jurisdictions. (Cosentino, 2022)	Data systems lack standardization, making it hard to track and classify e-waste accurately.

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Sectoral & Operational Barriers	Reporting varies across consumer, commercial, and institutional streams. Collection methods complicate data consolidation. Funding, IT capacity, staffing, and interagency data-sharing are limited. (De Micco, *et al.*, 2021; Du Toit, 2024)	Operational challenges and sectoral differences hinder effective monitoring and coordination.

DISCUSSION

The review confirms that fragmented governance remains the most significant structural weakness in U.S. e-waste oversight. Federal authority, constrained by the Resource Conservation and Recovery Act (RCRA), provides limited traceability for hazardous streams, while non-hazardous and "used" electronics fall to a patchwork of state regulations, voluntary registries, and inconsistent reporting frameworks (Kalmenovitz *et al.*, 2022). This decentralization produces overlapping mandates, data incompatibility, and uneven enforcement, undermining national accountability.

State experiences illustrate both progress and disparity. California's *Covered Electronic Waste* (CEW) program, New York's manufacturer-run *Electronic Equipment Recycling and Reuse Act*, and Oregon's *E-Cycles* program have developed stable fee-funded collection and reporting mechanisms, achieving higher recovery rates and more complete datasets (Das, *et al.*, 2023). In contrast, states without dedicated e-waste statutes or with voluntary take-back systems, such as Alabama or Wyoming, struggle to track export flows or maintain compliance reporting (Agbemabiese, 2020; De Micco, *et al.*, 2021). These contrasts expose the tension between regulatory ambition and administrative capacity: stronger traceability increases oversight quality but amplifies compliance costs, especially for small recyclers with limited IT infrastructure (Talukdar, *et al.*, 2023).

Technological interventions, particularly unique device serialization, emerge as a recurring anchor in the policy roadmap. Serialization paired with electronic manifests, API-based data exchange, and exploratory blockchain pilots could enable tamper-resistant chain-of-custody records (Santhuja & Anbarasu, 2023; Bułkowska, *et al.*, 2023). However, large-scale deployment remains constrained by cost, interoperability challenges, and privacy concerns related to device-level identifiers. As such, serialization should target high-risk, high-value streams (servers, telecom, or export-bound equipment) and be phased in alongside technical support and cost-sharing mechanisms.

Equity safeguards can be codified through statutory measures that include EPR-funded grant programs, tiered reporting thresholds, and temporary compliance exemptions for small processors and states with limited resources (Simon, *et al.*, 2025). These provisions would institutionalize fairness while ensuring regulatory reach. Ultimately, overcoming fragmented governance requires harmonized federal-state data standards, privacy-conscious digital infrastructure, and enforceable incentives that balance traceability, cost, and equity.

Recommendations and Policy Reforms

National Taxonomy and Reporting Standards

Develop a unified national e-waste taxonomy with harmonized reporting fields across jurisdictions to eliminate definitional ambiguity. Standardized categories and data fields will ensure consistent classification, enhance national comparability, and strengthen data reliability for policy and enforcement purposes.

National Electronic Manifest and Export-Permit System

Establish a mandatory, machine-readable e-manifest and export-permit system that ensures auditable, end-to-end chain-of-custody documentation for all regulated e-waste. This digital platform should link federal and state systems, reduce data silos and support automated validation and risk-flagging for export activities.

Unique Device and Asset Serialization

Implement unique identifiers for high-risk device categories for instance, servers, telecom equipment, and batteries where technically and economically feasible, to improve traceability and prevent illegal exports. A fully national serialization mandate is technically achievable but faces cost, privacy, and administrative barriers. It should therefore be pursued selectively, focusing first on high-risk or high-value streams, and preceded by pilot testing and cost–benefit analyses.

Interoperable Data Architecture (API-Based Integration)

Develop an API-first data architecture with a shared schema connecting EPA, state agencies, customs authorities, licensed processors, and major generators. This interoperability will facilitate

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seamless data exchange, minimize duplication, and allow for real-time analytics to support enforcement.

Strengthened Customs Integration and Trade Enforcement

Integrate manifest data directly with customs and port systems to enhance risk scoring and early detection of undocumented or misclassified exports. Expand targeted audits for high-risk trade routes and strengthen international cooperation on export documentation and destination-country monitoring.

Extended Producer Responsibility (EPR) Financing and Incentives

Expand EPR-based financing mechanisms to fund IT infrastructure, compliance monitoring, and capacity building. Link EPR fees to measurable compliance outcomes and provide financial incentives for producers and recyclers demonstrating exemplary data reporting and environmental performance.

Capacity Building and Equity Safeguards

Provide technical assistance, training, and grant support for states and small processors to ensure equitable participation. Codify equity safeguards through phased compliance timelines, exemptions for low-volume operators, and EPR-funded assistance programs to prevent disproportionate burdens.

Transparency and Public Accountability

Require third-party data verification and the publication of public dashboards showing aggregated e-waste flows and compliance metrics. These transparency measures will strengthen accountability and public trust while maintaining data privacy protections.

