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Advancing Sustainability: Raising Awareness for E-Waste Management in Penang

Goh Deng Zia[1,*], Suriani Sukri[1]

[1] Business Department, Faculty of Business and Communication, University Malaysia Perlis, Perlis, Malaysia

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ABSTRACT

The rising volume of electronic and electrical waste (e-waste), driven by population growth, rapid economic development, and shorter lifespans of electronic devices, has become a pressing environmental concern. In Malaysia, particularly in the Penang community, e-waste management remains challenging despite growing global awareness. The problem lies in insufficient public participation and the lack of effective recycling practices, contributing to environmental degradation and health risks. This study aims to explore the factors influencing e-waste management awareness and sustainability practices in Penang, addressing the gap in existing knowledge regarding the role of individual and systemic factors in promoting sustainable e-waste disposal behaviours. Six key variables were examined: awareness, knowledge, attitude, government influence, moral obligation, and subjective norms. A structured questionnaire survey was used to collect data from 384 respondents in Penang. Quantitative analysis evaluated the relationship between these variables and e-waste management awareness. The results revealed that attitude, government influence, moral obligation, and subjective norms predict sustainable e-waste management practices significantly. Conversely, awareness and knowledge, integral components of the Theory of Planned Behaviour (TPB), did not demonstrate significant impacts. These results suggest that enhancing habitual recycling behaviours requires awareness campaigns and practical interventions, such as government-led initiatives and community-based cues, to drive long-term change. The study concludes by offering social and practical implications, including recommendations for refining e-waste recycling policies, fostering community participation, and promoting sustainability practices. These insights aim to guide policymakers and stakeholders in addressing the e-waste crisis effectively and sustainably.

1. Introduction

1.1 Background of Study

Electronic waste (e-waste) is one of the fastest-growing waste streams globally, with 53.6 million metric tons (Mt) generated in 2019[1]. By 2022, global e-waste will reach 62 million metric tons (Mt), with Asia contributing nearly half (24.9 Mt) [6]. Projections suggest it could rise to 74.7

* *Corresponding author.*
E-mail address: gohdengzia0925@gmail.com

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Mt by 2030 and 120 Mt by 2050. Despite this growth, only 22.3% of e-waste was recycled correctly in 2022, highlighting the urgent need for sustainable management [12].

This rapid increase is driven by technological advancements, shorter product lifespans, and growing consumption of electronic devices [4]. Alarmingly, only 20% of global e-waste undergoes proper recycling, while the remainder contributes to environmental degradation and health risks due to hazardous substances like lead, mercury, and cadmium [10].

Malaysia's government has initiated programs like the Extended Producer Responsibility (EPR) policy and the KITARecycle initiative to address e-waste management issues [16]. These efforts align with the United Nations' Sustainable Development Goals (SDGs), particularly SDG 12: Responsible Consumption and Production, which emphasizes sustainable resource management, and SDG 13: Climate Action, highlighting the need to mitigate environmental pollution from improper e-waste disposal. Additionally, SDG 3: Good Health and Well-being addresses health risks posed by hazardous materials in e-waste [17]. In Penang, an industrial and technological hub, improper e-waste disposal exacerbates environmental concerns. While programs like KITARecycle and promoting the circular economy aim to minimize Malaysia's ecological footprint, limited public awareness, weak enforcement, and low participation hinder their success [19].

1.2 Problem Statement

Despite growing public awareness of the environmental and health risks associated with e-waste, Penang's recycling rates remain insufficient. The state's challenges are structural and behavioural, as negative attitudes toward e-waste management, coupled with low moral obligation and limited adherence to social norms, exacerbate the issue [7]. The rapid growth of its electronics manufacturing sector, improper disposal practices, and limited public understanding of sustainable waste management further complicate these challenges [21]. The lack of adequate infrastructure, limited government enforcement, and insufficient public participation hinder sustainable e-waste disposal. Comparisons with countries like Japan and Singapore, where robust recycling systems and policies are in place, further highlight the gaps in Malaysia's approach to e-waste management [16]. Improper disposal of hazardous e-waste materials such as lead and mercury poses serious environmental and health risks, including soil and water contamination and long-term health impacts [11].

