



Strengthening e-waste governance: A decision framework for sustainable transboundary movements under the Swiss-Ghana Amendments

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ABSTRACT

The Swiss-Ghana Amendments to the Basel Convention mark a significant milestone in global e-waste (electronic waste) management, requiring Prior Informed Consent (PIC) for all transboundary movements of Waste Electrical and Electronic Equipment (WEEE), regardless of their hazard classification. However, developing nations encounter substantial challenges in adhering to these amendments due to regulatory gaps, limited infrastructure, and an increasing influx of illicit e-waste imports. This study uses Malaysia as a case study to evaluate the readiness of developing nations to implement amendments, highlighting transferable solutions and recommendations. This study employs a mixed-methods approach that combines qualitative thematic analysis and bibliometric mapping to analyze academic literature, official reports, and international case studies. The findings reveal that while Malaysia has foundational policies in place, significant challenges remain in addressing informal recycling practices, improving enforcement mechanisms, and building the institutional capacity to implement PIC procedures effectively. This study identifies key areas for improvement, including regulatory reforms, infrastructure development, and enhanced monitoring systems. To address these issues, this study proposes a six-key Integrated Decision Framework that emphasizes legislative and regulatory updates, infrastructure development, international cooperation, capacity building and training, public awareness and engagement, and robust monitoring and enforcement mechanisms. Although tailored to Malaysia, the framework offers transferable solutions to align e-waste management systems with the Swiss-Ghana Amendments, providing a pathway for developing nations to strengthen regulatory readiness, mitigate environmental risks, and contribute to global sustainability.

1. Introduction

In this era of rapid technological advancement, the world is facing an unprecedented environmental crisis: the rapid increase in electronic waste. By 2030, global e-waste (electronic waste) generation is projected to reach a staggering 82 million tons annually, equivalent to over 8 000 Eiffel Towers (Baldé et al., 2024; Flynn, 2023). Global e-waste is the fastest-growing waste stream, increasing by 3%–5% annually, with only 17% being recycled appropriately (Ghulam and Abushammala, 2023; Liu et al., 2023). This growth, which is five times faster than recycling efforts, severely threatens human health and global ecosystems. As discarded electronics release toxic substances into the soil, water, and air, they contaminate food sources, pollute drinking water, and contribute to a myriad of health issues, including chronic lung diseases, cancer, and reproductive disorders.

This growth poses significant environmental and public health risks, particularly in developing nations where regulatory frameworks are often insufficient, recycling infrastructure is underdeveloped, and informal recycling practices dominate (Omondi, 2022).

According to the Global E-Waste Monitor (2024) (Baldé et al., 2024), the transboundary movement of e-waste remains a significant global problem. Approximately 800 million kilograms of e-waste are uncontrollably exported to low- and lower-middle-income countries. Investigations have shown that many of these shipments contain non-functional and hazardous waste, resulting in severe environmental degradation and health risks for informal recyclers, particularly in Africa and Asia (Mihai et al., 2022). This study also highlights that a substantial proportion of e-waste originating from high-income countries is exported to developing nations as second-hand goods. Despite international agreements, such as the Basel Convention, regulatory

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loopholes have allowed substantial volumes of non-hazardous e-waste to evade strict oversight, exacerbating the challenges faced by recipient countries (Abalansa et al., 2021).

Malaysia exemplifies the challenges faced by developing countries, with e-waste volumes projected to reach 24.5 million units by 2025 (Baldé et al., 2024; Yusof et al., 2023). Despite existing laws such as the Environmental Quality Act 1974 and the Scheduled Waste Regulations 2005, the country faces significant hurdles in e-waste management. These challenges include regulatory enforcement gaps, underdeveloped infrastructure, persistent informal recycling practices, and inefficient implementation of the Prior Informed Consent (PIC) procedure under the Basel Convention. The lack of skilled labor and unauthorized imports further exacerbate these issues, contributing to environmental pollution and public health risks. Recent policy developments, such as the introduction of Extended Producer Responsibility (EPR) principles within the 12th Malaysian Plan, have signaled efforts to align with international standards. However, informal recycling and unauthorized imports pose significant challenges, underscoring the need for comprehensive reforms of Malaysia's e-waste management system (Basel Convention, 2024; Yong et al., 2019).

Adopted in 1989, the Basel Convention regulates the transboundary movement of hazardous waste, including e-waste, to prevent developing nations from becoming dumping grounds for electronic waste (Basel Convention, 2023a). However, loopholes in the existing regulations have allowed both hazardous and non-hazardous Waste Electrical and Electronic Equipment (WEEE) to continue to flow into these nations. The Swiss-Ghana Amendment, a landmark update of the Basel Convention, introduced stricter PIC procedures for all types of WEEE to enhance accountability and environmental protection (Basel Convention, 2022), representing a transformative shift in global e-waste governance (Swissinfo, 2021). Unlike previous regulations that primarily targeted hazardous e-waste, these amendments mandated PIC procedures for all types of WEEE, regardless of hazard classification. This comprehensive approach closes critical loopholes that previously allowed non-hazardous e-waste to bypass strict monitoring, marking a significant step toward environmental justice for developing nations (Waste Management World, 2022).

In Malaysia, where the challenges of end-of-life electronics and illicit imports persist, these amendments impose significant obligations to improve regulatory enforcement and management practices (Liu et al., 2023; Yusof et al., 2023). However, these challenges are not exclusive to Malaysia; rather, they reflect the broader systemic issues encountered by developing nations worldwide.

This study assessed Malaysia's readiness to implement the Swiss-Ghana Amendments as a case study to address systemic gaps in e-waste management within developing nations. It identified critical areas for improvement, including legislative reforms, capacity building, infrastructure development, public engagement, international collaboration, and monitoring mechanisms. Furthermore, the study proposes a decision-making framework that is adaptable not only to Malaysia but also to other countries facing similar challenges in effectively managing electronic waste. This approach ensures compliance with international standards and fosters sustainable e-waste management. While the existing research has focused on individual regulatory aspects or national-level policies, this study addresses this critical gap by offering a holistic and integrated approach to e-waste management in developing nations. This study provides a comprehensive framework for effectively implementing the Swiss-Ghana Amendments by combining legislative, infrastructural, and policy recommendations. These findings aim to support policymakers, regulators, and industry stakeholders in developing strategic responses to the evolving Basel Convention framework, ultimately contributing to more effective global e-waste governance.

2. Methods

This study uses a systematic narrative review approach that integrates bibliometric mapping and qualitative thematic analysis to evaluate the readiness of developing nations to implement the Swiss-Ghana amendments under the Basel Convention, using Malaysia as a case study. As the transboundary e-waste trade continues to pose significant environmental and regulatory challenges, existing studies are fragmented and unstructured regarding assessing the policy adoption of these new amendments (Jain et al., 2023; Shahabuddin et al., 2023). By incorporating an advanced bibliometric analysis, this study identified critical knowledge gaps, highlighted regulatory weaknesses, and identified actionable strategies for compliance. This dual-approach framework synthesizes research to provide an evidence-based assessment of e-waste governance (Grandhi et al., 2024; Suffia and Dutta, 2024).

The methodology integrates literature analysis and bibliometric mapping to identify key challenges, systemic gaps, and actionable solutions, as depicted in the flowchart in Figure 1. This approach is divided into several steps, including a comprehensive literature review, bibliometric analysis using VOSviewer, qualitative thematic analysis of key documents, synthesis of findings, and identification of systemic gaps. Data were retrieved from Scopus, the largest abstract and citation database, to ensure a focus on high-quality peer-reviewed resources. The search was restricted to literature published between 2019 and 2025 to ensure the relevance and inclusion of recent discussions on e-waste management and Basel Convention amendments. Relevant keywords were used to align the focus of this study. The reviewed documents included journal articles, conference proceedings, book chapters, and UNEP reports emphasizing regulatory challenges, e-waste trade governance, and compliance with PIC procedures. Additional context-specific data for Malaysia were sourced from Malaysia's Department of Environment (DOE) and related government reports. The keywords were systematically identified using the Publish or Perish software, focusing on terms relevant to the study. These keywords were selected to ensure comprehensive coverage of the academic literature and official reports related to e-waste management and the Basel Convention amendments. The refined keywords guided the bibliometric mapping process using VOSviewer, which analyzed research trends and highlighted thematic gaps in the literature.

This study employs a dual-approach analytical framework integrating qualitative thematic analysis and bibliometric mapping to explore e-waste management systematically. The qualitative thematic analysis was structured into three main themes: integrated e-waste management, which examines best practices and existing frameworks for e-waste management; gaps and challenges, identifying national and global barriers that hinder effective e-waste governance; and PIC challenges, which highlight specific difficulties in implementing PIC procedures, as outlined in the UNEP and Basel Convention reports (UNEP, 2024). Additionally, Bibliometric Mapping Using VOSviewer was applied to analyze research trends, revealing keyword co-occurrences and thematic clusters that shaped the field.

