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Carbon Footprint of Food Waste for Campus Sustainability: Insights from UniKL MICET

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ABSTRACT

Inefficient food waste management poses significant environmental challenges, particularly through the release of methane, a potent greenhouse gas. This study quantifies the carbon footprint of campus food waste at Universiti Kuala Lumpur Malaysian Institute of Chemical & Bioengineering Technology (UniKL MICET) and provides baseline evidence for evaluating the sustainability performance of existing waste management practices. A campus-based food waste audit was conducted across three sampling cycles, covering all cafeterias and two collection points (CPs), and food waste was categorized into animal-based, plant-based, and spoiled food. Carbon emissions were estimated using both generalized and type-specific emission factors. Results indicate that the majority of waste (96%) originates from campus cafeterias, with animal-based food contributing disproportionately to emissions. The total greenhouse gas emissions per sampling cycle were estimated at 150.3 kg CO_2-eq, translating to an annual potential of 12.21 tonnes CO_2-eq. Animal-based waste, although only 24.5% of the total mass, accounted for over half of total emissions, emphasizing its high carbon intensity. Plant-based and spoiled food contributed comparatively lower emissions. These findings provide a basis for designing targeted interventions to reduce campus food waste and mitigate its environmental impact. The study supports Sustainable Development Goal 12 and 13, offering insights to advance a circular, low-carbon food system on campus.

Keywords: Food waste; carbon footprint; campus sustainability; greenhouse gas emissions; emission factors

INTRODUCTION

Inefficient management of food waste imposes a substantial environmental burden. Notably, the decomposition of food waste releases substantial amounts of methane (Kah and Chen 2024; Kamaruddin, Jantira, and Alrozi 2020; Nordin et al. 2020). This decomposition process contributes to global warming, as methane has a heat-trapping capacity approximately 21 times greater than that of carbon dioxide (Mohajan 2017). Alarmingly, if global food waste were considered a nation, it would rank as the third-largest emitter of greenhouse gases worldwide (Shen et al. 2023). Emissions from food waste contribute to global climate change, affecting water and soil resources and reducing the resilience of natural ecosystems (Kamaruddin, Jantira, and Alrozi 2020). This growing environmental threat positions sustainable management as a decisive component of global climate mitigation efforts, requiring urgent and coordinated action across all sectors of society.

In Malaysia, food waste constitutes one of the biggest fractions of municipal solid waste, representing 31–45% of total daily waste generation (Kasmuri et al. 2023; Naim and Rahman 2020). Food waste makes up nearly one-third of the 39,000 tonnes of municipal solid waste generated daily (Ghazali et al. 2025a). Regrettably, about 3,000 tonnes of the discarded food retain their edibility (Zainal and Hassan 2019). This persistent issue shows significant inefficiencies in food consumption and waste management practices across the country. The continued dependence on landfilling is largely driven by their low cost and minimal technical requirements for food waste disposal (Ghafar 2017; Hashim et al. 2021; Nordin et al. 2020). Such practices exacerbate environmental problems, producing not only greenhouse gas emissions but also large volumes of leachate that contaminate soil and groundwater. Several initiatives, including the Action Plan for a Clean and Beautiful Malaysia (ABC), the National Solid Waste Management Policy, the 3R Program, and the National Circular Economy Council (NCEC) launched by the Madani Government, have been introduced; however, their implementation has not yet shown meaningful progress, including in educational institution (Bashir et al. 2018: Ghazali et al. 2025b). This gap between policy and practice underscores the need for localized, evidence-based assessments that can drive tangible improvements.

In the higher learning institution, cafeterias and residential facilities are major generators of food waste due to large-scale food preparation and consumption activities. Therefore, integrating sustainability into campus operations is essential to reduce the environmental footprint of institutional activities. Varón-Hoyos et al. (2021) and Ridhosari & Rahman (2020) conducted carbon footprint analyses at their respective institutions, where food waste was grouped together with solid waste. Their study indicates that through carbon footprint assessments, universities can measure their overall carbon emissions and implement appropriate measures to mitigate them in the future. Li et al. (2015) reported that food-related activities are a major contributor to the university's carbon footprint, with dining alone accounting for 34% of total emissions per student. This finding highlights the substantial impact of food production, consumption, and waste management on the environment, thereby reinforcing the aims of the Sustainable Development Goals (SDGs).