While the Malaysian government has introduced various initiatives, such as the Extended Producer Responsibility (EPR) program, the effectiveness of these measures in Penang remains to be determined. Individuals often lack the moral obligation to act responsibly, with some viewing e-waste disposal as someone else's responsibility, which undermines collective recycling efforts [7]. Subjective norms, such as societal pressure to participate in sustainable practices, remain weak in Penang, with limited social reinforcement to encourage proper recycling behaviors [14]. Government programs like the Department of Environment's Household E-Waste Collection initiative have yet to achieve widespread public participation, indicating the need for more effective awareness campaigns and enforcement strategies [13].

Existing studies on e-waste management in Malaysia often focus on general practices and national-level policies, with limited exploration of localized contexts, such as Penang. Furthermore, while previous research highlights the importance of attitudes and subjective norms, other behavioural-social factors, including moral obligation and systemic drivers, still need to be explored. Addressing this gap is critical to understanding Penang's unique barriers and enablers of sustainable e-waste management.

This research addresses the problem of low public engagement in e-waste recycling and explores the systemic and individual factors contributing to this issue. By identifying and analyzing these factors, the study seeks to bridge the gap between awareness and action, providing targeted recommendations to improve e-waste management in Penang.

1.3 Literature Review

1.3.1 The theory of planned behaviour (TPB)

The TPB is a psychological theory that links beliefs and behavior. It provides a robust framework for analyzing pro-environmental behaviors, positing attitudes, subjective norms, and perceived behavioral control influence decision-making [2]. Previous studies reveal that factors such as knowledge, attitudes, and government policies significantly impact recycling behaviors [16]. Comparisons with countries such as Japan and Singapore highlight the effectiveness of strict recycling regulations and community-driven initiatives in enhancing e-waste management systems. For example, Singapore's e-waste management framework integrates extended producer responsibility (EPR) schemes with public awareness campaigns, while Japan leverages advanced recycling technology and stringent enforcement measures to achieve high recycling rates [20]. These approaches underscore the importance of a well-rounded strategy combining policy, technology, and public participation. However, gaps remain in the practical translation of awareness into action, particularly in developing countries like Malaysia. Comparisons with countries such as Japan and Singapore highlight the effectiveness of strict recycling regulations and community-driven initiatives in enhancing e-waste management systems [20]. Therefore, research suggests that TPB's constructs can help explain why individuals fail to adopt sustainable behaviors despite being aware of the issues [19].

1.3.2 Research purpose

This study investigates the interplay between awareness, knowledge, attitudes, government influence, moral obligation, and subjective norms in shaping e-waste management awareness toward sustainability in Penang. Limited studies have also addressed how economic and technological barriers hinder e-waste recycling practices. For instance, high costs associated with recycling processes, inadequate incentives, and a lack of accessible recycling facilities often deters public participation. Addressing these barriers is critical to creating effective, localized solutions. Despite extensive research on e-waste management, limited studies have focused on how behavioral and social drivers, such as attitudes and subjective norms, influence sustainable e-waste disposal sustainable e-waste disposal [16,14]. Furthermore, the effectiveness of government programs like the Extended Producer Responsibility (EPR) policy remains underexplored in Penang's electronics-driven industrial context [9]. The research is significant as it addresses these gaps by examining individual behaviors and systemic factors hindering public participation in e-waste recycling. By bridging the gap between awareness and action, this study aims to provide actionable insights and recommendations for policymakers, stakeholders, and local communities to enhance e-waste management strategies that are effective, sustainable, and tailored to Penang's unique context.

2. Methodology

2.1 Research Design

A quantitative research design was employed, guided by the TPB framework, to explore the factors influencing sustainable e-waste management practices in Penang. The study analysed the relationship between six independent variables—awareness, knowledge, attitudes, government influence, moral obligation, and subjective norms—and the dependent variable, sustainability. This design was chosen to allow for statistical analysis of the relationships between variables and to quantify the significance of behavioural and systemic factors in influencing e-waste management practices.