This bibliometric method visually represents knowledge progression and identifies gaps and fragmented research connections. It provides a comprehensive overview, supports researchers in generating innovative research ideas, and helps them strategically position their contributions in the field (Donthu et al., 2021). The overlay visualization further illustrates the temporal trends in e-waste discussions, exposing a limited focus on implementing the Swiss-Ghana Amendments, thereby underscoring the novelty and significance of this study. Owing to resource constraints, this study did not incorporate direct input from stakeholders, such as interviews or surveys. Such data can provide practical insights into the PIC implementation challenges for regulators, recyclers, and industry representatives (Basel Convention, 2024). Additionally, the reliance on Scopus may exclude relevant non-indexed studies that could be addressed in future re-

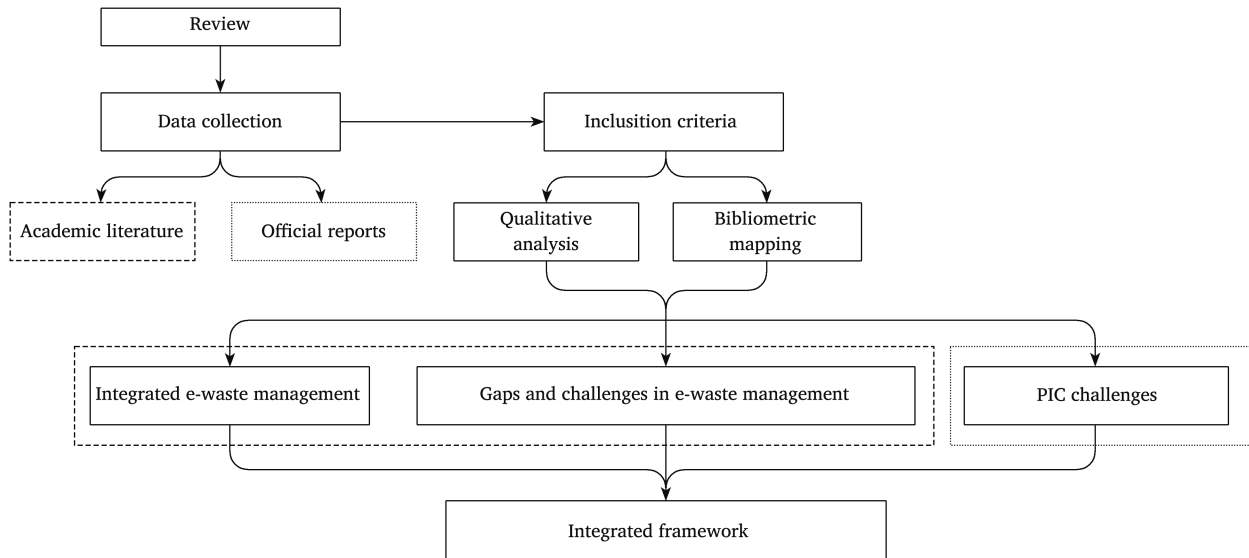


Figure 1. Methodology structure

search.

The Swiss-Ghana Amendments introduced a paradigm shift in transboundary e-waste governance, but no prior study has systematically evaluated adoption readiness in developing nations. By integrating bibliometric insights with qualitative thematic analysis, this study provides a holistic perspective on the evolving e-waste management governance landscape (Veres et al., 2025). The contribution of this study lies in the integration of bibliometric insights with qualitative findings, resulting in an integrated framework that bridges global best practices with region-specific challenges. While previous research has mainly focused on e-waste classification, regulatory enforcement, and recycling efficiency in isolation, this study presents a holistic policy-driven assessment that informs researchers and policymakers. By applying a structured thematic analysis, we systematically examined the gaps in e-waste governance, the implementation challenges of PIC procedures, and the broader implications of the transboundary e-waste movement (Basel Convention, 2023a, 2023b; FOEN and EPA Ghana, 2022). These findings provide policymakers with a foundation to develop effective strategies for sustainable e-waste trade under the Basel Convention.

3. Results

A bibliometric analysis was conducted to explore research trends in e-waste management, regulatory frameworks, and transboundary movements. The analysis was performed using VOSviewer with keywords obtained from systematic literature searches in Scopus using the Publish or Perish software. The keyword search strategy was designed to maximize coverage by considering relevant terms found throughout the journal content. To ensure an extensive and representative dataset, the search strategy incorporated keywords spanning multiple research dimensions and was validated through manual screening to ensure relevance to the study's objectives. These findings are summarized in Table 1.

A total of 32 distinct keywords were used in the bibliometric analysis, yielding 2 028 publications. The selection of keywords was intended to provide a comprehensive overview of the various dimensions of e-waste management, including regulatory frameworks, transboundary movements, and sustainability practices. The prevalence of high-frequency keywords such as “Circular Economy AND Electronic Waste”, “Electronic Waste Management”, and “WEEE Management” suggests that research on broader waste management strategies domi-

nates this field. In contrast, terms with lower frequencies, such as “Swiss-Ghana Amendment” and “Cross Border Electronic Waste Trade”, indicate a research gap in specific regulatory and international governance aspects, emphasizing the necessity for further studies in these areas. The results demonstrate that substantial attention has been paid to sustainability frameworks; however, there remains limited discussion on the enforcement mechanisms and cross-border regulatory cooperation necessary to address illicit e-waste flows. The VOSviewer visualization (Figure 2) revealed distinct clusters, indicating segmented research domains rather than an integrated discussion. Studies on regulatory policies (green clusters) appear disconnected from those focusing on trade enforcement and environmental governance (red clusters).

The VOSviewer visualization in Figure 2 reveals the apparent fragmentation in e-waste governance studies, with distinct clusters emerging rather than a unified body of research. The green cluster highlights research on regulatory policies (e.g., “Basel Convention”, “EPR”), while the red cluster focuses on enforcement challenges (e.g., “illegal e-waste trade”, “transboundary movements”). The lack of overlap between clusters underscores the critical gap in interdisciplinary research. Policy and regulatory compliance research appears to have been detached from discussions on trade enforcement and environmental governance. The lack of cross-disciplinary integration suggests that existing literature does not comprehensively address how international agreements translate into actual implementation challenges (Lo et al., 2020). Most concerning is the absence of substantial connections to the Swiss-Ghana Amendments despite their intended role in strengthening Basel Convention enforcement. This signals a significant gap in the discourse on policy changes; however, scholarly evaluations of their effectiveness remain scarce (Thapa et al., 2023). These findings reveal an urgent need for studies that bridge policy-making with real-world enforcement, particularly in regions where transboundary e-waste trade remains a regulatory challenge (Parajuly and Fitzpatrick, 2020).

The disconnection between research clusters reinforces the urgency for a more structured and solution-oriented approach to e-waste governance. The results indicate that despite ongoing regulatory amendments, research has not adequately kept pace with the evolving enforcement challenges (Ghimire and Ariya, 2020). The disconnect between policy research and enforcement studies indicates that existing literature is inadequate for understanding how transboundary regulations—such as the Swiss-Ghana Amendments—are

Table 1
Keywords used in Publish or Perish

No.	Keywords	Number of Results
1	Circular Economy AND Electronic Waste	200
2	Circular Economy AND WEEE	200
3	Electronic Waste Management	200
4	WEEE Management	200
5	Electronic Waste Management AND Regulation	200
6	Health Risks AND Electronic Waste	200
7	Informal Electronic Waste Recycling	200
8	WEEE AND Regulation	140
9	Extended Producer Responsibility (EPR) AND Electronic Waste	99
10	Illegal Electronic Waste	89
11	Health Risks AND WEEE	63
12	International Electronic Waste Trade	52
13	Basel Convention AND Electronic Waste	31
14	Transboundary Movement AND Electronic Waste	30
15	Transboundary Waste Trade	27
16	Sustainable E-waste Trade	26
17	Illegal Electronic Waste AND Trade	13
18	Transboundary Movement AND WEEE	12
19	Basel Convention Enforcement	11
20	Basel Convention AND WEEE	9
21	Basel Convention Compliance	9
22	Illegal Electronic Waste AND Shipment	4
23	Prior Informed Consent AND Basel Convention	4
24	Sustainable WEEE AND Trade	3
25	Electronic Waste Trafficking	2
26	Cross Border AND WEEE	2
27	Basel Convention AND Electronic Waste AND Amendment	1
28	Cross Border Electronic Waste Trade	1
29	Basel Convention AND WEEE AND Amendment	0
30	Swiss-Ghana AND Electronic Waste	0
31	Swiss-Ghana Amendment	0
32	Prior Informed Consent AND WEEE	0
Total		2 028

implemented at the national level. It also fails to identify the specific governance weaknesses that undermine compliance, particularly in developing economies. Moreover, the literature does not sufficiently highlight the importance of a transparent and standardized classification system for hazardous and non-hazardous e-waste, which is crucial for enhancing regulatory consistency and effectiveness. The findings of this study highlight the urgency of reassessing global e-waste governance structures, particularly to ensure that regulatory innovations do not remain theoretical but translate into practical, enforceable policies (Okposin, 2019). Without greater interdisciplinary collaboration, key amendments under the Basel Convention remain underutilized, leaving compliance gaps unresolved (Roy and Basu, 2023).