United Nation SDG 12 on responsible consumption and production, and SDG 13 on climate action are directly linked to sustainable food waste management (Giordano et al. 2022; Kumar et al. 2022; Nazibudin, Sabri, and Manaf 2025). The sustainability of food waste management today is anchored in a hierarchical approach that emphasizes prevention, reuse, and recycling, with landfilling as the least preferred option. Despite this, landfills continue to dominate, contributing 65.8% of total GHG emissions in 2017 (Bian et al. 2022). Nearly 95% of food waste is still disposed of in landfills, where it decomposes anaerobically to release methane and other greenhouse gases (Nordin et al. 2020). These emissions considerably elevate the carbon footprint of the waste sector, emphasizing the urgent need for sustainable approaches that move beyond traditional disposal methods.

Our previous studies examined the awareness-to-action relationship and institutional readiness for sustainable food waste management within the five-pillar framework (Ghazali et al. 2025a; Ghazali et al. 2025b). The present study addresses a different gap by quantifying the carbon emissions associated with campus food waste and establishing baseline data for sustainability performance assessment of Universiti Kuala Lumpur Malaysian Institute of Chemical & Bioengineering Technology (UniKL MICET). The study combines quantitative waste audit data with carbon emission estimates to provide a holistic understanding of campus food waste impacts. . While we do not evaluate multiple waste management scenarios experimentally, our findings serve as an evidence base for scenario planning and benchmarking of current practices against sustainable alternatives. Ultimately, the findings aim to inform a carbon-conscious food waste management framework and support Malaysia's transition toward a circular, low-carbon economy.

METHODOLOGY

A comprehensive audit of food waste was undertaken at Universiti Kuala Lumpur Malaysian Institute of Chemical & Bioengineering Technology (UniKL MICET) to measure and profile the generation of food waste across campus dining facilities. The campus currently follows a conventional waste management approach, and its moderate scale along with centralized cafeteria operations provided an ideal setting for detailed monitoring of food waste flows and management practices.

The study focused on a population of around 800 individuals, including students, staff, and food service personnel who frequently use the campus cafeterias. Food waste samples were gathered from three campus cafés and two collection point (CPs) over three separate sampling cycles. This sampling campaign was conducted as a pilot project; therefore, three cycles may not be fully representative of full-scale operations. However, it provides a valid initial benchmark for carbon footprint estimation and waste characterization. Data collection took place during regular operational hours, from 8:00 a.m. to 5:00 p.m., covering breakfast, brunch, and lunch periods; dinner service was not included. This temporal scope was chosen to capture the highest food service activity periods while maintaining consistency across sampling cycles.

DATA COLLECTION

A full-coverage sampling strategy was implemented, wherein all food waste from the cafés and CPs was collected, sorted, and weighed over three consecutive cycles. Pre-consumer waste from the cafés included preparation scraps, spoiled items, and expired food, whereas post-consumer waste from the CPs consisted of plate waste discarded by diners. Each sample was weighed using a calibrated digital scale, and data were recorded in kilograms. Per capita waste was determined by dividing total waste by the estimated 800 café users. All measurements were conducted in triplicate to ensure accuracy and reproducibility.

FOOD WASTE AUDIT

To simplify analysis and carbon footprint estimation, all food waste was classified into animal-based and plant-based categories for both cafés and the CPs:

1. Cafés (pre-consumer)
   a. Animal-based: Meat, fish, and bones from preparation or trimming.
   b. Plant-based: Fruits, vegetables, and other plant-derived scraps.
   c. Spoiled food.

2. CPs (post-consumer)
   a. Animal-based: Uneaten meat, fish, and bones from plate waste.
   b. Plant-based: Uneaten rice, noodles, vegetables, and other plant-derived foods.

This classification system allowed for a more nuanced understanding of emission sources and facilitated targeted mitigation recommendation. It also offers practical advantages for campus staff who may implement future waste reduction programs.

CARBON FOOTPRINT ASSESSMENT

This study applies a simplified emission factor method using research-supported data to estimate carbon emissions from food waste. Emission factors were taken from Balbaa et al. (2023), FAO (2015), and Scholz et al. (2015), and a two-pronged approach was employed to capture both overall and category-specific perspectives. First, the total food waste approach multiplies the average waste per sampling cycle by a generalized emission factor of 2.5 kg CO_2-eq/kg food waste (Balbaa et al. 2023; FAO 2015) to calculate CO_2-equivalent emissions. This factor captures full life-cycle emissions from agricultural production, processing, transportation, and landfill decomposition, making it suitable for estimating the total carbon footprint of food waste from farm to disposal.

