International Review of Management and Marketing

ISSN: 2146-4405

available at http: www.econjournals.com

International Review of Management and Marketing, 2026, 16(4), 102-109.

Empowering Sustainable E-Waste Recycling through Reverse Vending Machine Adoption among Generation Z in Malaysia

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Received: 23 December 2025 **Accepted:** 01 April 2026 **DOI:** https://doi.org/10.32479/irmm.23273

ABSTRACT

The accelerating generation of electronic waste (e-waste) presents substantial environmental and public health challenges, particularly in developing economies with weak household-level management systems. In Malaysia, the rapid diffusion of electronic products has increased the urgency for efficient, scalable, and user-oriented e-waste collection mechanisms. Reverse vending machines (RVMs) represent a decentralised and incentive-based technological solution, yet empirical evidence explaining their adoption for e-waste recycling remains limited. Grounded in Rogers' diffusion of innovations theory, this study examines the determinants of e-waste RVM adoption intention among Generation Z university students in Malaysia. Sustainable awareness was included as a moderating variable to evaluate the influence of environmental values on adoption behaviour. Data from 153 respondents were gathered using a quantitative cross-sectional survey and evaluated using partial least squares structural equation modelling (PLS-SEM). The results indicate that trialability significantly enhances adoption intention. In contrast, relative advantage, complexity, compatibility, and observability do not demonstrate significant direct effects. Furthermore, sustainable awareness significantly strengthens the relationship between trialability and adoption intention. This indicates that environmentally aware individuals are more inclined to translate experiential interaction into adoption behaviour. Overall, the results emphasise the significance of hands-on exposure and sustainability-oriented values in promoting technology-enabled e-waste recycling among digitally native cohorts. This study extends the Diffusion of Innovations framework by demonstrating the conditional role of sustainable awareness in the adoption process. It also provides practical implications for policymakers and practitioners to prioritise pilot initiatives, experiential engagement, and targeted sustainability communication strategies.

Keywords: Reverse Vending Machines, Electronic Waste Recycling, Diffusion of Innovations Theory, Sustainable Awareness, Generation Z
JEL Classifications: M0, M3, O3

1. INTRODUCTION

The rapid advancement of electronic technologies has significantly increased the global generation of electronic waste (e-waste). In 2022 alone, around 62 million metric tonnes of e-waste were generated globally with Asia contributing nearly half of this volume (Baldé et al., 2024). Despite this significant growth, only about 20% of e-waste is formally collected and recycled, resulting in widespread improper management and the loss of valuable secondary resources worth billions of dollars annually (Mudali et al., 2021). The consequences are profound as uncontrolled disposal practices release hazardous substances, including mercury lead to endangering public health and the integrity of the ecosystem (Kumar, 2025). These challenges are particularly pronounced in developing economies, where recycling infrastructure remains inadequate and e-waste is predominantly handled by informal sectors operating under unsafe conditions (Samantaray et al., 2026). Consequently, resource recovery remains suboptimal, undermining broader global sustainability objectives.

Malaysia mirrors these global challenges, experiencing a rapid increase in e-waste generation driven by rising consumption of electronic products. The Department of Environment Malaysia (DOE) reported that the country generated about 24.5 million units of e-waste in 2025 (Department of Environment, 2024). E-waste management in Malaysia is governed by the Environmental Quality Act 1974 and the Environmental Quality (Scheduled Wastes) Regulations 2005, under which e-waste is classified as Scheduled Waste SW110. Notably, Malaysian regulations distinguish between industrial e-waste originating from manufacturing and commercial activities and household e-waste which generated from consumer electronics. While industrial e-waste is subject to regulatory control and enforcement, household e-waste remains largely unregulated. This regulatory gap has resulted in widespread improper disposal practices, with household e-waste is often disposed of improperly endangering human health and the environment (Department of Environment, 2024).