4. Discussions

4.1. Impacts and objectives of the Swiss-Ghana Amendments

The Swiss-Ghana Amendments mark a significant enhancement of the Basel Convention, designed to strengthen global oversight of

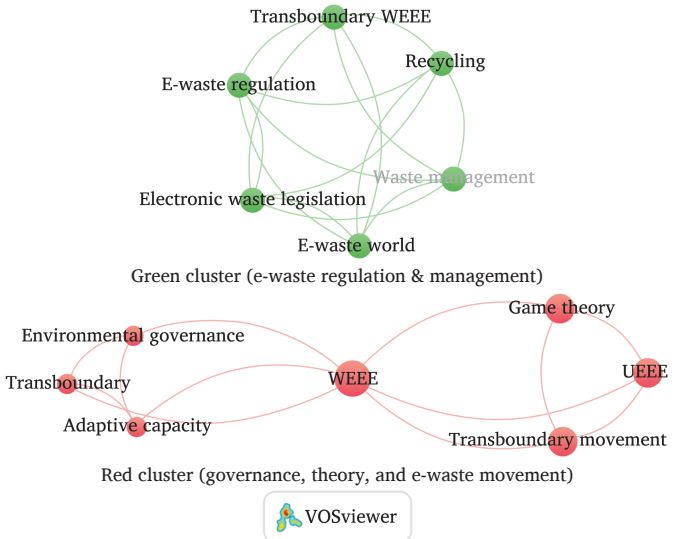


Figure 2. Keyword co-occurrence network

the transboundary movement of WEEE. Adopted at the COP15 meeting in Geneva, these amendments redefined hazardous and non-hazardous e-waste, mandating the application of the PIC procedure to all WEEE shipments, regardless of hazard classification (Baldé et al., 2022; Waste Management World, 2022). This expanded scope addresses the regulatory loopholes that previously allowed non-hazardous e-waste to be exported with little oversight, leading to severe environmental and health consequences in recipient countries. (Forti et al., 2020).

Ghana is a prominent example of these consequences, particularly in Agbogbloshie, Accra, which is one of the largest e-waste dumping sites globally. Due to insufficient regulatory mechanisms, approximately 10 000 informal workers dismantle and burn e-waste using rudimentary methods without protective measures, exposing themselves to toxic metal contamination and severe health risks, including lead poisoning and respiratory illnesses (Yeung, 2019). Soil analysis of Agbogbloshie revealed alarmingly high concentrations of Cu (15 841 mg/kg) and Pb (6 106 mg/kg), significantly exceeding the safe exposure limits (Dodd et al., 2023). These hazardous metals with high bioaccessibility further contaminate food and water sources, thereby affecting humans and livestock. Furthermore, informal recycling in Ghana processes 13 090–17 094 tons of e-waste annually, representing 39% of the country’s total e-waste volume and contributing to widespread environmental degradation (Owusu-Sekyere et al., 2022). The persistent inflow of second-hand and discarded electronics into Ghana under the guise of “reuse” underscores the urgency of implementing stricter oversight mechanisms to prevent unregulated e-waste shipments and mitigate their environmental and health impacts, as outlined in the Swiss-Ghana Amendments.

A key feature of the amendments is the inclusion of the Y49 entry in Annex II, which covers non-hazardous WEEE, and the replacement of A1180 with A1181 in Annex VIII for hazardous e-waste. These changes mandate that all WEEE shipments, whether hazardous or non-hazardous, undergo notification, consent, and documentation procedures to ensure environmentally sound management (ESM) (Forti et al., 2020; SK Tes, 2022). This approach aims to prevent illegal e-waste trade while minimizing the risk of unauthorized dumping in developing countries. It seeks to promote the global adoption of ESM practices by ensuring strict enforcement and compliance with regulatory frameworks. Additionally, the amendments emphasize enhancing the transparency and monitoring mechanisms for WEEE transboundary movements through more stringent reporting and data-sharing requirements among participating nations (Khan, 2016; Rukanova et al., 2024).

This evolution in regulatory oversight marks a significant shift toward a more holistic approach to e-waste management. Figure 3 compares the current baseline framework and the proposed Swiss-Ghana amendments for managing hazardous and non-hazardous WEEE. Under the Swiss-Ghana Amendments, non-hazardous WEEE (Y49) now requires PIC procedures and stricter monitoring, closing loopholes that previously allowed uncontrolled shipments. Hazardous WEEE (A1181) retains PIC requirements but integrates enhanced reporting mechanisms.

This illustrates the disparity between the existing frameworks for non-hazardous e-waste, characterized by minimal oversight, and the proposed Swiss-Ghana framework, effective January 1, 2025. The latter incorporates the PIC procedure, strengthens control over transboundary movements, and improves monitoring mechanisms. For hazardous e-waste, the framework maintains consistent controls, including the PIC procedure and the Basel Ban Amendment. Understanding Ghana and Switzerland's distinct yet complementary contributions to the Swiss-Ghana Amendments is essential for appreciating their collaborative efforts to advance international e-waste regulations. Ghana offers invaluable perspectives based on its direct experience as a major recipient of e-waste. At the same time, Switzerland applies its regulatory expertise and environmental leadership to advocate for rigorous controls and sustainable practices. With a collection rate of approximately 16–17 kg per capita annually, Switzerland is recognized as one of the leading nations in WEEE management (Sharma et al., 2023; Ylä-Mella and Román, 2019). However, challenges persist, particularly regarding classifying and tracking exported second-hand electronic devices (Habib et al., 2022). Approximately 67% of mobile phones returned to retailers in Switzerland are exported rather than recycled domestically, raising concerns about the transparency of transboundary e-waste movements (Duygan and Meylan, 2015). Additionally, approximately 30% of the generated e-waste lacks precise classification in the Swiss reporting systems, particularly in the medical device and monitoring equipment sectors (Ylä-Mella and Román, 2019).

Despite strict national regulations, an estimated 0.5 million tons of e-waste are illegally exported from Europe annually, including Switzerland, indicating persistent enforcement gaps (Duygan and Meylan, 2015). The Swiss-Ghana Amendments seek to address these challenges by enhancing transboundary monitoring, ensuring the proper classification of all WEEE movements, and reinforcing regulatory compliance with the second-hand electronics trade. By strengthening reporting mechanisms and promoting transparency, these amendments could contribute to a more accountable global e-waste management framework.

While the PIC procedure aims to ensure controlled management of the transboundary movement of hazardous and non-hazardous waste, several challenges persist in its implementation. These chal-

lenges are related to difficulties in information exchange between competent authorities, capacity constraints, inconsistencies in decision-making processes, and varying interpretations of key terms and definitions.

The level of impact of these challenges is ranged, reflecting the urgency and scale of the issues faced by different parties (UNEP, 2024). Figure 4 summarizes the main challenges reported, the parties involved, their respective levels of impact, and the steps that have been or could be taken to address them.

The Swiss-Ghana Amendments highlight a pivotal collaboration between developed and developing nations to tackle the global e-waste crisis through more stringent regulations and sustainable management practices. While these amendments represent significant progress in closing regulatory gaps and ensuring better oversight of transboundary e-waste movements, the challenges of implementing the PIC procedure, as documented by various parties, underscore the complexity of achieving global compliance. Communication difficulties between competent authorities, capacity constraints, and inconsistencies in decision-making processes highlight the need for enhanced technical support, harmonized guidelines, and financial assistance for parties with limited resources. Addressing these challenges is critical for realizing the full potential of amendments to minimize the environmental and health impacts caused by the unregulated e-waste trade. By leveraging the unique strengths of Switzerland's technical expertise and Ghana's advocacy to protect recipient countries, the amendments set a benchmark for international cooperation. However, their success ultimately depends on the collective efforts of all parties to address implementation challenges, promote capacity building, and harmonize global waste management standards (Kumar, 2023).

