

E-Waste Recycling in Developed and Developing Countries: A Comparative Analysis

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ABSTRACT

Electrical and electronic solid waste (e-waste) is one of the most complex categories of solid waste to manage and has become a critical global issue, particularly in relation to waste generation, management practices, reuse, legal enforcement, and final disposal methods. This study aimed to analyse and compare e-waste solid waste management between a developed country and a developing country, with Japan and Malaysia selected as case studies. The comparative framework focused on legal and enforcement mechanisms, management infrastructure, public awareness, and the role of the private sector. The findings indicated that Japan has established a more effective and comprehensive e-waste management system, supported by robust legislation, consistent enforcement, well-developed infrastructure, and active participation from both the private sector and the public. In contrast, Malaysia continues to face several challenges, including policy implementation gaps, infrastructural limitations, technological constraints, and a moderate level of public participation. The implications of this study highlight the need for Malaysia to strengthen its regulatory framework and enforcement, enhance infrastructure capacity, and promote stronger public-private collaboration to achieve more sustainable e-waste management.

Keywords: E-Waste Recycling in Developed and Developing Countries

1. INTRODUCTION

Recycling is widely recognised as one of the most effective approaches for controlling solid waste generation within a country (Chen & Yuan, 2023). According to the United Nations Environment Programme (UNEP, 2024), global solid waste generation has reached an alarming level of approximately 2.1 billion tonnes in 2023 and is projected to increase to 3.8 billion tonnes by 2050 if systematic and sustainable waste management practices are not implemented. In this context, recycling is regarded as a key stage in the solid waste lifecycle, whether through controlled disposal, reuse, or transformation into new materials for specific purposes, thereby reducing reliance on landfill sites.

Alongside rapid technological advancement and increased consumption of electrical and electronic equipment, the generation of electrical and electronic waste (e-waste) has grown significantly on a global scale. The continuous production and upgrading of products such as mobile phones, household appliances, electric vehicles, and entertainment devices have contributed substantially to the rising volume of e-waste. According to Chakraborty et al. (2025), a notable surge in global e-waste generation occurred in 2019, with the total accumulated volume reaching 53.6 million tonnes. If e-waste is not managed effectively, it poses serious risks to human health and threatens environmental sustainability due to exposure to hazardous substances and heavy metals (Nawaz et al., 2025).

Recent statistics reported by Baldé et al. (2024) as shown in Table 1 identified ten countries as the largest generators of e-waste worldwide. China ranked first, producing approximately 12 million tonnes of e-waste in 2022, followed by the United States with 7.2 million tons annually and India with 4.1 million tonnes. Japan was also among the major contributors, generating 2.6 million tonnes per year, while France recorded the lowest figure among the top ten producers at 1.36 million tonnes annually. These data clearly demonstrate that e-waste management is a critical issue affecting both developed and developing nations.

Table 1. Top ten countries generating e-waste solid waste.

Quantities	Country	E Waste (Tonnes)
1	China	12,000,000
2	Amerika Syarikat	7,200,000
3	India	4,100,000
4	Jepun	2,600,000
5	Brazil	2,140,000
6	Rusia	1,630,000
7	Indonesia	1,610,000
8	Jerman	1,600,000
9	England	1,590,000
10	Perancis	1,360,000

Despite the growing body of literature on e-waste management, a significant research gap remains in comparative analyses between developed and developing countries, particularly with regard to regulatory frameworks, infrastructure capacity, public awareness, and private sector involvement. Therefore, this study aims to compare e-waste solid waste management practices in Japan, as a developed country, and Malaysia, as a developing country, in order to identify key challenges and best practices. The significance of this study lies in its contribution to a deeper understanding of contrasting e-waste management approaches and its potential to inform policy formulation, system improvements, and the development of more sustainable e-waste recycling strategies, particularly in the Malaysian context.

