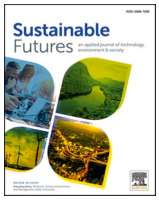
Sustainable Futures 10 (2025) 101463

Contents lists available at ScienceDirect

Sustainable Futures

journal homepage: www.sciencedirect.com/journal/sustainable-futures



Sustainable food waste management: A cross-country study of Australian and Sri Lankan hotel sector

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ARTICLE INFO

Keywords:
Consumer waste
Food wastage
Hospitality industry
Hotels
Waste management

ABSTRACT

Food wastage constitutes a critical global issue, with an estimated one-third of the food produced worldwide being wasted annually. The hotel sector represents a key contributor to this problem; however, it has received limited attention in the existing body of research. Therefore, this study seeks to undertake a comprehensive analysis of the underlying drivers of food wastage, the challenges encountered, and the strategies implemented to mitigate this issue within the hotel industry. Addressing the different contexts in developed and developing countries, this study has selected hoteliers in Australia and Sri Lanka. Data was collected from 20 hotel employees from both countries who are responsible for food handling and were analyzed thematically. The findings identified transportation waste, kitchen waste, and consumer waste as critical points of food wastage. Additionally, the role of technological equipment, combined with food safety precautions and regulatory measures, emerged as pivotal in managing food waste. These aspects are examined in detail alongside proposed mitigation strategies. Even though hospitality sector is largely contributed to these issues, the studies conducted on this sector in relation to the food wastage is very limited. Thus, this study focuses on filling the void in the literature by conducting an in-depth investigation on this topic.

1. Introduction

Food wastage refers to food that is no longer meant for human consumption and is redirected towards non-consumption purposes including feeding of animals and disposal of food items [21]. Importantly food loss generally occurs at earlier stages of the supply chain (production, post harvest, and processing), whereas food waster occurs closer to the consumer end, particularly in retail, hospitality, and household contexts [21]. This paper focuses specifically on food waste in hotels, where consumer-facing services are central.

This issue is not only an environmental concern but also a financial one. According to the Food and Agriculture Organization in 2022, around 1.3 billion tonnes of food that is made for human consumption is wasted [21]. Further, it was identified that food service provisions generate a significant amount of food wastage [56]. The focus on food wastage has intensified due to its significant social, economic, and environmental impacts. Consequently, food enthusiasts, food handlers, and policymakers have increasingly prioritized efforts to reduce wastage and mitigate its global implications. Given its increasing significance in the hospitality industry, food waste has grabbed the attention of global societal concerns identifying an essential knowledge gap and a fast-expanding study subject.

Recent studies reinforce that the largest share of avoidable food waste occurs at the final consumption stage, particularly in food services such as hotels, restaurants, school and hospital canteens, as well as in households. In fact, it is estimated that the hospitality sector alone accounts for nearly 12 % of total food waste in Europe, while households contribute more than 50 % [5,43]. These figures emphasize that while upstream inefficiencies exist, the consumption end is the most critical intervention point for policy and practice

The hotel industry can be considered as one of main force of global food waste. According to the data from the American Hotel & Lodging Association around 63 million tons of food is wasted each year in the United States of America with 40 % contributed from consumer-facing businesses which includes restaurants and hotels [1]. Further, according to the International Hotel Environmental Initiative, it was observed

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https://doi.org/10.1016/j.sftr.2025.101463
Received 20 December 2024; Received in revised form 21 September 2025; Accepted 20 October 2025
Available online 26 October 2025

that around 0.8 to 1.2 kg of food is wasted on an average per guest [17]. Therefore, hoteliers have to pay more attention to the reduction of food wastage in their premises.

Food wastage is a globally significant issue that impacts both developing and developed nations. In the context of a developed country like Australia, approximately 7.6 million tons of food are wasted annually across the consumer and supply chain, equating to an average of 312 kg per person. This includes both retail and household levels, with Australian households alone generating an estimated 2.5 million tons of *food waste* annually [46,51] highlighting the role of consumer practices in driving the overall figure. According to a study done by WRAP, the most binned items by Australians are vegetables at 29 %, leafy greens at 24 %, fruit at 22 %, and baked goods at 21 % [60]. According to the study in 2021 done by the UNEP, it was identified that Australia is within the top 10 countries with the most food waste making it interesting for research study [56].

In the case of a developing country such as Sri Lanka, over 80 % of the organic waste generated consists of short-term biodegradable food waste, amounting to approximately 353 tons per day. The Methotamulla garbage dump collapse in 2017 tragically killed 32 people and destroyed 146 houses, drawing national and global attention to the dangers of unmanaged waste accumulation [41]. This disaster starkly illustrated the risks of poor waste governance and underscored the urgent need for sustainable waste management policies in Sri Lanka. After this incident in Colombo, public attention was driven to food waste, with the source segregation policy implemented in 2017. “Source segregation” refers to the separation of biodegradable, recyclable, and non-recyclable waste streams at the point of generation, which allows for more efficient recycling and composting [37]. It was observed that over 110 tons were collected per day from the restaurant within the Colombo district [47]. Hence showing the significant impact that food waste can have on the economy.

Even though it was observed that there is an immense accumulation of food wastage within the hospitality sector globally, research studies were found to be under researched [26,50,53,61].This was mainly due to businesses inability to get primary data, and most of the organizations are unwilling in revealing information considering it to be a sensitive corporate issue [15]. In fact, a key limitation across the literature is the lack of reliable and comparable data on food waste volumes, which constrains the ability of both researchers and policymakers to design effective interventions [4,14]. This lack of measurement capacity is particularly acute in the hospitality sector, where operational sensitivities limit transparency, thus justifying the methodological choices of this study.

In the hotel sector specifically, prior studies have identified a range of underlying drivers of food waste. These include consumer behaviour such as over-ordering, cultural expectations of abundance, and plate waste [9,44]; operational inefficiencies such as overproduction, poor forecasting, and buffet-style service [24]; and supply chain limitations like inappropriate storage and quality standards [12]. Hoteliers also face challenges including limited staff training, lack of monitoring systems, and the perception that food waste reduction conflicts with food safety and service quality standards [42]. In response, a number of mitigation strategies have been proposed and tested, including portion control, redesigning buffets, donation programs, staff and consumer awareness campaigns, and technological interventions such as smart metering of kitchen waste [29,45,48]. Despite these efforts, the literature highlights that adoption remains uneven, particularly in developing country contexts where infrastructure and policy support are weak. This underscores the need for comparative research across contrasting settings such as Australia and Sri Lanka.

Hence, this study focuses on in-depth investigation of this issue and identify what are the main sources of food waste and what challenges hoteliers face in dealing with this issue. In addition to that, the mitigation techniques that they are practicing. These elements have been addressed in developed and developing country settings.

This study provides valuable insights for the industry by introducing food waste mitigation techniques, which can facilitate the implementation of effective waste management strategies to reduce costs and enhance sustainability initiatives. Furthermore, it offers significant contributions to policymakers by identifying food waste minimization strategies employed in developed countries, enabling the adaptation and implementation of suitable techniques and methodologies to mitigate waste generated within the sector.

