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SUSTAINING THE ENVIRONMENT THROUGH E-WASTE RECYCLING

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Abstract

Millions of electrical and electronic devices are thrown away annually due to items breaking or needing to be updated. These discarded electronics are referred to as e-waste. Using an online survey with a quantitative approach, this study examined the interrelationships among knowledge of hazards of e-waste, attitude towards e-waste recycling, pro-environmental intention, and e-waste recycling behaviour among households in Kelantan, Malaysia (n=300). Partial Least Squares Structural Equation Modeling (PLS-SEM) was used to examine the relationships between the variables. The findings of this study reveal a favourable relationship between knowledge of the hazards of e-waste and attitude towards e-waste recycling with pro-environmental intentions. Furthermore, an appropriate relationship was discovered between the intention to e-waste recycling behaviour. The study provides theoretical insights and practical suggestions relevant to regulators and practitioners, focusing on encouraging e-waste recycling to support environmental sustainability.

Keywords: E-waste, Recycling, Environmental, Sustainable

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INTRODUCTION

The global surge in electronic and electrical equipment (EEE) consumption has emerged as a pivotal concern due to the growing popularity of electrical and electronic equipment. This escalating usage has rapidly increased electronic waste (e-waste), posing a common challenge for developing nations worldwide. The proliferation of e-waste is outpacing general waste, with its growth rate being three times faster (Ramzan et al., 2021; Yuan et al., 2019). In 2019, the world witnessed a historic high in electronic waste (e-waste) generation, reaching 53.6 million metric tons (MMT). Forecasts indicate a substantial increase, with an expected surge to 74 MMT by 2030, almost double the amount recorded in 2014. Notably, Asia stands out as the leading contributor, annually generating 18.2 MMT of e-waste (Sabbir et al., 2023). The growing issue of electrical and electronic waste nowadays has sparked concern about the inability of recycling activities to compete with the usage of e-waste generated by regular users.

Electronic waste includes a wide range of devices such as mobile phones, laptops, televisions, dishwashers, freezers, and air conditioners. E-waste is a term that describes electrical and electronic products that are no longer working, have exceeded their useful life, or have become obsolete. It can be broken down into two main sources, either wastes generated from the industrial sector or the residential sector. According to Code SW110, First Schedule, Environmental Quality (Scheduled Wastes) Regulations 2005, electronic waste in Malaysia is categorised as being under the category of Scheduled Waste. Sofian et al. (2023) explained that the organisation in charge of managing electronic trash in the country is the Department of Environment (DOE). Thukral et al. (2023) and Sofian et al. (2023) described that components that fall under Code SW110 for electrical and electronic waste include things like mercury switches, accumulators, cathode ray tube glass, activated glass, polychlorinated biphenyl capacitors, or lead, nickel, chromium, copper, lithium, silver, manganese, or contamination with polychlorinated biphenyls. These types of waste are classified as hazardous waste.

Unutilised and unharmed devices, when appropriately maintained, typically do not have any adverse impact on human health or the environment. However, it is different for devices that are left out in the heat, in the rain, or in a humid atmosphere, as it encourages the synthesis of toxic substances. Similarly, the toxic substances on electronic devices will degrade and seep into the environment through the soil or underground water if they get thrown in a trash can or somewhere else that is not a designated landfill (Mahmod et al., 2021).

Recycling methods are among the most effective ways to manage electronic waste, providing a sustainable approach to handling and repurposing devices and minimising environmental impact. E-waste recycling involves breaking down electronic waste into small fragments through shredding to extract valuable materials. These recovered materials can then be reused in the manufacturing of new electronic appliances. The recycling program in Malaysia is still in its nascent phase, and there is a conspicuous dearth of involvement among the residents. The recycling rate in the country is significantly lower in comparison to other developed countries (Afroz et al., 2020).