While the amendments signify progress in tackling the global e-waste crisis, they also pose significant challenges for developing nations such as Malaysia. Despite ongoing efforts, a key challenge remains in integrating the PIC procedure into national policies, as regulatory alignment with the Basel Convention amendments requires improved coordination among agencies and better reporting mechanisms. Similar challenges have been observed in other developing nations, such as India, China, and Nigeria, where e-waste management is hindered by inconsistent enforcement, inadequate collection infrastructure, and a lack of formalized recycling systems, limiting their ability to fully comply with international standards (Noorakma et al., 2024).

The Swiss-Ghana Amendments present challenges and opportunities for developing nations. Effectively addressing these issues requires a structured framework that integrates six key areas: legislative and regulatory updates, capacity building, infrastructure development, public awareness, international cooperation, and monitoring and enforcement.

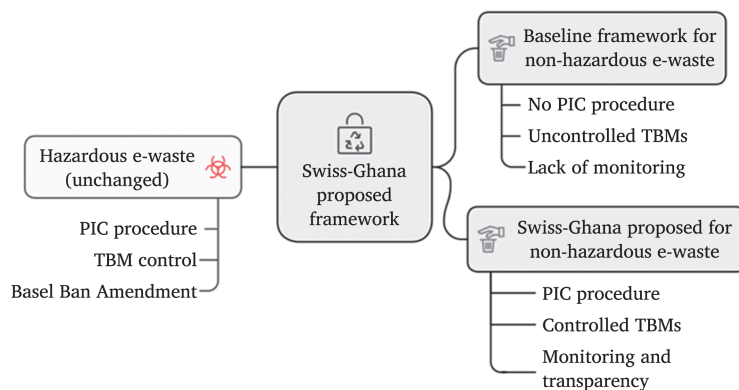


Figure 3. Comparison of current and proposed frameworks for hazardous and non-hazardous e-waste management under the Swiss-Ghana Amendments
Sources: Basel Convention (2022).

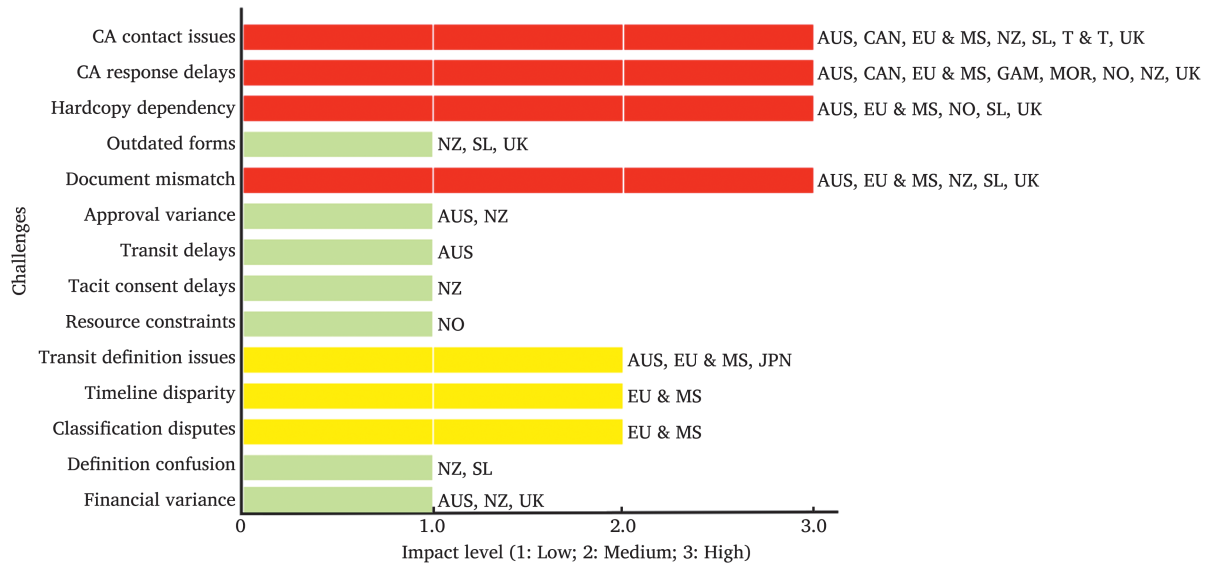


Figure 4. Challenges and level impact in the implementation of the PIC procedure

Notes: Australia, AUS; Canada, CAN; European Union and its Member States, EU & MS; Gambia, GAM; Japan, JPN; New Zealand, NZ; Norway, NO; Morocco, MOR; Sri Lanka, SL; Trinidad and Tobago, T & T; United Kingdom, UK.

Sources: UNEP (2024).

4.2. Addressing PIC challenges through collaboration and regional implementation

The implementation of the PIC procedure presents a spectrum of challenges across countries—as illustrated in Figure 4—ranging from communication barriers between competent authorities to inconsistencies in the decision-making processes. Table 2 complements this global perspective by providing a detailed overview of key gaps and challenges faced by Malaysia's e-waste management system. Juxtaposing these two frameworks reveals the interconnected nature of challenges in PIC implementation and broader e-waste governance issues. This comprehensive view highlights how local constraints in Malaysia reflect and interact with global difficulties in operationalizing the PIC procedure.

To address these complex challenges, this study proposed a six-key framework tailored to Malaysia's context but with broader applicability to other developing nations. This framework was derived from the global difficulties illustrated in Figure 4 and adapted to Malaysia's unique circumstances, as detailed in Table 2. This offers a targeted and systematic approach to strengthen overall e-waste management practices, address PIC-specific obstacles, and address broader governance issues. The proposed framework provides a foundation for overcoming multifaceted challenges associated with the PIC process while simultaneously enhancing the broader e-waste management landscape. Integrating global insights with local contexts provides a holistic approach that can be tailored to other developing countries facing similar systemic challenges.

The collaborative graphics in Figure 5 depict the intersection of the PIC challenges with Malaysia's specific gaps, highlighting how the six-key framework provides actionable solutions. The framework illustrates how capacity building supports monitoring mechanisms, whereas legislative reforms create an enabling environment for infrastructure development. It offers a systematic approach to overcoming PIC-related obstacles while strengthening e-waste management practices. It emphasizes fostering regional alignment through knowledge-sharing initiatives and capacity-building partnerships to create a more resilient and compliant e-waste governance system across developing nations.

The proposed framework adopts a holistic approach, addressing regulatory and infrastructural deficiencies while offering adaptable

Table 2

Key gaps and challenges in e-waste management in Malaysia

Aspects	Gaps and challenges	References
Regulatory gaps	Household e-waste is largely unregulated under the Environmental Quality (Scheduled Wastes) Regulations 2005.	(Ismail and Hanafiah, 2021; Shad, 2020)
Capacity limitations	Inconsistent training and a lack of technical knowledge among informal recyclers hinder environmentally sound management.	(El-Gawhari et al., 2024)
	Insufficient recycling facilities and skilled labor constrain safe e-waste processing.	(El-Gawhari et al., 2024; Yong et al., 2019)
Inadequate infrastructure	Lack of sufficient infrastructure for e-waste recycling leads to environmental risks and reliance on informal sectors.	(Shad, 2020; Yong et al., 2019)
Informal sector dominance	Informal recycling dominates, using unsafe methods and undermining formal regulatory efforts.	(Ismail and Hanafiah, 2021; Shad, 2020)
PIC implementation issues	Delays and inefficiencies in processing PIC requests hinder control of legal and illegal e-waste imports.	(Shad et al., 2020a; Yong et al., 2019)
	Lack of monitoring and enforcement mechanisms exacerbates unauthorized e-waste activities.	(El-Gawhari et al., 2024; Yong et al., 2019)
Public awareness deficit	Low public awareness results in improper e-waste disposal and high rates of informal handling.	(El-Gawhari et al., 2024; Yong et al., 2019)

and scalable solutions tailored to the unique needs of developing nations facing similar systemic barriers. Focusing on these six key areas, the framework enables countries to align their e-waste management practices with international standards. Importantly, the findings emphasize the interconnected nature of the challenges in PIC implementation and e-waste management, where weaknesses in one area can exacerbate other issues. This approach addresses the immediate challenges in Malaysia. It provides a blueprint for other countries to strengthen their regulatory readiness, mitigate environmental risks, and contribute to global sustainability efforts in e-waste management.