Although the Malaysia's laws governing household e-waste in Malaysia is still evolving, this sector represents a substantial and growing share of national e-waste generation. DOE statistics indicate that 2,459 tonnes of household e-waste were gathered in 2021, with televisions, laptops, and mobile phones accounting for the largest proportion (Department of Environment (DOE), 2025). Developing effective policies and regulatory mechanisms for household e-waste management therefore requires a comprehensive understanding of the key stakeholders involved. Among these, consumers were identified by the DOE as e-waste generators. The effectiveness of the household e-waste management system depends heavily on consumers' willingness to dispose of obsolete electronics through formal channels includings authorised collectors, designated collection centres, or retailer take-back schemes.

In this context, the deployment of e-waste reverse vending machines (RVMs) represents a promising strategy to enhance household e-waste collection in Malaysia by offering accessible and incentive-based disposal options for small electronic devices and batteries (Omar et al., 2025). RVMs should be strategically installed in high-traffic public locations involving shopping malls, transportation hubs, community centres, university campuses, integrated with DOE-authorised collectors and licensed recyclers to ensure regulatory compliance under SW110 (DOE, 2024). Essential system features include secure data-wiping or physical data-destruction mechanisms, clear labelling of accepted items, tamper-proof compartments, automated sorting for different material streams, and real-time inventory and transaction reporting. These functionalities are critical for establishing transparent, traceable, and accountable collection systems that support regulatory oversight and extended producer responsibility initiatives (Faradillah et al., 2025).

To assess the potential adoption of RVMs, this study examines the acceptance of technology among Generation Z students towards e-waste reverse vending machines (RVMs) by drawing on Rogers' (2003) diffusion of innovation theory. Specifically, relative advantages, complexity, compatibility, trialability, and observability are operationalised as key determinants of adoption intention. In addition, sustainable awareness is incorporated as a moderating variable to examine the extent to which environmental consciousness influences the relationships between innovation attributes and behavioural intentions to use e-waste RVMs.

2. LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

This section reviews prior studies on reverse vending machines (RVMs) and e-waste recycling in Malaysia, followed by the diffusion of innovations (DOI) theory (Rogers, 2003). It then discusses the theoretical relationships between DOI attributes and e-waste RVM adoption, with sustainable awareness conceptualised as a moderating variable. The section concludes by outlining the theoretical foundation underpinning the proposed research framework.

2.1. Reverse Vending Machines and E-Waste Recycling in Malaysia

Reverse vending machines (RVMs) offer a decentralised and incentive-based mechanism for collecting small e-waste items, thereby improving waste segregation and traceability at the point of disposal (Baldé et al., 2024). In Malaysia, pilot RVM initiatives have been implemented primarily in Selangor and Kuala Lumpur, led by firms such as KLEAN in collaboration with partners including TM, ERTH, and KDEB. These systems enable users to deposit e-waste and receive digital rewards through platforms such as DuitNow, while AI- and IoT-enabled features facilitate automated sorting and monitoring to enhance material recovery efficiency. Despite these initiatives, public participation and awareness of formal e-waste recycling schemes in Malaysia remain limited, which continues to constrain adoption rates (Baldé et al., 2024).

2.2. Diffusion of Innovations Theory

The diffusion of innovations theory clarifies about how new technologies expanded within a social system by examining communication processes, social influence, and decision-making stages that shape adoption behaviour (Rogers, 2003). The framework has been widely applied in technology adoption research (Aransyah et al., 2025; Moraes et al., 2025) and more recent sustainability-oriented studies (Rodzi et al., 2023; Zayed and Yaseen, 2025). These studies demonstrate its effectiveness in identifying innovation attributes that accelerate or hinder diffusion through targeted interventions such as demonstrations and trial opportunities. Accordingly, this study adopts the Diffusion of Innovations theory to examine e-waste RVM adoption among Generation Z, with particular attention to experiential exposure, visibility, and value alignment.

2.3. Relative Advantage

Relative advantage implies extent to which technology is seeming as superior to existing options and is a central predictor of adoption within the diffusion of innovations framework (Rogers, 2003). In the context of reverse vending machines, perceived benefits such as convenience, reduced disposal effort, immediate incentives and environmental contribution have been shown to enhance

perceived usefulness and adoption intention (Marzuki et al., 2025; Kappagantu et al., 2025). When users recognise tangible advantages over conventional disposal methods it will automatically reduced uncertainty and the perceived net value of adoption increases (Vedavyas et al., 2025). Prior empirical evidence indicates that incentive mechanisms and user convenience significantly reinforce perceptions of relative advantage in RVM adoption (Lantoria et al., 2026). Consequently, the subsequent hypothesis is posited:

H_1: Relative advantage positively influences the adoption of e-waste reverse vending machines.