2. LAWS AND ENFORCEMENT

This article compares the approaches to electrical and electronic waste (e-waste) management between Japan, as a developed country, and Malaysia, as a developing country, with particular emphasis on legal frameworks and enforcement mechanisms. In Japan, e-waste management is governed by the Home Appliance Recycling Law (HARL), which has been enforced since 2001 (Fernando & Tsuji, 2024). The effectiveness of this legislation lies in its clearly defined allocation of responsibilities, whereby consumers are required to pay recycling fees and return end-of-life electrical and electronic appliances, while producers are obligated to collect, transport, and recycle the e-waste. This structured mechanism ensures a controlled flow of e-waste, reduces illegal disposal, and enhances the recovery of valuable materials.

In addition to HARL, Japan strictly regulates e-waste management through compliance with the Basel Convention, which classifies 36 types of e-waste into three main categories as shown in Table 2 (Mihai et al., 2022). This detailed classification system facilitates more effective enforcement by ensuring that each category of waste is managed according to its specific risk profile and treatment requirements. Consistent enforcement, supported by advanced recycling infrastructure and high public awareness, has contributed significantly to the effectiveness and sustainability of Japan's e-waste management system.

Table 2. Three categories of e-waste.

Quantities	Category	E Waste Type
1	Home Appliances	Air Conditioner
2		Television (Cathode Ray Tube, Plasma, Liquid Crystal Display)
3		Refrigerator and Freezer
4		Washing Machine and Clothes Dryer
5	Small Household Appliances	Telephones, Fax Machines, and Wired Communication Devices
6		Mobile Phone Terminals and Televisions
7		Radio and Television Receivers
8		Digital Cameras, DVD Recorders and Other Related Devices)
9		Digital Audio Players, Stereo Sets, Other Electro-Acoustic Devices
10		Personal Computer

11		Optical Discs, Magnetic Discs, and Storage Devices
12		Printers and Equipment
13		Displays and Other Display Devices
14		Electronic Book Terminal
15		Electric Sewing Machine
16		Blenders, Drills, and Other Electric Tools
17		Calculators and Other Electronic Office Equipment
18		Electronic Health Measuring Devices
19		Electric Vacuum Cleaners, Other Electromechanical Equipment
20		Film Camera
21		Rice Cookers, Oven Heaters, Other Electronic Kitchen Appliances
22		Electric Fans, Dehumidifiers, Other Air Conditioning Equipment
23		Irons, Vacuum Cleaners, and Other Electric Appliances
24		Water Heaters and Other Heating Appliances
25		Hair Dryers, Shavers, and Other Electric Appliances
26		Electric Massagers
27		Treadmills and Other Exercise Equipment
28		Electric Lawn Mowers and Other Electric Appliances
29		Fluorescent Lamps and Other Lamps
30		Electric Clock
31		Electric and Electronic Musical Instruments
32		Electric Gaming Equipment
33	Others	Water Heater
34		Power Distribution Board
35		Uninterruptible Power Supply
36		Refrigeration Compressor Equipment (Containing Oil)

In contrast, Malaysia regulates e-waste management under the Scheduled Wastes Management Regulations 2005, administered by the Department of Environment (DOE, 2025). Although this regulatory framework provides a legal basis for managing hazardous waste, including e-waste, its implementation primarily focuses on industrial waste streams and does not comprehensively address household e-waste. Malaysia has also proposed the adoption of an Extended Producer Responsibility (EPR) policy to shift the responsibility for e-waste management to manufacturers (Malaysia E-Waste Management, 2023). However, the effectiveness of this policy remains limited, as it has yet to be fully implemented due to low public awareness, institutional constraints, and the absence of robust enforcement mechanisms.

According to Suhaili and Abdullah (2023), Malaysia still lacks an effective and integrated e-waste management system, particularly in terms of household e-waste collection and recycling. Low levels of public awareness and passive attitudes toward the return of obsolete electrical and electronic equipment have slowed the implementation of existing policies, despite widespread recognition of the health and environmental risks associated with e-waste. This situation indicates that the primary weaknesses in Malaysia's e-waste management stem not only from policy gaps but also from implementation deficiencies, weak enforcement, and inadequate infrastructural support.

Overall, this comparative analysis demonstrates that the effectiveness of e-waste legislation and policy depends heavily on the clarity of responsibility allocation, the strength of enforcement mechanisms, the level of public awareness, and the availability of supporting infrastructure. Japan's success in e-waste management illustrates how strong legal frameworks combined with consistent enforcement can result in an efficient and sustainable system, whereas Malaysia's experience highlights the urgent need to strengthen policy implementation in line with international best practices.

