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Operationalizing Circular Economy Goals through Food-Waste Composting: A GREEN Framework for Hawker Centers

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Abstract

Hawker centres operated by Malaysian local authorities (or *Pihak Berkuasa Tempatan, PBT*) generate heterogeneous streams of food waste—including pre-preparation trimmings, in-process losses, plate leftovers, and expired inventory—that require site-specific interventions. This paper introduces the GREEN framework (Generate, Review, Establish, Engage, Normalise), developed through a review of international best practices and adapted to the Malaysian context. The framework is applied to a PBT-managed *medan selera* or food court or hawker centers producing 40–50 kg of food waste per day across multiple vendors. It integrates a food waste audit and composition analysis with operational diagnostics of vendor practices to identify feasible diversion pathways and inform the sizing of an on-site, low-footprint composting system. Building on evidence from community-scale initiatives in tropical settings, an aerated static pile (ASP) configuration is proposed, using locally available bulking agents such as rice husk, sawdust, and dry leaves to achieve optimal process conditions (55–65% moisture; C:N ratio ≈ 25–30). Literature further supports the use of bulking and biochar amendments to enhance porosity, thermophilic stability, and nitrogen retention. The system design must include siting, odor and leachate controls, safety measures, and municipal landscaping applications for the compost output. The contribution of this study is twofold: (i) the articulation of a replicable GREEN framework that PBTs can deploy rapidly with limited capital, and (ii) an evidence-based design specification suited for small-scale, decentralised composting. Findings align with regional policy directions and demonstrate that composting at the 40–50 kg per day scale is technically feasible, environmentally beneficial, and socio-institutionally acceptable when vendor segregation and bulking logistics are embedded into routine operations.

Keywords: Food Waste Composting, Baseline-Analysis-Design Framework, Hawker Centers, Decentralized Waste Management, Circular Economy

Introduction

Food waste is increasingly recognized as one of the most pressing environmental and social challenges of the twenty-first century. Globally, approximately one-third of all food produced is lost or wasted, with downstream consequences for climate change, resource efficiency, and municipal solid waste (MSW) management systems (Nordahl et al., 2020). In Malaysia, the situation is particularly acute. Studies estimate that food waste comprises nearly 40–50% of the MSW stream, with generation rates rising alongside rapid urbanisation and a flourishing food-service sector (Phooi et al., 2022; Ariffin et al., 2023). At the same time, policy attention to organics diversion is intensifying, with both national frameworks and local authority mandates urging reductions in landfill dependency and greater uptake of circular-economy solutions (Abdul Halim, 2025; IIUM Law Majalla, 2025). Within this national picture, hawker centres—locally termed medan selera—constitute a distinctive subsystem of food waste generation. These centres, often operated by Pihak Berkuasa Tempatan (PBT), aggregate multiple vendors in high-density layouts and produce heterogeneous waste streams that include pre-preparation trimmings, in-process residues, plate leftovers, and expired inventory. Unlike household waste, hawker-centre waste is consistently wet, nutritionally rich, and generated in daily pulses that demand site-specific management strategies (Ng et al., 2021).

Food waste composition in the food service sector is highly heterogeneous, reflecting the diversity of preparation methods, cuisines, and consumer behaviors. Tong et al. (2018) provide one of the most detailed characterizations of food waste generated in eateries, distinguishing between kitchen-derived waste streams and table leftovers. Their findings highlight that kitchen food waste (FW)—comprising trimmings, peels, and off-cuts from food preparation—is relatively cleaner, more homogeneous, and less contaminated with oils, condiments, or packaging. In contrast, table FW—consisting of unfinished meals and plate residues—tends to be wetter, saltier, and more variable in composition, presenting higher challenges for valorization. Quantitatively, their study established useful baseline benchmarks: kitchen FW averaged approximately 91 g per person per meal, while table FW was significantly higher at around 118 g per person per meal. These figures underscore the importance of source-specific strategies, as the volume and quality of FW differ between pre-consumer and post-consumer streams. For instance, kitchen FW is more amenable to composting or anaerobic digestion, whereas table FW may require additional segregation or pre-treatment. By providing standardized metrics, Tong et al. (2018) offer critical reference points for waste audits in similar institutional or community-scale settings, facilitating evidence-based planning for sustainable food-waste diversion systems

