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Unified Green E-Waste Management Framework for Sustainable Campus Development: Case Study of Malaysian Public Universities

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ABSTRACT

Electronic waste (e-waste) has become the fastest-growing waste stream globally, presenting complex environmental and regulatory challenges that are particularly evident in higher education institutions. In Malaysia, public universities are significant contributors to e-waste generation due to their extensive reliance on information and communication technologies, laboratory equipment, and administrative devices. Although regulatory frameworks, such as the Environmental Quality (Scheduled Wastes) Regulations 2005, exist, current practices in universities remain fragmented, focusing largely on asset disposal under Ministry of Finance guidelines and neglecting gaps in behavioral, infrastructural, and policy integration. This study introduces the Unified Green E-waste Management Framework (UGEMF), a holistic model specifically designed for Malaysian public universities. The framework was developed through qualitative methods, including document analysis, in-depth interviews with key stakeholders, and a review of institutional practices, regulatory documents, and best-practice case studies. The findings highlight barriers, including limited awareness, bureaucratic constraints, and the absence of institutionalized policies, while also identifying emerging best practices, such as refurbishment initiatives, decentralized collection points, and cross-sector collaborations. By operationalizing circular economy principles within the higher education context, UGEMF contributes theoretically to sustainability and waste management literature, while offering practical guidance for policymakers and administrators. Its adoption can transform e-waste management in Malaysian public universities from fragmented compliance processes into comprehensive, integrated sustainability strategies. This approach supports national green growth targets and sustainable campus development.

HIGHLIGHTS

This study highlights a Unified Green E-waste Management Framework (UGEMF) that integrates four core components: stakeholder engagement, green strategies, policy and regulatory alignment, and monitoring and evaluation. Anchored in circular economy principles, it emphasizes prevention, reuse, repair, and refurbishment alongside responsible disposal. Furthermore, the framework incorporates behavioral change initiatives, green procurement practices, and data-driven monitoring to build a transparent, accountable, and sustainable system at public universities in Malaysia.

1. INTRODUCTION

Electronic waste (e-waste) is the fastest-growing solid waste stream globally. The Global E-waste Monitor 2024 reports that 62 million tonnes were generated in 2022, an 82% increase since 2010, with projections exceeding 82 million tonnes by 2030 if current trends persist (ITU and UNITAR, 2024). This rapid growth, driven by shorter product lifecycles and continuous technological innovation, is not matched by formal recycling, which remains at only 22.3%. Consistent with the global rise, Malaysia's e-waste stream is also substantial. Recent reports estimate that approximately 280,000 tonnes of e-waste are generated nationally, equivalent to roughly 8.8 kilograms per person. In 2023, documented collection reached 65,280 tonnes, with 13,760 tonnes recovered, resulting in a recovery rate of about 21.1% (The Edge Malaysia, 2024). As a result, large volumes of e-waste

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are unmanaged or processed informally, posing risks to resource recovery and environmental sustainability.

Unmanaged e-waste releases hazardous substances such as lead and mercury, thereby contaminating ecosystems and threatening biodiversity (Mlelwa and Rother, 2024; Okeke et al., 2024). Valuable materials such as gold and copper are lost outside formal recycling systems, undermining circular economy efforts. The WHO (2021) warns that informal recycling also endangers human health, especially among vulnerable groups (Andeobu et al., 2023). These concerns have prompted the global expansion of e-waste regulations, with extended producer responsibility (EPR) emerging as a central strategy (Ramasubramanian et al., 2023; Grandhi et al., 2024). Countries such as Japan, South Korea, and EU members have implemented mandatory EPR schemes involving take-back obligations, eco-design standards, and recycling targets (Noranarttakun and Pharino, 2021), which have significantly improved recovery rates and reduced hazardous components.

In Malaysia, e-waste management is governed by the Environmental Quality Act 1974 and the Environmental Quality (Scheduled Wastes) Regulations 2005, which classify e-waste as SW110 and require documentation, secure storage, and disposal through licensed facilities (DOE, 2005; DOE, 2022). While these regulation ensures traceability and compliance with the Basel Convention (DOE, 2021), these regulations focus primarily on downstream control. Recent initiatives such as Government Green Procurement (GGP) and the MyHIJAU eco-label encourage the purchase of certified green and durable products (MGTC, 2018), while the Circular Economy Policy Framework emphasizes the gradual adoption of mandatory EPR schemes in Malaysia (MITI, 2024). These developments create opportunities for universities to strengthen e-waste governance and sustainability strategies (KPMG Malaysia, 2023).

