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# Recent Malaysian Food Waste Generation Trends, Enacted Policies and Challenges in Food Waste Management

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## ABSTRACT

*Food waste (FW) presents a significant global challenge, particularly in Malaysia, where guidance on waste composition and management issues remains limited. This review examines current trends, policies, and obstacles in managing FW in Malaysia by systematically analyzing a range of publications and conference proceedings from the last 15 years (2008-2023). The methodology involved a comprehensive literature review, focusing on studies that address FW management practices and its challenges, technological advancements, and policy frameworks. Key challenges identified include incomplete data, low public awareness, underdeveloped digestion technologies, and insufficient knowledge of FW treatment methods. Effective FW management is contingent upon enhancing public awareness, improving waste segregation, and upgrading infrastructure. In light of current practices and policies, this review proposes an integrated management framework that combines wet anaerobic digestion with aerobic windrow composting, leading to the conversion of FW into biogas and final landfilling. This approach aims to minimize landfill dependency and promote a circular economy by transforming FW into renewable energy sources.*

*Keywords: Food Waste; Waste Management; Anaerobic Digestion; Aerobic Windrow Composting; Landfill*

## INTRODUCTION

Food waste (FW) is a prevalent issue impacting many countries globally. In urban regions, managing the waste produced by municipalities has become a substantial problem for the environment, with FW making up a large portion-approximately 44% globally and 70% in low-income nations [1-2]. Despite Malaysia's rich food variety, food wastage remains a common habit within the community, reflecting a concerning cultural practice [3].

The rising issue of FW in Malaysia, driven by urbanization and changing consumption patterns, necessitates a comprehensive evaluation of current policies and practices to identify gaps and challenges in public awareness, infrastructure, technology adoption, and stakeholder coordination. Many waste management researches at Malaysia focus on waste valorization and composting procedures [1], [4-5]. However, extensive explanations on recent Malaysian FW generation trends, enacted policies and challenges in FW management are frequently insufficient or omitted from the evaluations. Awareness about food waste recycling among Malaysians remains low. It is extremely helpful to recycle FW into a variety of products with added value.

Thus, this study reviews recent research on Malaysian FW generation, policies, and management challenges. This study is essential for addressing the rising FW issue in Malaysia. It aims to evaluate current policies, identify gaps, and explore challenges in public awareness, infrastructure, technology adoption, and stakeholder coordination. By incorporating behavioral insights and data analysis, the study seeks to provide comprehensive policy recommendations and innovative solutions for sustainable FW management in Malaysia. The study also outlines future research needs and perspectives.

## REVIEW METHODOLOGY

This section describes the approach used to collect articles on recent trends in food waste generation in Malaysia, the policies implemented, and the challenges in managing FW. The study methodology for this review involved examining different management strategies discussed in prior studies and publications related to food waste in Malaysia. Figure 1 illustrates the flowchart for the article selection and review process.

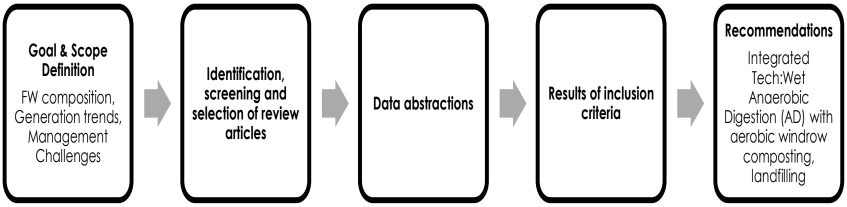



**Figure 1: Flowchart for the article selection and review procedure.**

Three primary databases were utilized for selecting research articles: Scopus, Google Scholar, and ResearchGate. Additionally, manual searches were performed to include relevant journals and conference proceedings. The following paragraph define the article selection criteria, keywords used, time period, sources and leagues, and finally the quality appraisal.

**Article Selection Criteria**: The articles selected for this review are chosen based on their relevance to FW issues in Malaysia, specifically focusing on FW generation trends, enacted policies, and management challenges. Each article must be directly related to food waste in Malaysia and provide either quantitative data, policy insights, or qualitative evaluations of current practices in the country. The studies should ideally explore broader implications on waste management to ensure a comprehensive analysis.