Yahya et al. (2022) stressed that knowledge plays a crucial role in influencing public attitudes and promoting responsible practices to reduce electronic waste generation. By increasing awareness and understanding, we can encourage the public to actively contribute to E-waste reduction efforts. Mahat et al. (2019) stated that improving Malaysians' negative outlook on recycling e-waste is crucial to solving the country's primary e-waste problem. Shifting perspectives and fostering a more positive approach can be key to promoting responsible disposal and recycling habits among the population. Thus, appropriate e-waste disposal and recycling programs are becoming a global concern for academics, practitioners, and governments. An efficient management system for collecting, processing, and recycling e-waste is crucial.

Based on the issue raised above, this study aims to explore the relationships between knowledge of e-waste hazards (K) and attitudes towards e-waste recycling (A) in households, which influence pro-environmental intention (I). Additionally, the study investigated the relationship between pro-environmental intention (I) and e-waste recycling behaviour (B). Finally, the study aims to examine how pro-environmental intention (I) mediates the relationship between knowledge of e-waste hazards (K) and e-waste recycling behaviour (B), as well as between attitudes towards e-waste recycling (A) and e-waste recycling behaviour (B).

DEVELOPMENT OF RESEARCH FRAMEWORK AND HYPOTHESES

Figure 1 illustrates the research framework employed in this study. The following hypothesis is proposed:

H_1: Knowledge of the hazards of e-waste (K) significantly influencing pro-environmental intention (I).
H_2: Attitude towards e-waste recycling (A) significantly influencing pro-environmental intention (I).
H_3: Pro-environmental intention (I) significantly influences e-waste recycling behaviour (B).
H_4: Knowledge of the hazards of e-waste (K) has positive impacts on pro-environmental intention (I) to execute the e-waste recycling behaviour (B).
H_5: Attitude towards e-waste recycling (A) has positive impacts on pro-environmental intention (I) to execute the e-waste recycling behaviour (B).

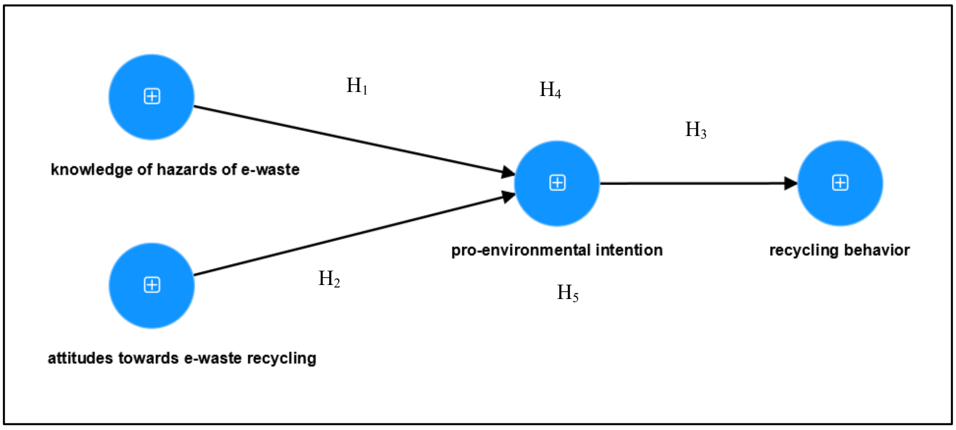

Figure 1: Research Framework

RESEARCH METHODOLOGY

This study has chosen households in Kelantan as the primary target respondents due to the significant amount of e-waste generated by households annually with a sample size of 300 participants (n=300). In this study, a questionnaire was designed to collect primary data from the intended respondents using survey research, a quantitative approach. Google Forms was used to disseminate the questionnaires online. The three measurement items of knowledge of hazards of e-waste, three measurement items of attitude towards e-waste recycling, and four measurement items of e-waste recycling behaviour were adapted from Akhtar et al. (2014). Furthermore, the three pro-environmental intentions were modified and embraced by Thoo et al.'s (2022) research. The survey employed a five-point Likert Scale, encompassing from 1 (Strongly disagree) to 5 (Strongly agree). Following the data collection phase, the obtained data underwent screening, processing, and analysis utilising the Statistical Package for the Social Sciences (SPSS) and SmartPLS software. The decision to use SmartPLS was driven by the research framework of the application, which involved modelling relationships between several components.

