

Critical success factors (CSFs) in implementing smart solid waste management in Banda Hilir, Melaka

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ABSTRACT

Smart Solid Waste Management (SSWM) employs advanced technologies to enhance the efficiency, environmental sustainability, and regulatory compliance of waste management systems. However, its adoption in Malaysia remains limited, largely due to inadequate stakeholder awareness and insufficient community engagement. This study investigates the core features, implementation barriers, and critical success factors (CSFs) of SSWM in Banda Hilir, Melaka, offering empirical insights to address existing adoption challenges. A quantitative approach was employed, using convenience sampling of 293 respondents from key institutional stakeholders, including the Melaka Solid Waste Corporation (SWCorp Melaka), Melaka City Council, and SWM Environment Sdn. Bhd. Descriptive statistical analysis identified low-carbon technologies (mean=4.42), multi-stakeholder collaboration (mean=4.35), and intelligent routing systems (mean=4.26) as the most critical features. Key barriers to implementation included financial constraints (mean=3.93), high initial investment costs (mean=3.82), and technological limitations within current waste systems (mean=3.42). These barriers align with four critical success factors (CSFs) which are financial support (mean=4.48), stakeholder acceptance (mean=4.12), stakeholder awareness (mean=4.11), and the availability of adequate facilities and technology (mean=4.06). The findings offer evidence-based policy recommendations to support the wider adoption of SSWM, contributing to sustainable urban development and aligning with Malaysia's environmental sustainability objectives.

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1. INTRODUCTION

The rapid urbanisation and population growth in developing countries have intensified the challenges of municipal solid waste management (SWM), often overwhelming existing infrastructures and institutional capacities. Municipal authorities, particularly in Malaysia, face persistent difficulties in monitoring and regulating the performance of waste collection service providers, who frequently deviate from contractual schedules (Omar et al., 2016; Azahari et al., 2021). These inefficiencies contribute to an increase in uncollected waste, illegal dumping, and overburdened landfills, resulting in severe environmental consequences such as elevated greenhouse gas emissions, air and water pollution, and the acceleration of climate change (Abas et al., 2021).

Smart Solid Waste Management (SSWM) has emerged as a transformative approach that integrates digital technologies, data analytics, and automation to optimise waste collection, reduce landfill dependence, and foster environmentally sustainable practices (Lakhouit, 2025). By

leveraging innovations such as intelligent routing, smart bins, and real-time monitoring systems, SSWM holds the potential to significantly reduce waste volumes, prevent illegal dumping, and promote circular economy principles (Goh et al., 2024). When implemented effectively, SSWM contributes to healthier urban environments and aligns with broader global sustainability goals (Khan & Ali, 2022).

However, the adoption of SSWM in Malaysia remains limited (Ebekozi et al., 2023; Bazrbachi et al., 2023). For instance, the state of Melaka, despite its reputation as a progressive city, faces escalating waste generation, with the average daily waste volume reaching approximately 941.9 tonnes in 2020, exceeding the landfill's design capacity of 760 tonnes (Nasir et al., 2021). This trend underscores the urgency for innovative waste management strategies that can respond to growing demand and environmental pressures. Yet, implementation of SSWM systems in developing countries is hindered by a range of institutional, economic, and technical barriers (Fidje et al., 2023). These include inadequate financial resources, limited infrastructure, stakeholder resistance, and insufficient awareness of the

benefits and functionalities of smart technologies (Zhang et al., 2019; Wang et al., 2010).

The effectiveness of SSWM depends not only on technological readiness but also on the identification and alignment of critical success factors (CSFs), such as multi-stakeholder collaboration, financial support, stakeholder acceptance, and the availability of adequate facilities. According to Iyamu et al. (2022), the design, development, and operationalisation of solid waste systems are influenced by a nexus of institutional, financial, social, technical, and environmental factors. Without addressing these CSFs, attempts to implement SSWM may remain fragmented or fail to achieve their intended impact.

In this context, the present study examines the core features, implementation barriers, and critical success factors of smart solid waste management in Banda Hilir, Melaka. A historically significant and urbanised zone experiencing rapid development and waste-related challenges. Through a quantitative analysis of key institutional stakeholders, this research provides empirical insights to guide evidence-based policymaking and strategic interventions aimed at scaling up SSWM adoption in Malaysian municipalities.