2.4. Complexity

Complexity relate to the extent which an improvement is regarded as difficult to comprehend or apply and it is theorised to impede acceptance by expanding perceived effort and uncertainty (Rogers, 2003). Studies on reverse vending machines and related recycling technologies suggest that unclear operational procedures, complex interfaces, or ambiguous reward systems reduce perceived ease of use and weaken behavioural intention (Calabrese et al., 2026). Higher perceived complexity elevates cognitive costs, discourages trial behaviour and reinforces reliance on familiar disposal practices (Nabawagga et al., 2026). Hence, complexity is expected to negatively affect adoption.

H_2: Perceived complexity negatively influences the adoption of e-waste reverse vending machines.

2.5. System Compatibility

System compatibility refers to how well an innovation corresponds with users' established values, experiences and routine practices (Rogers, 2003). Prior research indicates that compatibility with household routines, waste disposal habits, and local infrastructure enhances acceptance of recycling technologies and facilitates sustained usage (Shan et al., 2025). When RVM systems integrate seamlessly into existing waste management practices, behavioural resistance decreases and adoption likelihood increases (Fernandes, 2025). Accordingly, The subsequent hypothesis is stated:

H_3: System compatibility positively influences the adoption of e-waste reverse vending machines.

2.6. Trialability

Trialability refers to the ability to test an invention on a limited basis, enabling users to reduce uncertainty through direct experience (Rogers, 2003). Empirical studies demonstrate that pilot deployments, demonstrations, and temporary installations of reverse vending machines enhance perceived ease of use and user confidence (Agwu et al., 2024). By facilitating experiential learning and reducing perceived risk, trialability accelerates progression through the innovation decision process and supports habit formation (Jiang et al., 2024). Thus, the following hypothesis is proposed:

H_4: Trialability positively influences the adoption of e-waste reverse vending machines.

2.7. Observability

Observability relates to the degree to which the outcomes and advantages of an innovation are visible to others, thereby supporting social learning and legitimising adoption (Rogers, 2003). In reverse vending systems, visible indicators includings collection volumes, publicised incentives, and peer participation enhance perceived credibility and stimulate adoption through normative influence (Moore and Benbasat, 1991; Moraes et al., 2025). Enhanced observability reduces uncertainty and facilitates diffusion within social networks (Calabrese et al., 2026). Accordingly, the following hypothesis is proposed:

H_5: Observability positively influences the adoption of e-waste reverse vending machines.

2.8. Sustainable Awareness as a Moderating Variable

Sustainable awareness encompassing environmental knowledge and pro-environmental values that able to increases the likelihood of adopting recycling technologies by strengthening perceived moral and functional benefits (Abonomi, 2026). In vending-based collection systems, individuals with higher sustainable awareness are more receptive to incentive mechanisms and less deterred by operational barriers (Hasbullah et al., 2025; Liu et al., 2026). Sustainable awareness also amplifies the effects of trialability and observability as environmentally conscious users are more likely to translate hands-on experience and visible outcomes into sustained behavioural intention (Rustam et al., 2020). Prior studies further suggest that awareness-raising initiatives indirectly promote adoption by reinforcing perceived value and supportive social norms (Abonomi, 2026; Liu and Cao, 2024). Consequently, sustainable awareness is conceptualised as a moderating variable that strengthens the relationships between DOI attributes and RVM adoption.

H_{1a}: Sustainable awareness positively moderates the relationship between relative advantage and e-waste RVM adoption.

H_{2a}: Sustainable awareness positively moderates the relationship between complexity and e-waste RVM adoption.

H_{3a}: Sustainable awareness positively moderates the relationship between system compatibility and e-waste RVM adoption.