Higher education institutions (HEIs) consume large volumes of electronic equipment and are expected to demonstrate sustainability leadership (Molina-Motos et al., 2023). The UI GreenMetric includes waste, hazardous waste, and recycling indicators (UI GreenMetric, 2024), motivating universities to adopt sustainability initiatives. However, global evidence shows that campus e-waste management remains fragmented, with institutions focusing more on energy and water conservation while overlooking e-waste despite its toxicity and resource recovery potential (Oliveira and Proença, 2025; Dawodu et al., 2022). Many efforts, such as refurbishment programs and awareness campaigns, remain ad hoc and lack policy-level integration (Dayaday and Galleto, 2022).

Recent Malaysian studies reveal similar issues. Hashim et al. (2025) highlight bureaucratic hurdles and limited centralized guidance for public universities. Student surveys indicate inconsistent awareness and disposal practices (Yaacob et al., 2025; Yee et al., 2024; Barcelo et al., 2024). Although promising practices exist, such as refurbishment for student use, decentralized collection points, and partnerships with certified recyclers, these initiatives remain fragmented and lack a unified strategy.

E-waste is also recognized globally as hazardous waste due to toxic components such as lead, mercury, cadmium, and brominated flame retardants, which pose significant risks to human health and the environment if improperly managed. (WHO, 2021; WHO, 2024; Mlelwa and Rother, 2024). In Malaysia, e-waste is formally classified as Scheduled Waste SW110 under the Environmental Quality (Scheduled Wastes) Regulations 2005, requiring strict handling, storage, and disposal procedures (DOE, 2005; DOE, 2022). This hazardous classification underscores the urgency for universities to adopt structured and legally compliant e-waste management approaches.

The circular economy (CE) framework provides a powerful conceptual lens for rethinking e-waste management in universities. By emphasizing prevention, reuse, refurbishment, repair, and recycling, CE framework shifts the focus from linear disposal models to systems that maximize resource efficiency (Korhonen et al., 2018; Stankevičienė et al., 2020). In higher education, this involves embedding principles of circularity into procurement, IT asset management, and end-of-life practices, while fostering awareness among students and staff (Rodríguez-Guerreiro et al., 2024). Universities, as living laboratories, are uniquely positioned to demonstrate circular practices while integrating them into teaching and research (Sugiarto et al., 2022; Giurea et al., 2024).

Digital technologies such as IoT sensors, RFID tagging, and blockchain tracking can enhance transparency in waste systems by improving inventory control, ensuring secure data wiping, and providing auditable chains of custody (Ahmed et al., 2024; Borges et al., 2024). However, technological solutions alone are insufficient. Effective governance, policy alignment, and community engagement remain critical

for achieving durable impacts (Ermayendri et al., 2025; Molina-Motos et al., 2023).

Additional insights can be drawn from community-based e-waste bank models in Indonesia, where decentralized collection points, transparent valuation mechanisms, and formal partnerships with recyclers encourage participation (Rimantho et al., 2022). Such principles can be adapted to university settings.

The Unified Green E-waste Management Framework (UGEMF) integrates governance, infrastructure, and engagement to address fragmented campus practices. It promotes regulatory alignment, efficient collection and processing systems, and behavioral change through participation. UGEMF has also informed broader municipal and industrial applications (Andeobu et al., 2023; Barcelo et al., 2024), demonstrating its adaptability. Compared to other frameworks, such as the Circular Campus Framework (Sugiarto et al., 2022), the Sustainable Campus Framework (Oliveira and Proença, 2025), and extended producer responsibility or EPR-based models (Noranarttakun and Pharino, 2021), UGEMF provides an integrated, context-specific approach suited to Malaysian HEIs.

This paper proposes UGEMF, developed through qualitative research involving document analysis and stakeholder interviews. Its contributions are threefold: advancing circular economy scholarship in Malaysian higher education, offering practical pathways for universities to shift from compliance-based disposal to integrated sustainability strategies, and supporting national aspirations for circular economy and sustainable development.