2. MATERIALS AND METHODS

2.1 Study area

This study was conducted in Banda Hilir, an urban precinct within Melaka Tengah District, Malaysia, and a key part of the Melaka Historic City, a UNESCO World Heritage Site. As a major tourist destination known for its historical landmarks such as A Famosa (Abdul Aziz et al., 2023). Banda Hilir attracts large volumes of both domestic and international tourists, generating substantial solid waste daily from commercial, hospitality, and public activities (Jamaliidin & Sulaiman., 2018). The high volume of waste presents a challenge to existing waste management infrastructure and influences tourists' perceptions of environmental cleanliness and urban sustainability (Koliotasi et al., 2023). The area thus provides a strategic and relevant case study for evaluating the implementation and CSFs of SSWM, particularly in a tourism-driven, heritage-focused urban setting.

2.2 Data collection

This study was conducted among two key waste management agencies in Melaka: Melaka City Council and Melaka Solid Waste Corporation (SWCorp). Data were collected using a questionnaire survey administered to employees from both agencies. The sampling technique employed was convenience sampling, a non-probability method that selects readily available respondents (Barudin et al., 2021). This approach was suitable given the accessibility of the target population, the relatively small size of the

agencies, and the need for cost- and time-efficient data collection.

Based on the Krejcie and Morgan (1970) sample size determination table, a sample size of 291 respondents was identified from a total population of approximately 1,200 employees across agencies. The questionnaire was designed to assess three main components: (i) characteristics of SSWM, (ii) constraints to its implementation, and (iii) CSFs for successful adoption in Banda Hilir, Melaka.

The questionnaire comprised four sections. Section A gathered socio-demographic data including gender, age, educational background, agency affiliation, current position, and experience in waste management. Section B focused on key characteristics of SSWM, such as real-time data monitoring, low-carbon technologies, waste bin tracking, intelligent routing, and multi-stakeholder cooperation. Section C addressed implementation constraints, including financial limitations, lack of stakeholder participation, high installation costs, and technological readiness. Section D explored CSFs such as stakeholder acceptance, stakeholder awareness, availability of expertise and facilities, and financial support. Items in Sections B to D were structured using a five-point Likert scale, ranging from "strongly disagree" to "strongly agree".

Prior to full deployment, the questionnaire was validated by subject-matter experts for content accuracy and relevance. A pilot study involving 30 respondents from Kota Bharu Municipal Council was conducted to assess the clarity, reliability, and feasibility of the instrument. According to Abas et al. (2020), a pilot sample of this size provides a sufficient range to assess survey consistency and question suitability. The feedback obtained was used to refine the final questionnaire for the main study.

2.3 Data analysis

This study employed descriptive statistical analysis to examine and interpret the data collected in line with the study's three objectives: (i) to identify the characteristics of SSWM, (ii) to examine the constraints faced by stakeholders in its implementation, and (iii) to analyse the CSFs for effective SSWM in Banda Hilir, Melaka. Descriptive analysis is a fundamental quantitative method used to summarise and organise data in a meaningful way, allowing researchers to observe patterns, trends, and relationships within a dataset (Teo et al., 2021).

Data were analysed and presented using frequencies, percentages, means, and standard deviations. Frequencies and percentages were primarily used to describe the socio-demographic profiles of respondents, including age, gender, education level, agency affiliation, current position, and years of experience in the waste management sector.

These descriptive measures offer insights into the respondent composition and contextualise the interpretations of the main variables.

To address the core variables characteristics of SSWM, implementation constraints, and critical success factors. The analysis focused on computing the mean scores and standard deviations of items measured using a five-point Likert scale. This enabled the identification of the most prominent features, barriers, and enablers based on stakeholder perceptions. Higher mean values indicated stronger agreement among respondents, while standard deviations reflected the variability in responses (Seow et al., 2022).

The selection of descriptive analysis was appropriate given the exploratory nature of the study and the focus on understanding stakeholder perspectives. This approach provided a comprehensive overview of the current landscape of smart waste management in the study area, supporting evidence-based discussions and recommendations.

