ORIGINAL ARTICLE

Environmental Impacts of Indian Muslim (*Mamak*) Restaurant Daily Operation in Two Suburban Malaysian Districts: A Cross-sectional Study

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ABSTRACT

Introduction: Food waste has gained significant attention from the public, academic, and government due to its significant contribution to greenhouse gas emissions. However, little information is available on the magnitude and patterns of food waste of Indian Muslim (also known as *Mamak*) restaurants in the foodservice industry. This study aimed to explore food waste generation and carbon footprint of daily activities at *Mamak* restaurants in North Seberang Perai (NSP), Penang and Semenyih, Selangor. **Materials and methods:** Direct weighing food waste method was adopted in ten *Mamak* restaurants within the study areas, which were chosen mainly based on their operation hours. These districts were selected due to their increasing development as suburban areas. Waste from preparation loss was weighed at the end of the restaurant's operation. Electricity and water consumption were recorded and calculated for carbon footprint. **Results:** : A total of 78.09 kg and 88.91 kg of food waste were generated per week in NSP and Semenyih, respectively, making up 40.78% of the total carbon footprint from both districts, amounting to 122.85 kgCO_2e. This constituted the second-largest contributor after energy consumption, which accounted for 45.99% of the total emissions. **Conclusion:** Our findings highlight the significant role of food waste in the carbon footprint of *Mamak* restaurants, underscoring the need for sustainable waste management practices. Potential intervention includes exploring black soldier fly larvae composting for waste management. This study also suggests that *Mamak* restaurants in suburban areas generate similar levels of food waste compared to urban areas, emphasizing the need for industry-wide solutions.
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Keywords: *Mamak* restaurants, Food waste, Carbon footprint, Daily operation, Malaysia

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INTRODUCTION

Food waste is a ubiquitous issue that plagues societies all over the globe. The Dutch researchers argue that every individual across the world is responsible for wasting approximately 500 calories of food on a daily basis (1). This may be attributed to the pressure on time experienced by working adults, which has led to a change in consumer behaviour from purchasing grocery store foods to opting for restaurant meals (2). When discussing the proportion of food wasted in the worldwide foodservice industry, the numbers from European (EU) FUSIONS (3) and United Kingdom (UK) Waste and Resources Action Programme (WRAP) (4) are frequently referenced. According to these data, foodservice businesses in the EU-28 countries and the UK generate roughly 11 and 1.1 mega tonnes of food waste per year, respectively. This represents approximately 12% of the total food waste produced across the food supply chain in both regions. By extending this figure globally, based on the total food waste of 1.3 billion tonnes (5), it is estimated that the global foodservice industry may waste over 150 million tonnes of food annually. Research has also revealed that a substantial portion of the world's greenhouse gas (GHG) emissions, amounting to 26%, can be attributed to food production (6). It is noteworthy that 24% of this can be linked to food waste. Besides, not only food waste has detrimental effects on resource preservation, food security, and the environment, but it also incurs social and economic expenses.

Malaysia is a nation that is renowned for its cultural diversity, which is reflected in its people, customs, and cuisine. The diverse ethnic makeup of Malaysia has had a profound impact on the local food scene, as evidenced by the growing number of restaurants that cater to a variety of tastes and preferences (7). This trend

aligns with the expansion of the foodservice industry. In particular, Indian Muslim, or *Mamak*, restaurants have gained immense popularity among Malaysians and are poised for continued success in the years to come. These restaurants have become an integral part of Malaysian culture and daily life, just as Westerners frequent bars and pubs, according to Zawawi and Ibrahim (8). The factors that have contributed to the success of *Mamak* restaurants include their location, ambiance, food offerings, facilities, and pricing (7). The President of the Malaysian Muslim Restaurants Operators Association (PRESMA) stated that the *Mamak* restaurant industry brings in significant revenue and contributes roughly US$ 1.7 billion to the Malaysian economy (9). This indicates that *Mamak* restaurants, as small and medium-sized enterprises, make a substantial contribution to the Malaysian economy compared to other ethnic-based restaurants (7).

Mamak restaurants offer a wide variety of food items in their menus to attract a large number of customers, who are then able to select from the diverse options available. However, increasing the variety of food options can also lead to an increase in food waste, as significant amount of surplus food are produced and results in a substantial quantity of leftover food waste (10). This problem is further compounded when economic incentives and customer behaviour conflict with other societal goals of reducing food waste (11). As a result, restaurants play an important role in managing food production and addressing this issue. Overproduction of food leads to an increase food waste, which represents a loss of energy, water, and agricultural resources in the food production. Furthermore, the lack of effective waste management strategies, such as proper tracking of surplus food or the implementation of sustainable disposal methods, exacerbates the issue of food waste. Many food establishments in Malaysia, including *Mamak* restaurants, operate without structured systems to monitor, reduce, or repurpose food waste, which contributes to inefficiencies and environmental burdens. Despite the growing awareness of food waste's environmental impacts, specific data on waste management practices and their role in GHG emissions from *Mamak* restaurants remain limited.