Despite existing regulations and emerging initiatives, Malaysian public universities still lack a unified and systematic approach to e-waste management. Therefore, this study addresses the problem of fragmented governance, inconsistent practices, and limited engagement by proposing UGEMF as a structured solution for Malaysian HEIs.

2. METHODOLOGY

2.1 Research design

This study employed a qualitative research design to develop the Unified Green E-waste Management Framework (UGEMF) for Malaysian public universities. Qualitative inquiry was considered appropriate because the objective was not to quantify e-waste generation or statistically measure behavioral patterns statistically, but rather to explore processes, institutional practices, and stakeholder perceptions that underpin e-waste management. As Creswell and Poth (2018) argue, qualitative methods are particularly useful when the goal is to understand complex social phenomena and to generate models or frameworks grounded in stakeholder experiences.

The study followed an exploratory multiple-case study approach, with several Malaysian public universities serving as embedded units of analysis. This approach enabled the researcher to examine similarities and differences across institutions, thereby identifying both common barriers and context-specific unique practices in e-waste management. Such a design is aligned with Yin's (2018) proposition that multiple case studies provide stronger theoretical grounding by permitting cross-case comparisons and replication logic.

In terms of research setting and context, Malaysia currently hosts more than 20 public universities, all of which play a significant role in advancing the country's sustainability agenda. These institutions are major consumers of electronic devices due to their dependence on information and communication technologies (ICT), laboratory equipment, and digital services. At the same time, public universities are subject to national regulations such as the Environmental Quality (Scheduled Wastes) Regulations 2005 (SW110) and Government Green Procurement (GGP) guidelines. However, past studies suggest that universities often face difficulties in translating these national frameworks into coherent institutional strategies (Hashim et al., 2025; Yaacob et al., 2025). This study, therefore, situates its exploration within public universities as both significant e-waste generators and critical agents of change for sustainable campus development.

A purposive sampling strategy was adopted to identify participants who possessed direct knowledge of and responsibility for e-waste management. Stakeholders included university administrators responsible for asset management, procurement, and sustainability policies; IT department staff managing the lifecycle of ICT equipment; and facilities and estate managers overseeing campus waste management practices. In total, six respondents participated in the study, one from each university. Table 1 presents their institutional background and positions. This selection ensured that findings were not overly context-specific but captured a broad range of operational realities in Malaysian higher education.

Table 1. Interview participants

Respondent	Region	Position	Unit/Department
R1	North	Director	Dept. of Development and Asset Management
R2	North	Administrative Assistant	IT Department
R3	Central	Head of Operation and Service Section	Occupational Safety and Health Management Office
R4	Central	Director	Department of Development and Infrastructure
R5	Central	Evaluation Officer	Department of Development and Estate Maintenance
R6	South	Deputy Director	Campus Sustainability Office

2.2 Data collection methods and analysis

Policy documents, procurement guidelines, e-waste management reports, and sustainability strategies were systematically collected and reviewed. These included internal university policies and standard operating procedures (SOPs) as well as national-level instruments (e.g., the DOE's Scheduled Wastes Regulations, the Government Green Procurement/MyHIJAU programme, and the Circular Economy Policy Framework) that shape e-waste governance in public universities. Document analysis served to map the existing institutional and regulatory frameworks shaping e-waste practices. It also provided triangulation to validate data obtained through interviews (Bowen, 2009). In addition, the semi-structured interviews were conducted with key informants across the six universities. An interview protocol was designed to cover themes such as institutional policies on e-waste management, challenges and barriers encountered in practice, existing practices of reuse, refurbishment, and recycling, awareness and training initiatives targeting students and staff, and partnerships with recyclers, government agencies, and suppliers. Each interview lasted between 45-90 minutes and was conducted in either English or Malay, depending on the participant's preference. All interviews were audio-recorded with consent and later transcribed verbatim for analysis.