3. RESULTS AND DISCUSSION

3.1 Socio-demographic profile of respondents

Table 1 presents the socio-demographic profile of 293 respondents from three key waste management agencies involved in smart solid waste management (SSWM) in Banda Hilir, Melaka: SWCorp Melaka (n=98; 33.4%), Melaka City Council (n=95; 32.4%), and SWM Environment Sdn. Bhd. (n=100; 34.2%). The gender distribution shows a slightly higher proportion of males (57.0%) than females (43.0%), which is consistent with the operational nature of the waste management sector.

A significant majority of respondents (75.4%) were aged between 30 and 39 years, indicating a predominantly young and potentially adaptive workforce. Most respondents had 6 to 10 years of experience (57.3%), with others having either more than 11 years (20.5%) or between 2 to 5 years (22.2%) of experience. Educationally, most held STPM or diploma qualifications (57.0%), followed by degree holders (26.3%) and SPM certificate holders (16.7%), reflecting a technically trained workforce suited to operational roles but potentially in need of upskilling for technology-driven systems.

In terms of organisational roles, most respondents (53.2%) were in first-line management, responsible for daily operations, while non-managerial staff comprised 23.2%. Middle and top management represented 16.4% and 7.2%, respectively. This distribution is significant, as it highlights that most feedback comes from those directly engaged in on-the-ground implementation, offering insights into practical constraints and opportunities.

The balanced agency representation and diverse respondent profiles enhance the reliability of the findings, ensuring perspectives from both policy and operational levels are captured. These characteristics provide a strong foundation for analysing the barriers and critical success factors in implementing SSWM, and suggest that future strategies must include managerial training, multi-level stakeholder engagement, and targeted investment in human capital development.

Table 1: Socio-demographic profile of respondents.

Demographic	Frequency (%)
Gender	
- Male	167 (57%)
- Female	126 (43%)
Age	
- 20-29 years old	13 (4.4%)
- 30-39 years old	221 (75.4%)
- 40-49 years old	50 (17.1%)
- >50 years old	9 (3.1%)
Affiliation	
- SWCorp Melaka	98 (33.4%)
- Melaka City Council	95 (32.4%)
- SWM Environment Sdn. Bhd.	100 (34.2%)
Working experience	
- 2-5 years	65 (22.2%)
- 6-10 years	168 (57.3%)
- >11 years	60 (20.5%)
Education Level	
- High School	49 (16.7%)
- Certificate/Diploma	167 (57%)
- Bachelor's degree	77 (26.3%)
Current position	
- Top management (manager/general manager)	21 (7.2%)
- Middle management (assistant manager)	48 (16.4%)
- First line management (supervisor)	156 (53.2%)
- Non-managerial (general workers)	68 (23.2%)

3.2 Characteristics of SSWM

Table 2 illustrates stakeholder perceptions of key features that define SSWM, based on a five-point Likert scale. The highest-rated characteristic was the implementation of low-carbon emission systems (Mean = 4.42, SD = 0.52), with 98.6% of respondents either agreeing or strongly agreeing, indicating a strong consensus that environmental sustainability is a critical aspect of modern waste management. Similarly, multi-stakeholder cooperation between waste concessionaires and local communities received a high level of agreement (Mean = 4.35, SD = 0.50), reflecting an awareness that SSWM success hinges not only on technology, but also on community engagement and participatory governance. The intelligent routing of waste trucks was also highly rated (Mean = 4.26, SD = 0.44), suggesting that operational efficiency through route optimisation is viewed as a priority area for waste system improvement.

Other features, while still positively rated, showed relatively lower mean scores, indicating areas where awareness or perceived importance may be less pronounced. For instance, the real-time monitoring of waste bin fill status (Mean = 3.58, SD = 0.68) and availability of technology/software experts (Mean = 3.60, SD = 0.70) scored

lower, revealing possible gaps in technical capacity or stakeholder exposure to digital monitoring applications. Interestingly, although smart tracking systems for waste bins were broadly acknowledged (Mean = 3.80), the standard deviation and response spread suggest varied levels of familiarity or conviction.

Table 2: Characteristics of SSWM.