This study aims to investigate food waste generation patterns and their associated GHG emissions within *Mamak* restaurants in Malaysia, focusing on two developing suburban districts, North Seberang Perai (NSP) and Semenyih. By addressing a gap in existing research on food waste in *Mamak* establishments (12-14), this study builds upon prior research on food waste patterns in restaurants (15), and emission hotspots in the Malaysian food industry (16). Food preparation losses in *Mamak* restaurants were measured and patterns across the establishments were analysed. Water and electricity usage was monitored daily, and Material Flow Analysis (MFA) was employed to visualize the carbon footprint associated with these resources and food waste. This would also delineate the proportion of each studied emission released by the restaurants, encompassing raw materials and energy utilized throughout their operations. A systematic literature review on the relationship between food waste, carbon footprint and restaurant was conducted prior to find gaps in the literature and address the need of conducting this study. By providing a comprehensive picture of food waste generation and its related GHG emissions in *Mamak* restaurants, this study can inform the development of effective green prevention and intervention strategies. These strategies can then be implemented by restaurants to mitigate the social, economic, and environmental consequences of wasting food, energy and water resources.

MATERIALS AND METHODS

Systematic literature review

A systematic review was conducted across three prominent databases: Web of Science, Scopus, and ScienceDirect, to assess the literature on the relationship between food waste, carbon footprint, and restaurants. This review followed key principles outlined in the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) framework to ensure a transparent and rigorous selection process. This systematic review was intended to provide a solid foundation for this study, which aimed to broaden the understanding of the environmental impact of restaurant operations by (i) providing a robust knowledge base on current knowledge gaps, methodologies, and key findings related to food waste and carbon footprint in restaurant operations, and (ii) enabling benchmarking of environmental impacts across different types of restaurants, geographical regions, and operational practices. The search on the databases utilized three specific keywords: "food waste" AND "carbon footprint" AND restaurant. Filters were applied to include only references from 2023-2024, articles as the document type, and English as the language. This approach ensured a focused and current overview of relevant studies. Initial searches yielded 3 studies from Web of Science, 5 from Scopus, and 117 from ScienceDirect. The retrieved articles were then screened for duplicates and relevance to the keywords, resulting in the exclusion of duplicate entries and unrelated studies.

Type of restaurant and site selection

Mamak restaurants, which are an essential part of Malaysian culture and serve a large customer base late into the night, likely generate a significant amount of food waste due to their generous portion sizes and extended operating hours. Reducing food waste in these establishments can lead to cost savings by adjusting portion sizes and ordering practices, thereby lowering operational expenses and boosting profits. From an environmental standpoint, studying food waste in *Mamak* restaurants can help pinpoint areas where

methane emissions, a potent greenhouse gas found in landfills, can be reduced. This, in turn, can help mitigate the impact of climate change. For this study, five *Mamak* restaurants, from Semenyih, Selangor, and NSP, Penang, were selected and participated for one week. The duration of observation and the quantity of the food premises selected were deemed appropriate based on prior research in Finland that utilised the same parameters (17).

Selangor, with approximately 27,000 eateries, has the highest number of registered foodservices in Malaysia (18). Semenyih is a developing residential and educational area that experiences rapid growth in food businesses around college campuses due to predictable business cycles and a customer base. As a result, the area is of interest because both residents and college students frequent *Mamak* restaurants for social gatherings and affordable meals. It is crucial to evaluate food waste in Semenyih's restaurants, as nationally, Malaysia discards a significant amount of food daily (over 17000 tonnes) (19), and Semenyih's restaurants are likely contributing to this total. Given that Semenyih is part of the Hulu Langat district, which has a population exceeding 1.4 million (20), and undergoes development projects expected to attract more residents and businesses, studying food waste now can establish sustainable practices that will benefit the environment by reducing methane emissions from landfills, address hunger through food bank donations, and improve restaurant economics through lower food purchase costs. Meanwhile, NSP was selected due to its status as an administrative district on the mainland of Penang State, Malaysia, covering a total area of 267 km^2 (21). Studying food waste in restaurants of NSP, a developing region with a population of approximately 340,000, of which 60% are Malays, 28% are Chinese and 6% are Indians, is crucial. While specific restaurant waste data is lacking, a pilot programme in Seberang Perai called "Circular Neighbourhood" documented significant food waste generation (about 1.35 tonnes daily) around Tambun Indah Market, which likely includes restaurant discards (22). As the region undergoes development projects that are expected to increase population, studying food waste now can establish sustainable practices to manage waste effectively, benefiting the local economy, environment, and society. Importantly, *Mamak* restaurants originated from Penang, where *nasi kandar* is a staple food in the local population.

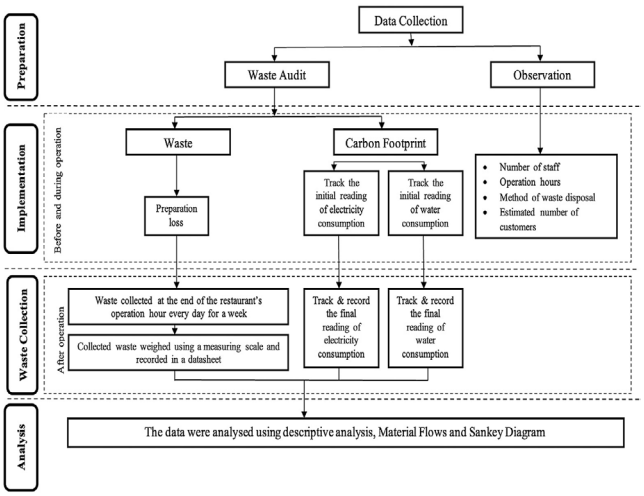

Figure 1: Study framework to elucidate GHG emissions from the daily activities of Mamak restaurants.