Designing a food-waste composting programme requires a systematic process that begins with a thorough food waste audit. This step quantifies the overall volume of food waste generated daily and categorises it into distinct streams such as pre-preparation trimmings, plate leftovers, in-process losses, and expired food inventory. Establishing these categories is essential, as different types of food waste vary in their suitability for composting and require different handling approaches. Following quantification, a waste composition analysis is conducted to examine the physical and chemical characteristics of the identified streams. Critical parameters such as moisture content and the carbon-to-nitrogen (C:N) ratio are evaluated, as they directly influence microbial activity and composting performance. This analysis allows for the identification of fractions most suitable for composting and highlights

materials that may require additional treatment or exclusion. Equally important is the assessment of vendor practices through operational diagnostics. This involves observing how food vendors manage waste in their daily routines, including methods of storage, segregation behavior, and the timing of waste generation. Such diagnostics reveal the extent to which source separation is practiced and identify practical barriers, such as contamination with non-organic materials, that could undermine composting efficiency. The integration of audit results, composition analysis, and vendor diagnostics enables the identification of feasible diversion pathways. These pathways specify which waste streams can realistically be diverted from landfill to composting, taking into account operational constraints, vendor willingness, and the availability of bulking agents. This step ensures that the composting intervention is not only technically feasible but also socially and institutionally viable. Finally, the data generated informs the sizing and design of the composting system. By matching daily waste volumes with appropriate composting technologies, planners can select a low-footprint solution suited to hawker-centre conditions, such as an aerated static pile system. The design phase also includes consideration of end-use pathways for the compost product, ensuring that the process contributes to broader circular economy goals by reintegrating nutrients into municipal landscaping, community gardens, or local agriculture.

Decentralised composting offers a promising pathway to valorise these waste streams. Empirical evidence from Malaysian institutions shows that simple aerated static piles (ASP) or passive bin systems can stabilise food waste effectively when combined with appropriate bulking agents such as rice husk, sawdust, or leaf litter (Ng et al., 2021). International and regional reviews further confirm that decentralised systems deliver favourable environmental performance, particularly when contrasted with landfilling, and that they are adaptable to constrained urban sites (Sánchez, 2022; NEA, 2024). However, small-scale composting is not without challenges: high moisture content, odour potential, and contamination from mixed plate scrapings necessitate careful baseline assessment, process design, and social engagement to ensure sustained operation (Parab et al., 2024; Ebrahimi et al., 2024). Against this backdrop, a uniform and sustainable framework becomes essential. Baselining through stratified audits allows for the disaggregation of food-waste categories and the quantification of daily generation rates (Ariffin et al., 2023). Analytical phases, including proximate composition and C:N ratio estimation, enable the identification of feasible bulking mixes and the sizing of composting units (Wang et al., 2024). Finally, the design stage requires the specification of siting arrangements, infrastructure, leachate and odour controls, and end-use pathways for the finished compost in municipal landscaping (Lee, 2024). Such a structured approach responds to a recurrent weakness identified in Malaysian practice, namely the premature procurement of composting technologies without site-specific data, often resulting in underutilisation or outright failure (Abdul Halim, 2025).

This paper contributes by operationalising the proposed framework within the context of a PBT-managed hawker centre in Malaysia. Specifically, it seeks to: (i) establish a baseline by characterising the composition and generation patterns of hawker-centre food waste, in line with the National Solid Waste Management Policy's emphasis on source reduction and monitoring; (ii) identify and evaluate locally available bulking agents and process control strategies, supporting SDG 12 on responsible consumption and production; and (iii) design and recommend a decentralised, low-footprint composting system appropriate for daily flows of 40–50 kg, thereby contributing to SDG 11 on sustainable cities and SDG 13 on climate action

by reducing landfill dependency and methane emissions. In doing so, the study addresses both technical and socio-organisational dimensions, advancing Malaysia's circular economy agenda while offering a replicable and context-sensitive model for adoption by PBTs nationwide.

Literature Review

Why a Site-Specific Baseline Matters in Malaysian Hawker Centres

Malaysia's food-waste challenge is sizable, with household and food-service contributions both material; recent syntheses and surveys report food waste as a dominant stream in MSW, and highlight under-segregation at source as a persistent barrier (Phooi et al., 2022; Ariffin et al., 2023; Abdul Halim, 2025). Within this context, PBT-managed hawker centres ("medan selera") concentrate diverse food types and preparation modes in compact spaces, producing wet, variable wastes that complicate one-size-fits-all solutions. A site-level baseline that distinguishes pre-preparation waste (highly compostable, often low in salt/oil), service leftovers (higher contamination risk), and expired inventory (periodic spikes) is therefore prerequisite to technology selection and sizing. Recent Malaysian reviews emphasise that evidence-based characterisation should precede infrastructure procurement to avoid stranded assets (Abdul Halim, 2025).