2.2 Sampling and Data Collection

The total population of the Penang community is 1,740,405 people. The target population consisted of Penang residents aged 21 and above, selected due to their ability to purchase electronic products and higher usage of electronic devices. Using Krejcie and Morgan's [5] sampling formula, a sample size of 384 respondents was determined. A convenience sampling method was applied, and data was collected through a structured questionnaire distributed online and in person. Efforts were made to include participants from diverse age groups, educational backgrounds, socioeconomic statuses, and districts to ensure representativeness. Convenience sampling was used due to time constraints; data was collected through a structured questionnaire distributed online and in person to increase accessibility and response rates.

2.3 Instrumentation

A 5-point Likert scale ranging from "strongly disagree" to "strongly agree" was used to measure responses. The questionnaire comprised sections on demographic information, awareness, knowledge, attitudes, government influence, moral obligation, subjective norms, and sustainability. The questionnaire was pre-tested with 30 respondents to ensure clarity and reliability of the items before full-scale distribution.

2.4 Data Analysis

Data were analysed using SPSS software. Descriptive statistics summarized demographic data, while Pearson's correlation and multiple regression analyses examined relationships between variables. Reliability was assessed using Cronbach's alpha, with a threshold of 0.8 indicating satisfactory or reliable [18]. Additionally, diagnostic tests for multicollinearity and normality were performed to validate the assumptions of regression analysis. Findings were presented using tables and graphs for better interpretability.

3. Results

3.1 Demographic Profile of the Respondents

The demographics of the respondents have been examined in this section. The distributed questionnaire contains eight questions designed to collect demographic information from respondents. Table 1 presents the demographics of 384 respondents residing in Penang. The distribution of responses was almost balanced, with 187 males (48.7%) and 197 females (51.3%).

The results indicate that the predominant age group of respondents in this survey was between 21 to 30 years old, comprising 63% of the total participants. The subsequent age groups were 31 to 40 years old (10.4%), 41 to 50 years old (11.7%), 51 to 60 years old (6.8%), and over 61 years old (8.1%). The racial composition of the responses indicated that the predominant group was Chinese, at 280 (72.9%), followed by Malays at 73 (19%) and Indians at 31 (8.1%). Next, the majority of respondents had resided in Penang State for 0-5 years, with 174 (45.3%), followed by 57 (14.8%) for 6-10 years, 47 (12.2%) for 11-15 years, and 106 (27.6%) for beyond 15 years. Among the respondents, (37.8%) with 145 responses resided on Penang Island, namely Georgetown and Bayan Lepas, while the rest, 239 (62.3%), lived in Penang Mainland, including Butterworth, Kepala Batas, Bukit Mertajam, and Nibong Tebal. Furthermore, the educational background of respondents is a significant factor by Al-Khateeb et al., [3] since those with higher education levels are more inclined to react favourably to a specific stimulus. In this survey, most respondents attained Higher Education qualification (Diploma/bachelor's degree/master's degree/PhD), totaling 222 individuals (57.8%), followed by 37 responses, with 9.6% of respondents taking Primary Education (Standard 1 to 6), 72 responses with 18.8% of respondents who are taking Secondary Education (SPM), and 53 responses with 13.8% of respondents who are taking Post-Secondary Education (STPM/Matriculation).

Table 1
Distribution of the respondents by demographic (n=384)

Demographic Background		Frequency (n)	Percentage (%)
Gender	Male	187	48.7
	Female	197	51.3
Age	21-30	242	63.0
	31-40	40	10.4
	41-50	45	11.7
	51-60	26	6.8
	61 and above	31	8.1
Races	Chinese	280	72.9
	Malay	73	19.0
	India	31	8.1
How many years have you been staying in Penang State?	0-5 years	174	45.3
	6-10 years	57	14.8
	11-15 years	47	12.2
	> 15 years	106	27.6
District	North Seberang Perai (Butterworth, Kepala Batas)	72	18.8
	Central Seberang Perai (Bukit Mertajam)	89	23.2
	South Seberang Perai (Nibong Tebal)	78	20.3
	Northeast Penang Island (Georgetown)	74	19.3
	Southwest Penang Island (Bayan Lepas)	71	18.5
Education Background	Primary Education (Standard 1 to 6)	37	9.6
	Secondary Education (SPM)	72	18.8
	Post-Secondary Education (STPM/Matriculation)	53	13.8
	Higher Education (Diploma/Bahelor's Degree/ master's degree/PhD)	222	57.8
Occupation	Student	117	30.5
	Employed	206	53.6
	Unemployed	61	15.9
Have you ever heard about what is electronic waste?	Yes	299	77.9
	No	85	22.1