Food waste assessment

This study employed a targeted approach to select *Mamak* restaurants within the chosen areas. Unlike random selection, restaurants were chosen based on observable characteristics to ensure a representative sample (23). Instead of random selection, *Mamak* restaurants were chosen based on three key characteristics, aiming for similarity in each: average daily customers, their operating hours, and number of staff. Restaurants with similar average daily customer counts were included. This helps control for potential differences in waste generation based on clientele size. Since operating hours can influence food preparation practices and potentially waste, restaurants with similar operating hours were considered. Staff numbers can impact food preparation methods and potentially waste generation. Therefore, restaurants with a similar number of staff members were included. Focusing on quantifiable waste, this study measured preparation waste (PREP). This involved weighing the food waste generated during preparation and cooking activities after the restaurants closed (14). PREP waste typically includes items like vegetable peels and spoiled ingredients, collected before and during the cooking process. This approach avoids subjectivity in categorizing waste during busy operating hours. The collected data on waste weights from each restaurant were systematically computed and analysed using Microsoft Excel. Initially, the raw data were organized into a structured format to facilitate accurate calculations. The food waste data from each restaurant location were averaged daily to identify patterns and

trends in waste generation. This analysis aimed to uncover any potential relationships between food waste and the specific restaurant locations, providing insights into how different districts might influence waste levels.

Carbon footprint measurement

To arrive at the carbon emissions of this study, a detailed and systematic approach was undertaken, involving the estimation of emissions from both food waste and daily activities such as electricity and water consumption. Food waste generated by the restaurants was collected and subsequently disposed of in landfills. This practice is typical for the areas under study, and thus, the emissions were estimated based on this end-of-life scenario. The carbon footprint for the food waste was estimated using an emission factor of 300 $kgCO_2e$/tonne for conventional landfills of mixed waste, as established by Manfredi *et al.* (24). This factor accounts for the GHGs released during the decomposition of organic waste in a landfill environment.

Meanwhile, the daily activities of the restaurants, specifically their electricity and water consumption, were meticulously recorded twice daily — in the morning and evening before and after the daily operation hours. We documented the readings from the restaurants' utility meters. This approach ensured that all consumption data was accurately recorded, reflecting the actual usage patterns throughout the day. By using direct meter readings, we eliminated potential inaccuracies associated with estimations or indirect measurements. This comprehensive and systematic recording process provided a reliable basis for tracking resource use and precisely calculating the associated emissions. The collected data on daily electricity and water consumption were averaged based on each restaurant's location and subsequently plotted using a combination of line and histogram graphs. These visual tools illustrated trends and fluctuations in resource use over time, offering clear insights into the daily operational patterns of the restaurants. By examining these graphs, we could identify peak usage periods and potential areas for resource efficiency improvements.

The values of electricity and water consumption were then converted into GHG emissions using established emission factors (EFs) (25), which are specific to the local electricity grid mix. These values were inserted into Equation (1) as activity data. EF indicates the amount of carbon dioxide (CO_2) emitted by an Activity Data unit. The Emission Factor values are listed in Supplemental Information I.

Carbon footprint ($kgCO_2e$) = Activity Data (AD) * Emission Factor (EF) (1)

Finally, we integrated food waste, electricity, and water consumption data into a Material Flow Analysis (MFA). MFA is a powerful tool that goes beyond individual metrics. It traces the flow of materials through the entire restaurant system, from resource acquisition (food, water, electricity) to waste generation (food waste, wastewater). This approach enabled us to identify the restaurant activities that contribute the most to its carbon footprint. We focused on quantifiable metrics within the MFA framework, such as kilograms of food waste generated per customer or litres of water used per dish washed. By pinpointing these environmental hotspots, we can develop targeted strategies for emission reduction. For instance, if our MFA identified high food waste generation as a dominant hotspot, we might recommend improved menu planning to reduce excess preparation or explore staff training on portion control. Similarly, high water consumption could indicate inefficiencies in dishwashing or food preparation practices, prompting us to suggest equipment upgrades or water-saving techniques.

Ethical clearance

This study has obtained an Ethics Review Exemption - Faculty Ethics Review Committee (Ref no: FERC/FSK/EM/2022/00035).

RESULTS

Environmental impact of global restaurant operations with respect to food waste and carbon emissions

The initial search across the three databases resulted in a total of 125 articles. After screening for duplicates, 3 studies from Scopus and 1 from ScienceDirect were identified as duplicates. Further evaluation of the remaining articles from ScienceDirect revealed that 91 studies were unrelated to the keywords, 18 focused on unrelated types of waste or different venues, and 5 were review papers rather than original research articles. After these exclusions, 7 studies remained that directly matched the keywords and met all inclusion criteria. These 7 studies provide insights into the relationship between food waste, carbon footprint, and restaurants, and their details and outcomes are summarized in Table I.

Table I: Overview of recent research on food waste and the environmental impact of restaurant operations.