These values are then extrapolated to estimate annual campus-level emissions, with per capita emissions calculated to contextualize individual contributions. This normalization metric, commonly used in previous studies (Dagiliūtė and Musteikytė 2019; Pinto et al. 2018), enables valid cross-comparison with other institutional and national waste generation data. Second, the type-specific waste approach classifies waste into animal-based, plant-based, and spoiled food, further differentiated by source. Category-specific emission factors from Scholz et al. (2015) are applied to each type to estimate CO_2-eq emissions from decomposition, enabling the identification of high-impact waste categories, particularly those contributing disproportionately to the overall carbon footprint. This dual approach strengthens the validity of the findings and allows for cross-verification of emission estimates.

EXTRAPOLATION AND ASSUMPTIONS

The annual carbon footprint was extrapolated from the measured decomposition emission per cycle based on the following assumptions:

1. Each sampling cycle represents one typical operating day.
2. Campus cafeterias operate five days per week (Monday to Friday).
3. There are approximately 52 weeks per year, totaling 260 operating days.
4. Semester breaks and public holidays are excluded, as cafeterias are not operational during these periods
5. Dinner service was excluded as it was not part of the sampling period.

A generalized emission factor of 2.5 kg CO_2-eq/kg waste was applied, as it accounts for full life-cycle emissions.

RESULTS AND DISCUSSION

FOOD WASTE AUDIT

The food waste audit identified two main parameters relevant to carbon footprint assessment: the quantity of food waste generated and the types of food waste discarded. Both indicators play a crucial role in estimating emissions and serve as essential references for planning future waste reduction and sustainability strategies.

FOOD WASTE GENERATION

Figure 1 illustrates the total amount of food waste generated per sampling cycle (in kilograms), covering three cafeterias and two central collection points. The findings indicate that the food waste generation rate per period exceeds 60 kilograms, with average of 66.9 kilogram. Significantly, this finding provides the foundation for measuring the carbon footprint, as larger quantities of food waste lead to proportionally higher greenhouse gas emissions during decomposition. Under unsustainable management practices, if such waste is disposed of in landfills, it becomes a major contributor to emissions. According to Nordin et al. (2020), approximately 95% of food waste in Malaysia ends up in landfills, where it undergoes anaerobic decomposition and is converted into methane.

Correspondingly, the audit highlights the importance of assessing waste generation per capita. Based on an estimated 800 café users, the average food waste per person per cycle was approximately 0.079–0.093 kg. This amount is significantly lower than the average Malaysian household, which generates approximately 0.5 to 0.8 kg of food waste per day (Ghafar, 2017). Although the value is comparatively lower than those reported in previous studies, this can be primarily attributed to the exclusion of dinner sessions from the sampling period. Comparable studies at local universities have reported per capita waste values ranging from 0.01–0.141 kg/cap/day (Kamaruddin, Jantira, and Alrozi 2020; Mohd Rodzi et al. 2019). The finding suggests that the waste generation per capita in UniKL MICET is within a comparable range, which indicates moderate food waste generation at the campus level. Collectively, this audit provides a key indication for carbon footprint assessment and future waste reduction strategies on campus, supporting Malaysia's commitment to SDG 12 on responsible consumption and production.