**Keywords Used**: Key search terms include "Food Waste Management," "Food Waste Generation Trends," "Malaysia Food Waste," "Food Waste Policies Malaysia," and "Waste Management Challenges Malaysia," among others. These keywords are carefully chosen to capture studies that delve into various aspects of FW, including management practices, environmental impact, policy-making, and specific challenges related to urban FW in Malaysia. By using these targeted keywords, the review aims to encompass diverse perspectives and insights on FW handling in Malaysia.

**Time Period**: The review covers a 15-year timeframe leading up to the publication date, capturing recent and relevant developments in FW trends, policies, and challenges in Malaysia. This period is chosen to reflect recent changes and adaptations in response to FW challenges while providing enough historical context to observe significant shifts over time. For instance, if the publication year is 2024, articles from 2008 onward are included, creating a balanced view of long-term trends and recent innovations.

**Sources and Leagues**: The review draws from a mix of peer-reviewed academic journals, reputable conference proceedings, and government reports that focus on waste management, environmental science, public policy, and sustainable development. Additionally, international sources, particularly those covering ASEAN or regions with similar economic and cultural contexts, are included to provide comparative insights. This diverse set of sources ensures the review incorporates authoritative perspectives on food waste challenges and solutions.

**Quality Appraisal**: Articles are appraised based on consistency with the review's core themes, methodological rigor, and depth. Only studies that meet a baseline of relevance, quality, and recentness are included, with a preference for those offering data-driven insights or in-depth policy evaluations. This consistent quality control ensures a well-rounded and credible foundation for analyzing recent trends, policy enactments, and challenges in Malaysia's FW management efforts.

## RESULTS AND DISCUSSIONS

### Recent Malaysian FW Composition, Generation Trends, Enacted Policies

In 2019, FW constituted 44.5% of Malaysia's municipal solid waste, emphasizing the significant role of FW as a major component of organic waste globally. Contributing factors include rapid urbanization and population growth, which result in substantial amounts of organic waste annually. This information underscores the urgency for efficient food waste management strategies and might benefit from additional citations to solidify its credibility.

In Malaysia, a substantial amount of FW is produced by eateries and food courts, where busy lifestyles drive people to dine out frequently. This trend parallels observations in Singapore, where similar urban lifestyles and a reliance on food courts, hawker centers, and eateries also lead to significant FW, highlighting shared regional concerns [6]. Other major sources include supermarkets, households, commercial establishments, and the beverage industry. Table 1 shows the FW composition in Malaysia and the data were extracted from several sources.

**Table 1: Percentage of Malaysian MSW composition as reported by multiple authors.**

| Material | a* | b* | c* | d* | e |
|---|---|---|---|---|---|
| Food/organic/ yard waste | 44.7 | 55 | 40.61 | 46.94 | 50.3 |
| Plastic | 12.9 | 13 | 18.92 | 20.28 | 13.2 |
| Paper | 18 | 19 | 16.78 | 17.89 | 8.5 |
| Glass | 2.2 | 2 | 2.68 | 2.6 | 3.3 |
| Metals | 2.0 | 3 | 3.4 | 4.31 | 2.7 |
| Textile/rubber/ leather | 8.6 | 4 | 5.1 | 0.17* | 5.3 |
| Tetra Pak | - | - | - | - | 1.6 |
| Wood | 1.4 | 1 | 3.78 | - | 1.4 |
| Organic fines | - | - | 4.47 | - | - |
| Diapers | - | - | - | - | 12.1 |
| Others | 10.2 | 3 | 7.16 | 7.81 | 1.8 |
| Total (%) | 100 | 100 | 100 | 100 | 100 |

[a] Kalantarifard and Yang [7]; [b] Agamuthu and Fauziah [8]; [c] Noor *et al.*, [9]; [d] extracted from Abba [10], [e] SWCorp [11]

Over the past three years, food waste from uneaten food in Malaysia has doubled, with nearly half of the 31,000 tons of daily solid waste consisting of organic kitchen waste [12]. A 2005 study revealed that Malaysia generated 7.34 million tons of municipal solid waste, with projections indicating an increase to 10.9 million tons by 2020. Food waste accounted for 60% of this total. From 2002 to 2010, local authorities consistently found FW to be the largest component of solid waste each year, with 56.3% of the total waste generated in 2003 being FW [10].