References	Country	Study design	Study period	Sample size	Foodservice establishment	Outcome	Database
(Sha'ari et al., 2023)	Malaysia	Observational	1 week	15	Casual dining restaurants	• There is a significant issue with food waste during the preparation stage, which could be repurposed as feed for livestock. • Energy usage has a larger impact on carbon footprint compared to water consumption, highlighting a need for better kitchen procedures and equipment.	WoS, Scopus
(Pang et al., 2023)	China	Case	1 year	1	Hotpot	• Involve a lot of overeating, especially of meat, with an average of 588.7 grams per person per meal. • High carbon footprint of 3.5 kg CO_2e per meal, similar to a whole day's recommended diet in China. • Use a lot of water and create more waste compared to other restaurant meals, with 80.4 grams of waste per person compared to 54.1 to 75.0 grams for other foods. • Possible intervention options include the use of smaller portion plates and the incorporation of plant-based meat alternatives.	WoS, Scopus, ScienceDirect
(Razali et al., 2023)	Malaysia	Observational	1 week	15	Food stall, casual dining, steamboat	• The level of food waste reached its peak during weekends. • Plate waste accounted for the most amount of food waste per week, averaging 84.75 kg, while serving loss was the lowest, totalling 21.68 kg. • Steamboat restaurants consumed the most amount of power and water each week, with 141.4 kWh of electricity and 15.46 kg CO_2e of carbon footprint, and 13.05 m of water and 5.5 kg CO_2e of carbon footprint. • To minimise food waste, refrain from excessive consumption and meticulously strategize food preparation.	Scopus
(Wongrattanatham & Pasukphun, 2023)	Thailand	Case	1 month	6	Western fast-food restaurants, Thai fast-food restaurants	• The restaurants emitted a total of 521,571.46 kg of CO_2 per year. • The direct GHG emissions from the restaurants per year was lower than the indirect GHG emissions originating from other sources than energy, followed by the indirect GHG emissions from restaurants' electricity usage. • Electricity consumption for appliances and electronic gadgets was the primary contributor to emissions in both Western and Thai restaurants. • The most significant environmental expense was the annual cost of water treatment, amounting to US$ I,632.	Scopus
(Costa & Bexiga, 2023)	Portugal	Case	8 days	1	Traditional Portuguese restaurant	• The restaurant menus exceeded the recommended levels of energy, protein, fat, and salt. • Among the menus, the one with the highest carbon footprint comprised three varieties of meat and chorizo. • The menu with the lowest carbon footprint featured a vegetable appetizer and a main course with appropriate portion size.	ScienceDirect
(Lйvesque et al., 2023)	Canada	Observational	5	1	High end restaurant	• An evaluation of food waste based solely on weight measurement is inadequate and should be supplemented with Life Cycle Assessment data to identify food waste with significant environmental impact. • Around 20% of the food that was bought ended up being thrown away. • Decreasing food waste could potentially decrease up to 17% of the environmental effects linked to food. • The categories that experienced significant increase are meat and seafood items.	ScienceDirect

CONTINUE

Table I: Overview of recent research on food waste and the environmental impact of restaurant operations. (CONT.)

References	Country	Study design	Study period	Sample size	Foodservice establishment	Outcome	Database
(Filimonau et al., 2023)	Iraq	Observational	4 months	18	Eastern restaurants, Western restaurants, Eastern-Western restaurants	• The national culture in Iraq is identified as a primary factor contributing to food waste in the country's foodservices. • The study focuses on innovative and efficient methods of managing food waste that are particularly relevant for the Middle Eastern market, such as demand forecasting, wasted food as staff meals, and collection by farmers after closing. • The study examines how these techniques might be implemented and encouraged within sectors and across different countries, through the promotion of awareness, encouraging philanthropic endeavours, and fostering cooperation with farmers.	ScienceDirect

Amount of food waste generated onsite restaurants

Figure 2 shows a fluctuating trend in food waste generation from *Mamak* restaurants in the NSP and Semenyih Districts. The PREP loss for both districts increases towards the middle of the week: 5.06% from Weekday (WD) 1 to WD 3 (Wed) for NSP, and 8.71% from WD1 (Mon) to WD4 (Thurs) for Semenyih. Both districts then demonstrate a decrease in PREP loss (by 8.95 % for NSP on WD4 (Thurs) and 9.24% for Semenyih on WD5 (Fri)), and then increases again during the weekend. However, food waste generated by NSP restaurants decreases on Weekend (WE) 2, from 11.45kg to 11.07kg. Importantly, the PREP loss in NSP's and Semenyih's restaurants peaks on different days: WD3 (Wed) and WE2 (Sun), respectively. Nevertheless, the amount of PREP loss generated by *Mamak* restaurants in NSP is always lower than in Semenyih throughout the week.

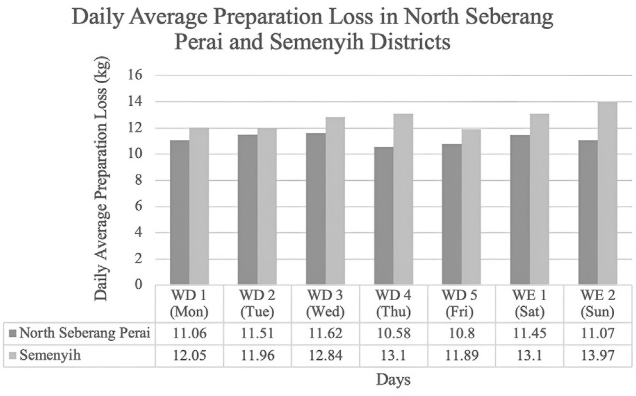

Figure 2: Daily average preparation loss of Mamak restaurants in Semenyih and North Seberang Perai.

Contribution of electricity consumption to carbon footprint

Energy consumption is an important indicator of the operation of foodservice establishments. In this study, the highest electricity consumption is recorded on WE1 (Sat) at 49kWh for *Mamak* restaurants in Semenyih, and on WD5 (Fri) at 31kWh for NSP (Figure 3). Meanwhile, both districts consume the least electricity on WD3 (Wed) at 27.6kWh and 42kWh for NSP and Semenyih, respectively. The carbon footprint release associated with the largest electricity consumption in Semenyih contributes to 5.37kgCO_2e while NSP emits up to 3.38kgCO_2e, which makes up 15.62% and 15.28%, respectively, from the total electricity-related carbon emission in a week.