Data were then analysed following a thematic analysis approach as outlined by Braun and Clarke (2021). This involved six stages: familiarization with the data through repeated reading of transcripts and documents, initial coding of meaningful units relevant to the research questions, searching for themes by grouping codes into broader categories, reviewing themes to ensure coherence and distinction, defining and naming themes to align them with conceptual elements of e-waste management, and producing the report by linking themes to theoretical and policy frameworks. NVivo 12 software was employed to manage and organize data, enabling systematic coding and retrieval of excerpts. To enhance validity, peer debriefing was conducted with two qualitative research experts who reviewed a subset of codes to ensure coding consistency. Discrepancies were discussed and reconciled through consensus, thus improving analytical reliability.

The thematic analysis produced four major thematic categories, namely stakeholder engagement, green strategies, policy and regulatory alignment, and monitoring and evaluation, which became the foundation of the proposed UGEMF. Figure 1 summarizes the research design process, starting with document analysis, followed by semi-structured interviews across six universities, and concluding with thematic analysis. It highlights the triangulation of methods, the purposive sampling of key stakeholders, and the iterative process of coding and theme development that led to the formulation of UGEMF.

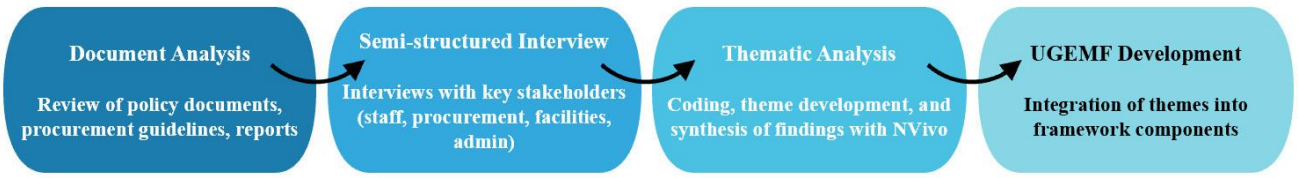


Figure 1. Research design of the study

2.3 Trustworthiness of the study and ethical considerations

To ensure rigor, the study adhered to Lincoln and Guba's (1985) criteria for trustworthiness. Credibility was achieved through data triangulation (documents and interviews) and member checking, where preliminary findings were shared with selected participants for validation. Transferability was supported through a thick description of institutional contexts, allowing readers to assess applicability to other HEIs. Dependability was ensured by maintaining a detailed audit trail documenting research decisions, coding procedures, and analytic steps. Confirmability was reinforced through reflexivity, with the researcher maintaining a reflective journal to bracket personal assumptions. Moreover, ethical approval was obtained from the relevant university research ethics committee prior to data collection. Participation was voluntary, with informed consent obtained from all interviewees. Anonymity and confidentiality were assured, and sensitive data were handled in accordance with research ethics guidelines. Data were stored securely with restricted access to ensure participant privacy.

2.4 Methodological limitations

As with most qualitative studies, several limitations apply. First, the reliance on interviews introduces the possibility of subjectivity bias, as responses may reflect personal interpretations or institutional sensitivities. Second, the small number of respondents, which is appropriate for an exploratory case study design, limits the generalizability to all Malaysian HEIs. However, the purpose was depth rather than breadth, and the multiple-case approach enhanced analytical richness. Finally, while triangulation and peer checking were employed, interpretation remains influenced by the researcher's perspective despite the use of reflexive measures.

3. RESULTS

3.1 Development of the unified green e-waste management framework (UGEMF)

The findings of this study led to the development of the Unified Green E-waste Management Framework (UGEMF). The findings were analyzed comparatively across the six universities, highlighting both similarities and variations in e-waste management practices that informed the formulation of the UGEMF. This framework brings together people, policies, and practices to improve the management of electronic waste within Malaysian public universities. It is designed to move universities away from fragmented, disposal-based approaches and toward a more sustainable, circular system. The framework is illustrated in Figure 2: the Unified Green E-waste Management Framework, which shows the four main components: stakeholder engagement, green strategies, policy and regulatory alignment, and monitoring and evaluation. Together, these components ensure that e-waste is not only disposed of safely but also prevented, reused, refurbished, and tracked in a way that benefits the environment, the institution, and the wider community.