Statements	Frequency (%)					Mean (SD)
	1	2	3	4	5	
Smart tracking system for waste bins/containers is an important feature of smart solid waste management.	0	2 (0.7)	70 (23.9)	205 (70.0)	16 (5.5)	3.80 (0.53)
Intelligent routing of waste trucks/conveyors for maximizing efficiency is an important feature of smart solid waste management.	0	0	1 (0.3)	215 (73.4)	77 (26.3)	4.26 (0.44)
Smart solid waste management software to optimise waste collection routes is an important feature of smart solid waste management.	0	2 (0.7)	93 (31.7)	176 (60.1)	22 (7.5)	3.74 (0.59)
Technology and software expert is an important feature of smart solid waste management.	0	16 (5.5)	107 (36.5)	149 (50.9)	21 (7.2)	3.60 (0.70)
Cooperation between waste concession and local community is an important feature of smart solid waste management.	0	0	4 (1.4)	182 (62.1)	107 (36.5)	4.35 (0.50)
Real-time data on waste bins/containers full status is an important feature of smart solid waste management.	0	19 (6.5)	98 (33.4)	163 (55.6)	13 (4.4)	3.58 (0.68)
Solid waste management system with low carbon emission is an important feature of smart solid waste management.	0	0	4 (1.4)	163 (55.6)	126 (43.0)	4.42 (0.52)

(1=Strongly disagree, 2=disagree, 3=moderately agree, 4=agree, 5=strongly agree)

Overall, the findings indicate strong stakeholder support for environmentally sustainable and efficiency-enhancing technologies yet also reveal persistent gaps in institutional and human-resource capacity, especially for real-time data integration and digital analytics where needed to operationalise comprehensive SSWM in Banda Hilir, Melaka. This capacity gap mirrors earlier Malaysian evidence that implementation lags policy ambition due to constraints in governance, technical skills, and inter-agency coordination (Johari et al., 2014; Cheng et al., 2022).

In Melaka specifically, household-level behaviour and participation have been identified as inconsistent, with relatively lower eco-behaviours in recycling and waste handling than benchmark states (Abu Bakar et al., 2020) and mixed determinants of recycling intention in the World Heritage City context. Our results extend these strands by showing that even when public support for “green” solutions is high, outcomes depend critically on institutional readiness to ingest, analyse, and act on high-frequency data streams across collection, sorting, and recovery workflows

3.3 Constraints on SSWM Implementation

Table 3 presents stakeholder’s feedback on the key constraints affecting the implementation of SSWM in Banda Hilir, Melaka. The most prominent constraint identified was the financial burden to stakeholders, which received the highest

mean score (Mean = 3.93, SD = 0.57), with nearly 80% of respondents agreeing and 8.5% strongly agreeing. This highlights that funding and budget limitations remain a major barrier to adopting smart technologies, particularly in developing urban contexts. Similarly, the high installation costs associated with advanced technologies (Mean = 3.82, SD = 0.64) were also perceived as a significant obstacle. These findings are consistent with previous studies emphasizing cost-related challenges as one of the most persistent barriers to smart waste innovation in Southeast Asia. Additionally, limitations in waste collection infrastructure (Mean = 3.42) and storage technology (Mean = 3.25) suggest infrastructural inadequacies that hinder the practical deployment of smart solutions.

On the other hand, constraints related to stakeholder readiness and awareness were perceived to be less critical, albeit still relevant. For example, the statement regarding lack of knowledge among stakeholders recorded a relatively low mean score (Mean = 2.09, SD = 0.70), indicating that most stakeholders do not perceive themselves as uninformed. Similarly, the lack of willingness to participate in smart initiatives (Mean = 2.67) was not strongly agreed upon, which may reflect a generally supportive or neutral attitude toward future involvement. However, the lack of information dissemination to agencies, industries, and communities (Mean = 3.03) received more moderate support, suggesting

that communication and outreach remain areas for improvement.

Collectively, the results point to a clear gap between stakeholder willingness and the institutional & infrastructural readiness required for comprehensive SSWM: community awareness and interest exist, but implementation hinges on

unblocking financial, technical, and infrastructure bottlenecks via policy support, investment, and capacity-building. This pattern aligns with cross-country evidence that institutional capacity, stable financing, and system integration, not enthusiasm alone determine outcomes (Guerrero et al., 2013; Marshall & Farahbakhsh, 2013; Wilson, 2015).

Table 3: Constraints of SSWM.