The paper is organized into four chapters. The first chapter introduces the research study, followed by the second chapter, which outlines the methodology. The third chapter presents the findings and discussion, while the final chapter concludes the study.

2. Methodology

This section outlines the methodological approach adopted for the study. We begin by describing the research design chosen to explore food waste practices in hotels across Australia and Sri Lanka. This is followed by a discussion of the study area and sampling strategy, the data collection methods employed, and the procedures used for data analysis. Each subsection is structured to provide clarity on how the study was conducted and to ensure transparency and rigor in the research process.

2.1. Research design

An exploratory approach was employed for this study, which aimed to develop insights into food waste in the hotel industry rather than measure causal relationships. This approach was considered appropriate as the topic of food waste in hotels, particularly in cross-country contexts, remains underexplored, and exploratory qualitative studies enable the identification of drivers, challenges, and practices in settings where limited prior research exists. We therefore deliberately adopted a qualitative, inductive design to capture subjective experiences and contextual insights rather than attempting causal explanation.

Instead of enumerating alternative designs, we focused on selecting the most suitable strategy for our objectives: semi-structured interviews and thematic analysis. This design provided the flexibility to explore hoteliers lived experiences while ensuring sufficient depth and richness of data

2.2. Selection of study area and sampling

The study was conducted in Australia and Sri Lanka, selected deliberately to enable a developed–developing country comparison. Australia was chosen because it is among the top ten food-wasting nations globally [56], with an estimated 7.6 million tons of food wasted annually and an advanced hospitality sector that is increasingly pressured to adopt sustainability measures. Sri Lanka, in contrast, faces systemic challenges in waste governance and infrastructure, and incidents such as the Methotamulla tragedy (2017) highlight the urgency of addressing waste. By juxtaposing these two contexts, we aim to capture both the opportunities and constraints faced by hoteliers across contrasting economic and regulatory environments.

The study faced limitations in the field due to the lack of accurate data on waste management, which is often kept private within organizations [49]. Research by [25] indicates that restaurant managers significantly influence food wastage levels on their premises. Therefore, our study concentrated on gathering data from individuals in positions that impact food practices, as well as those who play critical roles in operational procedures and kitchen design. The total population for this study comprised hotel employees from Australia and Sri Lanka who are responsible for food handling

In total, 24 participants were interviewed (14 from Sri Lanka and 10 from Australia). This size was deemed sufficient for qualitative inquiry as data saturation was reached when no new codes or themes emerged

after repeated interviews. Maximum variation sampling allowed us to capture perspectives from chefs, kitchen managers, and general managers across different hotel categories (luxury, mid-range, and boutique).

This demographic allows for the use of maximum variation sampling, also known as heterogeneous sampling. Such heterogeneity in the sample can provide evidence that the findings are not limited to a specific population, time, or place, thereby helping to demonstrate the applicability of a theory across different contexts [39]. Additionally, cross-cultural qualitative research necessitates a diverse sample to effectively compare and contrast individuals from various cultures [59].

Participants worked in a range of property types—including international chains and independent hotels, across 3–5 star categories, in urban business hotels and resort properties. Their food-and-beverage operations covered buffet and à la carte outlets, banqueting/catering, and in-room dining. This variation provided operationally rich accounts of where and how waste arises (e.g., buffet overproduction, banqueting yield losses, plate-waste patterns) and which mitigation options are feasible under different service formats. By "local," we refer to citizens or permanent residents employed in hotels within the respective study country; by "international hoteliers," we mean expatriate staff or professionals on cross-border assignments (e.g., chefs/managers seconded to properties in Australia or Sri Lanka). This mix allowed us to capture country-specific practices alongside comparative reflections from personnel with experience across both contexts.

Consequently, our study includes both local and international hoteliers from different cultural backgrounds, enriching our findings with insights into similarities and differences. The interviews focused on full-service restaurants, where customers can dine in and enjoy a complete menu. Participants from Australia with prior experience in Sri Lankan restaurants will facilitate a comparison of food waste management practices between the two countries.

For this study, snowball sampling was employed due to the absence of a comprehensive database of hotel employees. This non-probability approach was particularly useful in accessing participants in sensitive organizational contexts, where initial referrals built trust. Recruitment continued until thematic saturation was achieved.

The participants' profiles are shown in Table 1. The authors familiarized themselves with the transcripts and designed the analytical framework inductively from the interview findings, which were then analyzed thematically

Table 1
Respondents' profile.

Participants	Type	Gender	Position	Industry Experience
S1	Chain - Affiliated	Male	Executive chef	30 years
S2	Independent	Male	Executive chef	30 years
S3	Chain - Affiliated	Male	Chef steward	10 years
S4	Independent	Male	Banquet Corporation Manager	40 years
S5	Chain - Affiliated	Male	Chief Engineer Female, HR Executive, Male, Cost controller	6years 2years 11 years
S6	Independent	Male	Executive chef	42 years
S7	Independent	Male	Chef de cuisine	31 years
S8	Chain - Affiliated	Male	Executive chef Male, Front Office Executive	25years 12 years
S9	Independent	Male	Executive chef	40 years
S10	Chain -Affiliated	Male	Executive chef, Cost Controller	20years 14 years
S11	Chain - Affiliated	Male	Executive Sous chef	20 years
S12	Independent	Male	Executive chef	25 years
A1	Chain – Affiliated	Male	Banquet chef	20 years
A2	Chain - affiliated	Male	Chef	10 years
A3	Chain - Affiliated	Male	Head chef	30 years
A4	Chain – affiliated	Male	Chef	23 years
A5	Independent	Male	Head chef	2 years
A6	Independent	Male	Chef	20 years
A7	Chain – affiliated	Male	Chef	2 years
A8	Chain - Affiliated	Male	Head chef	3years

Notes – 'S' represents – Sri Lankans and 'A' represents – Australians, Chain-affiliated (Chain): A hotel that operates under a national or international brand or group and follows brand standards and shared systems. Independent: A non-branded/stand-alone hotel that sets policies and procurement locally and does not follow a chain's brand standards.

2.3. Data collection and measures

Primary data was obtained through interviews conducted from December 2023 to July 2024. The existing literature and the research question informed the development of the interview questions and guided the study's analytical direction. Semi-structured interviews were utilized to gather the primary data.

Instrument development: The interview guide was developed based on themes identified in the literature review (e.g., drivers of food waste, operational challenges, mitigation practices) and the specific research questions of this study. The guide consisted of 15 open-ended questions with suggested probes, allowing flexibility to explore participants' unique perspectives. Two pilot interviews with hotel managers were conducted to ensure clarity and appropriateness of questions, after which minor revisions were made (e.g., simplifying wording and adding prompts related to food donation practices) [13,34].

