Unlocking the Challenges of Household E-Waste Recycling in Malaysia

Zahari Md Rodzi[1*], Farah Azaliney Mohd Amin[2], Sarahiza Mohmad[3], Ashraf Al-Quran[4]

[1,2,3] Kolej Pengajian Pengkomputeran, Informatik dan Matematik, Universiti Teknologi MARA Cawangan Negeri Sembilan, Malaysia
[4] Basic Sciences Department, Preparatory Year Deanship, King Faisal University, Al Hofuf 31982, Saudi Arabia
zahari@uitm.edu.my

Abstract. The present research utilizes the Decision-Making Trial and Evaluation Laboratory (DEMATEL) analytical technique to elucidate the intricate network of barriers impeding the effective recycling of electronic waste (e-waste) in Seremban, Malaysia. Through an analysis of the causal linkages among seven prominent barriers, this study provides insights into the interrelated nature of these issues and puts forward feasible remedies. The research identifies "Lack of Awareness" as a primary causative factor that impacts many barriers, including restricted collecting accessibility, worries over data security, and the high expenses associated with recycling. The results of the study include specific approaches, such as the implementation of extensive awareness initiatives, the provision of financial incentives, the improvement of infrastructure, and the enforcement of regulations. The study furthermore proposes potential areas for future investigation, including examining social and economic ramifications, technical advancements, and utilizing sophisticated theoretical frameworks such as fuzzy set theory and neutrosophic set extensions. These paths of inquiry aim to enhance recycling procedures and foster the adoption of sustainable practices.

Keywords: Barriers, E-waste, Recycling, DEMATEL analysis.

1 Introduction

The issue of e-waste has become a prominent environmental issue worldwide, mostly due to the fast progress of technology and the concurrent rise in the disposal of electronic equipment. The effective management and recycling of electronic waste (e-waste) have become crucial to address and minimize its potential environmental and health hazards. Similar issues are also encountered in Seremban, Malaysia's geographical and cultural setting. As an expanding metropolitan hub, Seremban encounters distinctive challenges in efficiently managing the recycling of electronic waste generated by households, requiring a targeted and all-encompassing strategy.

This study explores the complex network of barriers that impede the effective implementation of e-waste recycling initiatives. This research seeks to use the DEMATEL

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analysis, a robust tool for comprehending intricate interactions among variables, to reveal the interdependencies of barriers and provide valuable insights into viable remedies.

The central focus of this inquiry is on the acknowledgment that the process of e-waste recycling encompasses a variety of complex difficulties that go beyond just technical aspects. A combination of behavioural, cultural, and logistical variables influences the recycling behaviours among users in Seremban. Through the implementation of a comprehensive examination, our objective is to discern the primary barriers that impact users' determinations of the disposal and recycling of electronic waste.

The importance of this research is emphasized by the pressing need to tackle local e-waste concerns. The results contribute greatly to the existing literature on e-waste management and provide important insights for legislators, environmental groups, and local communities. This research analyses the intricate relationships between various barriers to provide a comprehensive guide for making well-informed decisions and implementing focused interventions. The goal is to cultivate a culture of responsible e-waste recycling among users in Seremban, Malaysia.

The following sections will thoroughly examine the barriers influencing e-waste recycling practices in Seremban. By thoroughly examining and interpreting the DEMATEL outcomes, our objective is to provide insights into the fundamental dynamics at play. This will allow us to propose viable methods to effectively address the identified barriers. By meticulously examining this complex fabric, our objective is to provide a foundation for sustainable and ethical e-waste recycling methodologies that foster an environmentally friendly and improved future for Seremban and its surrounding areas.