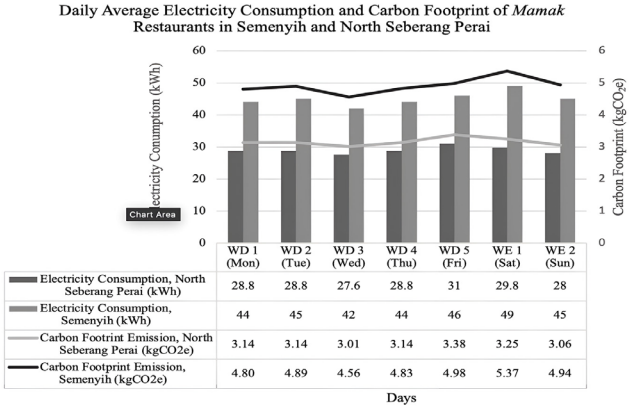

Figure 3: Electricity consumption and its associated carbon emission from the Mamak restaurants in Semenyih and North Seberang Perai in a week.

The total average energy usage in NSP *Mamak* restaurants was 202.8kWh, corresponding to 22.12kgCO_2e, while in Semenyih, it was 315 kWh, corresponding to 34.37kgCO_2e. Despite generating more food waste, Ampang's casual dining restaurants than *Mamak* premises in NSP and Semenyih, the former foodservice establishment only used 127kWh per week, with a carbon footprint of 13.87kgCO_2e (14). This was lower compared to Jasin's casual dining (142.2kWh, 15.54kgCO_2e), Kota Bharu cafñs (193.8kWh, 21.186kgCO_2e) (12), and Sungai Petani cafñs (146.4kWh, 15.98kgCO_2e) (13). Appliance usage patterns, such as the frequent operation of high-energy-consuming equipment like deep fryers and industrial stoves, are common in *Mamak* restaurants due to the bulk preparation of food for buffet-style serving. This differs from other food establishments that prepare food on demand, potentially contributing to higher energy consumption in *Mamak* restaurants. These findings suggest that *Mamak* restaurants in NSP and Semenyih may be using energy inefficiently, leading to higher

carbon emissions. Adopting energy-efficient appliances and optimizing energy management practices could significantly reduce their environmental impact.

Contribution of water consumption to carbon footprint

The average daily water consumption of the ten *Mamak* restaurants from Semenyih and NSP, as well as its contribution to GHG emissions are depicted in Figure 4. The differences in water consumption and carbon footprint emission are visible between Semenyih and NSP districts throughout the week. A visible fluctuating trend can be observed for NSP, where water consumption drops from 3.68m^3 to 3.38m^3 on WD4 (Thu) and WE2 (Sun) uses the largest amount of water at 3.89m^3. Less visible fluctuation is demonstrated by the *Mamak* food premises in Semenyih, where their carbon footprint remains under 1kgCO_2e throughout the week.

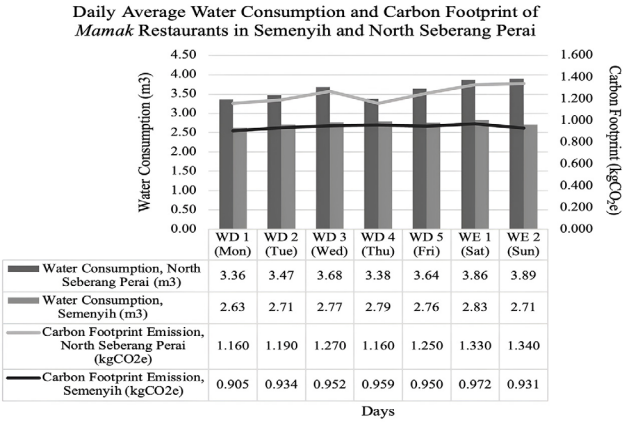

Figure 4: Water consumption and its associated carbon emission from the Mamak restaurants in Semenyih and North Seberang Perai in a week.

Total carbon footprint emission throughout the operation of the *Mamak* restaurants

The overall carbon footprint emissions throughout the restaurant operation involving food waste, water consumption, and electricity consumption shows that energy is the largest factor (45.99% corresponds to 56.49kgCO_2e) contributing to GHG emissions from selected *Mamak* restaurants from both districts, followed by food waste (40.78% equates to 50.10kgCO_2e) and water consumption (13.23% equals to 16.26kgCO_2e) (Figure 5). Estimation of the carbon footprint of food waste was based on an emission factor of 300kgCO_2e/tonne for conventional landfills of mixed waste (24). Total average food waste produced in a week in NSP is 78.09kg, which contributes 23.43kgCO_2e of carbon while restaurants in Semenyih produced 88.91kg with 26.67kgCO_2e carbon.

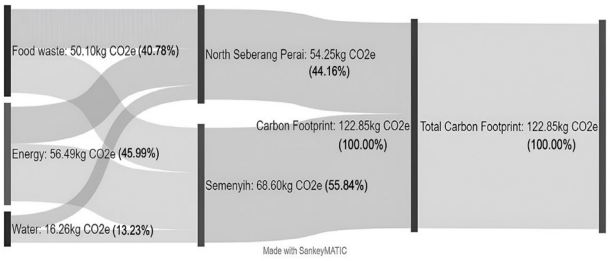

Figure 5: Schematic representation of the total GHG emissions (in percentage and kgCO2e) from the daily operation of Mamak restaurants in Semenyih and North Seberang Perai.