Training of interviewers: All members of the research team underwent preparatory training on qualitative interviewing, focusing on probing techniques, neutrality, and ethical handling of sensitive information. Mock interviews were conducted internally to standardize the interview approach and ensure reliability across interviewers

With the interviewees' permission, the interviews were audiotaped and transcribed verbatim. Respondents were initially contacted via email or telephone, where they received an information sheet about the study. Upon consent, interviews were scheduled at times convenient for participants. Depending on geographic feasibility, interviews were conducted either face-to-face (in hotel meeting rooms or offices) or virtually (via Zoom/Teams). Each interview lasted between 45 and 70 min. During interviews, in addition to audio recording, researchers also took field notes on non-verbal cues and contextual factors.

Data security and confidentiality: All audio files were stored securely with password protection, and participants' names were replaced with pseudonyms during transcription. Only the research team had access to identifiable data.

To ensure consistency in data collection, the researchers employed an interview guide based on existing literature. Thematic analysis was performed to analyze the collected data. When interacting with hotel employees, researchers consistently sought permission to record the conversations, ensuring the privacy and confidentiality of the information gathered.

2.4. Data analysis

To analyze the data gathered from the semi-structured interviews, we utilized thematic analysis. This process began with familiarizing ourselves with the data obtained. While reviewing the interview transcripts, all authors conducted independent parallel coding to generate initial codes. Subsequently, we convened to discuss these identified codes. During this compilation, we found that some codes overlapped.

We selected these overlapping codes for further analysis, as this approach enhances the validity of qualitative data analysis. Additionally, we maintained two country-specific code sets to preserve contextual nuance; consistent with Section 2.2, "local" refers to citizens or permanent residents employed in hotels within the respective study country, while "international" refers to expatriate or cross-border staff working in that setting. Upon compiling both sets, we observed overlapping concepts that indicated meaningful saturation in the data collected from the from the interviews. Furthermore, we employed a general inductive approach for the data analysis, which offers a systematic and user-friendly procedure for analyzing qualitative data, yielding reliable and valid findings. This approach provides a straightforward method for obtaining results relevant to focused evaluation questions [52]. Therefore, this analytical approach is well-suited for evaluating the semi-structured interview transcripts in this study. Preliminary codes were assigned to the data to describe its content, and sub-themes were identified before generating the final themes from the interview codes. The themes were then examined and defined as necessary. Based on these highlighted themes, the researchers investigated the barriers to reducing food waste and the mitigation techniques used in Australia and Sri Lanka. The results of the data analysis were reviewed, leading to the formation of conclusions. To guide analysis, we used reflexive thematic analysis—a systematic approach to identifying, analysing, and reporting patterned meanings ("themes") in qualitative data. Following established guidance (see, for example, [30,35]), our process involved (i) familiarisation with transcripts, (ii) coding, (iii) iterative theme development and review, and (iv) producing a transparent evidentiary chain linking themes to coded data. We combined a light deductive scaffold anchored to our research questions (drivers, challenges, mitigation, governance) with inductive, line-by-line coding to allow unanticipated concepts to surface; theme construction privileged meaning over frequency and attended to convergence and divergence across the two country contexts.

Analytic orientation and rationale. In this cross-country, practice-focused study, we combined a **general inductive approach** [52] with **reflexive thematic analysis** to surface patterned meanings across hotel contexts while staying close to participants' language and experiences. This was appropriate because our aim was to explain *how and why* food waste emerges and is managed in **hotel operations** rather than to test predefined hypotheses.

Step 1 – Familiarisation. Audio recordings were transcribed verbatim and checked against the recordings. The lead author read each transcript twice while writing brief **analytic memos** on salient operational episodes (e.g., buffet overproduction, plate waste patterns, storage issues) and context notes (property type, service model).

Step 2 – Hybrid coding (deductive + inductive). We began with a **light deductive scaffold** derived from the literature and our research questions (drivers, operational challenges, mitigation practices, governance/context), then applied **line-by-line inductive coding** to remain open to emergent concepts (e.g., "portioning rituals," "display expectations," "supplier MOQs"). Codes were created directly from participants' words where possible to preserve meaning-in-context.

Step 3 – Codebook development and calibration. An initial **codebook v1** defined each code, inclusion/exclusion rules, and examples. Two researchers independently coded a **subset of transcripts from each country** to calibrate interpretations, then met to reconcile differences and refine definitions. Given our **reflexive TA** orientation, we emphasised **consensus-building and transparency** (documented in meeting notes and memo trail) rather than statistical inter-coder coefficients.

Step 4 – Theme construction. We grouped related codes into **candidate sub-themes** (e.g., "forecasting and production planning," "layout and service style," "consumer expectations," "training and monitoring," "policy/CSR commitments," "infrastructure constraints"). Through iterative discussion, we elevated these to **themes** that accounted for both convergence and divergence **within** and **across** countries. Each theme was supported by **thick description** and representative excerpts. To make the analytic path transparent, we organised the analysis from first-cycle codes → sub-themes → themes and produced a thematic analysis tree (Fig. 1). First-cycle were grouped into sub-themes by shared mechanism or intent (e.g., delivery accidents, cold-chain gaps, equipment availability → Inadequate infrastructure; portioning rituals, offcuts reuse, forecasting buffers → Cooking inefficiencies; buffet over-serving, plate-waste, doggy-bag uptake → Waste in consumption). Sub-theme names privileged participants' phrasing where possible; themes were deduced when sub-themes cohered conceptually, were distinct from neighbouring clusters, and helped explain how/why food waste arises or is mitigated in hotel operations. We tracked patterns within each country and then compared them in a country × theme matrix.

Step 5 – Within-country and cross-country comparison. To apply the analysis to our **Australia–Sri Lanka** design, we used a **framework matrix** (country × theme) to compare patterns. This allowed us to trace which drivers and practices were shared (e.g., buffet overproduction) and which were context-specific (e.g., infrastructure and supply constraints in Sri Lanka; audit/reporting pressures in Australia). We iterated between **within-case depth** and **cross-case explanation** to avoid flattening local nuance.

Step 6 – Saturation and stability checks. We judged **code saturation** when no substantively new codes emerged over several consecutive interviews, then conducted additional interviews to confirm **meaning saturation** (i.e., no new dimensions of existing codes). We also **searched for negative cases** (instances that contradicted dominant patterns) to test the robustness of interpretations.

We enhanced credibility through analyst triangulation, deliberate negative-case analysis, and use of verbatim extracts; dependability through a documented analytic protocol and stable procedures across transcripts; confirmability via reflexive notes acknowledging researcher positionality and an audit trail linking raw data to codes and themes; and transferability by providing thick description of context, so readers can judge applicability to other settings. Consistent with qualitative inquiry, we do not claim statistical generalisation; rather, we offer analytic generalisation grounded in transparent methods and evidence (e.g., [33,6,36]).

Final themes directly structured the **Results/Discussion**, where we report **verbatim extracts** and applied, operations-focused implications (e.g., forecasting protocols, buffet redesign, staff training, monitoring/metrics, donation/redistribution), explicitly indicating **country-specific** and **cross-country** insights.