In Japan, the government has implemented stringent practices and advanced technologies in restaurant premises to effectively manage food waste, resulting in minimal or no bad odor and leachate. Japanese restaurants typically separate food waste meticulously at the source, distinguishing between pre-preparation waste, leftovers, and expired inventory, which aligns with the need for site-specific baselines noted in Malaysian hawker centers. Moreover, many establishments use specialized composting and anaerobic digestion technologies that quickly break down organic waste, reducing microbial activity and odors. Japan also enforces strict waste segregation regulations combined with frequent collection schedules, preventing prolonged waste storage that could cause odor or leachate problems. These measures are enhanced by ongoing governmental support for research and development in food waste treatment infrastructure, ensuring that solutions are tailored to the specific waste characteristics of each establishment, thus avoiding the pitfalls of one-size-fits-all approaches. This holistic and proactive management of food waste shows how evidence-based characterization and technology selection can prevent environmental nuisances while promoting sustainability (Taniguchi et al., 2021; Yoshikawa & Funamizu, 2020; Ministry of the Environment Japan, 2023).

Decentralized/Community-Scale Composting in Tropical Settings

Peer-reviewed Malaysian and regional studies demonstrate feasibility of decentralised or community-scale composting in humid tropics when good feedstock preparation and bulking are in place. A life-cycle-assessment-supported case at University of Nottingham Malaysia implemented an open-air, static-aerated system co-composting food waste with leaf litter; the mixture targeted ~63% initial moisture and C:N ~27 and achieved compliant compost quality under Malaysian standards (Ebrahimi et al., 2024). Complementary LCA work at institutional scale in Malaysia found passive aerated static piles can meet stability criteria and offer net climate benefits versus landfilling (Ng et al., 2021). More broadly, a 2022 review of decentralised composting highlights performance sensitivities in small systems (temperature stratification, sanitation

assurance), but affirms their environmental potential when bulking and aeration are properly managed (Sánchez, 2022).

Technology Choice for 40 to 50kg FW per day

At the 40–50 kg day^{-1} throughput typical of a small PBT hawker centre, simple aerated static piles (ASP) or compact, passively aerated bins are operationally appropriate: they minimise moving parts, tolerate daily feed variability, and fit small footprints. International and regional practice note that source-segregation and pre-processing (depackaging, size reduction) are decisive, and that ASPs deliver favourable greenhouse-gas profiles relative to landfilling and can compare well with other biological options in certain mixes (Nordahl et al., 2020; Sánchez, 2022). Hawker-centre pilots in neighbouring Singapore show the practicality of colocating treatment near generation and using co-collected food and landscaping wastes as feedstock/bulking, with municipal facilitation for collection and siting (NEA, 2024; Channel NewsAsia, 2021).

Bulking Agents, Biochar, And Process Control

Bulking is not optional in wet tropical food waste: it governs porosity, free air space, and ammonia control. Recent experimental studies report that adding structured bulking agents (sawdust, rice husk, shredded leaves) improves thermophilic performance and maturity indices; some show optimal windows for agent type and loading in fed-batch and heap systems (Wang et al., 2024; Parab et al., 2024). A 2024 systematic review finds biochar amendments can retain nitrogen, raise core temperatures more consistently, and reduce NH_3 losses—useful for odour management in dense urban contexts (Ebrahimi et al., 2024). These findings triangulate with Malaysian case practice that successfully used leaf litter as bulking at scale (Ebrahimi et al., 2024). For a hawker-centre design, locally available rice husk and sawdust (from nearby mills), plus seasonal dry leaves from municipal groundskeeping, are pragmatic first-line choices; biochar can be piloted as a performance enhancer where supplies exist.

Siting, Odour/Leachate, and Operations in PBT Premises

Operational experience foregrounds siting within existing PBT compounds with paved, drained hardstands; roofed ASP bays or lidded bins; condensate/leachate capture; and buffer measures (wind-direction, housekeeping) to protect neighbouring uses. Regional guidance underscores integrating vendor-side segregation (separate caddies for pre-prep vs plate scrapings) to reduce contamination and odour, and aligning collection routes/timing with stall workflows (NEA, 2024). In Malaysia, legal framing for organics diversion is evolving; while Act 672 underpins solid waste management, recent legal commentary argues for more specific reporting and diversion obligations for large food-waste generators—signals that local programmes should anticipate data logging and traceability (Lee, 2024; IIUM Law Majalla, 2025).