H_{4a}: Sustainable awareness positively moderates the relationship between trialability and e-waste RVM adoption.

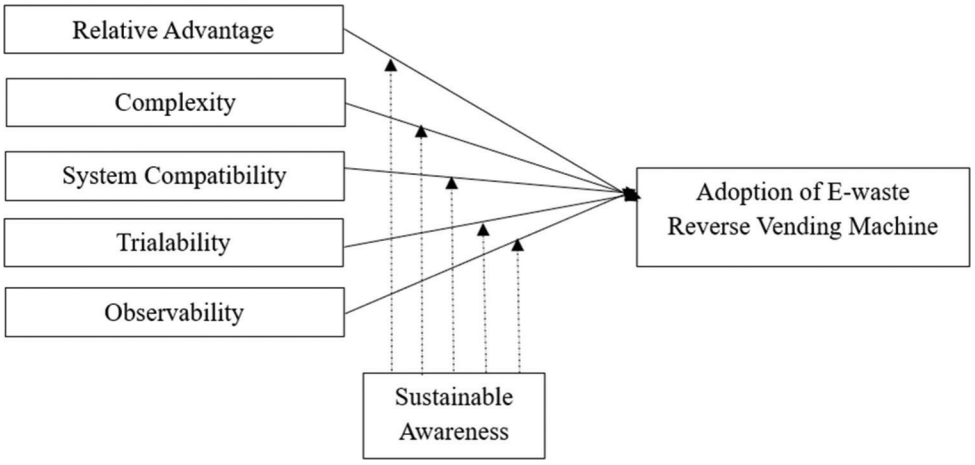
H_{5a}: Sustainable awareness positively moderates the relationship between observability and e-waste RVM adoption.

Figure 1 presents the proposed research framework grounded in the diffusion of innovations theory (Rogers, 2003). The model highlights the roles of relative advantage, complexity, compatibility, trialability, and observability in shaping e-waste reverse vending machine adoption, while extending the framework by incorporating sustainable awareness as a moderating construct.

3. RESEARCH METHODOLOGY

This study devoted a quantitative with purposive sampling to recruit Generation Z university students, coming from individuals who born between 1997 and 2008. Generation Z was selected due to their digital nativeness, high familiarity with smart and mobile technologies (Tjiptono et al., 2020). At the same time, this generation relatively have a stronger environmental awareness and pro-sustainability orientations compared to earlier cohorts (Vetrivel et al., 2024). As full-time university students, they frequently interact with campus environments and public spaces where technology-enabled recycling solutions, such as e-waste reverse vending machines (RVMs), are increasingly deployed.

Figure 1: Conceptual framework of this study



A structured questionnaire was developed using validated measurement scales grounded in the diffusion of innovations (DOI) theory (Rogers, 2003) and sustainable awareness constructs (Hassan et al., 2010). Data collection was conducted between September 2025 and November 2025, yielding 153 usable responses. Sample adequacy was established through an a priori power analysis using G*Power ($f^2 = 0.15$, $\alpha = 0.05$, power = 0.95, seven predictors), which indicated a minimum required sample size of 153 respondents. Data were analysed using partial least squares structural equation modelling (PLS-SEM), given its suitability for prediction-oriented research, complex model estimation, and small-to-medium sample sizes (Hair et al., 2019).

The questionnaire encompassed three sections. Section A included five items measuring adoption of e-waste reverse vending machines, adapted from prior studies. Section B consisted of thirty items assessing Diffusion of Innovations attributes and sustainable awareness constructs, adapted from established scales. Section C captured respondents' demographic characteristics, incorporating gender, age, ethnicity, and education level.

4. RESULT OF DATA ANALYSIS

4.1. Demographic Profile

Table 1 exhibits the demographic characteristics of the 153 Generation Z respondents. Female participants constituted the majority of the sample (99; 64.7%), while males accounted for 54 respondents (35.3%). In terms of age, the largest proportion of respondents fell within the 22-25 age group (62; 40.5%), followed by those aged 18-21 (57; 37.3%) and 26-29 (34; 22.2%).