The proposed integrated framework in Figure 5 illustrates the systemic interconnection between challenges in PIC implementation, Ma-

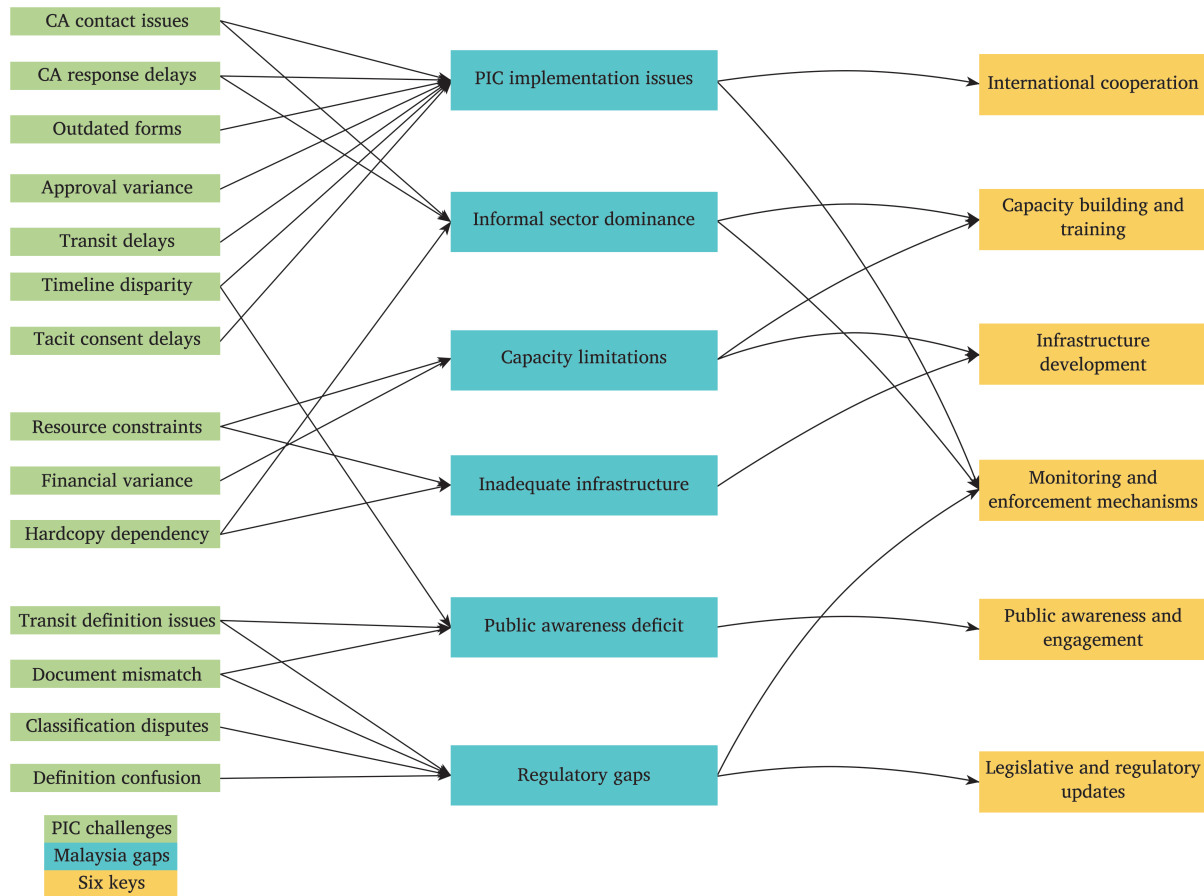


Figure 5. Proposed integrated framework for addressing PIC challenges in e-waste governance

laysia's governance gaps, and key intervention areas. This structure underscores how inefficiencies in PIC systems create compliance barriers and exacerbate broader structural weaknesses in e-waste management. A significant observation in Figure 5 is that most PIC-related challenges (green nodes) directly contribute to PIC Implementation Issues (blue nodes). These include competent authority contact issues and response delays, outdated forms, approval variances, transit delays, timeline disparities, and tacit sent delays. The clustering of these linkages indicates that procedural inefficiencies within the PIC system act as bottlenecks, hindering the smooth enforcement of transboundary e-waste regulations. This suggests that addressing implementation issues should be the highest priority, as resolving them would alleviate the cascading effects across the broader e-waste governance framework. For example, delays in obtaining prior consent due to administrative inefficiencies could directly affect enforcement, leading to unregulated shipments or informal recycling activities.

The regulatory gap node is another critical junction where multiple PIC challenges converge. Definition confusion, classification disputes, and document mismatches were the major contributors, highlighting the inconsistencies in e-waste classification and documentation procedures. These regulatory gaps impede compliance with the Swiss-Ghana Amendments and make enforcement efforts ineffective. Domestic and international stakeholders face uncertainties in determining hazardous and non-hazardous e-waste without harmonized definitions and clear classification criteria. This ambiguity increases the likelihood of non-compliant shipments, regulatory loopholes, and misinterpretations between exporting and importing nations.

The cascading effect of PIC implementation issues and regulatory gaps further exacerbates capacity limitations and the dominance of the informal sector. Capacity limitations arise due to resource con-

straints and financial variance, making it difficult for regulatory agencies to monitor and enforce compliance effectively. Simultaneously, informal sector dominance thrives in environments with weak enforcement, where unauthorized recyclers exploit regulatory loopholes, inadequate monitoring, and poor enforcement coordination. This interaction underscores the necessity of capacity-building initiatives and financial investment in formal waste management infrastructure to reduce reliance on informal e-waste handlers, who often operate outside regulatory oversight.

The six key intervention areas identified in Figure 5 provide a structured pathway to resolve governance inefficiencies and address these systemic challenges. International cooperation is crucial for fostering collaboration between nations to standardize PIC procedures and harmonize classification criteria, ensuring consistency in e-waste regulations. Capacity building and training initiatives are essential for enhancing the technical expertise of enforcement agencies, recyclers, and policymakers and equipping them with the necessary skills to manage compliance effectively. Strengthening monitoring and enforcement mechanisms through real-time tracking and improving cross-agency collaboration is pivotal to mitigating enforcement inconsistencies and reducing the risk of regulatory breaches.

Infrastructure development remains a critical component in expanding formal recycling and collection facilities, which helps minimize reliance on informal operations that often lack environmental safeguards. Public awareness and engagement initiatives foster a culture of compliance by educating stakeholders about the importance of regulatory adherence and the risks associated with illegal practices. Legislative and regulatory updates are equally vital as they ensure that national laws are reformed and aligned with Basel Convention Amendments, thereby reducing classification disputes and enhancing

procedural transparency. Together, these six intervention areas provide a comprehensive strategy for strengthening Malaysia's e-waste governance framework while improving its readiness for the Swiss-Ghana Amendments.

4.3. Strengthening readiness for the Swiss-Ghana Amendments

The Malaysian Implementation Model for the Swiss-Ghana Amendments requires a multifaceted approach to strengthen the country's e-waste management system in alignment with these new international standards. E-waste management in developing nations often encounters systemic inconsistencies ranging from regulatory gaps to inadequately resourced infrastructure, exacerbating environmental and public health risks (Gollakota, 2020). Addressing these challenges demands a comprehensive model that integrates the diverse components essential for effectively managing and overseeing e-waste.

Figure 6 shows this model, which identifies six key areas that are critical for Malaysia's effective adoption and integration of amendments: (i) legislative and regulatory updates, (ii) capacity building, (iii) infrastructure development, (iv) public awareness, (v) international cooperation, and (vi) monitoring and enforcement. These interconnected elements form the foundation of Malaysia's preparedness strategy for implementing the Basel Convention amendments effectively.

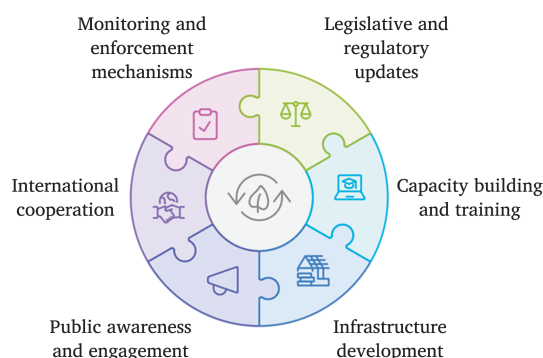


Figure 6. Strategic framework for strengthening Malaysia's readiness for the Swiss-Ghana Amendments

4.3.1. Legislative and regulatory updates

Implementing the Basel Convention amendments necessitates substantial modifications to Malaysia's regulatory framework to ensure alignment with international standards. The current regulatory structure, primarily governed by the Environmental Quality (Scheduled Wastes) Regulations 2005, provides foundational guidelines for managing industrial e-waste under Code SW110, but has limitations in its scope, particularly concerning household e-waste management (Shad et al., 2020b; Shaharudin et al., 2023). As Sanghvi (2023) noted, e-waste in Malaysia is categorized under SW110, which mandates that only licensed facilities handle industrial e-waste, leaving household e-waste largely unregulated and often disposed of along with general waste. This regulatory gap is particularly significant, given that household e-waste constitutes approximately 70% of Malaysia's total e-waste generation yet remains largely unmanaged. (Ismail and Hanafiah, 2021).