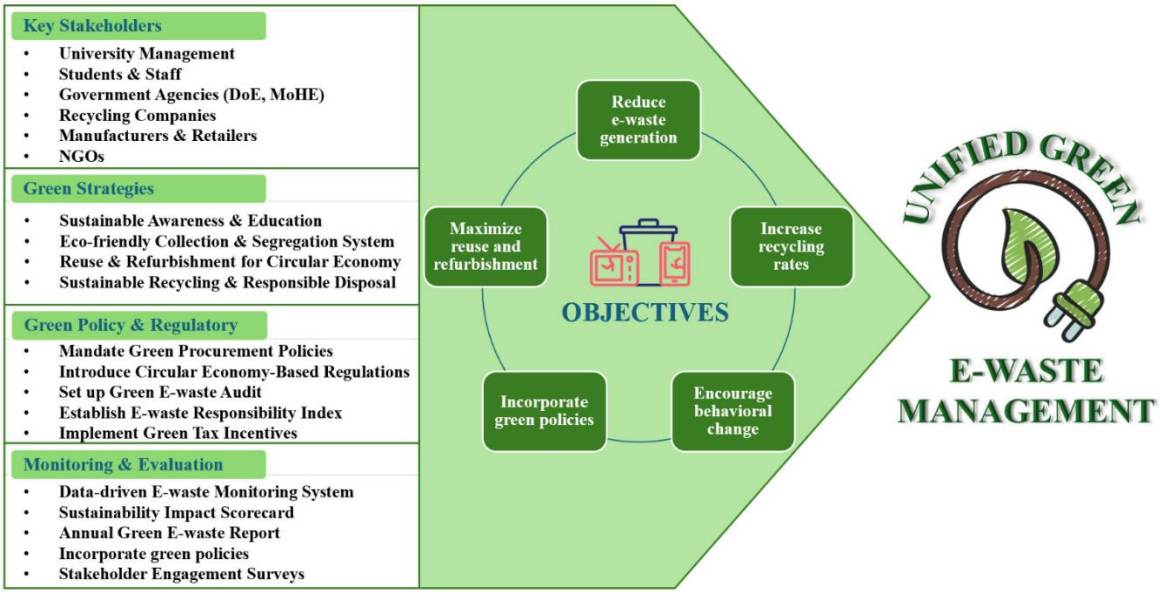


Figure 2. The Unified Green E-waste Management Framework

UGEMF functions as a holistic model to strengthen e-waste management across universities by embedding sustainability at every stage of the electronic device lifecycle. Details of the four main components are as follows:

3.1.1 Stakeholder engagement

The first component of the UGEMF stresses that e-waste management cannot be successful without the involvement of multiple stakeholders. Stakeholder engagement emerged as the central foundation of effective e-waste governance. The analysis showed that responsibilities were frequently distributed across multiple departments, including IT services, procurement, facilities management, and sustainability units, without formal mechanisms for coordination. As a result, universities often experienced inconsistent data sanitization processes, duplicated storage arrangements, delayed disposal, and limited participation from students and staff.

UGEMF addresses these issues through a clearly defined governance structure, as illustrated in Table 2, which outlines the roles of various stakeholders, ranging from university leadership to external recyclers. The framework positions university management as the strategic decision-makers responsible for policy approval and resource allocation. Technical units such as IT and facilities management serve as operational coordinators by managing asset tracking, data sanitization, and storage compliance. Students and staff play a complementary role by supporting awareness activities and participating in collection initiatives. External recyclers, manufacturers, and government agencies operate as compliance and recovery partners, providing certified treatment services and ensuring alignment with national policies. This shared responsibility ensures that e-waste management is not just a technical exercise but a collective effort.

Table 2. Key stakeholders and their responsibilities in UGEMF

Stakeholder group	Core responsibilities
University Top Management	Strategic leadership, policy approval, resource allocation
IT Department	Data sanitization, asset tracking, device cascading
Procurement Unit	Green procurement clauses, after-sales/take-back agreements
Facilities/Asset Management	Storage, scheduled waste compliance, recycler coordination
Students and Staff	Participation in collection campaigns and reuse initiatives
External Recyclers	Licensed treatment, reporting, recovery documentation
Government Agencies	Regulatory oversight, compliance support

3.1.2 Green strategies

The second component focuses on adopting strategies that reduce the amount of e-waste and make better use of what already existing resources. Findings from the study showed that universities often emphasize disposal, with little effort devoted into prevention or reuse. UGEMF offers a different approach by encouraging actions across the entire lifecycle of electronic devices.