With respect to ethnicity, Malay respondents formed the largest group (86; 56.2%), followed by Chinese (24; 15.7%), Indian (23; 15.0%), and other ethnic groups (20; 13.1%). Regarding educational attainment, most respondents held a bachelor's degree (83; 54.3%), while 60 respondents (39.2%) possessed a diploma. A smaller proportion reported postgraduate qualifications, including master's degrees (6; 3.9%) and doctoral degrees (4; 2.6%). Overall, the sample reflects a predominantly female, university-educated Generation Z cohort concentrated in the early adult age range.

Table 1: Demographic profile of the respondents

Details	Demographic variable	Frequency	Percentage
Gender	Male	54	35.3
	Female	99	64.7
Age	18-21	57	37.25
	22-25	62	40.5
	26-29	34	22.25
Ethnicity	Malay	86	56.2
	Chinese	24	15.69
	India	23	15.03
	Others	20	13.08
Education level	Diploma	60	39.22
	Bachelor's degree	83	54.25
	Master's degree	6	3.92
	PhD	4	2.61
	Others	0	

4.2. Fitness of the Measurement Model

The measurement model provides a critical foundation in quantitative research, particularly within structural equation modelling (SEM), by specifying the relationships between latent constructs and observed indicators. A well-specified measurement model enhances construct clarity and strengthens the credibility of empirical results (Sarstedt et al., 2021). Model evaluation was conducted using standard criteria incorporating factor loadings, composite reliability (CR), average variance extracted (AVE) and Cronbach's Alpha (CA).

Factor loadings assess the degree to which each indicator represents its underlying construct is evaluated. Higher loadings indicate stronger indicator-construct relationships, with values above 0.70 commonly regarded as acceptable (Hair et al., 2017). Several indicators, namely RA1, RA3, CO3, SC3, OBS3, and MA2, exhibited loadings below the recommended threshold and were therefore excluded to improve measurement quality.

Meanwhile, AVE evaluates the proportion of variance captured by a construct relative to variance due to measurement error. The values 0.50 or higher indicate adequate convergent validity, signifying that a construct accounts for more than half of the variation in its indicators (Fornell and Larcker, 1981). Following

item refinement, the AVE for Relative Advantage increased from 0.481 to 0.774, while the AVE for reverse vending machine adoption rose from 0.454 to 0.553, demonstrating improved convergent validity.

Besides, composite reliability evaluates internal consistency while accounting for differing indicator loadings. Values exceeding 0.70 indicate satisfactory reliability (Hair et al., 2019). All constructs fulfill the criterion while showing Complexity recording a CR value of 0.924, reflecting strong reliability.

Cronbach's Alpha was used as an additional indicator of internal consistency which values exceeding 0.70 considered acceptable (Hair et al., 2018). The removal of low-loading indicators improved reliability estimates, as evidenced by an increase in Cronbach's Alpha for relative advantage from 0.613 to 0.854 and for reverse vending machine adoption from 0.681 to 0.729.

Overall, the results portrayed on Table 2, confirm that the measurement model indicates adequate reliability and convergent validity, supporting its suitability for subsequent structural model analysis.

4.3. Fornell-Larcker Criterion

The Fornell-Larcker criterion was used to evaluate discriminant validity among the latent constructs in the structural equation model. Discriminant validity is demonstrated when the square root of a construct's Average Variance Extracted (AVE) surpasses its correlations with other constructs, indicating empirical distinctiveness (Fornell and Larcker, 1981). Compatibility has strong discriminant validity, with a square root of AVE of 0.857, exceeding correlations with Observability (0.708) and reverse vending machine adoption (0.749). In a similar vein, relative advantage also found to meets the requirement with a square root of AVE of 0.880, which exceeds inter-construct correlations. Across all constructs on Table 3, the square roots of AVE values surpass the corresponding correlation coefficients indicating satisfactory discriminant validity.