ANALYSIS AND DISCUSSION

Respondent's Characteristics

Table 1 presents the demographic characteristics of the 300 respondents. It covers aspects such as gender, age, education level, profession, and income distribution.

Table 1: Respondent's characteristics

Characteristics		**No. of respondents**	**%**
Gender			
	Male	150	50.0
	Female	150	50.0
Age			
	18 to 24	126	42.0
	25 to 34	75	25.0
	35 to 49	52	17.3
	50 to 64	26	8.7
	65 above	21	7.0
Education level			
	Primary school	13	4.3
	Secondary school	65	21.7
	STPM	15	5.0
	Certificate	31	10.3
	Diploma	51	17.0
	Degree	112	37.3
	Master/PhD	6	2.0
	Others	7	2.3
Profession			
	Public sector	49	16.3
	Private sector	77	25.7
	Self-employed	121	40.3
	Others	53	17.7
Income			
	Below RM1000	126	42.0
	RM1001 to RM3000	138	46
	RM3001 to RM5000	26	8.7
	RM5001 above	10	3.3

The sample has an equal gender distribution, with men and women each representing 50% (150) of the total respondents. This balance guarantees that the viewpoints of both genders are equally depicted in the survey findings. Most respondents are young adults, with 42% (126) aged 18 to 24 years and 25% (75) aged 25 to 34 years, indicating a predominantly younger population in the sample. There were 17.3% (52) respondents aged 35 to 49 years old, 8.7% (26) respondents aged 50 to 64, and 7.0% (21) respondents aged 60 and above. Next, the education level of respondents is varied, with the largest group holding a degree of 37.3% (112). A significant portion of respondents, 21.7% (65), have completed secondary school, while only a small percentage, 4.3% (13), have only primary school education. The low percentage of respondents with postgraduate education (Master/PhD) at 2.0% (6) suggests that the sample has a modest level of higher education overall. The largest group of respondents is self-employed, accounting for 40.3% (121) of the sample. This indicates a strong presence of entrepreneurship or freelance work within the population. The private sector employs 25.7% (77) of respondents, while 16.3% (49) work in the public sector. The other category, which could include students, retirees, or those not formally employed, makes up 17.7% (53) of the respondents. Lastly, income distribution shows that nearly half of the respondents, 46.0% (138), earn between RM1001 to RM3000, which could be considered a middle-income bracket. A significant 42.0% (126) of respondents have an income below RM1000, suggesting a substantial portion of the population is in the lower-income bracket. Only 8.7% (26) of respondents fall within the RM3001 to RM5000 income and a mere 3.3% (10) of respondents earn above RM500.

Assessment of the Measurement Model

The model assessment has two stages. Initial instrument validity and reliability assessments used the measurement model in accordance with Hair et al. (2019). The proposed paths were then examined using a structural model. A number of factors were used to construct the measurement model. These variables included loadings, composite reliability, and average variance extracted (AVE).

Table 2: Reflective Measurement Model Result

Latent Variable	Indicators	Outer Loadings	Composite Reliability	AVE	Cronbach Alpha
Knowledge of hazards of e-waste	C1	0.907	0.903	0.812	0.885
	C2	0.919			
	C3	0.876			
Attitude toward e-waste recycling	E1	0.937	0.907	0.832	0.898
	E2	0.949			
	E3	0.848			
Pro-environmental intention	H1	0.908	0.891	0.818	0.889
	H2	0.924			
	H3	0.881			
Recycling behaviour	J1	0.896	0.901	0.768	0.899
	J2	0.865			
	J3	0.883			
	J4	0.859			

The findings in Table 2 show that the reflective measurement paradigm demonstrates both reliability and validity. All of the loadings surpassed the threshold value of 0.7 (Hair et al., 2014), with item loadings ranging from 0.848 to 0.949. Similarly, the average variance extracted (AVE) values of the constructs surpassed the threshold of 0.50, ranging from 0.768 to 0.832. This result suggests that the items within each construct account for at least 50% of the variance in the latent constructs. The CR values also surpassed the minimum requirement of 0.70, confirming internal consistency in each construct. Convergent validity for the constructs is confirmed based on these indicators. The indicator loading is presented visually in Figure 2.