Behavioural and Organisational Dimensions

Social drivers are decisive in vendor compliance, segregation quality, and routine maintenance. Malaysian studies on awareness and behaviour emphasise the need for simple, visible feedback (e.g., diversion dashboards, compost reuse onsite) and training to normalise sorting behaviours (Phooi et al., 2022; Ariffin et al., 2023). Decentralised composting scholarship likewise highlights that outreach, co-ownership, and small-wins (e.g., landscaping

benefits) sustain participation and reduce NIMBY risks (Pai et al., 2019; Sánchez, 2022). For a PBT hawker centre, the literature supports appointing a custodian vendor or PBT staff champion, formalising daily SOPs, and providing bulking stocks and liners as municipal "enablers" rather than expecting vendors to self-supply.

Synthesis for Design

Drawing these strands together, a protocol for a 40–50 kg day^{-1} hawker centre should: (i) baseline via a 7–10-day stratified audit (by stream and time-of-day), plus moisture and bulk density checks; (ii) analyse feasible segregation and bulking supply chains (rice husk/sawdust/leaves; optional biochar); and (iii) design an ASP system with two to three parallel bays (to manage batch staging), a duty-cycled blower or passive aeration, roofed pads with leachate capture, and vendor SOPs for caddy use, depackaging, and end-use of compost in PBT landscaping. This is consistent with Malaysian institutional case evidence and with regional municipal pilots, and is aligned with evolving policy attention to food-waste metrics and diversion (Ng et al., 2021; NEA, 2024).

Study Approach

Study Context

This study focuses on hawker centres (*medan selera*) operated by Malaysian local authorities, or Pihak Berkuasa Tempatan (PBT). These facilities typically generate heterogeneous streams of organic waste, including pre-preparation trimmings, in-process losses, plate leftovers, and expired inventory. The chosen study site produces approximately 40–50 kg of food waste per day across three vendors, making it representative of small-to-medium scale PBT-operated food courts. Such settings pose challenges of limited space, modest capital availability, and varied vendor practices, which necessitate context-specific solutions rather than the adoption of imported high-cost technologies.

Paper Review Method

To derive the GREEN framework, a structured paper review method was employed. Literature was sourced from Scopus, Web of Science, and Google Scholar databases, with the timeframe restricted to 2018–2025 to capture recent developments in decentralised composting, municipal solid waste governance, and circular economy applications. Search strings included combinations of keywords such as "food waste composting," "hawker centres," "municipal solid waste," "decentralised composting," "Southeast Asia," and "circular economy." A two-stage screening process was applied:

a. Initial screening – Titles and abstracts were reviewed to exclude studies irrelevant to the scope, including those focused on landfill engineering, anaerobic digestion, or non-organic waste streams.
b. Full-text review – Inclusion criteria required studies to (i) report empirical findings or pilot projects on composting or decentralised waste systems, (ii) describe methodological details such as waste audits, composting practices, or governance models, and (iii) be relevant to tropical or developing-country contexts. Exclusion criteria ruled out theoretical-only papers without application, large-scale industrial incineration or biogas studies, and publications inaccessible in English.

This process yielded 52 relevant papers and reports, with emphasis placed on studies from Malaysia, Singapore, Indonesia, and Vietnam for contextual transferability. Selected

benchmarks from Japan, South Korea, and Europe were also examined, but only when their practices could be realistically adapted to Malaysia's socio-economic and infrastructural conditions.

Derivation of the GREEN Framework

Findings from the paper review were synthesised into the Governance–Review–Engagement–Engineering–Normalization (GREEN) framework. The derivation process involved comparing international best practices with Malaysian waste management realities, particularly PBT operational constraints. For example, while in-vessel composting was reported effective in high-income countries, the review highlighted that decentralised, low-footprint options such as aerated static piles (ASP) are more feasible for Malaysia due to lower costs, simplicity, and adaptability

Results and Discussion

From this synthesis, a framework named GREEN was formalized. The framework has a five-stage progression:

a. Generate Baseline: adapting established waste-audit methods (Phooi et al., 2022; Ariffin et al., 2023) to quantify and categorise hawker-centre food waste streams.
b. Review Analysis: applying composting science to interpret baseline findings into actionable parameters (C:N balancing, bulking-agent selection) (Ebrahimi et al., 2024).
c. Establish Design: specifying site-specific composting systems and operational protocols, consistent with municipal practices and circular-economy goals (Ng et al., 2021; Sánchez, 2022).
d. Engage Networks: mobilising vendors, PBT officers, and community stakeholders through training, awareness, and participatory monitoring.
e. Normalise Practice: institutionalising composting into daily routines, SOPs, and end-use applications such as municipal landscaping.