As the population grows faster than food production, it is essential to manage FW effectively to ensure that the food that is already produced is used wisely for the benefit of humanity. While economy is still accelerated, FW grows larger at the same time [12]. Consistent with the Master Plan (depicting Figure 2 as a reference), the government intends to reach a 22% recycling rate by 2020 [1], [3]. However, the implementation of Act 672 began on September 1, 2011, and the 2+1 garbage collection method became the new standard. In a week, recyclable garbage, including bulky and green waste, is collected over two (2) non-consecutive days, whereas residual rubbish is collected over one (1) day. It was mandatory for the citizens of the states of Johor, Pahang, Melaka, Negeri Sembilan, Perlis, and Kedah, as well as the Federal Territories of Kuala Lumpur and Putrajaya, to separate their waste into four categories: paper waste, plastic waste, residual waste, and other recyclable materials.

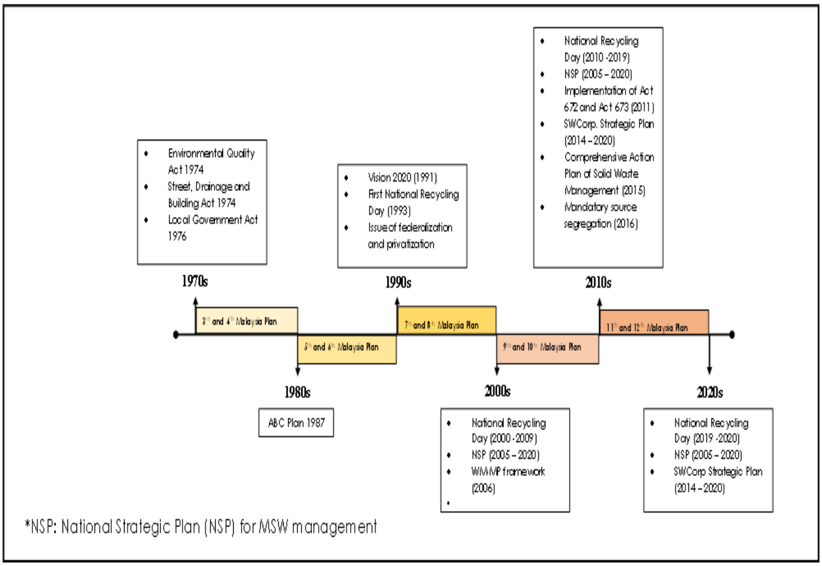



**Figure 2: The creation of national policies and programs for the management of MSW and FW in Malaysia [1].**

## Current FW Disposal Practice

In Malaysia, solid waste management has historically depended on landfilling. Currently, 93% of active landfills are categorized as open dumps, with only 7% designated as sanitary landfills. To address environmental issues, advanced landfill technologies have been introduced. Best practices are exemplified by landfills such as Pulau Burung, Seelong, Bukit Tagar, Jeram, and three others in East Malaysia, which are designated as Level 4-Sanitary landfills. These facilities adhere to Malaysian Technical Guidelines and feature soil cover, embankments, drainage systems, gas venting, leachate collection and treatment, and liners [13].

Alternative solid waste management methods in Malaysia include incineration, resource conservation, and recycling programs. More than 75% of municipal solid waste in Malaysia is recyclable, including materials like paper, glass, metal, plastics, and compostable organic waste. Several municipalities have increasingly focused on resource recovery and waste-to-energy technologies, such as generating biogas through anaerobic digestion (AD) of organic waste. A notable example is the modern dry AD plants developed in Malaysia, such as those operated by the Petaling Jaya City Council in Selangor. This council can process approximately 500 kg to 1 ton of food waste per day using dry AD technology [14].