3. INFRASTRUCTURE

From an infrastructure perspective as a Table 3, Japan has a mature, well-organized, and highly functional system for e-waste management and recycling. The implementation of user recycling fees, combined with strategically located collection points, has improved the formal return and collection of end-of-life electrical and electronic equipment. The application of *Extended Producer Responsibility*

(EPR) ensures that manufacturers are responsible for the entire lifecycle of e-waste for appliances such as air conditioners, televisions, and computers (Pehlivan & Akkaya, 2025).

In terms of performance indicators, Japan achieves a recycling rate exceeding 74% for major household appliances, including televisions and refrigerators, due to the integration of advanced recovery technologies and comprehensive recycling infrastructure (Zulkifli & Lim, 2025). The country also operates at least 47 specialized e-waste recycling centers, equipped with automated sorting systems, hazardous material treatment, and recovery of high-value metals such as copper and gold (Ternald, 2021). In addition, Japan maintains an efficient national logistics network that allows e-waste collection to be carried out systematically across both urban and rural areas.

Moreover, Japan regulates transboundary e-waste movement through strict compliance with the Basel Convention, including both imports and exports of hazardous electronic waste (Sakai, 2023). Enforcement is supported by digital documentation systems, customs monitoring, and well-equipped ports, which minimize illegal disposal and uncontrolled e-waste trade (United Nations Environment Programme [UNEP], 2024).

In contrast, Malaysia's e-waste management infrastructure remains underdeveloped and faces multiple constraints. In 2020, Malaysia generated approximately 368,000 tonnes of e-waste, but comprehensive official data on recycling rates, material recovery, and licensed processing centers are lacking (Hashim et al., 2024). The absence of reliable data reflects a significant implementation gap in monitoring and reporting systems at the national level.

Regarding network capacity, Malaysia has a limited number of licensed collection and processing facilities, concentrated mainly in industrial areas. The limited coverage of facilities in rural and residential areas hinders systematic household e-waste collection. Furthermore, the dismantling and recovery of e-waste in Malaysia largely occur informally and manually, with minimal use of advanced processing technologies (Nyeko et al., 2022). This not only restricts material recovery rates but also increases occupational health risks and environmental hazards from improper handling of hazardous substances.

Overall, performance indicators reveal a substantial gap between Japan and Malaysia in terms of recycling rates, number and coverage of facilities, technology usage, and efficiency of support networks. Japan's success is driven by robust infrastructure, consistent EPR implementation, and effective monitoring systems, whereas Malaysia continues to face significant challenges related to policy implementation gaps, technological limitations, insufficient network capacity, and the absence of clear performance indicators, highlighting the urgent need to enhance its e-waste management infrastructure comprehensively.

Table 3. Comparison infrastructure facility for e-waste between Japan and Malaysia.

Indicator	Japan	Malaysia	Source
Annual e-waste generation (tonnes, 2020–2022)	~2.6 million	368,000	Baldé et al., 2024; Sabri, 2022
Recycling rate (%)	>74% for major household appliances	<20% overall	Zulkifli & Lim, 2025; Baldé et al., 2024
Number of specialized recycling centers	47	Limited, mostly in industrial areas	Ternald, 2021; Thukral et al., 2022
Technology level of recycling facilities	Advanced automated sorting, hazardous material treatment, metal recovery	Mostly manual dismantling, minimal advanced technology	Ternald, 2021; Thukral et al., 2022
Network coverage	Nationwide, urban & rural areas	Limited, concentrated in major urban/industrial zones	Zulkifli & Lim, 2025; Sabri, 2022

Indicator	Japan	Malaysia	Source
Extended Producer Responsibility (EPR) implementation	Fully implemented for major appliances	Proposed, not fully implemented	Pehlivan & Akkaya 2025; Malaysia E-Waste Management, 2023
Transboundary e-waste regulation	Strict compliance with Basel Convention	Basel Convention ratified, enforcement limited	Sakai, 2023; UNTC, 1989