Thus, the GREEN framework is the outcome of an evidence-based synthesis: a structured methodology distilled from international best practices and refined for the Malaysian hawker-centre context, with explicit attention to technical feasibility, governance structures, and community engagement.realitiesThe GREEN framework demonstrates that food-waste composting at the hawker-centre scale is both technically feasible and institutionally sustainable when operationalised into staged outputs. Its primary contribution lies not in proposing novel composting technologies but in offering a structured governance and practice model. By linking waste audits, process analysis, system design, community engagement, and institutional normalisation into a coherent sequence, the framework translates theoretical best practices into practical routines for local authority implementation. This section presents how each stage of the framework was materialised into actionable outputs and discusses their implications for technical feasibility, stakeholder engagement, and policy alignment. Next is to translate the GREEN Framework into practice.

Results by the Framework Stage

G-Generate Baseline

Waste Audit and Segregation: The baseline stage produced a Waste Audit Checklist that separates food waste into categories (pre-preparation, plate leftovers, expired stock). Vendors are tasked with daily logging, while PBT officers supervise weekly segregation quality.

This mirrors findings that waste characterization is a foundational step in designing sustainable food-waste programs (Phooi et al., 2022; Ariffin et al., 2023). Tong et al. (2018) emphasize that food-waste characterization data are not merely descriptive but serve as essential inputs for technology selection and system design. By differentiating kitchen food waste (91 g/person/meal) from table waste (118 g/person/meal), the study highlights the need for treatment systems that can handle heterogeneous inputs with varying moisture, salinity, and contamination levels. When applied to hawker-center contexts in Malaysia, where daily flows typically range from 40–50 kg, these insights suggest that decentralized, low-footprint composting units are particularly suitable. Such systems can be sited close to waste generation points, reducing transport costs and odor risks, while accommodating the compact spatial constraints of urban food courts. Complementary research supports this direction, for example Sánchez (2022) advocates decentralized composting as a scalable solution for communities with moderate daily waste flows, while Keng et al. (2020) demonstrate through life-cycle assessment that community-scale systems offer favorable trade-offs in energy use and greenhouse gas emissions. Similarly, Maxianová and Vaverková (2020) underscore the importance of bulking agents, such as sawdust, for stabilizing wet food waste in small-scale operations. Collectively, these studies point towards modular composting designs—mechanically aerated bins or bio-digesters with simple leachate control—that align with the flow characteristics and space limitations of PBT-managed hawker centers.

Review Analysis

Composting Feasibility: At the review stage, feasibility analysis focuses on confirming whether site-level food waste streams can be processed into a stable compost product under tropical conditions. The output of this stage is a Feasibility Task List, which includes critical operational checks such as moisture content measurement, carbon-to-nitrogen (C:N) balancing, and bulking-agent requirements. Clear division of responsibilities is essential: vendors act as the first line of defence against contamination by segregating plastics and inerts at source; PBT officers oversee feedstock monitoring, ensuring moisture and C:N parameters remain within the optimal range; and community members supply supplementary bulking agents such as rice husks, sawdust, or dry leaves to counterbalance the high moisture and nitrogen-rich composition of tropical food waste.

Previous studies emphasize that structured bulking is indispensable for tropical contexts, where food waste streams are often too wet and unstable for direct composting. Keng et al. (2020) observed that effective bulking prevents anaerobic conditions and leachate generation, while Wang et al. (2024) demonstrated that bulking agents improve porosity and support microbial diversity, accelerating decomposition and reducing greenhouse gas emissions. Similar lessons have been drawn from Singapore's hawker-center pilot projects, where food waste was co-composted with wood chips to enhance aeration and minimize odor (Channel News Asia, 2021; National University of Singapore, 2021). These findings converge with broader regional evidence (Maxianová & Vaverková, 2020; Hibino et al., 2023), underscoring that the feasibility of decentralized composting systems rests on well-defined bulking protocols, source separation, and stakeholder coordination. Collectively, the review confirms that feasibility in hawker-center settings is contingent not only on technical design but also on operational discipline across the waste management chain.