In urban areas like Sunway City and the Sime Darby Convention Centre in Mount Kinrara, on-site aeration systems are preferred, capable of processing about 300 kg to 1 ton of FW per day. This service is provided by Mentari Alam EKO (MAEKO 2019), a Malaysian company specializing in FW management. Furthermore, in September 2019, the Japan International Cooperation Agency (JICA) and Merry Corporation provided support for the launch of a public-private partnership project in Cameron Highlands, Pahang, by the Solid Waste Corporation Malaysia [3]. Through this partnership, the benefits and efficiency of a composting system that tackles the problems associated with waste volume reduction will be demonstrated [3].

However, some private FW composting sites, such as Ban Foo in Ulu Tiram and Sutera Folo in Tanah Sutera Developments Johor, use windrow composting techniques, each handling around three tons of FW daily. While effective for certain types of organic waste, windrow composting can be challenging for food waste due to odor issues, attraction of pests, and space requirements, making it less suitable in densely populated or urban settings [14-15].

## Challenges in Food Waste Management

### Incomplete database on the Malaysian FW management

Because neither national study nor local authorities conduct regular and periodic research and records, Malaysian FW management information is insufficient, resulting in incomplete databases [3]. A thorough feasibility study was carried out to create a methodical, on-site, and fully operational organic waste treatment system because there is a dearth of comprehensive information on organic waste management in Malaysia. This program is intended to serve as the foundation for the development of a circular economy. FW has emerged as a novel raw material, accounting for more than 45% of municipal solid waste, especially in developing nations such as Malaysia [4].

By maximizing the reuse of products and raw materials for as long as possible, a circular economy aims to eradicate waste. Establishing an efficient treatment system that includes collection, preparation, processing, monitoring, and distribution of the finished product is necessary to achieve the aim of a circular economy, which is to recycle all organic waste and turn it into value-added products [4]. To fully support a circular economy in food waste management, an efficient treatment system must integrate all stages from collection to distribution of recycled organic products.

Malaysia's growing emphasis on food waste treatment facilities, including AD centres, has spotlighted the importance of structured collection and preparation processes that channel organic waste toward energy and fertilizer production rather than landfills. Studies emphasize that such systems require consistent monitoring and quality control to meet environmental standards and ensure that the final products, like biogas and compost, are safe and effective for public use [16].

An integrated approach, as seen in best practices from countries like Singapore, suggests the need for policies supporting local composting and AD sites, as well as technological advancements for efficient waste handling. Enhanced monitoring systems and streamlined waste-to-product conversion not only contribute to minimizing food waste but also generate economic value from it. Therefore, expanding Malaysia's AD facilities and setting quality standards at each stage of food waste processing could help achieve the aims of a circular economy. The addition of consistent oversight in processing and distribution can improve the effectiveness and sustainability of these circular systems [16-17].

## Low level of awareness among society

It has proven difficult to separate FW and other organic waste from the regular garbage stream in Malaysia. The lack of awareness among the local population is the main obstacle to implementing sustainable solid waste management [3-4]. The community's active involvement is crucial to the success of these programs, even in cases where there are explicit community guidelines or procedures for FW disposal. It is the responsibility of stakeholders to educate and inspire society to take an increased interest in environmental issues. The following guidelines should be added to the ISO 14001 recommendations to implement efficient waste management systems, such as a) facility improvement plan, the amount of financial and human resources available, and the existence of an environmental management plan; b) the control procedures in place (such as systematic environmental management, audits, and management reports); and c) the extent of community participation in the program.

Raising public awareness about food waste management in Malaysia can be effectively supported through initiatives like AD projects, which demonstrate how food waste can be transformed into renewable resources, thereby fostering understanding of sustainable practices. Government and municipal councils contribute significantly to these efforts by organizing campaigns, workshops, and public events that promote food waste segregation and recycling. Additionally, the active involvement of residents in waste separation, composting programs, and community-led food waste reduction campaigns plays a crucial role in the success of such initiatives.