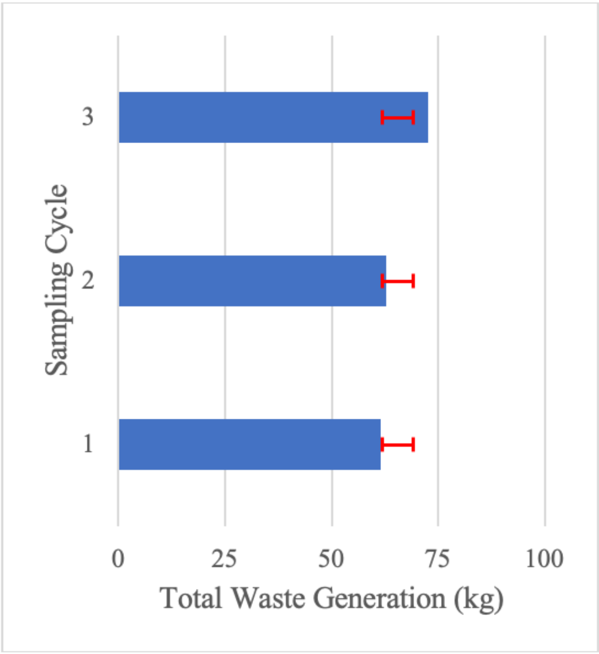

FIGURE 1. Food waste generation per sampling cycle

TYPE OF FOOD WASTE

Figure 2 indicates that approximately 96% of the total food waste originates from campus cafés, while only 4% is collected from the central collection points (CPs), which primarily consist of plate waste from patrons. This distribution highlights that the majority of food waste is generated during food preparation and on-premises operations, rather than from consumer leftovers. This pattern reflects inefficiencies in kitchen management, menu planning, and portion control, also behaviours. According to (Quested et al. 2013), these behaviours are typically complex and habitual, influenced by multiple, interacting activities that occur throughout the food preparation process. Conversely, a significant portion of the waste might be attributable to constraints such as limited kitchen infrastructure, suboptimal cold-storage management, and insufficient staff expertise in food handling and portion control (Kasavan, Mohamed, and Abdul Halim 2019). These factors is therefore essential not only for waste reduction but also for lowering the institution's indirect carbon emissions through improved operational efficiency and staff awareness.

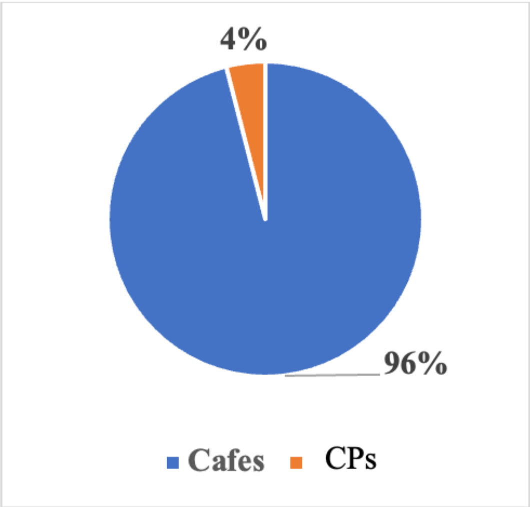

FIGURE 2. Breakdown of food waste generation from cafeterias and central collection point (CPs)

To better understand emission sources, the study distinguishes between types of waste discarded by cafeterias and CPs. Figure 3 presents the percentage breakdown of food waste generated by cafeterias, showing that preparation-related waste dominates (67.2 %), with 25.6 % animal-based and 41.5 % plant-based materials. The predominance of plant-based preparation scraps, such as peels, stems, and trimmings, indicates an opportunity for on-site composting or valorization into animal feed or other byproducts. This trend mirrors Keegan & Breadsell, (2021), who identified food scraps as the primary contributor to overall food waste and a major barrier to waste diversion. From a carbon-footprint standpoint, animal-derived food tends to have higher emissions than plant-based food, leading to greater impacts when wasted (Xu et al. 2021) This is due to its protein content and greater methane potential during decomposition (Muzenda 2014).

Meanwhile, the remaining 32.8% represents spoiled or expired food, reflecting improper storage or delayed usage. Such waste contributes directly to avoidable emissions because the embodied energy and resources in uneaten food are entirely lost. Mitigation strategies include stock rotation, accurate demand forecasting, and optimized cold chain management. Therefore, such measures offer dual benefits: decreasing the volume of waste requiring disposal and mitigating the corresponding greenhouse gas emissions. (Woolley et al. 2023).