In Malaysia, several influential efforts have been implemented to address the problem of e-waste. The government-led National E-waste Management Campaign aims to enhance public awareness about the proper disposal of e-waste utilizing organizing seminars and events. The MyKasih Foundation collaborates with national institutions and local communities to collect and repurpose electronic waste. Samsung, a prominent player in the electronics industry, actively encourages recycling via its Recycling Program. Similarly, the Malaysian Communications and Multimedia Commission (MCMC) promotes responsible disposal practices with its eCycle program. EcoKnights engages in educational activities via workshops, while GreenTech Malaysia takes charge of coordinating projects related to electronic waste management. These initiatives jointly advocate for correctly managing and recycling electronic waste, therefore positively contributing to environmental cleanliness.

2 Literature Review

The disposal of electronic equipment, generally referred to as electronic waste or e-waste, has become a significant environmental issue worldwide because of the fast progression of technology and accompanying growth in electronic equipment disposal. The effective handling and recycling of e-waste have become essential to address and minimize the possible environmental and health risks that arise from inadequate disposal practices [1]–[7]. Within the distinct geographical and cultural milieu of Seremban, Malaysia, comparable barriers to managing waste are experienced. As Seremban

undergoes urbanization and becomes a rapidly developing city, it has specific challenges in effectively managing the recycling of electronic waste created by households. This situation calls for a targeted and all-encompassing strategy to address these hurdles.

The issue of inadequate knowledge and education on the environmental impacts of inappropriate disposal of electronic waste continues to be a significant obstacle, as highlighted by [9]. Insufficient knowledge about e-waste management is a contributing factor to the difficulty, resulting in a lack of comprehension among users regarding the need of adopting responsible recycling procedures [10].

The presence of negative beliefs and attitudes about e-waste recycling acts as a deterrent for people, impeding their engagement in recycling endeavours [11], [12]. The unfavourable views towards a certain phenomenon are influenced by users' perceptions of annoyance and the absence of personal advantages.

Insufficient infrastructure and limited collection facility availability provide significant challenges to effectively recycling electronic waste [13]. The lack of conveniently located collection stations hampers users' inclination to engage in recycling activities, hence impeding their capacity to appropriately dispose of electronic waste [14].

The dearth of robust e-waste rules and efficient enforcement mechanisms diminishes the imperative of recycling [15], [16]. According to Johansson [17], individuals may not give priority to recycling activities if they perceive a dearth of legal consequences for inappropriate waste disposal.

The lack of robust economic incentives for recycling electronic waste contributes to the difficulty of ensuring proper disposal [4], [18]. If recycling does not provide substantial financial incentives, individuals may choose other disposal techniques that are more convenient [19].

The phenomenon of rapid technical improvements and the resulting obsolescence of electronic equipment has been shown to incentivize consumers to choose device replacement rather than recycling [20], [21]. The obstacle is further exacerbated by the prevalent practice of regularly upgrading electronic devices, resulting in a substantial flow of electronic waste [22]. Cultural and societal factors notably influence behaviours related to the disposal of electronic waste [11], [23]. The extent to which individuals conform to cultural norms and are influenced by social factors may influence their inclination to engage in e-waste recycling, either favourably or unfavourably [24], [25].

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique has emerged as a powerful analytical methodology for comprehending complicated linkages inside complex systems. In environmental research, the use of DEMATEL methodology proves to be beneficial in the identification and analysis of causal relationships and interdependencies among various factors [26]–[30]. The DEMATEL methodology, which has its roots in graph theory and matrix algebra, enables the conversion of qualitative data into quantitative findings. This approach has valuable implications for decision-making and the development of policies. Despite the constraints of relying on expert judgments and the possible subjectivity involved, the methodical approach of DEMATEL in visualizing cause-and-effect links shows great potential in tackling complex situations. The examination of the hurdles to home e-waste recycling in Seremban is facilitated using DEMATEL analysis, which serves as a helpful instrument in comprehending the intricate network of hindrances and directing focused approaches toward adopting responsible recycling practices.