To support community involvement, the ISO 14001 recommendations could integrate guidelines that emphasize public engagement. For example, involving residents in facility planning, promoting public feedback in environmental audits, and encouraging community participation in waste reduction programs can build trust and shared responsibility. Adding these elements to the ISO framework not only enhances transparency but also creates a robust system for sustainable waste management through active community involvement.

## Numerous underdeveloped aerobic and anaerobic digestion technologies

Large-scale aerobic composting technologies are poorly studied, particularly with regard to food waste, which is more varied than agricultural waste [4]. AD plants encounter various technical and managerial challenges, such as inadequate financial investment, significant distances from the electricity grid, a lack of skilled professionals, and the absence of a collaborative approach to tackle these issues. This is particularly evident in countries like Malaysia, where financial support for developing a comprehensive waste management system is limited [4].

In the year 2012, due mainly to inadequate research and development that has not kept up with technological advancement, the main factors influencing dry AD and integrated wet AD management are still largely unknown [18]. Since AD is still not widely recognized in Malaysia, it may be difficult to find highly skilled engineers and technicians to properly manage and maintain AD plants [19].

However, the recognition and implementation of AD in Malaysia have seen significant progress in recent years, particularly since the establishment of Malaysia’s first large-scale AD facility in Ampang Jaya in 2022. This facility processes FW from several sources, including hotels and food stalls, converting it into biogas and liquid compost. This has underscored AD's benefits, especially in food-waste-heavy regions, and demonstrates the potential for expanding this model across other areas in Malaysia as part of the broader sustainability agenda.

Although previously AD faced limited recognition, the approach is gaining momentum as municipalities increasingly see its environmental and economic advantages. The Ampang Jaya facility, for example, contributes to waste reduction efforts by diverting food waste from landfills, and it has already converted over 35,000 kg of food waste into compost within its first operational year. This development shows that the demand for skilled personnel to operate AD plants will likely grow as Malaysia moves toward scaling similar projects across the country. Nevertheless, given the relatively recent expansion, there may still be a shortage of specialized expertise, especially as new facilities develop and more advanced AD systems are implemented. For further reading, see sources like The Vibes and Business Today for detailed updates on Malaysia's AD expansion. While technological solutions are available and in use, significant improvements are needed [4].

Adopting a collaborative approach can address challenges in FW management by fostering partnerships that encourage information sharing, resource pooling, and coordinated actions among stakeholders [20], such as explanation follows:

i. Facilitating Information Sharing: Collaboration enables stakeholders, including government agencies, businesses, researchers, and waste management companies, to share valuable data on waste generation, effective technologies, and best practices. For example, businesses in the food industry can share insights into waste reduction practices, while researchers can provide data on innovative waste treatment methods. This collective knowledge helps identify effective solutions and reduces duplication of effort, allowing for quicker, more targeted improvements in FW management.

ii. Pooling Resources: Collaborative efforts often allow stakeholders to pool financial, technological, and logistical resources, which can significantly enhance FW management capabilities. For instance, a local government and private companies could co-invest in shared composting facilities or anaerobic digesters, reducing the cost burden on individual entities. Shared resources also make advanced technologies more accessible, facilitating large-scale FW treatment that might otherwise be financially prohibitive.

iii. Policy and Regulatory Support: Collaboration between policymakers and industry stakeholders enables the development of regulations and incentives that align with the capabilities and needs of all parties involved. When businesses and waste management entities work closely with regulatory bodies, they can help shape policies that are both practical and effective, such as tax incentives for companies adopting sustainable waste management practices or grants for research in innovative FW technologies.

iv. Creating Win-Win Solutions: By working together, stakeholders can create solutions that benefit multiple parties. For example, food businesses can reduce disposal costs by partnering with composting facilities that repurpose food waste into biofertilizer, which in turn can be used in local agriculture. This mutual benefit encourages ongoing collaboration and commitment to FW reduction efforts, creating a self-sustaining cycle that addresses food waste and supports environmental goals.

v. Community Engagement and Awareness: Collaborative efforts often extend to public education and awareness campaigns, which are critical for changing consumer behavior and promoting waste reduction. Government agencies, NGOs, and businesses can work together on awareness programs to educate communities on FW reduction, recycling, and responsible disposal practices. This helps build a culture of sustainability that extends beyond industry practices to everyday behaviors, further reducing FW at the source.