In response to these challenges, the Malaysian government has developed comprehensive regulations incorporating EPR principles within the 12th Malaysia Plan framework (EPU, 2021). The EPR mechanism represents a paradigm shift in waste management responsibility by transferring the financial and operational obligations of end-of-life product management from municipalities to producers (Brown et al., 2023). However, EPR implementation in developing economies often encounters significant obstacles owing to limited for-

mal recycling infrastructure and the complexity of shared cost models among producers, which can undermine the overall incentives for joint investment in recycling facilities (Gui, 2020). This transition is particularly crucial for Malaysia, as it addresses the current fragmentation of e-waste collection systems and establishes a more structured approach to waste management accountability.

The proposed regulatory framework encompasses several critical components to strengthen Malaysia's e-waste management system. First, the DOE has been working to enhance the Environmental Quality Act of 1974 by including household e-waste management provisions, mainly focusing on collection and recycling aspects that were previously unregulated (Halmi and Rahman, 2021). Second, under the new framework, licensed e-waste collection centers and treatment facilities must comply with the specific technical requirements outlined in the Guidelines for the Classification of Used Electrical and Electronic Equipment, ensuring environmentally sound management practices. Third, to align with the Basel Convention amendments, Malaysia is strengthening its documentation and tracking systems for transboundary e-waste movement, mainly by focusing on implementing rigorous PIC procedures to prevent illegal trafficking.

Furthermore, legislative and regulatory updates require a clear delineation of the roles and responsibilities of various stakeholders in the e-waste management chain (Liu et al., 2022). Following these regulations, e-waste management frameworks enforce licensing and reporting requirements while providing economic incentives to encourage stakeholders—such as producers, importers, collectors, and recyclers—to engage in formal recycling practices (Kumar et al., 2024). Through EPR programs and specific recycling targets, these frameworks can promote environmentally sound management practices in the e-waste sector.

4.3.2. Capacity building and training

The Swiss-Ghana Amendments require Malaysia to significantly enhance its capacity for e-waste management, mainly through targeted training programs for stakeholders across the formal and informal sectors. El-Gawhari et al. (2024) highlighted the limitations of Malaysia's current e-waste framework, in which inconsistencies in training and knowledge gaps among informal recyclers hinder ESM practices. The importance of community engagement and collaboration with industry actors is further underscored by Mohamed and Rasan (2021a), who advocate structured initiatives that integrate both sectors to support sustainable consumption and production and encourage responsible e-waste recovery practices. Such capacity-building measures address technical skill gaps and foster a sense of shared accountability and compliance.

Inadequate training programs for customs officials have exacerbated Malaysia's transboundary e-waste management challenges. A study by Baldé et al. (2022) revealed that only a small percentage of the Association of Southeast Asian Nations (ASEAN) customs officials are trained to distinguish between second-hand electronics and e-waste, leading to regulatory loopholes that facilitate illegal shipments. By contrast, Switzerland has implemented advanced training programs integrating blockchain-based tracking systems for e-waste shipments, reducing illegal exports by 38% by 2022. Technological literacy gaps persist among enforcement agencies and recyclers in Malaysia. While countries such as Nigeria have successfully adopted digital tools such as handheld XRF analyzers for waste classification, Malaysia continues to rely on manual reporting methods, which are prone to errors and inefficiencies (Elmosaad, 2024). Addressing these gaps requires comprehensive capacity-building initiatives incorporating technology-driven solutions to improve monitoring and compliance.

Moreover, technological innovations such as smart bins can optimize collection and sorting, enabling real-time monitoring and transparency in e-waste management (JosephNg et al., 2024). Ya'acob et al. (2023) emphasize that enhancing recycling behaviors among Ma-

laymans requires technology, sustained awareness campaigns, and training, especially for informal-sector workers who play a critical role in waste collection and sorting. Azem et al. (2019) state that a comprehensive capacity-building approach must extend beyond skill development to include institutional and interagency coordination. By implementing such measures, Malaysia can better align its practices with the international standards set forth by the Swiss-Ghana Amendments, thereby establishing a resilient and sustainable e-waste management system.

4.3.3. Infrastructure development

Developing a resilient e-waste infrastructure is essential for Malaysia to effectively implement the Swiss-Ghana Amendments and address the rising challenges of e-waste management. Malaysia's existing e-waste infrastructure includes 137 Collection Centers, 130 Collection Points, and 64 Recovery Facilities managed by the DOE Malaysia, forming the backbone of the country's formal e-waste collection and processing system (DOE Malaysia, 2024b). Figure 7 shows a spatial representation of Malaysia's e-waste infrastructure distribution, illustrating the concentration of collection centers and recovery facilities across the different states. Urban regions, such as Selangor, Kuala Lumpur, and Penang, exhibit a higher density of facilities, and remote areas—particularly Sabah and Sarawak—face infrastructural constraints that hinder efficient waste collection and processing.

Currently, infrastructure limitations in regions such as Sabah highlight the need for enhanced processing facilities and efficient collection and disposal systems to prevent informal dumping (Mohd Rahman et al., 2024). Addressing these disparities requires targeted investment in underserved regions, ensuring equitable access to formal e-waste management facilities while reducing dependency on informal recycling channels. Mobile phones account for the largest share, followed by personal computers. Televisions rank third, followed by washing machines and refrigerators. Air conditioners contribute the least. This trend highlights the continuous rise in e-waste production and underscores the growing challenge of effectively managing e-waste in the coming years (DOE Malaysia, 2024a). Figure 8 illustrates the steady increase in Malaysia's e-waste generation by millions of units (DOE Malaysia, 2024a) from 2016 to 2025.

In 2020, only 30% of the e-waste in Malaysia was recycled correctly, highlighting significant shortcomings in the country's waste management systems. Malaysia is projected to generate 24.5 million

units of e-waste by 2025, driven by rapid digitalization and increased consumption of electronic devices. These projections underscore the urgent need for enhanced recycling and strict waste management policies to address the escalating volumes of electronic waste. Despite existing regulatory frameworks such as the Environmental Quality (Scheduled Wastes) Regulations 2005, Malaysia faces persistent gaps in e-waste collection and processing infrastructure. Household e-waste management remains voluntary, with limited public awareness and inadequate reporting mechanisms. For example, only 5% of consumers will dispose of e-waste by 2021, and household recycling rates will remain far below the global average. These deficiencies contribute to environmental degradation and pose a risk to public health.

The data presented in Table 3 further emphasize the need for improved infrastructure to manage e-waste effectively. Incomplete data recording across different years reflects systemic issues in monitoring and reporting, which hinder the formulation of efficient waste management strategies. Addressing these gaps is critical for aligning Malaysia's practices with international standards such as those outlined by the Basel Convention and other global frameworks promoting EPR.

Malaysia's e-waste infrastructure has been criticized for its inability to meet growing demands as urbanization accelerates. Murthy and Ramakrishna (2022) emphasized the importance of an urban mining approach that focuses on extracting valuable materials from e-waste through advanced recycling technology to support Malaysia's transition towards a circular economy. Adopting EPR frameworks to strengthen infrastructure can drive collaborative investments in new recycling facilities and waste processing plants (Gui, 2020). Such investments would allow for a more specialized infrastructure and efficient processing channels, reducing the strain on existing facilities. Arya and Kumar (2020) suggested that Malaysia should adopt a multi-tiered infrastructure model in which regional and local facilities work with larger central processing centers to optimize logistical costs and minimize environmental risks. Moreover, Eastman (2024) this study highlights the importance of integrating advanced technologies and establishing a cohesive network for e-waste management facilities. This will be pivotal to Malaysia's efforts to meet international standards and sustainably manage e-waste under the Swiss-Ghana Amendments.