3. Results and discussions

Demographic details of hoteliers working in Sri Lanka and Australia are shown in Table 1 below. A total of 20 hoteliers were interviewed, consisting of 12 locals and 8 Australians. 12 were local nationals defined here as citizens or permanent residents employed in hotels within the respective study country and 8 were international/expatriate staff working in those settings

We organise the findings into three themes—Wastage drivers, Challenges in food waste reduction, and Mitigation approaches—each composed of named sub-themes derived from clusters of first-cycle codes. The hierarchy from codes to sub-themes and themes is visualised in Fig. 1 (thematic analysis tree). Beyond reporting themes, we make explicit the country-specific differences surfaced by the analysis. Interview evidence indicates higher transport/cold-chain loss in Sri Lanka (5–10 %) than in Australia (1–5 %), linked to vehicle conditions and storage capacity; more advanced equipment and process automation in Australia; mandatory food-handler certification in Australia shaping training and monitoring; greater use/acceptance of staff-meal practices in Sri Lanka; and a larger consumer-side share of waste in Sri Lanka relative to Australia. These contrasts inform context-tailored mitigation portfolios rather than generic recommendations and are

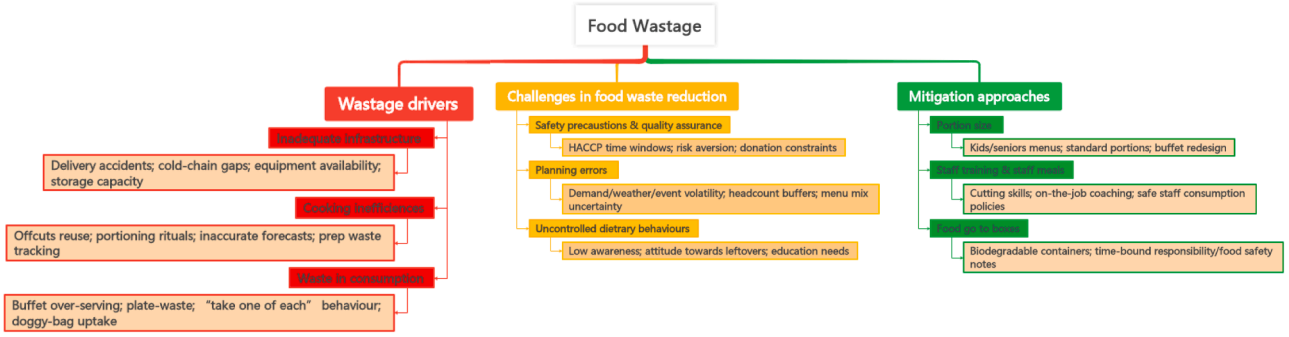


Fig. 1. Thematic analysis tree.

synthesised in Section 3.4

3.1. Wastage drivers

In examining the food supply chain and its associated wastage, researchers have identified various contributing factors. Commonly cited causes include food waste during preparation, consumption, and overproduction, as well as plate waste, employee skill levels, procurement practices, portion sizes, storage capacity, and cultural influences. These factors have been shown to correlate with the overall volume of food waste generated within the industry [18]. Moreover, a study has shown that the critical hotspots in accumulated wastage in the hotel sector were prediction, check of guest attendance, and supplier communication [3]. However, the study conducted observed the main wastage points as transportation waste, preparation waste, and consumer wastage to be the most contributory aspects of food wastage.

3.1.1. Inadequate infrastructure

Infrastructural conditions play a vital role in the food chain within the hotel industry. In the food sector, infrastructure can be identified as technology, storage facilities and transport facilities. The interviews carried out in both countries shed light on the infrastructure and its facilities contributing to the amount that is being wasted.

"The wastage is reduced a lot because the purchase is made after looking at the quality. Because we check the quality before purchasing. Then sometimes if we have a waste like during transport, we will measure it and reduce it by leaving a note about the food cost. 5–10 % will be wasted." (S5)

"Probably I would say 5 % on the deliveries. Not more than that. Sometimes you got to say, accidents happen on the deliveries. Still, it happens" (A3)

It was clear that the poor infrastructure of transportation within developing countries has caused more wastage before reaching the restaurant. While Australia shows 1–5 % of food wasted within the supply chain, Sri Lanka experiences 5–10 % of food wasted.

Moreover, the quality of the food can be preserved by maintaining the necessary conditions, which can only be done with the use of adequate facilities and infrastructure.

"The vehicles that those guys use to supply are vehicles which are made exclusively for them. Those vehicles have cool rooms related to each item and deliver the items according to their percentage. If they use their own vehicles the quality of the items will be destroyed." (A5)

The proper use of machinery and equipment also provides a steady flow of food without harming the integrity of the food. Preparing meals with minimum wastage, machinery and other use of technology helps to minimize human errors and make production more efficient.

"Here in Australia, we have machines. We don't do anything manually. It's very advanced, everything has cooking equipment. So that's how one person can manage. Here is very basic. You have to do a lot of stuff manually. So, then the speed is not there. Your production is very less. So, that's a difference between Australia and Sri Lanka. (A2)

"Apart from in Sri Lanka, I have never seen a spoiled rotten egg in the food industry. So, in Sri Lanka, when I was working, every probably 30 eggs, we have three, or four rotten eggs. That is unavoidable because of the humid weather, and the way they handle it, there are no cool rooms, and there are no chiller products. In the hot, humid vans, they deliver eggs. Obviously, they get spoiled. That's one simple example. The same thing applied to veggies, meat, seafood, everything." (A3)

These responses prove that proper use of infrastructure/technology in developed countries has enabled in reducing the wastage within the sector. Financial instabilities, transportation lags, storage deficiencies, and inadequate machinery have created food loss within the hotel industry of developing countries. With the levels of food wastage observed within the hotel industry, making changes, and improving facilities can make significant changes to the industry in reducing the amount of food that is being wasted unnecessarily.

These results in line with the Food Price Report shows that shown 56 % of the food is wasted by developed countries and in the meantime, developing countries account for the rest of 44 % mainly due to financial difficulties, inadequate storage, and impassable roads [16]. Further, within developing countries, it was observed that around 40 % of food is wasted during post-harvest and processing levels, and on the other hand developed countries have shown more than 40 % of food is wasted at consumer levels and retail [31]. Based on the results of the interviews the Fig. 2 has been drawn.

Fig. 2 maps out the supply chain and the food flow within a restaurant starting from the raw materials to its storage. The supply chains of restaurants play a major role in enabling their daily operations. This entails procurement of raw materials, distribution, sourcing, assembly, inventory management, and many more [58,62].