4. PUBLIC AND PRIVATE SECTOR RESPONSIBILITY

Japan demonstrates a high level of public discipline in disposing of electrical and electronic waste (e-waste). According to Arimura & Hibiki (2025), e-waste in Japan is recycled under the *Small Home Appliance Recycling Promotion Act* (April 2013) and the *Specified Household Appliance Recycling Law* (April 2001). These laws position Japan among the first countries to implement a comprehensive nationwide recycling system. The effectiveness of these policies relies not only on legal enforcement but also on public participation: despite disposal fees, citizens actively return e-waste through official channels, including government campaigns, collection programs, and awareness initiatives (Pehlivan & Akkaya, 2025). The private sector also plays a crucial role, as companies collect and recycle e-waste generated from their own products, thereby strengthening the recycling network and reducing informal or unsafe disposal practices (Liu et al., 2023). Behavioral studies suggest that Japan's high participation rates are influenced by societal norms, civic responsibility, and long-standing environmental education, which collectively reinforce compliance with recycling regulations (Trinh & Sakurai, 2025).

In contrast as a Table 4, Malaysia faces substantial challenges in public participation and private sector involvement. While certain procedures exist to incentivize citizens to return electrical and electronic appliances, implementation has been limited, and public engagement remains low (Afroz et al., 2020; Malaysia E-Waste Management, 2023). Research indicates that many Malaysians perceive minimal personal benefit from returning end-of-life appliances, and there is a general reluctance to participate due to inconvenience or lack of awareness of potential environmental and health impacts (Nadarajan et al., 2024). This behavioral barrier is compounded by insufficient private sector initiatives: while some companies have introduced take-back programs or collection drives, coverage is sporadic and predominantly restricted to urban centers, leaving rural communities underserved (Yusnita et al., 2023).

Education and community engagement are essential to fostering responsibility for e-waste management. Environmental education alone is insufficient to guarantee efficient disposal; coordinated action between communities, government, and private stakeholders is necessary to overcome behavioral, logistical, and motivational barriers (Nawaz et al., 2025; Jantakad & Chompunth, 2022). In Malaysia, informal disposal practices persist, where individuals dismantle and sell components to generate income, exposing themselves to hazardous substances and contributing to environmental pollution. Studies show that without structured incentives, public awareness campaigns, and active private sector participation, e-waste management in Malaysia will remain fragmented and largely informal (Nyeko et al., 2022).

Overall, comparative analysis indicates that Japan's success stems from an integrated system where legal frameworks, strong public behavioral compliance, and proactive private sector participation align effectively. In Malaysia, barriers such as low public motivation, limited awareness, and inconsistent private sector engagement hinder effective e-waste management. Addressing these gaps requires combined strategies: expanding incentives for households, improving private sector take-back schemes, and implementing targeted behavioral interventions to increase participation in formal recycling programs.

Table 4. Public and private sector responsibility comparison between Japan and Malaysia.

Indicator	Japan	Malaysia	Source
Public awareness & participation	High; citizens actively return e-waste via official programs and campaigns	Low; many citizens unaware or perceive little benefit from returning e-waste	Pehlivan & Akkaya, 2025; Zia & Sukri, 2024; Htet & Shahrir, 2025
Behavioral compliance	Strong; societal norms and civic responsibility promote adherence to recycling laws	Weak; behavioral barriers include inconvenience, low perceived benefit	Trinh & Sakurai, 2025; Izzah Az Zahra et al., 2025
Private sector involvement	Proactive; companies operate take-back programs and collect e-waste from own products	Limited; take-back programs exist but are sporadic and mostly urban	Lui et al., 2021; Yap et al., 2021
Incentives for public participation	Structured fee-based recycling with clear obligations	Existing incentive schemes not fully implemented or recognized by public	Pehlivan & Akkaya, 2025; Malaysia E-Waste Management, 2023
Education & community engagement	Integrated environmental education reinforces civic responsibility	Limited; awareness campaigns exist but community engagement is inconsistent	Nawaz et al., 2025; Jantakad & Chompunth, 2022
Informal disposal practices	Rare; formal collection and recycling prevent unsafe practices	Common; dismantling and resale by unskilled individuals exposes them to hazards	Nyeko et al., 2022; Yap et al., 2021
Regulatory compliance & enforcement	High; e-waste disposal regulated through HARL and related laws	Moderate to low; laws exist but enforcement and compliance are inconsistent	Arimura & Hibiki, 2025; Zia & Sukri, 2024