4.3.4. Public awareness and engagement

Raising public awareness and fostering engagement are critical

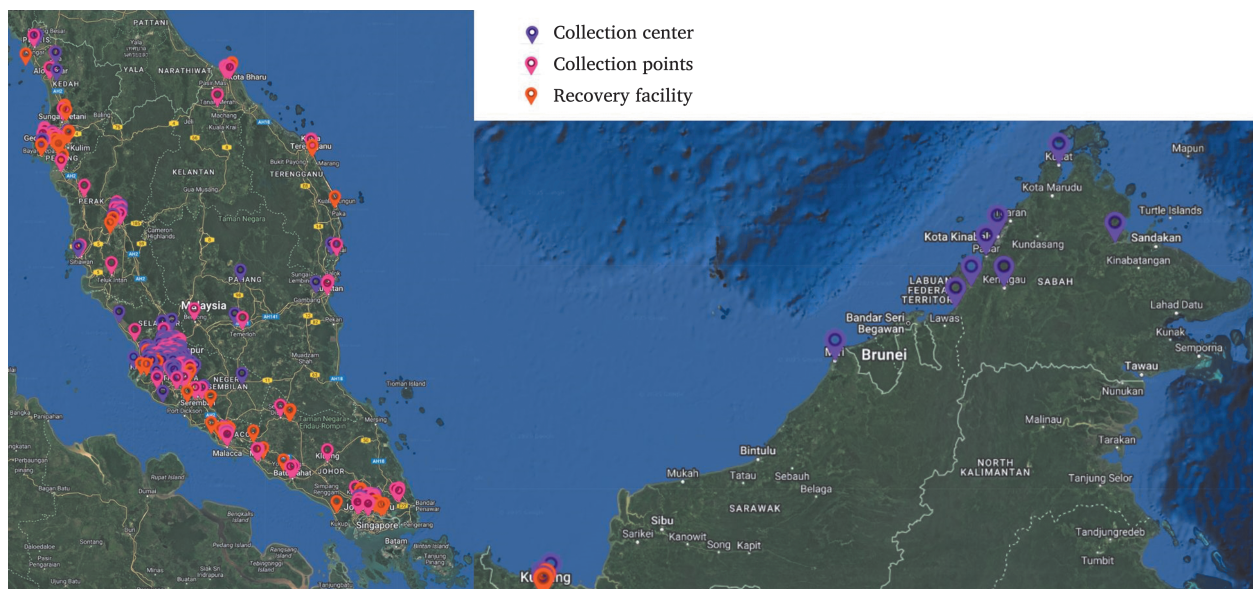


Figure 7. The geographical distribution of facilities

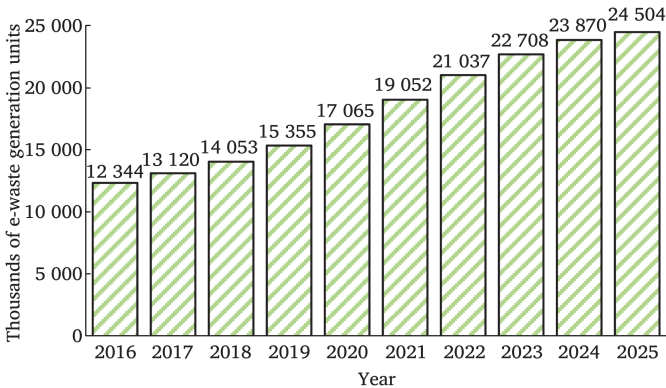


Figure 8. Projected e-waste generation in Malaysia (2016–2025)
Sources: DOE Malaysia (2024a).

Table 3

Malaysia’s e-waste generation, collection, and recovery trends (2020–2023) (Akhtar, 2024; Hussin et al., 2023; Palansamy, 2025a, 2025b; Ya’acob et al., 2023)

Year	E-waste Generated (mt)	E-waste Collected (mt)	E-waste Recovered (mt)	Recovery Rate (%)
2023	Not specified	65 280.14	13 759.98	21.1
2022	365 000*	Not specified	Not specified	Not specified
2021	280 000	2 459**	Not specified	Not specified
2020	904 008.90	Not specified	Not specified	30.67***

Notes: mt = metric ton. * This figure is an estimate based on projections. ** This figure represents only household e-waste collected. *** This percentage represents the overall recycling rate for solid waste in Malaysia in 2020, not specifically e-waste.

components of Malaysia’s approach to meeting the Swiss-Ghana Amendments standards for e-waste management. Studies have indicated that public awareness of proper e-waste disposal remains low in Malaysia, leading to high rates of informal and environmentally harmful disposal practices (Hanifah et al., 2019). Despite existing initiatives, public participation in formal e-waste recycling programs in Malaysia remains limited. Studies indicate that only 5% of Malaysians properly dispose of their e-waste through licensed collection centers, most opting for informal channels or storing unused electronics at home (Baldé et al., 2022). This behavior stems from a lack of knowledge about the available recycling facilities and the benefits of proper disposal. Furthermore, rural areas face additional challenges due to limited access to collection points and insufficient outreach efforts.

The absence of consistent educational campaigns has hindered efforts to build a culture of environmental responsibility for e-waste. For example, urban areas such as Penang have seen localized improvements through targeted campaigns such as workshops and community drives, but these initiatives have not been uniformly implemented nationwide (Zia and Sukri, 2024). Moreover, there is minimal integration of e-waste education into school curricula or public service announcements, which limits long-term behavioral changes. Building a more informed community regarding the impacts of e-waste and available disposal channels is crucial for enhancing participation in official recycling programs. Efforts, such as awareness campaigns and educational programs, can improve the community’s understanding of the importance of responsible e-waste disposal, as exemplified by studies showing that effective communication and visibility of drop-off points lead to increased participation (Afroz et al., 2020).

Moreover, successful engagement in e-waste initiatives often relies on addressing health and environmental concerns associated with

improper e-waste disposal, as highlighted by research on the impact of e-waste on human health and ecosystems (Rautela et al., 2021; Shahabuddin et al., 2023). Similar awareness programs implemented in other regions showed that tailored public outreach targeted at different demographics and accompanied by accessible collection points could significantly increase public involvement in e-waste recycling (Miner et al., 2020). Malaysia can leverage these insights by enhancing the availability of recycling centers and public access to information about the environmental and health effects of e-waste, fostering a community-wide commitment to sustainable e-waste management practices.

4.3.5. International cooperation

The Basel Convention has long served as a global framework for controlling the transboundary movement of hazardous waste, including e-waste. However, enforcement challenges and regulatory loopholes have allowed significant volumes of e-waste to flow into developing nations through second-hand goods. Strengthening international cooperation is essential to address these issues effectively. Collaborative efforts have enabled countries like Malaysia to access technical expertise, financial resources, and best practices from nations with advanced e-waste management systems (eCircular, 2024; ITU, 2024). For instance, partnerships between developed and developing nations under North-South cooperation frameworks facilitated knowledge transfer and technological support. Countries such as Switzerland have shared their expertise in implementing circular economy principles, prioritizing recycling and reuse over disposal. Similarly, South-South collaborations have effectively leveraged shared experiences and regional knowledge to address context-specific challenges. For example, Rwanda’s partnership with Zambia, under the guidance of the International Telecommunication Union, has resulted in the successful implementation of EPR systems tailored to local needs (ITU, 2024).

Strengthening international cooperation is essential for Malaysia to align with the Swiss-Ghana Amendments and foster effective e-waste management practices. Global collaboration offers valuable insights into standardized practices and shared technologies for sustainable e-waste processing, which can be particularly beneficial as Malaysia scales up its recycling infrastructure (Liu et al., 2023). For instance, partnerships with countries that have established robust e-waste systems can aid Malaysia in improving recycling efficiency, enabling access to advanced technological methods, and enhancing regulatory frameworks to address e-waste transboundary movements.

Malaysia’s cooperation with other Asia-Pacific countries offers a regional approach to tackling the everyday challenges of e-waste, including informal recycling and inadequate infrastructure, which are prevalent across the region (Andeobu et al., 2021). Collaborative efforts also extend to international forums, where countries jointly address policy gaps, develop unified reporting standards, and promote the responsible recovery and recycling of materials, thereby reducing the environmental and health impacts of e-waste (Santato and Alarco, 2022). As Malaysia advances its e-waste initiatives, transparency in firm-level disclosures regarding e-waste management and data sharing can enhance trust and accountability in global e-waste networks (Abd-Mutalib et al., 2021).

4.3.6. Monitoring and enforcement

Effective monitoring and enforcement of e-waste regulations are critical to Malaysia’s capacity to align with the Swiss-Ghana Amendments. Malaysia’s current e-waste management framework faces numerous enforcement challenges, including insufficient compliance mechanisms and limited resources for monitoring illegal e-waste imports and exports (Sanghvi, 2023). Despite Malaysia’s official ban on e-waste imports in 2012 and exports in 2017, illegal shipments continued to enter the country through undocumented transboundary movement (Raja, 2025). Reports from the Basel Action Network (BAN,

2024) indicate that Malaysia remains a significant destination for illicit e-waste trafficking, with illegal shipments entering key ports, particularly in North America. Investigations revealed a direct e-waste export pathway from the United States to Malaysia via the Port of Los Angeles, raising concerns about persistent regulatory loopholes.