DISCUSSION

Malaysia's food waste problem is staggering, with approximately 17000 tonnes being thrown away daily by Malaysians, enough to feed about 12 million people (19). This waste is partly the result of excessive food production in the foodservice industry, where supply outstrips demand. The mismatch between food waste and demand, coupled with the strain on natural resources needed to feed the global population, underscores the close relationship between food waste and food security (26). Our systematic literature review, conducted across reputable databases, identified only 7 relevant studies investigating the relationship between food waste, carbon footprint, and restaurants. This limited research suggests a significant knowledge gap regarding the environmental impact of *Mamak* restaurants specifically in Malaysia. Furthermore, the absence of a well-established system for managing food waste from restaurants in Malaysia highlights the urgency for more data in this area. This study serves as a pilot investigation, aiming to gather baseline data on food waste generation and its associated carbon footprint in *Mamak* restaurants. By establishing this data, we can contribute to a more comprehensive understanding of the environmental impact of the Malaysian *Mamak* restaurant industry. Making this data publicly available has a two-fold purpose. It can raise awareness among Malaysian food establishments regarding food waste generation and its link to their carbon footprint. This awareness can be a crucial first step towards adopting more sustainable practices. This data can serve as a valuable resource for policymakers to develop effective strategies for managing food waste and promoting sustainable practices in the Malaysian restaurant industry.

The total average PREP losses for *Mamak* eateries in the NSP and Semenyih Districts were 78.09 and 88.91kg, respectively. These figures are slightly greater than those of Jasin's casual dining restaurants (77.72kg) (14), Sungai

Petani cafés (51.86kg) (13), Kota Bharu cafés (40.60kg) (12), and Kota Bharu Thai food restaurants (48.18kg). Regardless, casual dining restaurants in Ampang (categorised as an urban area) recorded the highest PREP loss at 119.66kg (14). Surprisingly, the PREP losses from *Mamak* restaurants in NSP and Semenyih, which are considered developing districts, are catching up to those of Ampang's casual dining restaurants. Research has shown that overproduction in foodservice establishments due to inaccuracies in forecasting demand and portion sizes is the main cause of PREP loss, and this issue can be prevented with proper measures in place (27). In this study, effective waste management practices at *Mamak* restaurants in NSP resulted in a reduction of losses in food preparation. This is evident in their practice of maintaining an inventory of supplies and purchasing only what is necessary, which in turn decreases the volume of PREP loss at this stage. Implementing a food storage system that utilizes an ordering arrangement, such as "first-in, first-out" method, can also significantly improve inventory visibility and prevent food from being hidden. By doing so, it can efficiently minimise food waste.

From another perspective, a questionnaire-based study conducted at Universiti Putra Malaysia involving food vendors revealed that their level of knowledge, attitude, and practices (KAP) with regards to food waste management was moderate (12). Additionally, attendance in food waste management training has a noteworthy association with improved food waste management practices. Unfortunately, KAP on food waste management among restaurants staff was not assessed in the current study and therefore should be included in future studies investigating food waste in Malaysia. Further, operators should commit to minimising food waste through technology integration and staff training, emphasising the benefits of streamlined serving process, apart from obtaining customer feedback on portion satisfaction (28). Other than that, redistributing surplus food can be an effective solution to address both food waste and food insecurity (29). According to the food waste hierarchy, donating surplus food for human consumption is the next best strategy when it is not possible to prevent food waste. As such, this practice should be implemented by *Mamak* restaurants, which often serve buffets.

Electricity utilised at the *Mamak* restaurants was during the cooking process and for operating fans and lights throughout the establishments' operation. Our observations indicated that the kitchen consumes the most energy in the establishment. This was attributable to the employment of electrical appliances such as large automatic rice cookers, electric water boilers, and blenders during the preparation and cooking processes. Additionally, their refrigerators operate continuously, consuming a considerable amount of energy to store and prevent raw materials from spoiling, as well as to keep canned or bottled beverages. Dai and colleagues (30) attest that the primary energy-consuming categories in foodservice establishments are the HVAC and water systems, as well as cooking. These three groups collectively contribute to almost 90% of the total energy consumption. In 2016, it was estimated that around 30% of the anthropogenic GHG emissions across the globe were caused by the generation of electricity and heat, primarily as a consequence of fossil fuel combustion (31). One recent research indicates that cooking pulses such as lentils and chickpeas, which are commonly used in *Mamak* restaurants not only account for over 80% of the global warming potential, but it also contributes to over 75% of fossil resource scarcity, water consumption, freshwater and marine eutrophication (32). To minimize the environmental effects of *Mamak* restaurants' daily operations, it would be beneficial for them to adopt the circular economy concept. This involves preserving energy, materials, and labour through a closed loop system that incorporates the 4 R's: reduce, reuse, recycle, and remove (33). Additionally, using water- and energy-efficient equipment, as well as implementing food waste treatments such as composting and anaerobic digestion, can help recover resources and energy (34,35).

The total average weekly water usage and its related carbon footprint in NSP *Mamak* restaurants were 25.28m^3 and 8.7kgCO_2e, respectively. In Semenyih, weekly water usage was 19.2m^3 with a carbon emission of6.603 kgCO2e. These figures are comparable to Ampang's casual dining (23.02m^3, 7.92kgCO_2e) (14), Jasin's casual dining (17.11m^3, 5.88kgCO_2e), and Kota Bharu's cafйs (24.4m^3, 8.39kgCO_2e) (12). However, Kota Bharu Thai food restaurants and Sungai Petani cafйs had significantly lower water usage, contributing to only 3.63kgCO_2e and 5.52kgCO_2e, respectively (12, 13). This indicates that it is possible to reduce water usage in *Mamak* restaurants by adopting more efficient water management practices. Regardless, during our observation at the selected *Mamak* restaurants, we noted that various tasks required a significant amount of water usage, such as to wash raw materials, make drinks, dishwashing, hand washing for customers, and lavatory use. However, the use of air humidifiers and diffusers for sanitation and ventilation was lacking in Semenyih's restaurants. This explains Semenyih's lower water consumption and its associated carbon footprint compared to restaurants in NSP. One recent study by Zhang *et al.* highlighted the significance of modifying diet composition and food intake quantities (36). This is because animal-based products typically possess a higher water footprint compared to plant-based products (37), where most of the time, *Mamak* restaurants use chicken or beef in their menu compared to vegetables.