4.4. Heterotrait-Monotrait Ratio (HTMT)

The heterotrait-monotrait ratio (HTMT) was implemented to evaluate discriminant validity among latent constructs. All HTMT values are displayed below the required threshold of 1.00, demonstrating appropriate construct distinctiveness and the absence of multicollinearity concerns. These results provide additional support for the discriminant validity of the measurement

Table 2: Measurement model analysis

Construct	Items	Factor loadings before items deleted	Items deleted	Factor loadings after items deleted	AVE	CR	CA
Relative advantage	RA1	−0.074	RA1		0.481 (AVE before the removal of item) 0.774	0.911	0.613 (AVE before the removal of item) 0.854
	RA2	0.867	RA3	0.864			
	RA3	0.322					
	RA4	0.894		0.901			
	RA5	0.863		0.874			
Complexity	CO1	0.804		0.814	0.734	0.916	0.876
	CO2	0.939	CO3	0.943			
	CO3	0.363					
	CO4	0.757		0.750			
	CO5	0.902		0.906			
System compatibility	SC1	0.862		0.860	0.753	0.924	0.891
	SC2	0.876	SC3	0.879			
	SC3	0.212					
	SC4	0.841		0.839			
	SC5	0.890		0.893			
Trialability	TRI1	0.783		0.790	0.636	0.897	0.856
	TRI2	0.755		0.792			
	TRI3	0.827		0.751			
	TRI4	0.749		0.744			
	TRI5	0.868		0.800			
Observability	OBS1	0.787		0.797	0.697	0.911	0.854
	OBS2	0.919	OBS3	0.922			
	OBS3	0.303					
	OBS4	0.723		0.715			
	OBS5	0.883		0.888			
Sustainable awareness	SA1	0.790		0.790	0.602	0.883	0.835
	SA2	0.792		0.792			
	SA3	0.752		0.751			
	SA4	0.743		0.744			
	SA5	0.801		0.800			
Reverse vending machine adoption	MA1	0.814		0.821	0.454 (AVE before the removal of item) 0.553	0.831	0.681 (AVE before the removal of item) 0.729
	MA2	0.281	MA2				
	MA3	0.729		0.733			
	MA4	0.651		0.643			
	MA5	0.756		0.765			

Table 3: Fornell-Larcker result

Variables	CO	OBS	MA	RA	SA	SC	TRI
CO	0.857						
OBS	0.708	0.835					
MA	0.708	0.749	0.743				
RA	0.701	0.663	0.700	0.880			
SA	0.655	0.630	0.660	0.874	0.776		
SC	0.632	0.621	0.650	0.802	0.723	0.868	
TRI	0.620	0.610	0.643	0.821	0.700	0.765	0798

Table 4: Structural model assessment

H	Effect	B (Original)	Standard error	t-value	P-value	Result
H_1	RA>MA	0.234	0.414	0.565	0.572	Rejected
H_2	CO>MA	0.076	0.570	0.133	0.904	Rejected
H_3	SC>MA	0.441	0.412	1.071	0.285	Rejected
H_4	TRI>MA	0.998	0.359	2.779	0.006	Accepted
H_5	OBS>MA	0.534	0.394	1.357	0.175	Rejected
H_{1a}	RA>SA>MA	0.111	0.086	1.287	0.199	Rejected
H_{2a}	CO>SA>MA	0.121	0.142	0.853	0.394	Rejected
H_{3a}	SC>SA>MA	0.112	0.095	1.175	0.241	Rejected
H_{4a}	TRI>SA>MA	0.182	0.082	2.210	0.028	Accepted
H_{5a}	OBS>SA>MA	0.148	0.103	1.445	0.149	Rejected

model and confirm that the constructs represent conceptually distinct phenomena. Consequently, the structural relationships can be interpreted with greater confidence.

4.5. Fitness of the Structural Model

The structural model results presented in Table 4 indicate that hypotheses H_4 and H_{4a} are supported. H_4 demonstrates a significant direct effect, with the path coefficient indicating that trialability positively influences reverse vending machine adoption. H_{4a}, testing the moderating role of sustainable awareness, is also significant (P = 0.042), suggesting that Sustainable Awareness strengthens the relationship between Trialability and adoption. In contrast, H_1, H_2, and H_3 are not supported, with P-values indicating non-significant direct effects (H_1: P = 0.588; H_2: P = 0.125; H_3: P = 0.904). These findings indicate that while several direct relationships are not significant, both the direct effect of Trialability and its interaction with Sustainable Awareness are key drivers of reverse vending machine adoption.