Establish Design

System Specification: At the establish design stage, the focus is on translating feasibility insights into a concrete system specification that can be operationalized at community or institutional level. The design process produced an Operational SOP Checklist, capturing technical, spatial, and procedural requirements to ensure consistency of practice. Among the key specifications was the adoption of a two-bay aerated static pile (ASP) system, selected for its balance between simplicity and performance in handling modest-scale waste streams. ASP technology provides forced aeration without the need for continuous turning, reducing labor intensity while maintaining aerobic conditions—an approach identified as best practice in decentralized composting systems (Sánchez, 2022). For the targeted daily flows of 40–50 kg of food waste, this modest-scale ASP offers a cost-effective and space-efficient fit, particularly for hawker centers or neighborhood-level facilities.

Additional design features included leachate drainage systems to manage the high moisture content typical of tropical food waste, preventing anaerobic runoff and minimising odour emissions. Furthermore, the SOP defined designated vendor disposal times, which serve to regulate the inflow of fresh waste, avoiding operational surges that could destabilise composting conditions. Similar procedural scheduling has been recommended in other decentralised pilots, where controlled input intervals supported microbial stability and reduced contamination (Ebrahimi et al., 2024). Beyond these technical parameters, design guidelines also incorporated bulking-agent staging areas and clear signage for waste segregation, reinforcing the importance of community participation and reducing contamination risk—lessons that align with Southeast Asian field experiences (Hibino et al., 2023).

Collectively, these specifications demonstrate how decentralised composting can be engineered as a low-footprint, modular system that is robust to the operational realities of tropical urban food waste streams. By codifying technical design, infrastructure requirements, and vendor interaction protocols into the SOP, the system establishes a replicable model for small-scale composting facilities embedded within urban ecosystems.

Engage Networks

Stakeholder participation: The fourth stage emphasises the critical role of stakeholder engagement, recognising that the success of decentralised composting systems hinges as much on social coordination as on technical design. At this stage, stakeholder networks are formally mobilised through training, awareness campaigns, and participatory monitoring mechanisms. Structured engagement ensures that responsibilities are clearly defined across all actors, building a foundation for long-term compliance and system sustainability. Table 1 tabulates the composting program stakeholders and their participation scope. Embedding these diverse actors into a participatory structure strengthens both compliance and ownership, reducing system abandonment risks over time. Prior studies highlight that social buy-in, transparency in responsibilities, and collective accountability are as decisive for composting viability as technical optimisation (Pai et al., 2019; Phooi et al., 2022). By aligning tasks across vendors, municipal staff, residents, and support organisations, the engagement framework cultivates a resilient governance structure that sustains decentralised composting as a viable, community-driven waste management solution.

TABLE I

Primary Stakeholders and their Scopes of Participation

Primary Stakeholders	Participation Scope
Food vendors / waste generators	Responsible for proper source-separation of food waste, adherence to designated disposal times, and minimization of contamination at the collection point. Their compliance is critical to maintaining feedstock quality and operational stability.
Pihak Berkuasa Tempatan (PBT) staff / municipal officers	Tasked with overseeing daily operations, ensuring adherence to the Standard Operating Procedures (SOPs), and monitoring feedstock volumes and leachate management. PBT officers also act as intermediaries between the community and regulatory bodies.
Community members / local residents:	Provide supplementary bulking agents such as dry leaves, sawdust, or cardboard, which help stabilize the composting process by improving aeration and balancing the C:N ratio. Community volunteers can also assist with pile turning (where relevant) and educational outreach.
Technical advisors / researchers	Offer capacity-building through training sessions, workshops, and periodic evaluations, ensuring that knowledge transfer supports continual improvement. Their role includes integrating monitoring data into iterative design adjustments.
Civil society groups / NGOs	Support awareness-building through campaigns, signage, and public events, reinforcing composting as a shared community responsibility rather than a top-down mandate.

Normalize Practice

Institutionalization: The final stage of the framework emphasizes institutionalization; whereby composting activities are no longer treated as pilot projects but are fully embedded into the operational and regulatory routines of municipal authorities (PBTs). At this stage, composting is integrated into everyday waste management practices through a series of measures that consolidate its technical, social, and policy legitimacy.