3.2 Reliability Analysis

Reliability analysis evaluates the internal consistency of the study's data. Cronbach's Alpha is commonly used for this purpose, measuring how closely related a set of items are. According to Leonard [8], Alpha values below 0.6 indicate poor reliability, 0.6–0.7 indicates average reliability, 0.7–0.8 indicates good reliability, and values above 0.8 indicate very high reliability. Table 2 shows all variables demonstrate statistically significant positive correlations ($p < 0.001$). Awareness (0.874) indicates that higher awareness drives sustainable practices. Knowledge (0.836) shows that better understanding encourages sustainable E-waste management. Attitude (0.891) suggests that positive attitudes motivate recycling behaviours. Government influence (0.864) highlights the role of regulations in fostering responsible E-waste management. Moral obligation (0.907) emphasizes the importance of a sense of duty in promoting sustainable actions, while subjective norm (0.892) demonstrates how social pressure supports sustainable behaviours. In summary, the findings reveal that all independent factors significantly and positively impact sustainability, underlining their critical role in promoting responsible electronic waste management.

Table 2
Cronbach's Alpha values of this research

Variables	No. of items	Cronbach's Alpha	Internal consistency
Awareness	5	0.874	Good
Knowledge	5	0.836	Good
Attitude	5	0.891	Good
Government Influence	5	0.864	Good
Moral Obligation	5	0.907	Excellent
Subjective Norm	5	0.892	Good
Sustainability	5	0.889	Good

3.3 Correlation Analysis

The study examines the relationship between six independent variables—awareness, knowledge, attitude, government influence, moral obligation, and subjective norm—and the dependent variable, sustainability. The correlation values range from 0.61 to 0.80, indicating a strong positive relationship between these variables and sustainability. Ranked by correlation strength, moral obligation has the highest correlation (0.794 or 79.4%), followed by government influence (0.778 or 77.8%), subjective norm (0.755 or 75.5%), attitude (0.753 or 75.3%), knowledge (0.708 or 70.8%), and awareness (0.682 or 68.2%) as shown in Table 4.

Table 3
The scale of Pearson's Correlation Coefficient

Size of Correlation	Interpretation
$0.8 < r < 1.0$	Very high correlation
$0.6 < r < 0.79$	High correlation
$0.4 < r < 0.59$	Moderate correlation
$0.2 < r < 0.39$	Low correlation
$0 < r < 0.19$	Very low correlation

Table 4
Inter-correlation between variables p <.01

		Awareness	Knowledge	Attitude	Government Influence	Moral Obligation	Subjective Norm	Sustainability
Awareness	Pearson Correlation	1	.778**	.755**	.685**	.714**	.600**	.682**
	Sig. (1-tailed)		<.001	<.001	<.001	<.001	<.001	<.001
Knowledge	Pearson Correlation	.778**	1	.761**	.743**	.710**	.705**	.708**
	Sig. (1-tailed)	<.001		<.001	<.001	<.001	<.001	<.001
Attitude	Pearson Correlation	.755**	.761**	1	. 703**	.819**	.677**	.753**
	Sig. (1-tailed)	<.001	<.001		<.001	<.001	<.001	<.001
Government Influence	Pearson Correlation	.685**	.743**	.703**	1	. 737**	. 705**	. 778**
	Sig. (1-tailed)	<.001	<.001	<.001		<.001	<.001	<.001
Moral Obligation	Pearson Correlation	.714**	.710**	.819**	. 737**	1	. 646**	. 794**
	Sig. (1-tailed)	<.001	<.001	<.001	<.001		<.001	<.001
Subjective Norm	Pearson Correlation	.600**	.705**	.677**	. 705**	. 646**	1	. 755**
	Sig. (1-tailed)	<.001	<.001	<.001	<.001	<.001		<.001
Sustainability	Pearson Correlation	.682**	.708**	.753**	. 778**	. 794**	. 755**	1
	Sig. (1-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	

3.4 Regression Analysis

The R Square value of 0.761 (76.1%) indicates that 76.1% of the variance in sustainability, the dependent variable, is explained by the independent variables in this study. The Adjusted R Square, at 0.758 (75.8%), is close to the R Square value, suggesting the model effectively generalizes to the population. Regression diagnostics, including residual analysis, confirmed the model's validity and the absence of significant outliers.