3 Methodology

A well-structured and methodical process is important for effectively tackling the issues associated with home e-waste recycling in Seremban, Malaysia. This section presents a systematic methodology used to examine and evaluate the complex network of barriers impeding the successful implementation of e-waste recycling methods. The Decision-Making Trial and Evaluation Laboratory (DEMATEL) analytical approach has been selected due to its capacity to elucidate intricate interactions among variables and provide important insights into the interdependencies of barriers. The reseacrh methodology is shown in Fig. 1.

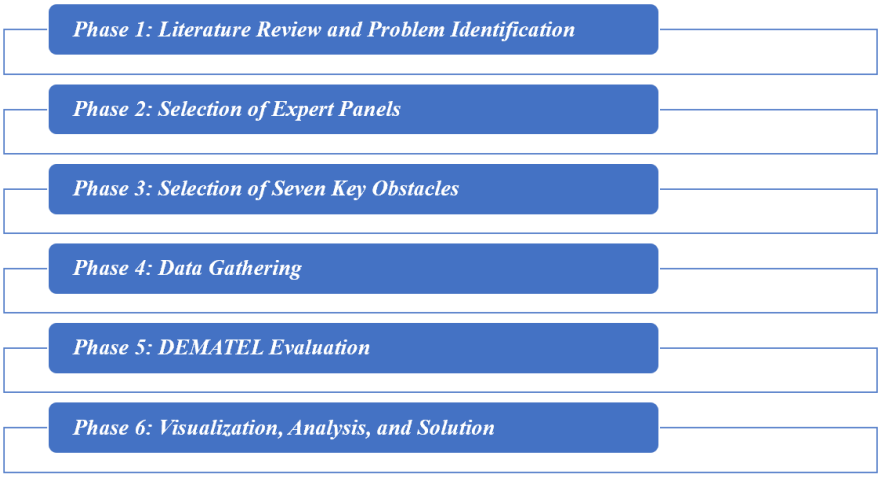

Fig 1. Research methodology.

Phase 1: Literature Review and Problem Identification
In this initial phase, a thorough literature review is conducted to thoroughly comprehend the extant research on e-waste recycling barriers and the application of DEMATEL analysis. This study aims to identify the most significant barriers to household e-waste recycling in Seremban, Malaysia. Through an analysis of previous studies, reports, and scholastic articles, this study seeks to identify the spectrum of barriers that impede effective e-waste recycling practices in the region. This phase is the basis for delineating the research problem and establishing the study's objectives.

Phase 2: Selection of Expert Panels
Before beginning data collection, a council of experts is meticulously chosen to ensure a diverse and well-informed perspective. The panel comprises distinguished individuals from diverse disciplines, including academia, waste management expertise, and representation from local households. The academic experts contribute theoretical knowledge and research insights, whereas the non-government waste expert offers practical knowledge of waste management policies. The household representatives' local knowledge and practical experiences are indispensable for identifying real-world

problems. This phase emphasizes the significance of multidisciplinary expertise in comprehensively addressing the complexities of e-waste recycling.

Phase 3: Selection of Seven Key Barriers

Based on the insights and deliberations of the expert council, this phase entails the meticulous selection of seven important barriers from the pool of identified barriers. The selected barriers are those regarded to have the greatest impact on the recycling of domestic e-waste in Seremban. An expert evaluation uses a Likert scale extending from 1 (very insignificant) to 7 (extremely essential). Each panel member evaluates the significance of the chosen barriers based on his or her expertise and insights. This phase ensures that the expert perspectives are systematically incorporated into the analysis, resulting in a qualitative evaluation of the significance of the barriers in the local context.

Phase 4: Data Gathering

The pairwise comparison method employing a scale ranging from 1 (very unrelated) to 7 (very related) depicts the complex interrelationships between these barriers. This exhaustive approach to data collection guarantees the incorporation of expert insights and the interrelation complexities of the selected barriers.