Data pertaining to carbon footprint of the *Mamak* restaurant industry is crucial to be recognised and acknowledged, as it provides insight into the amount of GHG released, which could potentially have

environmental and ecological impacts, including biomass and nutritional quality (38,39). The "2021 Food Waste Index" from the United Nations Environment Programme revealed approximately 9% of worldwide carbon emissions is attributable to food waste (40). Unfortunately, we did not include serving and plate loss in our research, which might lead to underestimation of the GHG emissions generated by food waste generated from *Mamak* restaurants in NSP and Semenyih could be higher than what we reported in this study. To address the issue of food waste and its associated carbon footprint, various interventions by the foodservice industry can be done. Prevention strategies like menu redesign, advanced production methods, and prioritizing sustainably sourced ingredients (41) can minimize food waste generation at the source. Recent advancements in waste valorisation are exciting (Table II). Anaerobic digestion converts food waste into biogas, while research explores converting food waste into construction materials with remarkable compressive strengths. A particularly promising approach utilizes black soldier fly larvae for organic waste management, including food waste from landfills, which has already been launched in Kelantan, Malaysia (42). This method offers faster decomposition, reduced odour, and generates nutrient-rich frass, as highlighted by Dewi Apriliani *et al.* (43). This study has shown a potential reduction of up to 60% in food waste using black soldier fly larvae composting, making it a highly relevant option for the *Mamak* foodservice industry.

Table II: Summary of recent research on strategies to reduce GHG emissions.

References	Study design (Country)	Foodservice establishment	Food types / categories	Outcome	Opportunities	Constraints
(Ahire et al., 2024)	Bio-methane production via anaerobic digestion (India)	• Juice centre and vegetable markets • Supermarkets and bakeries	• Unprocessed food such as fruit (peels, pulps) and vegetable waste • Processed food such as cooked rice, cereal, cooked vegetable, roti, and expired food	• Cooked vegetables have a larger potential for energy generation compared to fruit pulp, which has the lowest potential at 426 ml/gmVS, followed by 207 ml/gmVS. • Fruit pulp exhibited the greatest quality biomethane, with a methane content of 59%. In contrast, the vegetable waste had the lowest quality methane, with a methane content of 44%.	• The tool identifies food scraps that create the most biomethane, allowing us to prioritize these for conversion. This reduces landfill waste and creates a valuable energy source. • The tool helps design biogas plants that perfectly match the type of food waste they receive, maximizing efficiency and methane production. • By highlighting the benefits of turning food waste into energy, the tool encourages investment and innovation in this eco-friendly approach. • Businesses, policymakers, and researchers can all use the tool's data to make informed choices. This could involve creating policies that support food waste diversion, optimizing waste collection systems, and focusing research on improving biogas technology.	• The tool's estimates need to be reliable. If the tool is not accurate, it could lead to bad decisions. • Food waste can be very different depending on where it comes from and what kind of food it is. The tool needs to account for this variety to be useful. • The tool needs to be affordable and accessible for everyone who can benefit from it, including small biogas plants. • Even with a great tool, there needs to be a system in place to collect and transport food waste to biogas plants. In some areas, this infrastructure might need improvement.

CONTINUE

Table II: Summary of recent research on strategies to reduce GHG emissions. (CONT.)

References	Study design (Country)	Foodservice establishment	Food types / categories	Outcome	Opportunities	Constraints
(Guinati et al., 2024)	Conversion of food waste into high-sulphur-content materials for use as construction materials, with elemental sulphur serving as the key component in this process (USA)	• Fast-food franchise	• French fries	• Elemental sulphur could be used to upcycle plant oil, unseparated biomass, and raw post-consumer food waste into valuable materials • These new materials could have applications in creating bioplastics, fertilizers, or other sustainable products, contributing to the circular economy	• By converting waste materials into useful products, the study provides a sustainable alternative to traditional waste disposal methods, thereby potentially decreasing landfill usage and greenhouse gas emissions. • This upcycling approach could offer economic benefits. By creating value-added products from waste, industries could reduce raw material costs and generate new revenue streams from waste by-products. • The use of elemental sulphur, which is abundant and inexpensive, offers a cost-effective approach to waste upcycling. Its versatility allows for the conversion of various types of waste, including plant oil, biomass, and food waste. • By transforming waste into useful materials, the study supports the principles of a circular economy, where resources are reused and recycled, minimizing waste and maximizing resource efficiency. • The development of new materials from waste through sulphur upcycling can lead to innovative applications in fields such as bioplastics, fertilizers, and other sustainable products.	• The feasibility of scaling up the laboratory findings to industrial-scale applications may present challenges, including the need for significant investment in new infrastructure and technology. • Ensuring the efficiency and consistency of the upcycling process across different types of waste materials may be complex, requiring further optimization and refinement of the methods used. • The introduction of new materials and processes may face regulatory hurdles, including ensuring that upcycled products meet safety and environmental standards.

CONTINUE

Table II: Summary of recent research on strategies to reduce GHG emissions. (CONT.)