Statements	Frequency (%)					Mean (SD)
	1	2	3	4	5	
Smart solid waste management is a financial burden to stakeholders.	3 (1.0)	5 (1.7)	26 (8.9)	234 (79.9)	25 (8.5)	3.93 (0.57)
The stakeholders are lacking knowledge on the smart solid waste management.	39 (13.3)	209 (71.3)	30 (10.2)	11 (3.8)	4 (1.4)	2.09 (0.70)
The agencies, industries and local community of Banda Hilir lack of information on smart solid waste management.	4 (1.4)	73 (24.9)	131 (44.7)	81 (27.6)	4 (1.4)	3.03 (0.79)
The stakeholders are not ready to participate in smart solid waste management initiative at Banda Hilir.	7 (2.4)	132 (45.1)	108 (36.9)	42 (14.3)	4 (1.4)	2.67 (0.70)
The cost of smart solid waste management installation is higher because of the advanced technology.	2 (0.7)	3 (1.0)	71 (24.2)	188 (64.2)	29 (9.9)	3.82 (0.64)
The waste storage for smart solid waste management needs advanced technology and very limited at Banda Hilir.	1 (0.3)	49 (16.7)	128 (43.7)	106 (36.2)	9 (3.1)	3.25 (0.77)
The waste collection system for smart solid waste management needs advanced technology and very limited at Banda Hilir.	1 (0.3)	18 (6.1)	139 (47.4)	127 (43.4)	8 (2.7)	3.42 (0.66)

(1=Strongly disagree, 2=disagree, 3=moderate agree, 4=agree, 5=strongly agree)

In the Malaysian context, recent reviews similarly stress that progress toward resilient municipal systems depends on governance, resourcing, and digital capabilities to integrate data and operations (Moh & Abd Manaf, 2017; Cheng et al., 2022). At the macro level, global diagnostics show that cities that pair community participation with targeted capital investment, professionalised operations, and transparent performance standards achieve durable improvements in collection, diversion, and recovery (Kaza et al., 2018).

Taken together, our findings reinforce the literature: willingness is necessary but insufficient; success requires structured financing mechanisms, fit-for-purpose infrastructure, and sustained capacity building to translate intent into measurable SSWM performance.

3.4 Critical success factors of SSWM

Table 4 presents the perceived critical success factors (CSFs) necessary for effective implementation of SSWM systems in Banda Hilir, Melaka. The data clearly show that financial support is viewed as the most crucial enabler (Mean = 4.48, SD = 0.54), with nearly 98% of respondents agreeing or strongly agreeing. This aligns with the identified financial constraints in Table 3, reinforcing the dual role of funding as both a challenge and a key success element. Closely following are stakeholder acceptance (Mean = 4.12) and awareness (Mean = 4.11), indicating that beyond technology and infrastructure, human factors such as engagement, trust, and buy-in are pivotal.

These findings highlight that stakeholder-centric strategies, including participatory planning and communication, are vital for SSWM adoption success, consistent with literature stressing public-private-community synergy in smart waste practices.

In addition, adequate facilities (Mean = 4.06) and training/education workshops (Mean = 4.03) were strongly supported as foundational CSFs. The emphasis on capacity building suggests that while technological readiness is important, human resource development and technical know-how remain equally critical. Meanwhile, availability of experts (Mean = 3.58) and cutting-edge technology (Mean = 3.69) received moderately high agreement, indicating recognition of the importance of technical infrastructure and specialised personnel, though perhaps not as urgent as financial and social elements.

The distribution of responses suggests that stakeholders recognise SSWM success depends not only on procuring physical infrastructure, but also on empowering the people and institutions that operate it. Evidence similarly shows that system-wide integration, which balances hardware with organisational capacity, skills, and coordination, achieves more lasting results than technology-led rollouts alone (Marshall & Farahbakhsh, 2013; Guerrero et al., 2013). Inclusive governance and recognition of diverse actors, including the informal sector, further strengthen performance and equity.

In the Malaysian context, progress has been linked to capacity-building and clear institutional arrangements to support source separation and recycling, rather than to capital

investment alone (Moh & Abd Manaf, 2017). Global diagnostics similarly emphasise coupling investments with professionalised operations, skills development, and transparent standards to achieve sustained improvements

(Kaza et al., 2018). Collectively, these studies support our interpretation: policy should prioritise integrated planning that balances equipment acquisition with soft-skill development and inclusive governance frameworks.