Before devices are purchased, universities can apply green procurement policies that require suppliers to provide equipment that is durable, repairable, and supported by after-sales services such as maintenance and take-back programs. This reduces the chances of devices becoming waste too quickly. During the use phase, UGEMF encourages refurbishment and reuse. For example, when computers are no longer suitable for high-performance tasks such as those in research labs, they can be reassigned to administrative offices or student labs where performance demands are lower. Slightly outdated devices can be refurbished and upgraded rather than discarded.

UGEMF also supports the establishment of campus-wide segregation and collection efforts. These include the placement of colour-coded or category-specific collection points to ensure that ICT devices, batteries, lamps, laboratory electronics, and other equipment are separated correctly before processing. This ensures that materials are easier to recycle and prevents hazardous components from mixing with general waste. Although the qualitative methodology did not produce precise numerical data, several interviewees shared indicative trends, such as low student awareness, which was often reflected in estimated participation rates of between 20 and 40 percent during collection programs, and increasing annual volumes of ICT disposals, which ranged from

800 to 1,500 units in larger institutions. These examples do not represent the formal collection of quantitative data but serve to illustrate the scale of the challenges faced and the importance of structured interventions.

3.1.3 Policy and regulatory alignment

The third component links university practices with national laws and internal policies. Malaysia already has regulations such as the Environmental Quality (Scheduled Wastes) Regulations 2005 (SW110), which classify e-waste as a scheduled waste that must be handled with care. However, the findings revealed that many universities treat these requirements as largely administrative rather than operational.

UGEMF bridges this gap by embedding policy into routine processes. Universities can develop their own e-waste policy that sets out responsibilities, procedures, and compliance requirements. Procurement rules can be updated to include green clauses, such as requiring vendors to handle end-of-life equipment responsibly. Regular e-waste audits can identify weak areas and ensure that reporting requirements are met. Incentives such as tax benefits or recognition schemes can encourage departments to follow the rules more closely. By aligning campus practices with both national regulations and university-level policies, UGEMF reduces the risk of non-compliance and builds a stronger culture of accountability. This alignment also supports national goals for the circular economy and sustainability, making universities role models for other institutions.

3.1.4 Monitoring and evaluation

The fourth component focuses on tracking progress and learning from experience. One of the main problems identified in the study was the lack of reliable data on how much e-waste is generated, reused, or recycled by universities. Without such data, it is difficult to plan or improve management practices.

UGEMF introduces a structured monitoring and evaluation system. Universities can use tracking tools to record the number and type of devices collected, refurbished, or recycled. Dashboards and sustainability scorecards make this information visible to administrators and the wider campus community. Annual reports can summarize achievements, highlight areas for improvement, and set new targets for the following year. Surveys can also be used to measure awareness and satisfaction among staff and students. Regular monitoring helps universities identify problems early. For example, if one faculty shows very low collection rates, additional awareness campaigns or collection points can be introduced. Over time, the data also allows universities to demonstrate their contribution to environmental goals, both at the institutional and national levels.

Together, these four interrelated functions; engagement, strategies, policy alignment, and monitoring, form a comprehensive system that transforms e-waste management from a reactive task into a proactive and sustainable practice. Through the UGEMF, universities are positioned not only as compliant institutions but also as leaders in sustainable campus development, offering a replicable model that can inspire similar transitions across the higher education sector.

3.2 Comparative positioning of UGEMF with prior e-waste frameworks

Although UGEMF is newly introduced in the context of Malaysian public universities, its principles resonate with global best practices and prior frameworks applied in both academic and non-academic contexts. For instance, Cristi (2024) assessed the e-waste management framework at the University of Leeds, emphasizing policy-practice alignment, stakeholder roles, and performance monitoring, which are elements that mirror the functions of UGEMF. Similarly, Hashim et al. (2025) highlighted how fragmented departmental responsibilities in Malaysian universities hinder systematic e-waste strategies, underscoring the need for unified approaches such as UGEMF.