In summary, a collaborative approach leverages the strengths of various stakeholders, fosters innovation, and builds a supportive regulatory and community environment. This unified effort enables more efficient, large-scale solutions to the complex challenges of FW management, ultimately benefiting all parties involved and enhancing sustainability [20].

## Lack of adequate knowledge for different facilities of FW treatment method

Proper solid waste management in Malaysia faces significant challenges, including a shortage of skilled technical teams and inadequate waste segregation facilities [18]. Moreover, many residents lack the knowledge necessary for effective composting [4]. Assessments often miss detailed information about the types of composting managed, as seen in studies by Azahari *et al.* [21], Abba *et al.* [10], Tarmudi *et al.* [22], Latifah *et al.* [23], and Samah *et al.* [24]. Different FW technologies present unique issues, such as varying emissions and energy needs, which affect their outcomes [25-26]. Figure 3 shows that proper management of FW composting entails adjusting parameters like as carbon-to-nitrogen ratio, pH, moisture content, particle size, aeration rate, and porosity. Overall, the various FW management strategies differ in their environmental efficacy, economic viability, and societal acceptability [27].

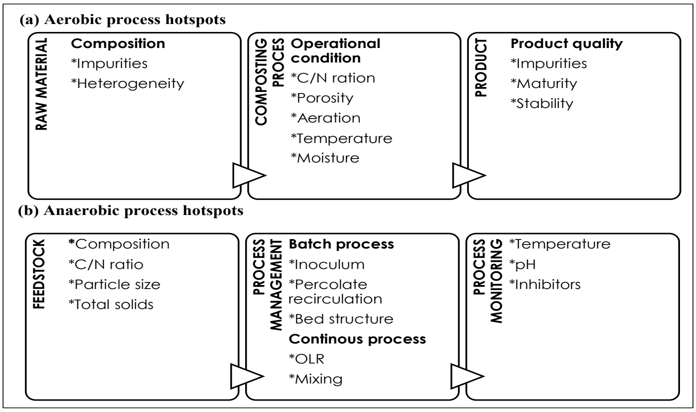
In composting, greenhouse gas emissions can arise from fossil fuel use during waste transport and processing, fugitive emissions during composting, and emissions from land after compost application [28]. Inaccuracies for preparing and procedure handling can lead to odour emissions, higher environmental impact, and the creation of poor-quality compost [29]. Assessing compost quality is complicated due to different methods for determining maturity and stability, particularly for FW, where contaminants must be considered. Compost quality influences its effectiveness for soil bioremediation and other uses [4]. In AD, pollutants contributing to global warming potential mainly stem from background operations like electricity generation and water usage [1].

Ozone depletion is a critical concern in wet AD processes primarily due to the high-water requirements and subsequent emissions associated with the treatment of FW [6]. Wet AD systems operate with significant amounts of water to maintain optimal moisture levels, which can lead to emissions of nitrogen oxides ($NO_x$) and ammonia ($NH_3$) that contribute to ozone depletion when released into the atmosphere. This environmental drawback makes it essential to explore alternatives or improvements in wet AD processes, such as enhanced waste gas treatment and water-efficient designs [6].

An alternative to wet AD is batch dry anaerobic digestion, which requires less water and may reduce emissions associated with ozone depletion. However, batch dry AD systems are less researched, and their efficiency depends on several factors, including the inoculum-to-substrate ratio, which affects microbial activity and digestion rate. Feedstock amount and particle size also play a crucial role, as smaller particles offer more surface area for microbial breakdown, enhancing biogas production. Fluid recirculating and bed compression further influence microbial access and gas distribution, potentially improving yield. Additionally, boosting agents like enzymes or microbial additives can accelerate the breakdown of organic materials, making batch dry AD a promising alternative that warrants further study [30].