This review recommends a focused, practical reform package that pairs clear rules with funding and phased implementation. It also recommends the adoption of a national taxonomy for e-waste categories and harmonized reporting fields to remove definitional ambiguity, by mandating a national electronic manifest and export-permit system, such as machine-readable, auditable, chain-of-custody enabled, and requiring unique device or asset serialization for clearly defined high-risk flows where technically and economically feasible. This review suggests the building of an interoperable data architecture, like an API-first and common data schema that links EPA, state agencies, customs, licensed processors, and major generators, and requires mandatory reporting across consumer, commercial, and institutional sectors with harmonized thresholds. It also advocates for strengthening customs and port screening and deploying targeted audits on high-risk routes by expanding Extended Producer Responsibility (EPR) financing and creating dedicated funding fees or grants to underwrite IT systems and enforcement. Lastly, it recommends the provision of technical assistance and competitive grants to states and small processors to avoid disproportionate burdens that require third-party data verification and public dashboards for transparency and accountability. There is also the urgent need to coordinate internationally to harmonize export documentation and support destination-country monitoring.

Implement reforms in phases, with a risk-based approach, exemptions for small actors, and clear metrics to ensure traceability, affordability, and equity.

PHASED IMPLEMENTATION ROADMAP

As a short-term implementation phase between 0-2 years, establish a national e-waste taxonomy and standard reporting fields that implement focused stakeholder consultations for states, recyclers, collectors, customs, industry, and NGOs by deploying e-manifest pilots in 2–3 volunteer states and at selected high-throughput ports with interoperable test APIs. For example, Reporting Completeness, defined as the proportion of pilot e-manifests that contain all required core data fields, namely, taxonomy code, material weight, generator identification, destination facility, and permit identification. A target threshold of ≥ 90% completeness is expected during the final six months of the pilot phase, serving as a benchmark for data quality and system usability. Design export-permit workflows and data validation rules that create training and grant templates to support small processors.

Within a 2–5-year medium-term phase, refine standards from pilot learnings and begin phased national e-manifest rollout with mandatory, machine-readable manifests. Integrate customs and port data feeds and enable automated risk-flagging for high-risk shipments. Example, Risk-Flag Detection Rate, defined as the proportion of automated risk flags that are subsequently validated through audits as instances of diversion or noncompliance. This metric serves as an indicator of the predictive accuracy and operational effectiveness of the risk-flagging system. A benchmark of ≥ 60% confirmed

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accuracy is recommended during the first year of national rollout to ensure meaningful targeting and resource allocation. Launch targeted Extended Producer Responsibility (EPR) pilots connected to financing for data systems and scale third-party verification and public dashboard prototypes to initiate routine targeted audits.

In the long-term implementation phase (beyond 5 years), the goal is to attain comprehensive interoperability across EPA, states, customs, and licensed processors. Deploy device or asset serialization for prioritized high-risk flows were cost-effective. Example, End-to-End Serialization Coverage (High-Risk Flows), defined as the percentage of prioritized device classes that are assigned unique identifiers and maintain complete chain-of-custody records throughout their lifecycle. This metric assesses the extent to which serialization enables traceability and accountability for high-risk electronic waste streams. A target coverage rate of ≥ 70% is recommended within three years of achieving full system interoperability. Institutionalize sustained enforcement funding (EPR fees, grants, fines) and national performance metrics and maintain continuous technical assistance, equity safeguards for small actors, and international coordination for export monitoring.

LIMITATIONS

This study is literature-based and therefore lacks primary empirical validation; conclusions reflect syntheses of published and official sources rather than direct measurements of compliance or material flows. State-level legal and programmatic diversity further constrains the applicability of one-size-fits-all recommendations, as statutory differences, administrative capacity, and local market structures necessitate context-specific adaptation. In addition, the rapid evolution of technologies such as serialization, blockchain, and digital manifests and the growing role of artificial intelligence in monitoring and data integration can both enable and disrupt proposed reforms. Dynamic trade patterns compound this uncertainty, underscoring the need to treat recommendations as adaptive pathways rather than fixed blueprints, to be refined through ongoing monitoring and iterative evaluation.

FUTURE RESEARCH DIRECTIONS

Future research should move from theory to measured practice. Priority studies include, (1) empirical pilot evaluations of e-manifest deployments using mixed methods and measurable outcomes such as detection rate of diversion, reporting completeness, time-to-clearance, stakeholder burden, (2) rigorous cost–benefit and sensitivity analyses for serialization and blockchain pilots that quantify capital/operational costs, fraud reduction, and recovery of critical materials, (3) longitudinal tracking of export flows and environmental or health outcomes before and after policy rollouts to assess durability and unintended consequences, and (4) comparative policy studies that examine high-performance models for example, Germany's mature Extended Producer Responsibility and take-back frameworks in the EU and Singapore's tightly coordinated customs or trade and digital-first controls in Asia to identify transferable legal instruments, data standards, and customs practices. Each study should explicitly evaluate equity and compliance impacts on small collectors, data-privacy tradeoffs, and practical interoperability requirements to ensure findings are actionable for policymakers.

CONCLUSION

The review found that U.S. e-waste governance active but fragmented, leaving substantial gaps in governance (patchwork federal-state roles and uneven oversight), data (inconsistent definitions, fragmented manifests, and poor interoperability), and enforcement (misclassification, weak customs scrutiny, and uneven permit regimes). A focused reform package, such as national taxonomy, mandatory machine-readable e-manifests and export permits, interoperable APIs, targeted serialization for high-risk flows, strengthened customs screening, and expanded Extended Producer Responsibility (EPR) funding with capacity support for states and small processors can close these gaps. Phased implementation, third-party verification, empirical pilots, and cost benefit studies are essential to ensure effectiveness, equity, and adaptability.

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