Beyond university contexts, national and community-based initiatives demonstrate comparable strategies. Rimantho et al. (2022) introduced an electronic waste bank model in Indonesia, which integrated decentralized collection, transparent valuation, and partnerships with recyclers. This approach parallels UGEMF's emphasis on stakeholder engagement and principles of circularity. In Malaysia, Yusof et al. (2023) analyzed e-waste sustainability efforts, revealing the importance of integrating green procurement, regulatory alignment, and behavioral change, which are key elements of UGEMF. Additionally, Shad (2020) discussed sustainable e-waste management from a legal and policy perspective, highlighting governance and enforcement mechanisms that reinforce the regulatory component of UGEMF.

These studies demonstrate that while UGEMF is unique in its unified design for Malaysian public universities, its functions align with broader international and community-based practices. Integrating such lessons ensures that UGEMF is not only contextually relevant but also consistent with the evolving global standards in e-waste management.

To situate UGEMF within the broader scholarly literature, Table 3 compares UGEMF with several existing e-waste management models. The comparison shows that while previous frameworks emphasize elements such as circularity, stakeholder roles, or regulatory compliance, UGEMF uniquely combines all three within a single governance model tailored to the needs of Malaysian HEIs.

Table 3. Comparison of UGEMF with existing e-waste frameworks

Framework/study	Scope	Key features	Alignment with UGEMF
Cristi (2024), Univ. of Leeds	HEI	Policy alignment, stakeholder roles	High-mirrors governance and monitoring emphasis
Rimantho et al. (2022), Indonesia	Community	Waste bank, decentralized collection	Medium-similar on engagement, different in scale
Yusof et al. (2023), Malaysia	National	Green procurement, behavior change	High-supports green purchasing and awareness
Shad (2020)	Legal/policy	Governance, strict enforcement	High-reinforces regulatory alignment
UGEMF (This Study)	Malaysian HEIs	Unified governance, lifecycle strategies, MEL	Unique integration of all components in HEI context

In the context of Malaysian public universities, the main advantage of UGEMF is its ability to unify governance structures. It translates national regulations and circular economy goals into practical campus actions by clearly defining responsibilities, implementation steps, and reporting mechanisms. This helps overcome common problems such as weak coordination and superficial regulatory compliance. The framework also supports device reuse and refurbishment, which can reduce costs and extend product lifecycles. In addition, its monitoring, evaluation, and learning (MEL) component improves transparency and allows universities to track progress and make continuous improvements. This aligns with global recommendations that higher education institutions should report clear and consistent sustainability metrics to maintain stakeholder trust and participation.

However, the main challenges of implementing UGEMF involve the complex coordination and capacity requirements. Successful adoption requires close collaboration between units handling data sanitization, procurement, storage, and licensed recycling, and many universities may initially struggle with these cross-departmental processes. There are also liability and market issues, such as ensuring data security, finding reliable recyclers, and managing inconsistent participation across faculties. As of 31 July 2025, Malaysia's Department of Environment reported 128 licensed e-waste recovery facilities nationwide (Bernama, 2025), reflecting growing formal capacity, while public registries (eSWIS) also list licensed transporters and recovery premises for SW110. Despite this expanding infrastructure, reliance on external recyclers and market conditions may still limit reuse opportunities when vendor capacity or incentives are weak. To address these risks, universities should consider a phased implementation, clear vendor agreements that include take-back and data-wiping requirements, and transparent dashboards to keep stakeholders informed and engaged.

4. DISCUSSION

The Global E-waste Monitor 2024 indicates that e-waste generation continues to grow rapidly worldwide, with projections suggesting a significant increase if current trends persist (ITU and UNITAR, 2024). This trend emphasizes the urgent need for structured institutional responses. UGEMF contributes to this agenda by operationalizing circular economy principles through coordinated governance, targeted procurement practices, comprehensive lifecycle strategies, and systematic monitoring and evaluation. Despite these strengths, the findings also highlight critical implementation challenges that universities will need to anticipate and manage.

The first major challenge concerns the hidden and indirect costs associated with implementing UGEMF. Although the model does not require significant capital expenditure, institutions may need

to allocate additional labour for data wiping, invest in secure storage infrastructure to ensure compliance with SW110 requirements, and provide regular training for staff involved in green procurement and monitoring. The introduction of digital systems for asset tracking, such as QR codes or RFID tagging, may also require careful financial planning.