3.1.2. Cooking inefficiencies: forecasting errors, prep waste, excess production

Challenges are met when preparing food, and these aspects influence the amount of food discarded without providing useful resources to the organization. According to a study, the majority of chefs have noted that the challenges faced in the kitchen have moderate amounts of food wastage [23]. Food scraps that accumulate while preparing food such as trimmings, bones, and peels are a few of the preparation waste observed in the hotel industry [38]. Moreover, partially used food during production is stored but may not end up being used before the expiry date, caused due to inaccurate forecasts [32]. Kitchen waste as an active contributory waste point has been inspected thoroughly and monitored by the management and the chefs to reduce food wastage.

"When we prep daily if we take vegetables, there are offcuts on them. But to reduce the wastage, we use these offcuts as much as we can, to make stock or a sauce. If there is a wastage after this process also, we measure the weight of it and stock it and it is helpful when we take inventory from stocks". (A8)

Food waste during preparation is often inevitable; however, chefs actively work to minimize it by training staff and providing education on strategies to reduce unnecessary waste.

"The same is when cooking. The only thing that is looked at there is training. The staff needs to be trained. If they don't even know how to cut an

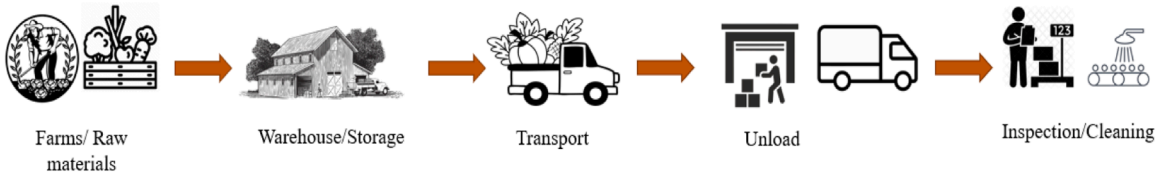


Fig. 2. Food supplying cycle.

onion or how to cut a tomato or a potato, you might remove a piece of the entire potion. Then the most important thing is the training." S5

Studies have shown that proper guidance and leadership motivate the kitchen staff to reduce waste [11]. Staff behaviour was considered an influential factor for food wastage when considering new recruits who have more tendency to make more mistakes while production causing more wastage [10].

In the hotel industry, food wastage occurs across various areas, with the kitchen being a critical focal point for implementing operational changes to minimize waste effectively. Consequently, significant emphasis is placed on reducing unnecessary waste through staff training, regular meetings, on-the-job learning, and other knowledge-sharing initiatives.

3.1.3. Waste in consumption: consumer behaviour and eating habits

When considering the key wastage points within the hotel industry, the post consumption waste stands out presenting the highest contribution to the food wastage. According to a study, it was evident that the most wastage was seen through lack of planning, over-purchasing, and food leftovers by the consumers which are non-reusable [19]. These wastages occur due to the careless eating behaviors within the consumers which poses extreme difficulties to the hotel industry in reducing the wastage. Similarly, [27] found that more than 60 % of the sample was uncaring of the food that is been wasted and only less than 40 % were caring consumers.

"A fairly good amount is wasted as people don't know what they are going to eat. They don't know their quantities. We don't know and sometimes you don't know either. Food is wasted so much more than from the kitchen. It's people who consume it waste more. You serve yourself a huge amount which you can't eat" (S4)

"Most of it happening from the customer side. We can't stop it. For example, some people come to the buffet, and we have three meats. so, they say I want to eat one from each. Some people say they want to eat two of each. And on top of that, we have a massive buffet. So, when they go to their tables sometimes, they might cut only one slice or each one slice. The rest all go to the bin. It depends on how people respect the food also. But we can't ask customers not to take any. (A4)

Previous studies conducted on food waste have found that a considerable amount of that is being wasted comes from customers with a lack of knowledge of food consumption, cooking techniques, and storage [7]. People don't care as much about how much food is wasted as they do about how much money is spent on facilities. according to the interviewers, who also suggested that people try to make up for that amount by serving more food. The irresponsible eating behaviours and attitudes have created a huge impact on the food industry creating hardships in reducing the waste. The Table 2 shows the cross country analysis of theme 1.

Table 2
Theme 1: cross-case mini-matrix.

Aspect	Australia (AU)	Sri Lanka (LK)	Implication
Supply/cold-chain	Refrigerated vehicles; cool rooms; low delivery loss (1–5 %)	Heat/humidity exposure; limited storage; higher loss (5–10 %)	AU: maintain audits; LK: invest in cold-chain & storage
Kitchen capability	Portioning tools; blast-chill; SOPs; repurpose safely	Manual workflows; limited chilling; skill-dependent	AU: SOP optimisation; LK: basic equipment + training
Consumption (buffet)	Smaller pans; prompts moderate plate waste	"Take one of each" behaviour; signage less effective	AU: continue nudges; LK: server-assisted portioning & bilingual prompts

3.2. Obstacles to reduce food waste

When exploring food wastage in the daily activities of the hotel industry, chefs and the management face difficulties in reducing the wastage even though the wastage roots are identified. During the study conducted it was observed that Safety Precautions and Quality Assurance, Planning Errors, and Uncontrolled Dietary Behaviours possess significant impacts on the food system of a hotel in reducing food wastage.

3.2.1. Safety precautions and quality assurance

Safety precautions and quality measures are followed by restaurants and hotels to ensure the safety of the customers as well as the food service provider. Many follow the HACCP management system which addresses the physical hazards, material production, procurement, handling, manufacturing, distribution, and consumption [2]. Following the guidelines will ensure the safety of the consumers while upholding satisfactory levels which reflects on the brand image of the restaurant. However, these precautions are considered as one of the major reasons that produce food wastage [55].

"The buffet is given two and a half hours only within two and a half hours you must consume the food." (S4)

During the interviews, chefs pointed out that as per the regulations and guidelines, there is a certain time frame allocated for food and its production. Even after reaching the given time frame food may be in perfect condition and can be consumed. However, due to the regulations, these food items that are in good condition are thrown away without any consumption.

"Yes, under this rule, if we store food outside for two hours, we can either store it in a fridge, use or sell it. If we store food under the temperature danger zone for 2 hours – 4 hours, we can use it or sell it, but we can't store it in a fridge again. If we store food under the temperature danger zone for more than four hours, we have to remove it." (A8)

"Now, milk doesn't really go bad in three hours. There is a regulation saying that it should be kept in a cool room for 2 hours or it should be removed, but even if it is kept for 3 hours, the milk can be used, but because of that regulation, a lot is thrown away. How much is that wastage? It is suitable for use, but due to the regulation, it has to be removed." (A5)

These regulations are imposed to ensure the safety of the consumers and act as a safety blanket for the hotel as well. However, chefs conveyed that certain rules contribute to more wastage within the operations which can be eliminated. Studies have also shown that the use of extensive precautionary safety concerns and quality controls creates large amounts of food wastage in the industry [22]. Coordination between food safety and food waste is vital in daily operational activities which should balance with scientific evidence along the precautionary principle to ensure that the avoidable waste is reduced. Moreover, attention towards practices and policies that cannot be justified by

scientific evidence that lead to unintended impacts on food waste and safety is paramount [55].