Phase 5: DEMATEL Evaluation

With expert opinions and relational data, the study conducts a DEMATEL analysis. A causal relationship matrix is constructed reflecting the direct and indirect influences between the selected barriers. The study quantifies the intensity of the relationships by calculating impact and dependence values, highlighting the most influential and dependent barriers. This phase illuminates the intricate network of relationships. It identifies causal loops and clusters, casting light on the complex dynamics that contribute to the e-waste recycling challenges faced by households.

The application of DEMATEL analysis involves a sequence of steps:

Step 1: Construction of a direct relationship matrix, denoted by x_{ij}^{k}, in which each element represents an expert-assigned integer score k, constitutes the initial phase. The metric, as defined by Equation (1), provides a quantitative measure of the effect of criterion *i* on criterion *j* within a *n x n* matrix. *L* represents the number of specialists. The disputed expression can be revised as follows:

$$a_{jj} = \frac{1}{L}\sum_{k=1}^{L} x_{ij}^{k} \tag{1}$$

Step 2: In the second stage, the matrices representing direct influence are normalized using equations (2) and (3).

$$S = k \cdot A \tag{2}$$

$$k = \min\left(\frac{1}{\max_{1\le i\le n}\sum_{j=1}^{n}\left[a_{ij}\right]}, \frac{1}{\max_{1\le j\le n}\sum_{i=1}^{n}\left[a_{ij}\right]}\right) i, j \in (1,2,...,n) \tag{3}$$

Step 3: The subsequent stage entails the creation of a comprehensive relations matrix. The computation of the total-relation matrix W utilizes formula (4), wherein the Identity Matrix *I* is applied following the normalization of the direct-relation matrix *M*.

$$M = S\left(I - S\right)^{-1} \tag{4}$$

Step 4: Equations (5) to (7) demonstrate the practical application of the *R*+*C* and *R*–*C* principles in the context of matrix *M*. In this context, the symbol R represents the summation of columns, while the symbol *C* represents the summation of rows. Criteria with positive *R*-*C* values have a more substantial influence on the remaining criteria. The word "dispatchers" is often used to refer to these personnel. Individuals with lower levels of *R*–*C* exhibit increased susceptibility to environmental effects. The entities are often denoted as recipients. On the other hand, the aggregation of variables *R* and *C* symbolizes the extent of correlation between a solitary criterion and the other variables.

$$M = \left[m_{ij} \right]_{n \times n} \quad i, j \in (1, 2, ..., n) \tag{5}$$

$$R_i = \sum_{j=1}^{n} \left[m_{ij} \right]_{n \times 1} = \left[m_i \right]_{n \times 1} \tag{6}$$

$$C_i = \sum_{i=1}^{n} \left[m_{ij} \right]_{1 \times n} = \left[m_j \right]_{1 \times n} \tag{7}$$

Step 5: Acquire the matrix representing internal dependencies and the diagram illustrating effect linkages. The dataset is mapped using the values of the sum of R and C, as well as the difference between *R* and *C*. The metric usually known as the threshold value is used to signify the degree of dependency present within a certain set of criteria.

Phase 6: Visualization and Analysis

The DEMATEL results are represented via graphs illustrating the relationships and concentrations between the selected barriers. Interpreting these results is essential, as it provides insight into the interconnected nature of the problems and identifies key factors that perpetuate them. For each of the selected barriers, targeted solutions and recommendations are proposed based on the DEMATEL analysis. This final phase synthesizes expert insights, relational complexities, and analysis results into actionable strategies designed to address identified challenges and promote effective household e-waste recycling practices in Seremban, Malaysia.

4 Result and Discussion

This section presents the outcomes derived from the DEMATEL analysis. This part concisely shows the quantitative results of the causal links between the identified barriers to e-waste recycling. The research conducted using a matrix-based approach provides valuable insights into the interconnectedness of various barriers, hence shedding light on their mutual effect. This part provides a succinct but instructive overview of the main results obtained from the study, serving as a foundation for a comprehensive

examination of the consequences and possible remedies for these barriers. Table 1 presents the barriers that have been chosen by experts and used for conducting a DEMATEL analysis.