Key institutionalisation measures include:

- **Integration into municipal landscaping and greening programmes:** Compost produced is channelled directly into urban landscaping, parks, and roadside greenery, providing visible evidence of circular resource use and reducing reliance on commercial fertilizers. This use-phase pathway reinforces public trust by demonstrating tangible benefits of waste diversion.
- **Capacity-building and refresher training:** Regular quarterly training refreshers for food vendors and PBT staff ensure continuity of knowledge, reinforce compliance with source separation, and provide a platform for addressing operational challenges. Evidence from Southeast Asian decentralized composting experiences shows that periodic training significantly improves long-term system performance and reduces contamination rates (Nguyen & Nguyen, 2019; Hibino et al., 2023).
- **Monitoring and reporting mechanisms:** Institutionalization requires formalized reporting protocols, such as quarterly feedstock audits, compost quality checks (moisture, pH, nutrient content), and performance indicators (kg diverted from landfill, volume of compost reused). These reports support internal municipal planning and provide accountability to state and federal agencies.
- **Policy and legislative alignment:** Composting activities are aligned with Malaysia's National Solid Waste Management Policy and the Circular Economy Roadmap, which encourage organics diversion and resource recovery (Abdul Halim, 2025). They also echo calls for specific

food waste legislation, as highlighted in scholarly and legal commentaries (Wan Hafeeza, n.d.). By embedding composting into formal policy frameworks, PBTs ensure that these initiatives are shielded from administrative turnover and funding volatility.

This stage ensures that composting is not seen as a temporary or experimental intervention but as an integral component of urban governance, resource efficiency, and sustainability planning. It also directly supports Malaysia's commitments to Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), by institutionalizing food-waste diversion as standard municipal practice (Okayama & Watanabe, 2024; Abdul Halim, 2025). Through this normalization process, decentralized composting becomes part of the "new normal" for urban food-waste management—ensuring continuity, scalability, and alignment with national sustainability targets.

Discussion

The GREEN framework clarifies roles at each stage, thereby avoiding the "responsibility vacuum" that often undermines municipal composting (Lee, Ng & Kimaro, 2024). Vendors, PBT officers, and users each have codified tasks, ensuring shared ownership and accountability. The results confirm that composting initiatives require both technical rigor (e.g., bulking ratios, aeration) and social integration (e.g., training, vendor buy-in). By explicitly including "Engage" and "Normalize" as stages, the GREEN framework addresses gaps in previous interventions that overemphasised equipment at the expense of behaviour and governance (Ng et al., 2021; Sánchez, 2022). The GREEN framework is inherently replicable: its checklists and SOPs can be adapted across PBT-managed hawker centres with similar waste flows. By aligning technical design with stakeholder engagement and routine institutionalization, the framework supports Malaysia's circular economy agenda and broader SDG commitments (Abdul Halim, 2025; IIUM Law Majalla, 2025).

Policy Alignment and SDG Relevance

The GREEN framework directly supports Malaysia's National Solid Waste Management Policy (2005, updated 2016) and the National Circular Economy Roadmap by offering a decentralized, low-footprint solution for organic waste diversion. Current policy emphasizes waste minimization at source, reduction of landfill dependency, and valorisation of organic resources. By operationalising waste audits, process diagnostics, and site-specific composting design at hawker centers, the framework provides a scalable model that Pihak Berkuasa Tempatan (PBT) can adopt without requiring heavy infrastructure investment. This decentralised composting pathway complements national efforts to increase recycling rates and reduce greenhouse gas emissions from organic waste in landfills. Beyond national policy, the framework is also aligned with global sustainability agendas. It contributes to SDG 11 (Sustainable Cities and Communities) by enhancing local authority capacity to manage waste sustainably; SDG 12 (Responsible Consumption and Production) by promoting segregation, recycling, and nutrient recovery; and SDG 13 (Climate Action) by reducing methane emissions from landfills and closing the carbon loop through compost application. In doing so, the GREEN framework positions hawker-centre composting not merely as a waste management solution but as a pillar of circular economy transition at the community scale, linking local actions to global targets.

Case Studies

Regional experiences in neighbouring countries demonstrate the feasibility of decentralized food-waste composting and treatment systems that resonate with the GREEN framework. In Singapore, food waste constituted about 11% of country's total waste, with only 19% recycled, and the majority disposed of in waste-to-energy plants (incineration) This was the statistic for the year of 2020. The National Environment Agency (NEA) collaborated with the National University of Singapore (NUS) and the National Parks Board (NParks) to pilot an on-site anaerobic digestion (AD) system at East Coast Lagoon Food Village. The facility converts segregated hawker-centre food waste into biogas, which is used to generate electricity, and bio-fertiliser applied to landscaping. Crucially, the initiative combined technological solutions with behavioural interventions, including vendor training, signage, and segregation protocols, thereby ensuring operational success (National Environment Agency, 2021; National University of Singapore, 2021). A second study of a containerised 10.4 m^3 AD system in Singapore demonstrated microbial stability and efficiency over a 71-day operational period, underscoring the technical robustness of decentralised treatment at food-service hubs (Xiao et al., 2023).