Regulations lacking a scientific foundation can unintentionally introduce adverse outcomes to the industry. To avoid such pitfalls, it is crucial to conduct in-depth studies and research prior to implementation, devoid of oversight in precautionary measures.

Moreover, during the interviews, it was identified that in Australia to enter the food service sector having an internationally recognized certificate is mandatory.

"It is an internationally recognized certificate that currently offered by Australia and New Zealand. It is a must to get this certificate for a food handler. Food handlers should take the responsibility to look out for food contamination and food allergies." (A8)

As the chefs interviewed in Australia had previous experience in the Sri Lankan food industry, they conveyed that having a certificate has benefits on its own. One of its benefits is the knowledge that they gain in handling food and reducing the amount of food that is wasted. Therefore, it helps to reduce wastage and contributes to overall operational activities rather than having inexperienced and ill-informed food handlers within the sector. These implications can be administered within developing countries to develop the sector that will reduce avoidable wastage.

3.2.2. Planning errors

In the hotel sector, food production operates as a carefully planned procedure. Chefs engage in predictive analysis to estimate daily customer volumes, devising meal arrangements accordingly. Inputs from management regarding the anticipated number of customers are forecasted and strategized. However, customer counts and characteristics tend to fluctuate. Product loss in food is a huge challenge for food and beverage manufacturers due to the short perishability of items that need to be forecasted to reduce waste [8]. The production scheduling and the quality controls of food within the food service sector are considered a top industry challenge faced [20]. This is due to numerous unpredictable factors revolving around the sector including functional events, weather conditions, time of the day, customer attitudes, attributes, age, gender, and many more changing aspects. For instance, dissimilar consumption patterns exist between children and adult groups.

"The planning also directly affects food wastage. Now let's think if the food cooked for an army function is prepared for a function where elderly parents come. There will be wastage. The right planning is necessary according to the right time. Not knowing that means food wastage." (S2)

Chefs try to address these issues with the use of both mathematical models and qualitative models to plan according to customer reviews and administrative experience within the sector [8].

Even though these measures are taken, chefs pointed out that these forecasts vary with the needed food production quantities and therefore produce wastage within the sector.

"The first factor that changes the prediction is the weather condition. Winter is here now, the seasonal pattern. It varies accordingly. The other thing is that if there is an event here when there are Sri Lankan events, people go to it, and after the party is over, they come for dinner. According to that, they forecast that this much came last week, so this week this much will come, it will not work. Because it changes according to seasonal patterns and events. Then there will be a big waste. There is overproduction. We cannot put it on the consumer's side" (A5)

As the interview suggested, predicting the production amount is a huge challenge for the industry due to various unpredictable factors. These factors included the weather conditions, events, time of the day, attitudes, and preferences among many more. However, chefs and the management try to face this as much as possible with the experience they have gathered in the field.

3.2.3. Uncontrolled dietary behaviours

The interviews conducted in the study showed that challenges in creating food wastage primarily stem from consumer behaviour and imprudent eating practices as discussed earlier. Hoteliers face limitations in tackling this issue, as they have minimal control over customers' eating habits. This uncontrollable factor resides outside the sphere of influence held by the hotels.

"We want to educate the customers, but we can't do that. We want to change customer attitude." (S12)

"Yes, from the consumer's side. We cannot control it. We need to eliminate this by advertising or putting it on TV. In many foreign countries, there are boards like that in cafeterias, they say in English, serve as much as you can eat. It happens less with most foreigners. I think it should be done by the schools" (S10)

During the study, it was observed that a huge portion of food is wasted from the consumer within Sri Lanka compared to Australia. Even though both countries mentioned that the consumer wastage is high, it was evident that the wastage from the consumers in Sri Lanka was weighted more due to the lack of knowledge and experience in the food service sector and the waste.

Probably, there is no from consumers. I don't believe it's from consumers. Here is what they said, "take what you eat, what you can eat, eat everything you take". (A3)

If we take the wastage from the consumer's side, the overall food wastage can be put at the level of 50–60 %. Generally, the food wastage is high in dine-ins like Fridays and Saturdays. (A5)

Consumer side waste is very less. Because food is also expensive, they don't have much to throw. (A2)

Both countries have shown that the wastage among consumers is out of the hotel's control and therefore try to reduce the wastage from other means. However, chefs in Sri Lanka and Australia conveyed that consumers should be educated starting at a young age with the help of government officials and respective parties along with media support to educate the customers as well the public of the serious issues in food

Table 3
Theme 2: cross-case mini-matrix.

Aspect	Australia (AU)	Sri Lanka (LK)	Implication
Safety precautions & quality assurance	Mandatory food-handler certification; strict time–temperature windows; clearer liability frameworks; regular QA audits	Variable enforcement; municipal collection schedules constrain safe holding; limited cold-chain capacity	**AU:** leverage certification-linked SOPs; expand donation within documented safe windows. **LK:** adopt pragmatic SOPs aligned to collection times; prioritise basic chilling/storage to enable compliance
Planning errors	More standardised banquet headcounts; better forecasting tools; tighter portion specs/batch sizes	Larger headcount buffers; erratic deliveries; menu-mix uncertainty driving over-production	**AU:** maintain forecasting protocols and portion specs. **LK:** use smaller batches, pre-commitments for banquets, flexible menus to absorb variability
Uncontrolled dietary behaviours	Signage/portion prompts generally effective; price sensitivity moderates plate waste	Higher reported plate waste; "take one of each" buffet behaviour; signage alone less effective	**AU:** continue nudges and portion guidance. **LK:** add server-assisted portioning, bilingual prompts, and brief guest education cues

wastage. The Table 3 below shows the cross country analysis of the theme 2.

3.3. Mitigation techniques

Food wastage is a growing concern in the world and attention is given to reducing it by taking necessary means. The food costs are high in terms of labour, production, raw materials, storage, serving, and disposal apart from adverse environmental impacts [54]. Avoidable food wastage including overproduction due to inadequate planning, large portion servings, leftovers, cooking errors, and poor inventory management are food wastages that could have been completely prevented [60]. Therefore, chefs and interested parties within the food service sector have incorporated different techniques to reduce wastage. During the study, we identified a few techniques that showed effective reduction in food waste.

3.3.1. Portion size controls

Food mitigation techniques were recommended by studies done on the food industry and advised to train their employees to serve food to customers according to their needs which will control the amount of portions served [40]. Moreover reducing the portion size in all-you-can-eat restaurants proceeds to reduced intake of food for most individuals and also reduces the plate waste [28].

"If we take a plate, there is a portion size. A dish is made from meat, starch, vegetables, and sauce. So, the total portion size will be approximately 350–400 g. So, every time, we have to plan the portion size for one person and look out the portion size. In here, our menus have two types, kids' menu, and seniors (60 years and above) menu" (A8)

Chefs have used their experience in the field to determine the amount of portion to be served to the customers without damaging the brand image and upholding customer satisfaction.