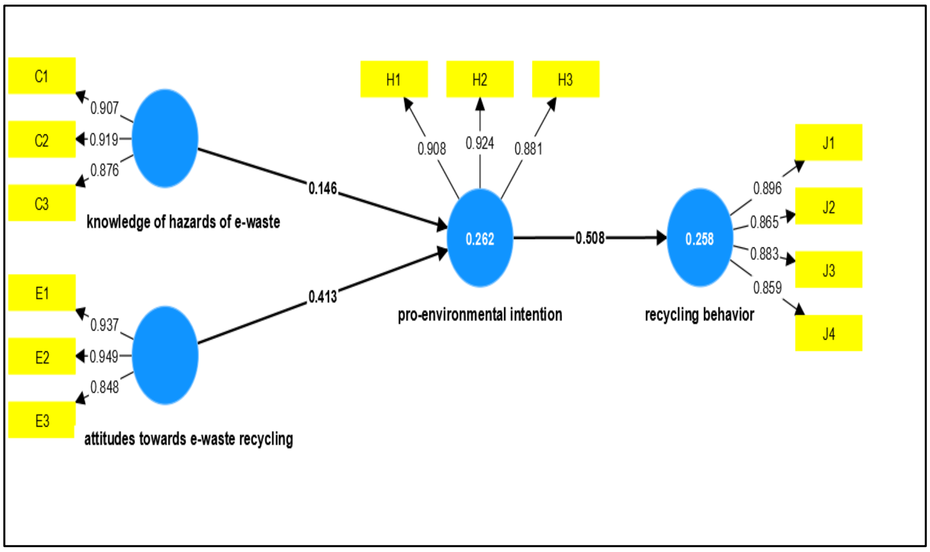

Figure 2: Measurement Model

Table 3: Heterotrait-monotrait ratio (HTMT)

	Knowledge of hazards of e-waste	Attitude toward e-waste recycling	Pro-environmental intention	Recycling behaviour
Attitude towards e-waste recycling				
Knowledge of hazards of e-waste	0.642			
Pro-environmental intention	0.555	0.429		
Recycling behaviour	0.532	0.437	0.566	

Discriminant validity was assessed through the use of the heterotrait monotrait (HTMT) criterion, as recommended by Hair et. al (2019). According to Hair et.al (2019), scores below 0.90 show that each construct is effectively measuring a unique theoretical notion. The results demonstrate that the latent variables' values are significantly lower than the threshold value, suggesting a lack of correlation between the concepts (Table 3). These validity tests indicate that the measurement items possess both validity and reliability. In general, the results of this investigation provided support for each indication in the measurement model, as depicted in Figure 2. This indicates that the measurement model exhibits appropriate levels of reliability and validity.

Assessment of the Structural Model

After establishing the validity of the measurement model, the next phase involves developing the structural model using a significant number of indicators. The evaluation of the Partial Least Squares Structural Equation Modeling (PLS-SEM) includes evaluating the coefficient of determination (R^2), estimating the path coefficient (β), measuring the effect size (f^2), and determining the prediction relevance (Q^2).

In the structural model, each assumption is represented by a pathway that connects two latent variables as the relationship between them. For the purpose of analysing the relationships between the independent factors and the dependent variables, the SmartPLS software was deployed. In order to determine the level of significance, the relationship between the variables that were defined in the framework was evaluated by analysing the value of the regression coefficient (β). A thorough evaluation of the significance of the regression coefficient β was conducted by examining the t-values that were obtained using the PLS Bootstrapping methodology. The output of the t-statistics was utilised to determine the relevance of each specific relationship. All of the suggested paths are presented in Table 3, together with their respective path coefficients, observed t-statistics, and significance levels. The hypotheses submitted were either approved or rejected based on the results received from the path evaluation, as described in the next section.