Table 4: Critical success factors of SSWM.

Statements	Frequency (%)					Mean (SD)
	1	2	3	4	5	
Stakeholder acceptance on the new system is the crucial success factors on smart solid waste management.	0	0	17 (5.8)	223 (76.1)	53 (18.1)	4.12 (0.47)
Facilities are the crucial success factors on smart solid waste management.	0	0	13 (4.4)	250 (85.3)	30 (10.2)	4.06 (0.37)
Enough financial support is the crucial success factors on smart solid waste management.	0	0	6 (2.0)	141 (48.1)	146 (49.8)	4.48 (0.54)
Availability of expert on the technology system is the crucial success factors on smart solid waste management.	0	14 (4.8)	107 (36.5)	159 (54.3)	13 (4.4)	3.58 (0.65)
Availability of cutting-edge technology is the crucial success factors on smart solid waste management.	0	5 (1.7)	97 (33.1)	175 (59.7)	16 (5.5)	3.69 (0.59)
Stakeholder awareness on the importance of smart solid waste management is the crucial success factors.	0	0	14 (4.8)	232 (79.2)	47 (16.0)	4.11 (0.44)
Education/training workshop on the smart solid waste management is the crucial success factors.	0	0	34 (11.6)	217 (74.1)	42 (14.3)	4.03 (0.50)

(1=Strongly disagree, 2=disagree, 3=moderate agree, 4=agree, 5=strongly agree)

Our empirical findings reveal that stakeholders in Banda Hilir regard financial support as the most pivotal success factor for implementing SSWM (Mean = 4.48), while also perceiving cost burden and high installation expense as major constraints. This reflects a persistent tension documented in Southeast Asian contexts, where limited fiscal capacity obstructs smart infrastructure adoption (Salleh et al., 2022). Stakeholders also prioritised acceptance, awareness, and availability of facilities and training over purely technical elements like expert presence or cutting-edge technology.

These results align with studies on Malaysian smart-city initiatives, which emphasise that stakeholder buy-in and digital literacy are critical to adoption success (Hamamurad et al., 2022; Waqar et al., 2023). Although respondents generally reject statements asserting lack of readiness or knowledge as major barriers, moderate agreement regarding information gaps suggests that structured engagement and communication remain essential. Collectively, these findings mirror the trajectory of Malaysian waste management efforts, where financial and technical readiness continues to lag social readiness and institutional support (Tahir et al., 2024; Rahman et al., 2024).

These findings are also consistent with Malaysia’s ongoing policy pivot toward a circular and green economy framework. The recently released Circular Economy Blueprint for Solid Waste (2025–2035) highlights measures such as Extended Producer Responsibility, Pay-As-You-Throw, and Zero Waste to Landfill Certification. All of which hinge on sufficient funding, stakeholder collaboration, and transparent systems (She & Wee, 2025). The stakeholder emphasis on

low-carbon emissions systems aligns with national ambitions under the Green Technology Master Plan and Green Transition agenda, which position waste management infrastructure as a pillar in reducing urban carbon footprint (Haris et al., 2024). Within the broader smart-city context articulated by the Malaysian Smart City Framework (MSCF), waste systems are considered vital components of intelligent urban infrastructure that serve Sustainable Development Goals (SDGs) by improving environmental quality and citizen well-being (Waqar et al., 2023).

Moreover, the findings indicate a consistent “finance-first, people-and-process second, hardware third” ordering of priorities for Banda Hilir, Melaka. Financial considerations emerge as paramount: respondents perceive SSWM as a financial burden and flag high installation costs for advanced technologies, while simultaneously ranking “enough financial support” as the most decisive CSFs. This configuration triangulates cleanly (constraint leads to high cost; CSFs indicates finance) and accords with global diagnostics that durable performance requires predictable funding streams for both capital and operations, rather than technology procurement alone, alongside professionalised routines and transparent standards (Kaza et al., 2018). Strategically, this speaks directly to SDG 11 (Sustainable Cities and Communities), especially on reducing cities environmental impact through improved municipal waste management and to SDG 12 (Responsible Consumption and Production) on waste reduction through prevention, reduction, recycling, and reuse.