"You have to minimize the portion size. If you serve like for an example, an omelet breakfast. So, then you have an idea. Okay, portion size wise it's made with two eggs. Buffet breakfast muffin is very small, and we are not going to make a bigger portion. Because after that you can't eat anything. So, portion wise its controlled" (A4)

Chefs have used various techniques in reducing the food portion with the experiences and knowledge they have gathered in the industry while taking customer feedback into account, ensuring that customers are satisfied.

"Yes. We do portion control. We have a Live restaurant." (S7)

During the study conducted, both countries showed interest in controlling the portion size of the servings for the customers as it was observed to be the most effective form of mitigation technique to reduce wastage without harming the brand image while keeping customers satisfied. Incorporating portion size controls is beneficial for the organization in reducing costs as well as unnecessary resources.

3.3.2. Staff training and staff meals

During the study, it was evident that chefs have given special care to the kitchen to reduce wastage. This was mainly due to the fact of controllable aspects and influential points where chefs can effectively mitigate wastage. Therefore, chefs have incorporated training for the employees while working on the job as well as educating them on proper cooking techniques to reduce preparation waste.

"Training our staff three or four times a month. In this training program, we teach How to manage the menu and cooking techniques" (S9)

Moreover, we found that in the case of overproduction, chefs try to reduce the amount of food that is discarded unnecessarily by allowing the staff to consume the food. In most cases, this was found to be a judgmental call from the chefs considering the organizational rules, the food conditions, and the personal beliefs in food wastage. Moreover, the study observed that the Sri Lankan chefs were more lenient towards providing the staff with the food prepared and this was mainly due to the cultural background of the country.

Buffet continues for approximately four hours, So, if the food remains good for consumption after these hours, we can provide it to the staff and minimize the wastage. But normally we are not doing it because it will be risky since food is served outside for four hours. (A8)

According to the study, it was evident that with proper training and knowledge food wastage can be reduced significantly rather than discarding perfectly good food.

3.3.3. Food go-to boxes

Among various techniques and solutions used in the hotel industry providing go-to boxes was one of the solutions that stands out. Allowing the customers to take home the leftovers was found to be a solution to address the extensive food wastage in the sector [57].

"We have bio-degradable takeaway containers, so upon customers request we offer takeaways also." (A8)

"We give food go-to boxes and takeaway is available. If the customer wants to bring food, it will be prepared. If something goes wrong within an hour or two of delivering the food, we take responsibility. After that, A complaint will not be accepted. There is a time, a maximum of three hours per meal. Complaints will not be accepted after that."(S8)

Even though providing doggy bags was considered a viable option in addressing food wastage, the chefs pointed out that the food should be eaten within a certain time while maintaining appropriate conditions.

Among the various food mitigation techniques followed by the restaurants, it was observed that the most effective form of mitigation was the portion size controls that help to reduce the food waste from the customer's plate which is the most contributory waste point in the sector.

3.3.4. Food mapping

During the study, authors were able to identify the food chain within the hospitality sector. Starting from the food raw materials to the end, a summarized food flow was drawn which is revealed through the study. Moreover, the wastage points within the system were identified and accordingly, the mitigation strategies were summarized as shown in the below Fig. 3. This presents the responses for different mitigation approaches adopted by restaurants to reduce food waste. It highlights the relative prevalence of each method. Staff trainings and portion size control emerged as the most highly practiced strategies (80–100 %) and effective methods used in restaurants (80–60 %), whereas pervasive communication was comparatively less considered (20–0 %). This representation provides a clearer comparative understanding of the extent to which each mitigation strategy is adopted in practice

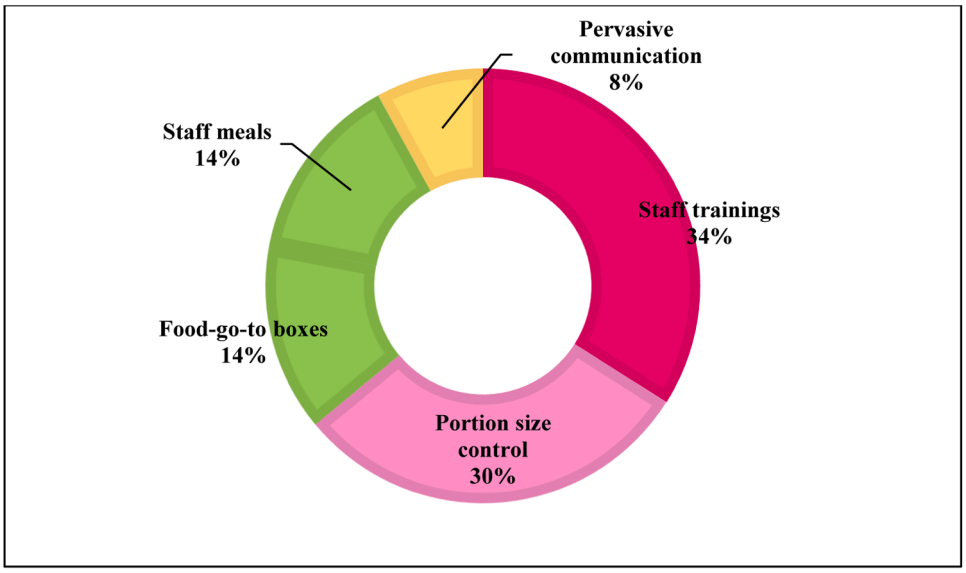
Table 4 below shows the cross-country analysis for theme 3 based on the above interviews conducted.

3.4. Comparative synthesis: country-specific contributions to hotel food-waste management

The Table 5 is presenting the comparative synthesis of the two countries and each country's contribution to hotel food wastage management.

3.5. Limitations and future research

This study offers in-depth, practice-level insights but has limitations typical of qualitative, comparative designs. First, findings are presented as **analytic generalisations** rather than statistical generalisations; the non-probability recruitment used to access sensitive operational roles may introduce selection and social-desirability bias. Second, the study **relies on interview evidence** because property-level waste-measurement data are often restricted; while this enabled candour about operational mechanisms, it limited triangulation with direct **weighing or smart-scale** data. Third, our **country samples** (Sri Lanka vs. Australia) reflect access realities and role diversity rather than proportional representation of each market segment; patterns should be interpreted with



100-80%	Highly practiced and followed
80-60%	Effective method used by restaurants
60-40%	Moderately viable solution
40-20%	Followed by some restaurants
20-0%	Less consideration

Fig. 3. Responses for mitigation approaches.

this balance in mind. Fourth, the **fieldwork window** (Dec-2023 to Jul-2024) may not fully capture seasonal or event-driven variability. Finally, the focus on **hotels** means that findings may not be transferred directly to other food-service formats (e.g., stand-alone restaurants, school or hospital canteens) without contextual adaptation.