Table 5
Summary model of sustainability

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.873[a]	.761	.758	.55216

a. Predictors: (Constant), awareness, knowledge, attitude, government influence, moral obligation, and subjective norm
b. Dependent Variables: sustainability

Table 6
ANOVA of sustainability

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	366.717	6	61.119	200.469	<.001 [b]
	Residual	114.940	377	.305		
	Total	481.657	383			

a. Dependent Variables: sustainability
b. Predictors: (Constant), awareness, knowledge, attitude, government influence, moral obligation, and subjective norm

The ANOVA results show the overall variance of the research model. The F-value is 200.469, derived from the Mean Square Regression (61.119) divided by the Mean Square Residual (0.305).

With a significance level of <0.001 [b], the independent variables effectively explain the variance in the dependent variable, confirming the model's significance.

The study analysed the impact of six independent variables on sustainability. Results showed that government influence (Beta = .249, p < .001), moral obligation (Beta = .328, p < .001), subjective norm (Beta = .292, p < .001), and attitude (Beta = .092, p = .072) significantly influenced sustainability, supporting their respective hypotheses (H3, H4, H5, H6). These findings align with theories emphasizing positive attitudes, moral obligation, and subjective norms as drivers of sustainable behaviours, reinforced by government initiatives like KITARecycle.

Table 7
Coefficient of sustainability

Model		Beta	t	Sig.
1	(Constant)		-554	.580
	Awareness	.054	1.214	.226
	Knowledge	-.028	-.574	.566
	Attitude	.092	1.802	.072
	Government Influence	.249	5.635	<.001
	Moral Obligation	.328	6.789	<.001
	Subjective Norm	.292	7.426	<.001

a. Dependent Variables: sustainability

However, awareness (Beta = .054, p = .226) and knowledge (Beta = -.028, p = .566) did not significantly correlate with sustainability, rejecting H1 and H2. Awareness may not translate to action due to obstacles like limited recycling facilities, while knowledge may need more depth to inspire behaviour. Structural support, such as incentives and accessible e-waste facilities, is necessary to enhance the effectiveness of these factors. Overall, the results highlight the importance of combining education, government policies, and community-driven efforts to promote sustainability effectively.

Table 8
Summary for hypothesis testing results

	Hypothesis	Remark
H_1	There is a relationship between awareness and the sustainability of e-waste management.	Rejected
H_2	There is a relationship between knowledge and the sustainability of e-waste management.	Rejected
H_3	There is a relationship between attitude and the sustainability of e-waste management.	Accepted
H_4	There is a relationship between government influence and the sustainability of e-waste management.	Accepted
H_5	There is a relationship between moral obligation and the sustainability of e-waste management.	Accepted
H_6	There is a relationship between subjective norm and the sustainability of e-waste management.	Accepted

4. Conclusions

This study demonstrates that systemic factors, including government policies, moral obligations, attitudes, and subjective norms, are critical in promoting sustainable e-waste management in Penang. While individual awareness and knowledge are essential, they are only sufficient with supportive policies and incentives to drive behavioural change. These findings directly address the

research objective of identifying the factors influencing e-waste management awareness and practices.

Policymakers should focus on strengthening enforcement mechanisms, incentivizing recycling, and incorporating sustainability education into public campaigns. Enhancing public participation and fostering stronger community norms are essential to bridging the gap between awareness and action. Additionally, economic incentives, such as subsidies for recycling businesses and monetary rewards for public participation, could significantly enhance engagement. Addressing technological barriers, such as the lack of accessible and efficient recycling facilities, is equally important to promote sustainable practices.

Future research should examine the long-term impacts of policy changes and explore how technological innovations can improve public engagement. The feasibility of integrating innovative technologies, such as e-waste tracking systems or automated recycling kiosks, could offer creative solutions to enhance recycling efficiency. By addressing these systemic and behavioural gaps, Malaysia can advance toward achieving its sustainability goals and mitigating the environmental risks of improper e-waste disposal.

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