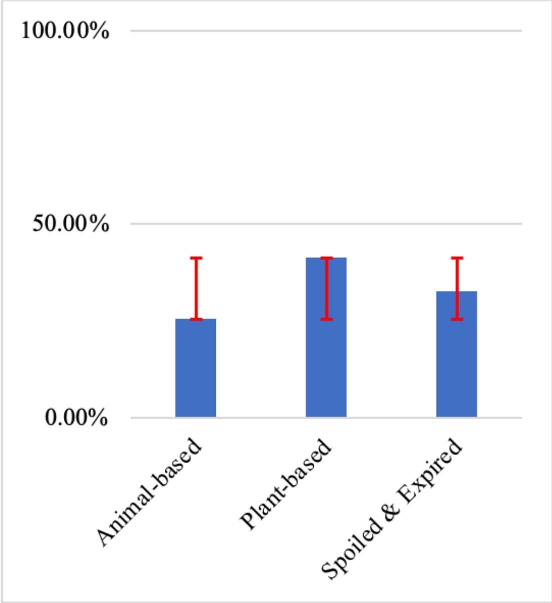

FIGURE 3. Composition of food waste collected at the cafeterias (pre-consumer)

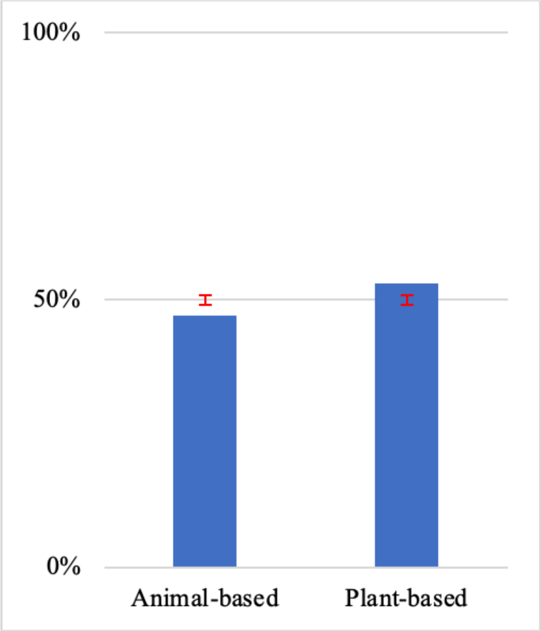

FIGURE 4. Composition of food waste collected at the collection points (post-consumer plate waste)

TABLE 1. Carbon footprint emission categorise waste type and source

Source	Type	Weight (kg)	S.D	EF (kg CO_2-eq /kg)*	CO_2-eq (kg)
Café	Animal-based	16.4	$\pm$ 0.7	4.6	75.4
	Plant-based	26.7	$\pm$ 1.4	1.4	37.4
	Spoiled food	21.1	$\pm$ 0.9	1.4	29.5
CPs	Animal-based	1.3	$\pm$ 0.2	4.6	6.0
	Plant-based	1.4	$\pm$ 0.2	1.4	2.0
Total		66.9		—	

Source: Emission factor adapted from Scholz et al. (2015)

Figure 4 presents the composition of food waste collected at the central collection points (CPs), which primarily represent plate waste from consumers. The data indicate that, on average, 53% of the discarded materials consisted of protein-rich food and bones, while 47% comprised carbohydrates and vegetables. From a carbon footprint perspective, the higher share of protein-based waste is environmentally significant, as animal-derived food possesses greater embedded emissions and higher methane generation potential during decomposition (Xu et al. 2021). Although CPs waste contributes a small generation of the total campus waste, the intensity of its emissions may not be underestimated. Because animal-based waste at the CPs has a high emission factor, even modest reductions in leftover meat and bones could yield measurable carbon savings. Hence, the need for portion-size adjustment and employing menu planning and awareness programs is necessary to minimize plate wastage. (Hatta et al. 2025).

CARBON FOOTPRINT ASSESSMENT OF FOOD WASTE

The previous subsection presents the actual situation of food waste management on campus, showing that most of the waste is disposed of in landfills. It is consistent with national trends but is nonetheless alarming given the availability of more sustainable alternatives. This finding highlights the urgent need for intervention to improve waste handling practices. To further support this observation, the carbon footprint assessment provides insights into the amount of carbon emissions generated from food waste at the campus level.