Table 1. The selected barriers.

Barriers	Brief Description
B1= Lack of Awareness	People may not be aware of the environmental and health risks associated with improperly disposing of e-waste.
B2 = Limited Access to Collection Points	Inadequate availability of convenient e-waste collection centers can discourage recycling efforts.
B3 = Data Security Concerns	Concerns about personal data security can deter individuals from recycling devices containing sensitive information.
B4 = High Cost of Recycling	The intricate processes involved in e-waste recycling can be expensive, deterring participation.
B5 = Inadequate Infrastructure	Insufficient recycling facilities and technology for handling e-waste can hinder effective recycling practices.
B6 = Lack of Regulatory Enforcement	Weak enforcement of e-waste recycling regulations undermines compliance and proper disposal.
B7 = Mixed Materials Complexity	E-waste items often consist of various materials that need intricate separation for recycling, making the process challenging and less appealing.

Table 2 presents an analysis of the causal relationship between barriers and their corresponding effects on e-waste recycling.

Table 2. The cause and effect of barriers.

Barriers	R+C	R-C	Rank	Cause/Effect
B1	5.4500	1.0269	1	cause
B2	4.4454	-0.6684	6	effect
B3	4.4941	-0.5832	5	effect
B4	4.7604	-0.2167	4	effect
B5	5.3959	0.3971	2	cause
B6	5.1789	0.5719	3	cause
B7	4.1424	-0.5275	7	effect

The research conducted in this study has yielded significant insights into the barriers that hinder the efficient management of electronic waste recycling. Every barrier found has been measured and classified according to its combined impact (R+C) and the discrepancy between the combined impact and the individual impact (R-C). Furthermore, the hurdles to e-waste recycling have been systematically assessed and categorized into several groups based on their nature as either causal factors or consequential outcomes.

The primary barrier identified as the most important reason is "Lack of Awareness" (B1), which is at the forefront. This highlights the significant importance of understanding in effectively tackling the issues associated with e-waste recycling. The inadequate comprehension of the environmental and health hazards linked to incorrect disposal considerably impedes recycling efforts. On the other hand, the barriers of "Limited Access to Collection Points" (B2), "Data Security Concerns" (B3), and the "High Cost of Recycling" (B4) are presented as consequences, suggesting that these barriers arise from various characteristics inherent in the recycling environment. The diminished excitement for recycling is influenced by several factors, including the limited availability of easily accessible collection locations, apprehensions over the protection of personal data, and the perceived high costs associated with recycling procedures.

Moreover, the key factors contributing to hurdles in e-waste recycling are recognized as "Inadequate Infrastructure" (B5) and "Lack of Regulatory Enforcement" (B6). The lack of adequate recycling infrastructure and ineffective enforcement of recycling policies are significant contributing factors that impede the implementation of efficient e-waste management strategies. The impact barrier known as "Mixed Materials Complexity" (B7) is acknowledged as a significant factor, underscoring the difficulties presented by the complicated composition of electronic waste products. The complex nature of the separation procedures involved in recycling mixed materials might potentially act as a deterrent for people when it comes to recycling their electronic equipment. Table 3 displays the comprehensive impact of each barrier on e-waste recycling in the Seremban region.

Table 3. Total Influence.

	B1	B2	B3	B4	B5	B6	B7
B1	0	1	1	1	1	1	1
B2	0	0	0	0	0	0	0
B3	0	0	0	0	0	0	0
B4	0	1	1	0	1	0	0
B5	1	1	1	1	0	1	1
B6	1	1	1	1	1	0	1
B7	0	0	0	0	0	0	0

The matrix presented provides a complete depiction of the causal connections among various barriers encountered in the process of e-waste recycling. The visual representation functions as a tool for analysing the interplay between various barriers in the intricate domain of electronic waste management. Within the present matrix, the numerical value "1" is used to denote a link in which the barrier situated in the row functions as the causal factor, hence influencing the barrier located in the column as the resultant consequence. On the contrary, a value of "0" indicates the lack of a causal connection between the variables.