Cohen (1988) and Ismail et. al (2023) have proven that f^2 values of 0.02, 0.15, and 0.35 correspond to modest, medium, and large effects, respectively. Table 3 shows that knowledge of the hazards of e-waste toward pro-environmental intention has a small effect size of 1.9%. Meanwhile, attitude towards pro-environmental intention has a medium effect size of 15%. At the same time, pro-environmental intention toward e-waste recycling behaviour has a large effect size of 35%.

Table 3: Path Coefficients of Testing Model

Hyp		ß	f^2	T-Statistics	P-Values	Results
H_1	K -> I	0.148	0.019	2.139	0.032	**Accepted**
H_2	A -> I	0.416	0.154	6.986	0.000	**Accepted**
H_3	I -> B	0.513	0.348	9.088	0.000	**Accepted**

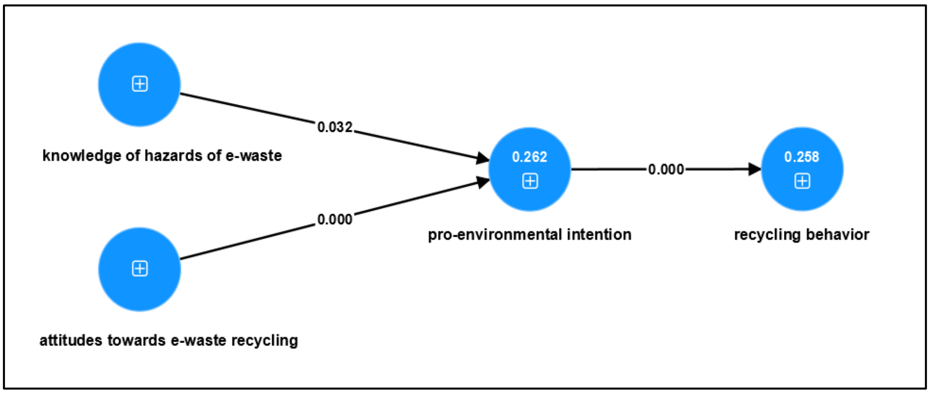

Figure 3: Structural model

A depiction of the path coefficients, observed t-statistics and significance levels of the structural model can be found in Table 3. Figure 3 above shows the structural model with the result of significance levels. If the significance of the path coefficients approaches or is above the 95% confidence level, then the path coefficients are deemed to be acceptable. Based on the findings shown in Table 3, a strong relationship was observed between knowledge related to intention (β=0.148; t=2.139; p-value=0.032). Given that the p-value is less than 0.05, the result is statistically significant, suggesting that the alternative hypothesis (H_1) is accepted. Consequently, understanding the dangers linked to e-waste might enhance consciousness regarding the significance of appropriate disposal and recycling. Increased awareness of the environmental and health hazards associated with e-waste is expected to foster a greater sense of accountability and environmental consciousness among individuals (Roslan et al., 2024; Ismail & Amin, 2020). Also, this knowledge can lead to a stronger intention to engage in pro-environmental behaviours, such as recycling electronics, reducing the purchase of unnecessary gadgets, supporting eco-friendly companies, and advocating for policies that promote sustainable e-waste management.

Secondly, the result specifically demonstrated that attitude toward e-waste recycling has significance towards pro-environmental intention (β=0.416; t=6.986; p-value=0.000). Statistically, the p-value is <0.05. Thus, H_2 was also accepted. A positive attitude towards e-waste recycling can strengthen a person's intention to act in environmentally responsible ways, such as reducing e-waste, reusing electronics, and supporting policies that promote sustainable practices. If individuals hold a positive attitude, they are more likely to be motivated to take specific actions that align with their beliefs, such as participating in recycling programs, choosing products with longer lifespans, or advocating for better e-waste management practices.

Lastly, the results show that pro-environmental intention has a significant relationship with e-waste recycling behaviour (β=0.513; t=9.088; p-value=0.000).

Therefore, H_3 was also accepted, meaning that a strong pro-environmental intention reflects a commitment to engage in behaviours like e-waste recycling. This intention acts as a driving force that motivates individuals to overcome barriers and take action.