A detailed state-wide analysis revealed the extent of these illegal e-waste operations across Malaysia. As shown in Table 4, Malaysia has identified multiple large-scale illegal e-waste operations across various states, with significant seizures of unlicensed electronic waste, scheduled waste, and ammunition-related materials. The data highlight a recurring trend of foreign involvement in unauthorized recycling and dismantling activities, particularly within industrial zones and concealed locations such as palm oil estates. Johor, Selangor, and Penang recorded the highest value of seizures resulting from enforcement operations that uncovered illegal facilities worth millions of ringgit, some of which were directly connected to the transboundary e-waste trade. The findings suggest that despite existing regulations,

enforcement inconsistencies and the adaptability of illicit networks continue to undermine Malaysia's compliance with Basel Convention Obligations.

The data in Table 4 underscores the urgent need for strengthened monitoring and enforcement mechanisms to combat the growing threats of unregulated e-waste activities. The scale of confiscated e-waste, valued in hundreds of millions of ringgits, reflect the widespread prevalence of unlawful imports and processing operations. Many of these operations exploit regulatory loopholes, allowing illicit activities to persist despite the existing bans on e-waste imports and exports. Malaysia has escalated enforcement actions, as demonstrated by drone surveillance in Penang and multistate-coordinated raids, indicating a proactive response against illegal operators. However, persistent gaps in licensing, reporting, and tracking systems across states emphasize the need for a more integrated enforcement framework that leverages digital tracking technologies and cross-agency collaboration to curb the unauthorized e-waste trade. Without systematic in-

Table 4
Malaysia's state-wise summary of illegal e-waste operations

State	Type of e-waste	Amount	Value	Action taken	Findings	References
Johor	Electronic waste (e.g., computers, phones, televisions)	Seizures worth RM 71.5 million	RM 71.5 million	Raids on three factories; arrest of two foreign workers	Operations are often disguised as scrap metal recycling; items are believed to have been imported from overseas	(Malay Mail, 2025b)
	Scheduled waste or e-waste (e.g., tin, batteries)	669 tons of tin, 1 290 tons of batteries	RM 41.41 million	Arrest of 11 individuals; seizure of equipment to process/melt e-waste	Operations involved illegal storage and processing of scheduled e-waste	(Musa, 2025)
	Aerospace components, e-waste, and ammunition	Over 46 000 kg of e-waste, parts of a commercial plane, and ammunition	Approximately RM 23.8 million	Arrest of three foreign nationals; seizure of machinery and equipment	Operations involved illegal storage and processing of e-waste and unauthorized possession of ammunition	(Asia News Network, 2025)
Selangor	Scheduled waste or e-waste (e.g., circuit boards, batteries)	Not specified	RM 721 million (part of multi-state operation)	Arrest of 47 individuals; seizures in 12 raids across four states	Many operations are located in industrial areas and hidden in palm oil estates	(Malay Mail, 2025c)
	Electronic waste (e.g., mixed e-waste, copper, aluminum)	1.23 million kg of e-waste	RM 33.18 million	Arrest of a local man; seizure of machinery and equipment	Operations often involved illegal foreign workers; e-waste sourced from abroad	(Aminnuraliff, 2025; Malay Mail, 2025b)
	Bullet casings, live ammunition, e-waste	Approximately 50 tons of bullet casings and live ammunition	Not specified	Arrest of four individuals; seizure of machinery and equipment	Operations involved illegal recycling of ammunition and e-waste without proper licenses	(Zolkepli and Gimino, 2025)
	Scrap iron and aluminum	1 036 844 kg (iron) + 625 904 kg (aluminum)	RM 13 million	Seized by the Royal Malaysian Customs Department (JKDM) in Ops Tinman	Imported without an import permit from the USA	(Zain, 2025)
Negeri Sembilan	Scheduled waste or e-waste (e.g., printers, scanners)	Not specified	RM 721 million (part of multi-state operation)	Part of the RM 721 million seizure across four states	Operations often involve foreign workers	(Malay Mail, 2025c)
Melaka	Scheduled waste or e-waste (e.g., monitors, keyboards)	Not specified	RM 721 million (part of multi-state operation)	Part of the RM 721 million seizure across four states	Lack of proper licensing and environmental controls	(Malay Mail, 2025c)
Pahang	Electronic waste (e.g., electronic components, unprocessed silver)	Dozens of sacks of electronic waste, over 670 tons of unprocessed silver	RM 410 million	Crippled a syndicate; seizure of various machines and machinery	Operations involved burning e-waste, causing air pollution; materials believed to have been imported from China	(Aminnuraliff, 2025)
Penang	Electronic waste (e.g., computers, phones, televisions)	500 000 kg of e-waste	RM 21.83 million	Dismantling of an illegal e-waste plant; arrest of 11 foreign workers	Use of drones for surveillance helped in detection; e-waste is imported from multiple countries	(Malay Mail, 2025a)
	Electronic waste (e.g., computers, phones, televisions)	E-waste valued at RM 60.5 million	RM 106.77 million (total seizure)	Arrest of three individuals; seizure of machinery and equipment	Operations involved illegal recycling without proper licenses	(Free Malaysia Today, 2025)
Perak	Electronic waste (e.g., copper, tin, aluminum)	Over 1 000 jumbo bags of e-waste	RM 10.75 million (part of RM 117.5 million operation)	Arrest of 19 foreign nationals; seizure of hazardous waste	Operations detected using drone surveillance; facilities lacked proper authorization	(Zulsyamini, 2025)
Kuching	Unprocessed e-waste components	Seizures worth RM 21.6 million	RM 21.6 million	Arrest of eight individuals; seizure of machinery and equipment	Operations involved illegal recycling without proper licenses	(Jon, 2025)

tervention, the objectives of the Swiss-Ghanaian Amendments to strengthen compliance and promote environmentally sound e-waste management may remain unrealized in Malaysia.

A more robust monitoring model is required to overcome these enforcement gaps by incorporating enhanced data-collection strategies and advanced tracking systems. Haziq and Mishima (2019) indicated that accurate and comprehensive e-waste data are essential for creating effective regulatory responses that mitigate unauthorized e-waste activities and improve overall management. Additionally, innovative digital tracking and smart monitoring models are promising solutions. Implementing digital e-waste tracking systems, such as those proposed in Rais (2022), could significantly improve Malaysia's ability to oversee e-waste flows, reduce illegal exports, and facilitate timely interventions. Beyond technological advancements, collaborative efforts with industry and local stakeholders are also necessary to strengthen enforcement capacity. Mohamed and Rasnan (2021) emphasized that engaging local industries, retailers, and informal waste collectors could enhance compliance efforts and contribute to sustainable e-waste recovery. By integrating technology and stakeholder engagement, Malaysia can create a more resilient and enforceable e-waste management system that is aligned with international standards.

4.3.7. Acknowledgment of limitations

This study had several limitations. First, reliance on indexed literature may exclude insights from non-indexed studies or gray literature on informal recycling practices. Second, resource constraints prevented direct stakeholder engagement (e.g., interviews with customs officials or informal recyclers), which could have provided practical insights into PIC implementation challenges. Third, although the proposed framework is theoretically robust, it requires empirical validation through pilot testing in Malaysia and other developing nations. Future research should address these gaps by incorporating primary data and longitudinal assessments of policy impact.

5. Conclusion

The Swiss-Ghana Amendments to the Basel Convention represent a significant step forward in global e-waste governance, mandating PIC for all transboundary movements of WEEE. These measures aim to enhance accountability, promote environmentally sound management, and reduce the risk of unregulated e-waste trade. However, their implementation poses substantial challenges for developing nations, such as Malaysia, which struggles with regulatory enforcement gaps, inadequate infrastructure, low public awareness, and reliance on informal recycling. This study examines Malaysia's readiness to adopt the Swiss-Ghana Amendments, revealing that while foundational policies exist, significant obstacles remain. Informal recycling practices prevail; household e-waste is largely unregulated, and enforcement is constrained by limited resources and poor public engagement. To address these issues, this study proposes an Integrated Decision Framework centered on six key areas: legislative reform, capacity building, infrastructure development, public awareness, international cooperation, and robust monitoring and enforcement. This framework offers actionable solutions for Malaysia and adaptable strategies for other developing nations. International collaboration is essential for effective implementation, particularly within ASEAN and with global bodies such as the UNEP and the International Telecommunication Union. Lessons from Ethiopia, Ghana, and Switzerland highlight the benefits of regional alliances and technological innovations for improving enforcement and transparency. Ultimately, this study underscores the interconnected nature of e-waste governance challenges and advocates for a holistic, integrated approach. By adopting this framework, Malaysia can strengthen its regulatory readiness, contribute to regional leadership in e-waste management, and provide a replicable model for developing countries. Successful imple-

mentation requires sustained and coordinated efforts from all stakeholders to build a resilient system and advance the global sustainability of electronic waste management.

Disclosure statement

No potential conflict of interest was reported by the authors.

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