The central focus of these connections is around the concept of "Lack of Awareness" (B1), which has been recognized as a significant contributing element. This element has a wide-ranging impact on many other barriers, such as "Limited Access to Collec-

tion Points" (B2), "Data Security Concerns" (B3), "High Cost of Recycling" (B4), "Inadequate Infrastructure" (B5), "Lack of Regulatory Enforcement" (B6), and "Mixed Materials Complexity" (B7). The significance of the "Lack of Awareness" as a causal factor emphasizes the interdependence of these barriers, illustrating how a deficiency in knowledge of the environmental and health hazards associated with e-waste may impact several aspects of the recycling system.

The issue of the high cost associated with recycling (B4) is identified as a contributing factor that affects limited access to collection points (B2), inadequate infrastructure (B5), and the complexity of handling mixed materials (B7). The challenges in creating easily accessible collection stations, investing in sufficient recycling infrastructure, and managing the complexity of mixed materials are compounded by the financial subtleties connected with e-waste recycling.

Furthermore, the criteria of "Inadequate Infrastructure" (B5) and "Lack of Regulatory Enforcement" (B6) are significant contributors to other barriers. The inadequate presence of appropriate recycling infrastructure and the limited implementation of rigorous regulatory measures have a significant impact on several aspects of the issues associated with e-waste recycling. The network relationship map is shown in Figure 2.

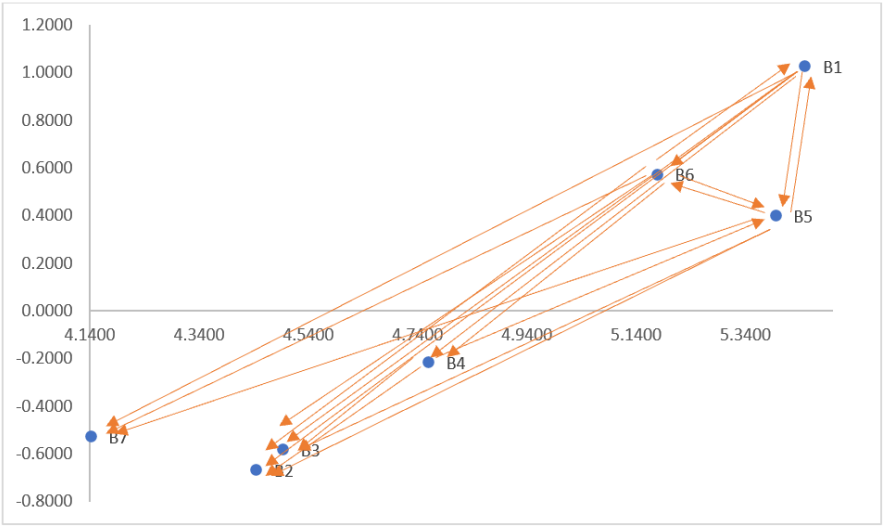

Fig. 2. Network relationship map.

It is essential to address the causal variables indicated in the matrix to facilitate the promotion of efficient e-waste recycling methods. The obstacle of "Lack of Awareness" (B1) presents itself as a noteworthy impediment that may be alleviated by the implementation of well-crafted educational efforts. Smith et al. (2019) propose the implementation of collaborative efforts between educational institutions, media outlets, and community groups to initiate comprehensive awareness campaigns. These campaigns aim to effectively communicate information on the environmental and health hazards linked to the incorrect disposal of electronic waste.