Human capital and institutional capability also feature prominently but unevenly. Stakeholders value technology expertise and real-time bin-status data; however, these items attract lower salience than route optimisation and low-carbon systems, suggesting ambition for efficiency and climate alignment may be running ahead of the data backbone and embedded digital roles required to sustain them. At the same time, respondents do not self-report a fundamental knowledge deficit; rather, they point to moderate information diffusion and mixed readiness to participate. In combination with the CSFs that emphasise training and the availability of experts, this pattern signals latent capability gaps, particularly in data engineering, analytics, and cross-agency protocols. Needed to translate high-frequency sensor data into operational decisions. The tension between perceived general awareness and specific digital readiness mirrors broader evidence that integrated, system-wide approaches outperform technology-led rollouts only when they balance hardware with organisational capacity, skills, and coordination (Guerrero et al., 2013; Moh & Abd Manaf, 2017). These findings align with SDG 9 (Industry, Innovation and Infrastructure), specifically on sustainable infrastructure and on enhancing scientific research and technological capabilities, and SDG 13 (Climate Action), particularly on integrating climate measures into local policies via low-carbon routing and operational optimisation.

Social partnership emerges as a unifying enabler. Strong endorsement of cooperation between the concessionaire and local communities on the “features” side aligns with CSFs that foreground stakeholder acceptance and awareness. This emphasis on inclusive governance reflects long-standing findings that the participation of diverse actors, including the informal sector, improves both operational performance and equity outcomes (Wilson, 2015). The demographic profile of respondents (experienced, largely operational staff) further supports the external validity of these insights: they originate from those who confront day-to-day constraints rather than from purely strategic vantage points, a vantage point often shown to anticipate implementation bottlenecks more accurately (Guerrero et al., 2013). This strand directly advances SDG 17 (Partnerships for the Goals), notably on multi-stakeholder partnerships and, where livelihood opportunities and safe, decent work for waste workers are strengthened, contributes to SDG 8 (Decent Work and Economic Growth), especially on supporting productive activities and micro-enterprises.

Critically, the triangulated finding adds nuance to the literature by separating high-consensus aspirations (low-carbon systems and efficient routing) from the moderately rated prerequisites (real-time data, expert capacity) that make these aspirations durable. Absent explicit investment in data

governance (standards, access, quality), integration tools, and analytics roles, which are codified in operating procedures that link sensor inputs to route, asset, and public-facing decisions, technology risks under-delivering. This finding is consistent with reviews documenting that financing, institutional routines, and capacity building are prerequisites for improving collection, diversion, and recovery at scale; technology is an amplifier, not a substitute, for these foundations (Moh & Abd Manaf, 2017). In short, willingness and ambition are necessary but insufficient; success depends on a sequenced programme that protects operating budgets, builds municipal data/IT capabilities, and institutionalises co-production with communities (Kaza et al., 2018; Wilson, 2015). This programmatic framing operationalises SDG 11 and SDG 12, while embedding climate co-benefits (SDG 13) and inclusive, skills-based capacity (SDG 9; SDG 8) through effective partnerships (SDG 17). Where interventions improve leachate control and contamination prevention through better collection and diversion, there are additional co-benefits for SDG 6 (Clean Water and Sanitation), particularly on improving water quality by reducing pollution.

4. CONCLUSION

The findings of this study highlighted the critical need for strategic, technologically integrated, and community-inclusive approaches to SSWM in Malaysia, particularly in urban heritage zones like Banda Hilir. The high agreement on key features such as intelligent routing, real-time bin tracking, and software optimization illustrates a strong recognition of the importance of digital innovation for sustainable waste practices. However, challenges such as financial constraints, technological limitations, and lack of stakeholder readiness, particularly in knowledge and infrastructure highlight the urgent need for policy intervention and capacity building. These insights reinforce the importance of integrating SSWM within broader national frameworks such as the Circular Economy Blueprint, Smart City strategies, and Green Economy initiatives. The study further supports Malaysia’s commitment to SDGs, especially SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). For future research, there is significant potential in exploring the cost-benefit analysis of smart waste infrastructure, comparative studies between different municipalities, and the role of behavioural change interventions in enhancing stakeholder readiness. Further studies could also investigate the scalability of smart waste technologies in rural and semi-urban settings, as well as the integration of Internet of Things (IoT), blockchain, and AI-driven decision systems into waste management governance for achieving a truly data-driven

circular economy.

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