5. CONCLUSION

The structural model analysis provides insights into the determinants of e-waste reverse vending machine adoption. Of the ten hypothesized relationships, only two were supported indicating that relative advantage, complexity, system compatibility, and observability do not exert significant direct effects on adoption decisions. These null results align with recent studies highlighting the context-dependent and nuanced influence of these constructs.

Trialability (H_4) was supported (B = 0.998, P < 0.001), indicating that hands-on experience is crucial for increasing user trust and adoption of e-waste collection machines. Rogers (2003) defines trialability as the ability to test an idea on a limited basis (Agwu et al., 2024). When prospective users can interact with reverse vending machines, perceived usability and benefits increase while adoption risks decline (Valizadeh et al., 2025). The moderating effect of sustainable awareness (H_{4a}) was also significant (B = 0.182, P = 0.042), indicating that environmentally conscious users are more inclined to convert trial experiences into adoption behaviour. This finding is consistent with evidence linking sustainability awareness to pro-environmental technology uptake (Rustam et al., 2020).

The non-significant effect of relative advantage (H_1) indicates that perceived benefits of e-waste reverse vending machines may not be sufficiently salient to influence adoption, supporting prior research suggesting that users sometimes prioritize usability and accessibility over abstract advantages (Khatri et al., 2025). Complexity (H_2) was also unsupported, implying that perceived difficulty did not substantially deter adoption, potentially due to heterogeneous technology competencies and the mitigating effects of direct experience or social influence (Al Breiki et al., 2023). The lack of significance for system compatibility (H_3) suggests that e-waste machines can be integrated into existing recycling infrastructures with minimal adaptation (Khan et al., 2022). Observability (H_5) was not significant, likely reflecting limited machine visibility or promotion in some contexts, consistent with studies emphasizing the context-specific nature of observability effects (Dilotsotlhe, 2022).

5.1. Theoretical and Practical Contributions

This research extends the diffusion of innovations framework by integrating sustainable awareness as a contextual moderator, demonstrating that environmental cognisance conditions the influence of DOI attributes on adoption (Rogers, 2003). Focusing on Generation Z enhances understanding of adopter heterogeneity and digitally mediated diffusion pathways among younger cohorts (Tjiptono et al., 2020). Empirical evidence identifies trialability and sustainable awareness as primary determinants of adoption, whereas other DOI attributes exhibit attenuated effects in this context.

From a practical standpoint, the findings emphasise the importance of pilot trials, visible demonstrations, and targeted sustainability campaigns to stimulate adoption and repeated use (Hasbullah et al., 2023). Integration of digital incentive mechanisms with producer responsibility frameworks can further improve scalability and system compatibility (Hasbullah et al., 2025; Pongen et al., 2024)

5.2. Limitations and Avenues for Future Research

Several constraints offer avenues for further investigation. The use of purposive sampling focusing exclusively on Generation Z in Malaysia limits the findings across other age groups and regions. Future research should employ probability sampling and explore different cohorts and countries to enhance external validity.

The cross-sectional design limits causal inference among constructs. Longitudinal or experimental studies would better capture adoption trajectories, behavioural stability, and post-adoption continuance over time. Finally, while the model integrates diffusion of innovations theory and sustainable awareness, it may not fully capture the complexity of technology-enabled e-waste recycling behaviour. Future studies could include psychological, institutional, and economic factors, as well as explore additional mediating and moderating mechanisms, to generate richer theoretical and practical insights.

6. ACKNOWLEDGMENT

The author(s) would like to acknowledge the financial support provided by the Ministry of Higher Education Malaysia under the Fundamental Research Grant Scheme for Early Career Researchers KPT: FRGS-EC/1/2024/SS01/UITM/02/33.

7. FUNDING

This study was granted funding by the Ministry of Higher Education Malaysia under the Fundamental Research Grant Scheme for Early Career Researchers KPT: FRGS-EC/1/2024/SS01/UITM/02/33.

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