To optimize continuous dry AD systems, which provide a steady and efficient approach to FW digestion, key operational factors must be closely managed. Feedstock composition directly impacts the microbial community and digestion efficiency; for example, higher carbohydrate content typically increases biogas yield. The organic feeding rate is also critical—too high a rate may overload the system, while too low a rate may slow down biogas production. Furthermore, blending procedures that ensure uniform distribution of feedstock can enhance the contact between microbes and substrates, further optimizing the digestion process [30].

In summary, while wet AD systems face challenges related to ozone depletion due to high water usage and emissions, both batch and continuous dry AD offer promising solutions with unique operational needs. Detailed research into these parameters can pave the way for more sustainable and efficient AD practices, ultimately reducing ozone depletion impacts while supporting renewable energy production from food waste [30].




*OLR: organic loading rate; pH: per hydrogen, C/N: Carbon to nitrogen ratio

**Figure 3: (a) Aerobic composting of FW research hotspots (Cerda *et al*., 2018); (b) Anaerobic treatment of FW research hotspots (Rocamora *et al.,* 2020)**

## RECOMMENDATIONS

Technological advancements have greatly enhanced FW treatment options, making it possible to redirect organic waste from landfills toward more sustainable solutions like composting and AD. Modern techniques, including biological, mechanical, chemical, and thermal treatments, allow FW to be processed efficiently. Composting and AD not only reduce the volume of waste going to landfills but also lower greenhouse gas emissions by capturing methane and carbon emissions. Additionally, these methods improve soil quality by converting organic material into valuable compost and biofertilizers, supporting sustainable agriculture and reducing the reliance on chemical fertilizers.

Furthermore, awareness is indeed one of the key factors in effective FW management. Raising awareness among consumers, businesses, and policymakers is essential for reducing FW generation, as it promotes more responsible behavior at every stage of the food chain—from production to consumption. Increased awareness helps individuals recognize the environmental, economic, and social impacts of FW, encouraging practices like proper meal planning, portion control, and donation of surplus food. Moreover, awareness campaigns can inform people about sustainable disposal methods, such as composting, recycling, and donation, reducing the amount of organic waste sent to landfills. When combined with policies, incentives, and accessible food waste management systems, awareness can drive behaviors change, making it one of the foundational elements for any successful FW management strategy.

Finally, effective waste segregation practices and appropriate infrastructure are essential for efficient FW management and achieving environmental sustainability.

i. Effective Waste Segregation Practices: Waste segregation involves sorting waste at the source (households, businesses, and institutions) into different categories—such as food waste, recyclables, and general waste. This separation allows FW to be directly processed through methods like composting or anaerobic digestion, while recyclables can be sent to recycling facilities. Effective segregation minimizes contamination of FW, improves the efficiency of downstream processes, and enhances the quality of byproducts like compost or biogas. Additionally, it reduces the volume of waste sent to landfills, lowering methane emissions and leachate production, which can harm the environment.

ii. Appropriate Infrastructure: Supporting waste segregation practices requires robust infrastructure that includes accessible collection points, specialized bins, and clearly labeled disposal options for different types of waste. Proper infrastructure enables systematic transportation of food waste to treatment facilities such as composting sites, anaerobic digestion plants, or biogas facilities. Well-developed infrastructure also involves logistics for regular and reliable collection, processing equipment suited to various waste types, and facilities for recycling, composting, or energy production. Such infrastructure ensures that segregated waste can be processed safely and efficiently, turning waste into valuable resources while minimizing environmental impact. Together, effective segregation and appropriate infrastructure form the backbone of a sustainable waste management system that not only diverts waste from landfills but also transforms it into beneficial byproducts, advancing a circular economy model.