CO_2-EQUIVALENT EMISSIONS VIA TOTAL AMOUNTS

Based on the audit data, the carbon footprint assessment was conducted using the average food waste generation of 66.9 kg per sampling cycle. Applying a conservative emission factor of 2.5 kg CO_2-eq per kilogram of food waste (Balbaa et al. 2023; FAO 2015), the total estimated emission from decomposition was 167.3 kg CO_2-eq per cycle. Extrapolating this value over one year, the projected annual emission from food waste generation at amounts to approximately 12.21 tonnes CO_2-eq per year. This value represents the potential greenhouse gas emissions produced through the anaerobic decomposition of food waste if disposed of in landfills without any recovery or treatment. Although this quantity may appear moderate, it signifies a substantial contribution to the overall carbon footprint, especially when considered cumulatively. On a per capita basis, with an estimated 800 café users, the carbon footprint is approximately 0.21 kg CO_2-eq per person per cycle. This value per cycle, when multiplied across multiple cycles each week and throughout the academic year, reveals each individual contributes meaningfully to the overall climate impact of the institution. These findings underline the significant environmental impact of campus food waste, as it directly contributes to greenhouse gas emissions and exacerbates climate change. Hence, the institution should implement targeted mitigation strategies to address the identified sources of emissions. Implementing proactive measures such as optimizing kitchen operations, enhancing portion control, and adopting sustainable waste management practices can effectively reduce future emissions.

CO_2-EQUIVALENT EMISSIONS VIA TYPE OF FOOD WASTE

Table 1 displays the calculated CO_2-eq for different categories of food waste. The total greenhouse gas emission from campus food waste was estimated at 150.3 kg CO_2-eq per average sampling cycle. Although there is a 10% deviation, it is not an error, as the generalized factor covers full life-cycle emissions, while the category-specific factor considers only end-of-life decomposition. The difference explains the analysis by highlighting that upstream emissions, from farming, processing, transportation and refrigeration, are a non-negligible part of the total carbon load of campus food waste. Among the different waste categories, animal-based food waste emerged as the most significant contributor to the total carbon footprint. Although it represented only 24.5% of the total waste mass, it accounted for approximately 81.4 kg CO_2-eq per cycle (combined from cafeterias and CPs), contributing more than half of the total emissions. This disproportionate contribution means that reducing animal-based waste by just 10% would achieve a greater carbon benefit than eliminating all plant-based waste entirely. This outcome reflects the inherently higher carbon intensity of meat and animal-derived products, as their protein- and fat-rich composition promotes microbial breakdown that releases hydrogen and carbon dioxide, which are subsequently converted by methanogenic bacteria into methane (Alemneh 2020).

In contrast, plant-based waste, though forming the largest portion of the waste mass at 39.9% (26.7 kg), contributed only 37.4 kg CO_2-eq, reflecting its comparatively lower emission factor. The spoiled food fraction, consisting mainly of mixed organic residues, added 29.5 kg CO_2-eq, while plant-based CP waste at 2.0 kg CO_2-eq. These figures collectively demonstrate that waste volume alone is a poor predictor of climate impact; emission factors must guide prioritization. Therefore, the findings highlight the need to prioritize reducing animal-based food waste, the largest contributor to the carbon footprint, thereby supporting SDG 12 and 13 through more sustainable food management practices.

CONCLUSION

The food waste audit at UniKL MICET revealed that the majority of waste was generated from campus cafés, accounting for approximately 96% of the total, while central collection points contributed only 4%. The carbon footprint assessment estimated that this waste produces an average of 150.3 kg CO_2-eq per sampling cycle, with potential annual emissions of 12.21 tonnes CO_2-eq. Remarkably, animal-based food waste, representing 26.5% of the total waste mass (17.7 kg out of 66.9 kg), contributed 81.4 kg CO_2-eq per cycle, which is more than half (54%) of the total 150.3 kg CO_2-eq emissions, highlighting its disproportionately high environmental impact. The data further show that pre-consumer waste from cafeterias (96% of total waste) dominates over post-consumer plate waste (4%), with preparation scraps (67.2% of cafeteria waste) and spoiled food (32.8% of cafeteria waste) representing the largest waste fractions. Based on these numerical results, reduction efforts should prioritize animal-based waste reduction through improved purchasing, storage, and portion control practices, thereby reducing the campus carbon footprint and supporting SDG 12 and 13.

Practically, this means that UniKL MICET should consider implementing staff training on waste-minimizing preparation techniques, revising menu cycles to better align with demand, and exploring partnerships with composting or biogas facilities. Regular follow-up audits should be conducted to track progress and refine strategies over time. Future research should expand sampling to include dinner services and explore the feasibility of composting or anaerobic digestion on campus.

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DECLARATION OF COMPETING INTEREST

None.

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