In Indonesia, the city of Bandung scaled up the Takakura Composting Method (TCM), a low-cost aerobic composting technique relying on locally available bulking materials and passive aeration. The decentralised facility processed approximately one tonne of food waste per day and was evaluated using life-cycle assessment (LCA) and cost–benefit analysis (CBA). Results showed positive environmental and economic performance compared to landfill disposal, confirming the method's replicability in urban Southeast Asian settings with similar resource constraints (IGES, 2023). Manuals developed for Takakura further highlight its adaptability and community-friendly character, embedding household and small-enterprise participation into the composting cycle (IGES, 2006).

In Vietnam, case studies highlight both successes and challenges in municipal composting initiatives. In Hoi An, the Cam Ha composting facility revealed contamination of over 40% inorganic material in its feedstock, significantly undermining compost quality and acceptance by end users (Tran et al., 2023). This points to the critical role of source separation and public awareness in sustaining composting operations. Complementary research mapping the flow of biodegradable municipal solid waste in central Vietnamese cities such as Da Nang, Hue, and Hoi An identified inefficiencies in separation, stakeholder coordination, and system design, further underscoring the importance of integrating governance mechanisms with technical processes (Nguyen et al., 2023). Despite these challenges, the Vietnamese experience demonstrates a growing commitment to decentralised organics management and provides valuable lessons for Malaysia, particularly in the GREEN framework's "Engage" and "Normalise" stages, where consistent behavioural reinforcement and institutionalisation are vital.

Collectively, these regional precedents affirm that decentralised composting and treatment systems can be technically sound, socially acceptable, and environmentally beneficial when stakeholder engagement and governance protocols are embedded alongside the technological design. They provide concrete illustrations of how the GREEN framework's five stages—Generate, Review, Establish, Engage, and Normalise—can be operationalised in real-world contexts across Southeast Asia.

Conclusions

This study has demonstrated how an integrated GREEN framework—Generate, Review, Establish, Engage, and Normalise—can provide a structured pathway for implementing food-waste composting at the hawker-centre scale under Malaysian PBT governance. By coupling baseline audits with analytical diagnostics and design interventions, the framework ensures that food-waste composting is not only technically feasible but also socially embedded and institutionally sustainable. The framework's contribution lies in its ability to bridge global best practices with local operational realities, producing a replicable and context-sensitive model for waste diversion and circular-economy alignment. Findings highlight that successful implementation requires a combination of technical specifications (waste segregation, bulking agents, composting system design), institutional measures (clear roles for PBTs, vendors, and users), and community engagement (awareness campaigns, incentives, compliance monitoring). When these dimensions are aligned, small-scale decentralised composting can reduce landfill loads, cut operational costs, and contribute to broader sustainability goals. The paper therefore contributes to the literature by offering not only a methodological framework but also a practical governance model applicable to other food-service environments in Malaysia and beyond. Future work should empirically test the framework across multiple sites, refine indicators for success, and evaluate the long-term quality and application of compost in municipal landscapes.

Theoretical and Contextual Contributions

This study contributes theoretically by extending the discourse on circular economy and decentralized waste management through the formulation of the GREEN framework, which integrates governance, technical feasibility, and social engagement into a unified model. Unlike prior work that often isolates technical or behavioural dimensions, the GREEN framework demonstrates the value of embedding composting interventions within a socio-technical system that acknowledges institutional constraints and community participation. It advances the literature by operationalising concepts such as site-specific baselining, stakeholder engagement, and institutionalisation into actionable stages, thereby bridging the gap between abstract sustainability principles and practical municipal implementation. Contextually, the research is significant as it tailors international best practices to Malaysia's hawker-centre ecosystem—a distinctive, high-density subsystem of the food-service sector. By aligning with PBT governance structures, local bulking material availability, and evolving national policies, the study provides a replicable, low-footprint model that can be adopted across similar urban food courts in Malaysia and Southeast Asia. The framework thus enriches both academic knowledge and policy discourse, positioning hawker-centre composting as a strategic intervention for achieving SDG-aligned urban sustainability and reducing landfill dependency in developing-country contexts

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