## Integrated Wet Anaerobic Digestion combined aerobic windrow composting with A Landfill technology for FW Management

FW management is crucial for renewable energy and sustainable development, particularly through biomethane potential (BMP) and resource recovery from biofertilizer via composting. This proposed technology for FW treatment combines anaerobic wet digestion with landfilling as illustrated by Figure 4. In an integrated approach to FW management, combining wet AD, aerobic windrow composting, and landfilling allows each method to complement the others, optimizing efficiency and enhancing environmental outcomes.

i. Wet Anaerobic Digestion (AD): This process is ideal for handling high-moisture food waste, breaking down organic material in an oxygen-free environment. It generates biogas—a renewable energy source that can offset fossil fuel use—and produces digestate, a nutrient-rich byproduct that can be used as biofertilizer. By diverting wet, organic-rich waste to AD, the approach reduces waste volume early in the process, lessening the load on other treatment methods.

ii. Aerobic Windrow Composting: For drier organic materials, windrow composting works well, decomposing organic matter in an oxygenated setting to produce compost, which improves soil structure and fertility. Using composting alongside AD provides a flexible solution for food waste that may not be suitable for AD, like certain solid or low-moisture materials. Composting also reduces the need for chemical fertilizers, enhancing the soil while capturing carbon in a stable form.

iii. Landfilling as a Last Resort: While landfills are typically considered the least sustainable option due to methane emissions and groundwater contamination risks, they serve a crucial role in handling residual waste that cannot be processed by AD or composting. By diverting the bulk of organic waste to AD and composting, the amount of waste reaching landfills is minimized, reducing the associated environmental impacts.

iv. Enhanced Efficiency and Environmental Benefits: By assigning each type of waste to the most suitable treatment method, an integrated approach reduces overall waste volume, minimizes greenhouse gas emissions, and generates valuable byproducts like biogas and compost. This synergy maximizes the strengths of each process while mitigating their individual limitations, such as AD's need for specific moisture levels and composting's space and odour considerations.

In this way, combining these techniques forms a holistic FW management system that not only manages FW more effectively but also aligns with environmental goals, contributing to sustainable energy production, soil enhancement, and waste reduction. Despite integration, complete elimination of landfilling is not feasible for either AD or composting, as a portion of inorganic waste residues after sorting still needs to be landfilled. Nevertheless, this portion has been scaled down [25]. Similar to the standalone system, the integrated wet AD system sends around 30% of its rejected food waste and contaminants (such plastics and metals) from pre- and post-treatment to a nearby conventional landfill.

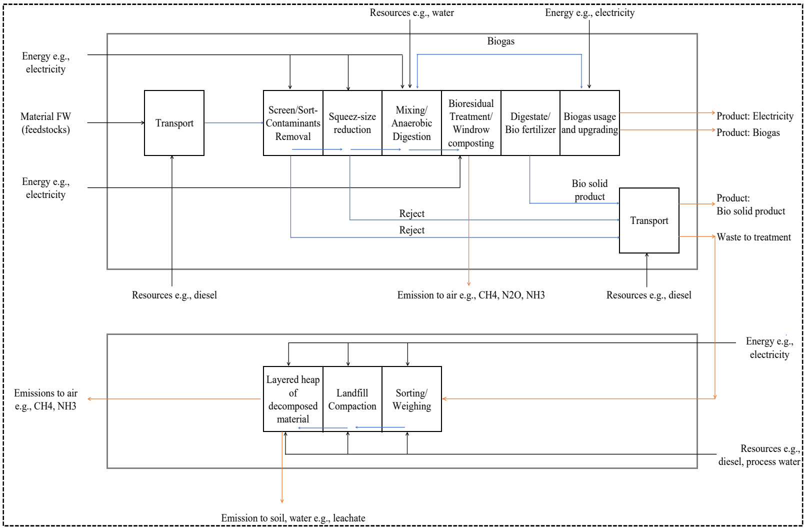



**Figure 4: The treatment systems that include integrated wet AD, coupled aerobic windrow and landfill.**

## CONCLUSIONS

This review highlights the recent composition, generation trends, policies, and challenges in managing FW in Malaysia, emphasizing issues like incomplete data, low public awareness, underdeveloped digestion technologies, and inadequate knowledge of FW treatment methods. Successful food waste management depends on public awareness, effective waste segregation practices, and appropriate infrastructure. Future research should take into account social, cultural, and technological factors to develop a sustainable system. Feasibility analyses for organic waste treatment systems and public education on FW segregation are crucial. A sustainable FW management strategy must integrate environmental, economic, social, and infrastructural factors.

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