Future research can address these constraints by: (i) implementing **mixed-methods designs** that pair interviews with **direct waste measurement** (smart scales, station-level logs) to validate volumes and hotspots; (ii) conducting **longitudinal or intervention** studies (e.g., buffet redesign, portion-size pilots, donation workflows) to estimate **pre–post** effects; (iii) expanding **multi-site, cross-country** comparisons (including additional developed/developing contexts) to test which mechanisms travel and which require tailoring; (iv) evaluating the **cost-benefit** and feasibility of mitigation bundles under different governance and infrastructure conditions; and (v) examining **guest-facing behavioural nudges** (signage, defaults) and **training models** (certification-linked curricula) using experimental or quasi-experimental designs. These steps would strengthen external validity and yield more precise estimates of impact while building on the operational mechanisms identified here.

4. Conclusion

This study examined food waste in hotels across Australia and Sri Lanka, highlighting the mechanisms that generate waste and the operational levers available for mitigation. The analysis revealed three main waste points - transport and delivery, kitchen production, and post-consumption - shaped by infrastructure, operational capabilities, and consumer behavior.

Key findings indicate that infrastructure and governance strongly influence waste outcomes: advanced cold-chain systems and certification-linked standards in Australia reduce losses, while Sri Lanka faces higher vulnerability due to storage and transport limitations. Kitchen capabilities further differentiate contexts, with Australian hotels benefiting from greater automation and standardized procedures, while Sri Lankan hotels depend more on manual processes and craft skills. At the consumer level, buffet service norms inflate plate waste in both countries, but the most effective mitigation strategies differ: portion prompts are more effective in Australia, while server-assisted portioning and bilingual guidance are better suited to Sri Lanka.

For stakeholders, the study underscores the need to prioritize investment in cold-chain and storage facilities, staff training, and portion-control practices, supported by practical policies that balance food safety with waste reduction. Importantly, policymakers in both developed and developing contexts must recognize that rigid regulatory frameworks, while necessary for consumer safety, can inadvertently increase wastage if not adapted to operational realities. Policies should therefore promote flexible but scientifically grounded safety standards, provide incentives for technological adoption, and encourage donation and redistribution schemes to minimize avoidable waste. In developing country contexts, such as Sri Lanka, integrated waste governance frameworks that align municipal collection, hotel operations, and public education are particularly critical.

Future research should extend this comparative approach to other regions and food service settings, using mixed methods that combine qualitative insights with direct measurement of waste volumes. Longitudinal studies could capture seasonal variations and test the effectiveness of interventions such as buffet redesign, portion control, and donation programs over time. Furthermore, policy-focused research is needed to evaluate the cost-effectiveness and feasibility of regulatory innovations, incentives, and cross-sector collaborations. By advancing these lines of inquiry, future studies can provide stronger evidence for scalable solutions that reduce food waste while supporting sustainability in the hospitality industry.

Ethical approval

This study was reviewed and approved by Prof. Wasantha

Table 4
Theme 3: cross-case mini-matrix.

Aspect	Australia (AU)	Sri Lanka (LK)	Implication
Portion size controls	Standard portion tools (ladles/scoops), menu engineering, buffet redesign (smaller pans, batch-cooking), portion prompts; easier calibration using property data	More manual portioning; larger default batches; server-assisted portioning and simple jigs feasible; culturally sensitive prompts needed	AU: keep refining specs and nudges; use data to tighten variance. LK: deploy low-cost portioning jigs + server-assisted service; phase down batch sizes; add bilingual prompts
Staff training & staff meals	Certification-linked refreshers; controlled repurposing within time–temperature windows; staff-meal use constrained by policy and risk	On-the-job coaching more common; staff meals frequently used to absorb surplus; need clear SOPs, safety cut-offs, and logging	AU: target refreshers based on audit findings; formalise safe repurposing. LK: codify staff-meal SOPs (cut-offs, labeling, logs); quick visual training aids
Food "go-to" boxes (takeaway of leftovers)	Offered selectively with allergen/safety notices; biodegradable containers; complemented by donation/ redistribution where feasible	Higher guest uptake; packaging cost sensitivity; policy/ regulatory ambiguity on liability and time–temperature	AU: maintain controlled offer with clear labeling; align with donation protocols. LK: introduce simple policy, low-cost containers, strict time windows, bilingual labels; align with local regulations

Table 5
Comparative analysis.

Category	Aspect	Australia (evidence/notes)	Sri Lanka (evidence/notes)
Context-invariant mechanisms	Buffet over-serving and plate waste	Observed across properties; display norms inflate leftovers	Observed across properties; display norms inflate leftovers
Context-invariant mechanisms	Forecasting volatility (events, seasonality, menu mix)	Creates planning buffers; risk of overproduction	Creates planning buffers; risk of overproduction
Context-invariant mechanisms	Portion-size control	Consistently feasible with minimal brand impact	Consistently feasible with minimal brand impact
Context-dependent mechanisms	Supply chain / infrastructure	1–5 % delivery loss; specialised vehicles/ cool rooms reduce spoilage	5–10 % delivery losses; hot, humid transport; limited cold-chain/storage
Context-dependent mechanisms	Kitchen capability	Greater equipment/ automation enabling tighter portioning and process control	More manual processing; higher dependence on staff skill
Context-dependent mechanisms	Safety / governance	Mandatory food-handler certification; time-window rules shape decisions	Compliance mediated by municipal collection and facility constraints
Context-dependent mechanisms	Workforce practices	Tighter risk controls limit staff-meal pathway	Staff-meal use commonly leveraged to reduce overproduction (subject to safety)
Context-dependent mechanisms	Consumer-side waste	Price sensitivity + signage/portioning moderate plate waste	Larger share of plate waste; awareness/ education gaps
Implications summary	Tailored mitigation portfolio	Prioritise forecasting protocols; buffet redesign; certification-linked training; consumer-facing signage/ portion guidance; maintain cold-chain; evaluate donation/ redistribution	Prioritise cold-chain upgrades and storage; basic equipment investments; targeted skill training; structured staff-meal policies; consumer education; align hotel practices with municipal collection/ segregation

Rajapakshe, Chairperson, SLIIT Business School Ethics Review Committee with the approval number: SLIIT/ERC/SBS/2022/06, dated 15/10/2022.

Funding statement

This research did not receive any specific grant from public, commercial, or not-for-profit funding agencies.

Consent to participate

All participants provided informed consent prior to participation in the research. The participants were informed of the study's purpose, procedures, potential risks, and benefits, as well as their right to withdraw at any stage without any adverse consequences.

CRediT authorship contribution statement

Nisha Jayasuriya: Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Colinie Wickramaarachchi:** Writing – original draft, Supervision, Project administration, Methodology, Formal analysis. **Heshan Wijesundara:** Writing – original draft, Methodology, Formal analysis, Data curation. **Udara Sriyananda:** Methodology, Data curation, Conceptualization. **Vishmi Rathnayake:** Formal analysis, Data curation. **Thamalsha Liyanage:** Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sftr.2025.101463.

Data availability

Data will be made available on request.

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