References	Study design (Country)	Foodservice establishment	Food types / categories	Outcome	Opportunities	Constraints
(Moussaoui et al., 2024)	Combination of solar drying with biogas production to manage food waste (Turkey)	Not specified	• Vegetable peels • Fruit peels	• The solar dryer effectively reduced the moisture content of food waste, demonstrating efficient drying kinetics. This process makes food waste more manageable and reduces its volume. • The dried food waste showed a significant potential for biogas production. By drying the waste before anaerobic digestion, the study indicates that biogas yields can be optimized, enhancing the overall efficiency of biogas production. • Using a solar dryer for food waste management contributes to environmental sustainability by utilizing renewable energy, reducing greenhouse gas emissions from wet waste, and minimizing the environmental impact of waste disposal. • Drying has the effect of diminishing the yield of biogas, which primarily comprises methane, a potent GHG.	• The study leverages solar energy, a renewable and sustainable resource, for drying food waste. This reduces reliance on non-renewable energy sources and contributes to environmental sustainability. • By effectively reducing the moisture content of food waste, the solar drying process decreases the overall volume of waste, making it easier to handle, transport, and process. • Drying food waste before anaerobic digestion can enhance biogas yields, providing a more efficient method for generating renewable energy from organic waste. • Combining solar drying with biogas production creates a synergistic approach to waste management, optimizing resource recovery and reducing the environmental impact of food waste disposal. • The principles of solar drying can be applied to various scales, from small household units to large industrial systems, making it a versatile solution for different contexts. • By reducing the moisture content and subsequently enhancing biogas production, the study helps in mitigating greenhouse gas emissions from decomposing wet waste in landfills.	• The efficiency of solar dryers is highly dependent on weather conditions. Cloudy or rainy days can significantly reduce the effectiveness of the drying process. • The setup cost for solar drying systems can be high, potentially limiting adoption, especially in low-resource settings. • Solar dryers require a considerable amount of space for installation, which may not be feasible in densely populated urban areas. • The time required to dry food waste using solar energy can be longer compared to conventional drying methods, which may affect the overall efficiency of the waste management process. • Solar dryers require regular maintenance and monitoring to ensure optimal performance, which can add to operational costs and labour requirements. • The variability in food waste composition can affect the drying process and the quality of the dried material, potentially impacting biogas production efficiency.

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Table II: Summary of recent research on strategies to reduce GHG emissions. (CONT.)

References	Study design (Country)	Foodservice establishment	Food types / categories	Outcome	Opportunities	Constraints
(Karaiskakis et al., 2024)	Anaerobic digestion in food waste management (USA)	Not specified	Not specified	• This model estimated the potential to reduce 21.8 million metric tons of CO_2 equivalent emissions per year (345 grams of CO_2 equivalent per kilogram of waste) and generate 161 trillion British thermal units of renewable natural gas annually for the entire USA by following the waste hierarchy in managing food waste. • This study identified states with the most efficient anaerobic digestion implementation potential in terms of CO_2 equivalent emissions avoidance. • It emphasized the significance of considering region-specific conditions, as feedstock diversion varies by state and accounts for up to 60% of the avoided emissions.	• The study uses Life Cycle Assessment (LCA) to provide a detailed evaluation of the global warming mitigation potential of anaerobic digestion for food waste management, offering a thorough understanding of its environmental benefits. • Anaerobic digestion processes generate biogas, a renewable energy source that can be used for electricity, heating, or as a vehicle fuel, thus reducing dependence on fossil fuels and enhancing energy security. • The digestate, a by-product of anaerobic digestion, can be used as a biofertilizer, recycling nutrients back into the soil and reducing the need for synthetic fertilizers.	• The initial investment and operational costs of anaerobic digestion facilities can be high, potentially limiting their adoption, especially in areas with limited financial resources. • Implementing anaerobic digestion on a large scale requires significant infrastructure development and coordination across various sectors, which can be logistically challenging. • Anaerobic digestion technology may face challenges related to feedstock variability, process optimization, and the management of by-products such as digestate. • Public perception and acceptance of anaerobic digestion facilities can vary, and there may be resistance due to concerns about odours, noise, and other local impacts.
(Dewi Apriliani et al., 2024)	Black soldier fly larvae (Indonesia)	Eateries	Not specified	• Employing black soldier fly larvae for food waste management is an effective strategy that can lead to a reduction of up to 62.6%. • Within a 14-day period, fresh larvae and compost are generated as a result of the bioconversion process.	• Faster decomposition times, reduced odour, and potentially generate nutrient-rich frass (insect manure) as a valuable by-product • Reduced reliance on landfills, lower GHG emissions, and potential for resource recovery through frass.	• Initial setup costs, optimizing rearing conditions for black soldier fly larvae, and ensuring proper management of the composting process.

CONCLUSION

This research investigated food waste generation and resource consumption (electricity and water) in *Mamak* restaurants across NSP and Semenyih. Our findings highlight the significant role of food waste in the carbon footprint of these establishments, with food waste accounting for 40.78% of total emissions, second only to energy consumption. The data suggest that optimizing preparation practices could reduce the environmental impact of food waste. While our study reveals a higher energy footprint compared to preparation loss, the total carbon footprint is likely underestimated due to the absence of data on plate and serve loss. Future research should aim to address this gap by including plate and serve loss measurement, as well as KAP assessment. Additionally, further studies should be conducted countrywide, expanding the geographical scope and timeframe, to align with Sustainable Development Goal targets and provide a comprehensive understanding of food waste's environmental impact. Given the substantial carbon footprint of the food system, proactive measures are crucial for achieving global carbon neutrality goals.

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