To address the issue of the "High Cost of Recycling" (B4), the implementation of subsidies and incentives might potentially have a significant impact. Governments and pertinent stakeholders can enforce monetary incentives for people, corporations, and recycling facilities that actively participate in e-waste recycling endeavours. According to the United Nations Environment Programme, the provision of subsidies may effectively mitigate the economic challenges connected with recycling procedures, therefore enhancing the feasibility of recycling as a financially sustainable choice.

The problem of "Inadequate Infrastructure" (B5) may be effectively mitigated by implementing strategic investments in recycling facilities. The creation or upgrading of recycling facilities capable of properly handling e-waste may be achieved via collaborative endeavours between governments and the private sector. The enhancement of recycling infrastructure via the allocation of resources may lead to improved efficiency and effectiveness in the recycling process.

One potential approach to addressing the difficulty identified as "Lack of Regulatory Enforcement" (B6) involves enhancing regulatory measures. Governments can pursue the implementation and enforcement of more stringent legislation about the management of electronic waste, which may include the imposition of fines for non-adherence. According to Baldé et al. (2017), the implementation of strong regulatory frameworks, together with effective monitoring and reporting procedures, may play a crucial role in ensuring adherence to appropriate disposal techniques and maintaining consistency in recycling efforts.

5 Conclusion

In conclusion, the examination of the causal connections between several barriers to e-waste recycling has provided insights into the intricate dynamics that impede the efficient management of electronic waste. The matrix-based methodology has identified many prominent causal variables, including "Insufficient Awareness," "Elevated Recycling Expenses," "Inadequate Infrastructure," and "Limited Regulatory Compliance." These issues together have a substantial influence in obstructing the implementation of sustainable e-waste recycling procedures. Through a comprehensive comprehension of these interconnections, stakeholders are endowed with enhanced capabilities to formulate precise strategies aimed at surmounting these barriers and cultivating a more conscientious attitude toward the disposal of electronic waste.

Based on the identified causal variables, several solutions may be proposed to effectively overcome the barriers and facilitate the promotion of efficient e-waste recycling. Comprehensive awareness campaigns implement educational initiatives at both local and global scales to enhance public knowledge of the detrimental environmental and health consequences linked to inadequate disposal practices of electronic waste. Engage in partnerships with educational institutions, media outlets, and community groups to facilitate the broad distribution of knowledge.

It is recommended that governmental bodies and relevant industry players contemplate the implementation of financial incentives and subsidies to foster participation in e-waste recycling among people, corporations, and recycling facilities. These incentives have the potential to mitigate the financial burdens associated with recycling procedures. The proposal entails fostering collaboration to build or improve recycling fa-

cilities that are adequately prepared to efficiently manage electronic waste. The collaboration between governmental entities and commercial enterprises has the potential to combine their resources to provide recycling infrastructure that is both technologically sophisticated and accessible. This infrastructure would be designed to effectively manage the increasing quantity of electronic waste.

The prioritization of regulatory strengthening is crucial for governments to enhance e-waste management. To guarantee strict adherence to recycling processes, it is essential to implement and enforce rigorous rules accompanied by penalties for non-compliance. The promotion of cross-sector cooperation entails the cultivation of cooperative efforts among governmental entities, industrial stakeholders, non-governmental organizations, and academic institutions, to formulate comprehensive solutions. The effective resolution of difficulties related to e-waste recycling necessitates a collaborative effort including several industries.

As a potential avenue for further investigation, an examination of the social and economic ramifications associated with the implementation of the proposed remedies might provide significant insights. Furthermore, an examination of the impact of technology and innovation on the improvement of e-waste recycling procedures may result in the advancement of more effective recycling methodologies. Moreover, doing a comparison analysis including several locations and nations may provide valuable insights into the efficacy of distinct tactics under varied contextual frameworks. Finally, the incorporation of theoretical frameworks such as extensions of fuzzy set theory [31], [32] and neutrosophic set extensions has the potential to augment comprehension of intricate interconnections within the domain of e-waste recycling. This integration may play a significant role in the advancement of more refined and sophisticated approaches to problem-solving.

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