The comparative analysis presented in the table indicates that Japan has established a highly coordinated e-waste management system in which public behavior, legal enforcement, and private sector engagement function in a mutually reinforcing manner. This integrated approach has significantly reduced the prevalence of informal e-waste disposal, as compliance is supported not only by robust legislation but also by strong societal norms and active industry participation. As a result, Japan demonstrates a well-regulated and efficient e-waste management framework.

In contrast, Malaysia exhibits several structural and behavioral gaps that hinder effective e-waste management. These include low levels of public participation, limited private sector involvement, and weak enforcement of existing regulations. Consequently, informal recycling practices remain widespread, posing environmental and health risks. This situation underscores the need for comprehensive behavioral interventions, broader incentive schemes to encourage public participation, and more structured and consistent engagement from the private sector.

Overall, the analysis highlights that effective e-waste management depends not only on the presence of legal and regulatory frameworks but also on behavioral factors, societal norms, and well-designed incentive mechanisms. The alignment of these elements is crucial for ensuring sustainable and efficient e-waste management systems, particularly in developing countries such as Malaysia.

5. RECOMMENDATIONS

To enhance the effectiveness of e-waste management in Malaysia, several actionable strategies should be implemented. First, capacity building and knowledge transfer initiatives should be strengthened through collaboration with Japan and other developed countries. Such cooperation would facilitate the exchange of technical expertise, advanced recycling technologies, automated sorting systems, and best practices for the safe handling of hazardous materials. These efforts would help Malaysia improve its technical capability and institutional readiness in managing e-waste more efficiently.

In addition, the full implementation of Extended Producer Responsibility (EPR) policies is essential to ensure that manufacturers and importers are accountable for the collection, recycling, and proper disposal of their products at the end of their life cycle. This requires the establishment of clear regulatory guidelines, effective monitoring frameworks, and strong enforcement mechanisms to enhance

compliance and minimize loopholes within the system. A well-implemented EPR framework would significantly reduce the burden on public waste management systems.

Furthermore, the expansion of e-waste collection infrastructure should be prioritized by establishing additional collection centers strategically across both urban and rural areas. Improving accessibility through mobile collection services and community-based drop-off points would encourage greater public participation and reduce the tendency toward improper disposal. Equitable infrastructure distribution is crucial to ensuring nationwide engagement in formal e-waste recycling programs.

Public awareness and behavioral interventions also play a critical role in improving e-waste management outcomes. Targeted awareness campaigns and educational programs should be introduced to highlight the environmental and health risks associated with improper e-waste disposal. These initiatives can be complemented by incentive-based schemes, such as rebates or discounts for returning obsolete electronic devices, to motivate positive behavioral change among citizens.

Moreover, greater involvement from the private sector should be encouraged through take-back programs, sponsorship of collection initiatives, and investment in recycling facilities. Public-private partnerships can strengthen the overall e-waste management ecosystem by integrating resources, expertise, and innovation, thereby improving system efficiency and coverage.

6. CONCLUSION

Japan demonstrates a well-established, systematic, and efficient e-waste management system, supported by strong legislation, high public responsibility, advanced infrastructure, and proactive private sector engagement. Its success reflects the integration of legal frameworks, societal compliance, technological capabilities, and coordinated institutional support.

In contrast, Malaysia is still in the process of developing its e-waste management system. Challenges include low public awareness, limited collection infrastructure, weak enforcement, and minimal private sector involvement. To improve, Malaysia should learn from Japan's experience, integrate e-waste management education into schools and universities, enhance public motivation to dispose of e-waste through proper channels, and implement structured policies such as EPR. By adopting these measures, Malaysia can move toward a more organized, systematic, and sustainable e-waste management system that benefits both public health and the environment.

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