A second challenge arises from bureaucratic resistance and the siloed organizational culture that is common in many public universities. Departments may be reluctant to collaborate due to unclear jurisdictional boundaries, concerns about assuming new responsibilities, or a preference for maintaining familiar, informal practices. Strong leadership commitment, clear SOPs, and regular communication channels are therefore essential for overcoming these barriers.

A third challenge relates to the variability in recycler reliability and the influence of market conditions. Several universities reported inconsistent pickup schedules, limited refurbishment capacity, and fluctuating market prices for recovered materials, all of which may weaken incentives for reuse and discourage sustained participation in collection initiatives.

A final challenge concerns the uneven levels of awareness and participation among students and staff. Although not measured quantitatively in this study, interview themes consistently suggested that many individuals were unsure about the proper channels for disposal or were unaware of institutional initiatives. Frequent turnover among students further complicates sustained behavioural change, making ongoing awareness campaigns and MEL feedback mechanisms essential.

Overall, UGEMF offers a structured and replicable approach that links circular economy principles, regulatory requirements, and institutional practices. By translating policy directives, such as extended producer responsibility, green procurement, and scheduled waste management, into practical campus-level actions, the framework addresses long-standing coordination problems and strengthens e-waste governance across Malaysian HEIs. Its comprehensive scope positions universities as key contributors to the nation's transition toward a circular and environmentally responsible future.

5. CONCLUSION

The Unified Green E-waste Management Framework (UGEMF) provides Malaysian public universities with a comprehensive approach to transition from fragmented, disposal-focused practices to an integrated, circular model that emphasizes prevention, reuse, refurbishment, and responsible recycling. By clearly defining stakeholder roles, embedding green procurement and extended producer responsibility (EPR) principles, and introducing structured monitoring and evaluation mechanisms, UGEMF strengthens institutional accountability while aligning campus practices with national regulations.

For practical implementation, universities can adopt a gradual, phased approach. Initially, institutions can focus on establishing governance structures and clarifying responsibilities across departments. The second phase may involve integrating green procurement requirements into tenders and promoting refurbishment and cascading of devices. Subsequently, universities can implement systematic monitoring and evaluation using dashboards and periodic reporting, coupled with awareness campaigns to engage students, staff, and external partners. Priority policies include ensuring compliance with Scheduled Waste SW110 regulations, formalizing take-back schemes with certified recyclers, and embedding circular economy principles into procurement and asset management processes.

UGEMF demonstrates that sustainable e-waste management is achievable without major capital investment, relying primarily on clear governance clarity, targeted policies, and transparent reporting. By adopting the framework, universities can mitigate environmental risks, maximize resource recovery, and foster a culture of shared responsibility among campus stakeholders.

For future research, field trials of UGEMF implementation in selected universities are recommended to evaluate its operational feasibility and identify context-specific challenges. Additionally, quantitative studies could measure the framework's effectiveness in reducing e-waste, improving reuse and recycling rates, and enhancing awareness among students and staff. Future studies could also complement the present findings by analyzing cost implications, developing data-risk mitigation guidelines, and designing phased implementation roadmaps to support the practical adoption of UGEMF across universities with varying resources and

capacities. Such investigations will further validate UGEMF and support its adaptation in other higher education institutions or public organizations regionally and globally.

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AUTHOR CONTRIBUTIONS

Conceptualization, Rushanim Hashim; Methodology, Validation, and Analysis, Fadhilah Mohd Zahari and Rushanim Hashim; Writing-Original Draft Preparation, Nurul Azita Salleh; Writing-Review and Editing, Jafni Azhan Ibrahim.

DECLARATION OF CONFLICT OF INTEREST

We declare that the manuscript entitled "Unified Green E-waste Management Framework Towards Sustainable Campus Development: Case Study of Malaysian Public Universities" is an original work, not previously published or under review elsewhere. All data, analyses, and interpretations are based on valid scientific methods, with proper citations provided for external contributions. The manuscript contains no plagiarism, and all authors listed have made significant contributions to the research and writing. We accept full responsibility for any breach of publication ethics.

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