The degree to which the independent variable influences the dependent variable is taken into consideration by the coefficient of determination (R^2). In particular, it shows how much the independent variable (or variables) may explain the dependent variable's treatment. How well the independent factors explain this number indicates the variation in the dependent variables. In the structural model of PLS analysis, Hair et al. (2014) say that R^2 values of 0.25, 0.50, and 0.75 mean that the relationship is weak, moderate, or large, in that order. Nevertheless, Hair et al. (2019) observe that the acceptable R^2 value can differ according to the research discipline. According to Cohen (1988), R^2 values of 0.26, 0.13, and 0.02 are considered to represent strong, moderate, and weak effects, respectively, in social science research.

The findings shown in Table 4 demonstrate a significant level of variability (R^2 values ranging from 0.262 to 0.258) in the pro-environmental intention and recycling behaviour construct, which may be accounted for by the suggested predictors. Table 4 indicates that the environmental attitude accounted for 28.8% of the observed variation. Table 4 shows that the understanding of the dangers of e-waste and the attitude towards recycling e-waste were able to account for 26% ($R^2 = 0.262$) of the variation in pro-environmental intention. Furthermore, the components related to pro-environmental intentions were able to account for 26% ($R^2 = 0.258$) of the variability in recycling behaviour. The R^2 score of 0.288 for pro-environmental intention and recycling activity was classified as weak due to its proximity to 0.25, suggesting a nearly weak level. Nevertheless, as said earlier, a value of R^2 more than 0.26 is a strong indicator of intention and behaviour in this particular field of social science research.

Table 4 indicates that the pro-environmental intention has a Q^2 value of 0.208, while the recycling behaviour has a Q^2 value of 0.194. All values were greater than zero, indicating that the model is adequately predictive.

Table 4: Coefficient of Determination (R^2) and Predictive Relevance (Q^2)

	R^2	Q^2
Pro-environmental intention	0.262	0.208
Recycling behaviour	0.258	0.194

A mediation effectiveness study was conducted to fully validate the proposed model. A mediator is a variable that helps explain the relationship between a predictor and an outcome. It acts as an intermediary in the causal route between the independent variable and the dependent variable.

Based on the findings of Table 5, the research affirms that pro-environmental conduct does not act as a mediator in the connection between knowledge and recycling behaviour. People are able to take independent action based on specialised information regarding electronic waste without being influenced by their overall environmental behaviours or attitudes, as this skill is available to them. Later on, it was shown that the pro-environmental intention had a role in linking attitude and recycling behaviour. Therefore, a higher level of positivity towards recycling directly correlates with a stronger inclination to recycle, which finally leads to the actual act of recycling.

Table 5: Mediation Analysis

Hyp		(ß)	SD	T-Statistics	P-Values	Results
H4	K -> I -> B	0.077	0.038	1.949	0.051	**Rejected**
H5	A -> I -> B	0.214	0.043	4.857	0.000	**Accepted**

CONCLUSION

This study highlights the crucial need to comprehend the hazards linked to e-waste and cultivate a positive attitude towards recycling e-waste. These factors significantly affect the development of environmentally friendly intentions, which in turn shape the actual recycling behaviours of households in Kelantan, Malaysia. The research confirms that both awareness and viewpoints significantly influence the propensity to engage in environmentally sensitive actions, such as recycling electronic waste. These findings offer valuable theoretical insights into the elements that impact recycling behaviour and have practical implications for policymakers and practitioners. The study suggests that by increasing public knowledge and fostering positive attitudes towards e-waste recycling, it is possible to effectively promote sustainable behaviour, thus making a substantial contribution to environmental conservation efforts. Properly disposing of electronic waste through recycling is an essential method for preserving the environment. Recycling e-waste helps protect the environment by reducing the harmful effects of toxic substances, conserving valuable resources, reducing greenhouse gas emissions, and promoting sustainable consumption. Collaboration among individuals, companies, and governments is necessary to effectively manage e-waste and prioritise environmental sustainability in light of technological advancements.

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