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Article

Pathways to Sustainable Hospitality: A Carbon Footprint Assessment of a Small-Scale Hotel

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Abstract: The hospitality sector is a significant contributor to global greenhouse gas (GHG) emissions due to its energy-intensive operations. This study quantifies the carbon footprint of a small-scale hotel in Sri Lanka, identifies major emission sources, and proposes mitigation pathways toward sustainable hospitality. It was conducted over 12 months from January 2025 to December 2025. A comprehensive assessment was conducted in accordance with the GHG Protocol and ISO 14064 guidelines, encompassing direct (Scope 1), indirect (Scope 2), and value chain-related (Scope 3) emissions. The total carbon footprint was estimated at 649,979 kg CO_2-eq, with Scope 1 emissions, primarily from refrigerant gases in air-conditioning systems (R-32 and R-22), constituting 77.22% of total emissions. Scope 3 emissions, including transportation of staff and food waste management, accounted for 12.55%, while Scope 2 emissions from grid electricity contributed 10.57%. Mitigation strategies, including transitioning to low-Global Warming Potential (GWP) refrigerants, enhancing energy efficiency through green roofs and cool roofs, adopting solar photovoltaic systems under Net Metering, optimizing LPG consumption, and improving food waste management, were identified as effective measures to reduce the hotel's carbon footprint. This study provides a critical benchmark for operational sustainability, offering actionable insights for hotel managers, policymakers, and the tourism sector to align hospitality operations with climate action and Sustainable Development Goals.

Keywords: Carbon Footprint Assessment, Sustainability, Tourism, and Hospitality Management

1. Introduction

Climate change is one of the most pressing global environmental challenges, primarily driven by anthropogenic greenhouse gas (GHG) emissions. As countries intensify efforts to achieve sustainable development and meet international climate commitments, reducing carbon emissions has become a global priority. The tourism and hospitality sector has emerged as a significant contributor to global GHG emissions due to its resource-intensive operations, including energy consumption, transportation, food services, and waste generation (Ali et al., 2023). In 2019, tourism accounted for approximately 8% of global carbon emissions (Scott, 2021), while generating an estimated annual economic output of nearly USD 6 trillion, demonstrating its substantial contribution to the global economy. This dual role as an economic driver and environmental burden underscores the urgent need to quantify and mitigate the carbon footprint associated with tourism activities.

Hotels constitute one of the most energy-intensive components of the tourism industry. Their daily operations, including accommodation services, food preparation, heating and cooling systems, lighting, laundry, water supply, wastewater treatment, and solid waste management, require substantial energy and material inputs. This results in a considerable amount of GHG emissions (Abeydeera and Karunasena, 2019). Consequently, improving the environmental performance of hotels has become a key priority within sustainable tourism and climate change mitigation initiatives.

In Sri Lanka, tourism is a vital contributor to economic development, with the Western Province, particularly Colombo and its surrounding tourist destinations, experiencing rapid growth in hotel establishments. The expansion of the hospitality sector has increased employment opportunities and tourism revenue. However, it has also intensified environmental pressures through higher energy demand, water consumption, transportation activities, and waste generation (Kanwal et al., 2024). Recent estimates indicate that the hospitality sector contributes approximately 15–20% of regional carbon emissions, emphasizing its importance in regional climate change mitigation efforts (Kadawatha Arachchige, 2025). As environmental sustainability becomes increasingly important for tourism development, hotels are under growing pressure to adopt low-carbon operational practices. These practices aim to minimize their environmental footprint while maintaining economic competitiveness.

Carbon footprint assessment has emerged as an effective tool for quantifying GHG emissions, identifying emission hotspots, and supporting evidence-based mitigation strategies. Such assessments contribute directly to achieving the Sustainable Development Goals (SDGs), particularly SDG 13 (Climate Action), by enabling organizations to monitor and reduce their GHG emissions (Mutanda, 2024). Furthermore, integrating carbon management into hotel operations improves resource efficiency and environmental performance. It also enhances competitiveness, responds to the growing demand for environmentally responsible accommodation, and supports national commitments under international climate agreements (Chaudhary, Singh and Ghosh, 2024).

Despite increasing attention to sustainable tourism, research on carbon footprint assessment within Sri Lanka's hospitality sector remains limited. Existing studies have predominantly focused on large star-class hotels, typically comprising more than 200 rooms, which generally possess the financial resources, technical expertise, and environmental management systems necessary to conduct a comprehensive GHG inventory (Abeydeera and Karunasena, 2019). In contrast, small-scale hotels, which constitute a substantial proportion of Sri Lanka's tourism accommodation sector, remain largely underrepresented in scientific literature. Consequently, there is limited understanding of their GHG emission profiles, operational emission hotspots, and mitigation potential.

Previous studies have primarily focused on conventional emission sources, including electricity consumption, fuel use, water consumption, wastewater generation, and solid waste management (Abeydeera and Karunasena, 2019). However, other potentially important emission sources, such as refrigerant leakage from cooling systems, transportation of major food ingredients and supplies, maintenance activities, and detailed solid waste management processes, have received comparatively little attention. Consequently, existing assessments may underestimate the overall carbon footprint of hotel operations and fail to capture emissions across the full operational system. Although the GHG Protocol and ISO 14064 provide recognized frameworks for greenhouse gas accounting, implementing these frameworks required extensive data collection and verification in the present study because operational data were dispersed across multiple hotel records. This highlights the need for practical and scientifically robust carbon accounting approaches that are suitable for resource-constrained hotels. Such approaches can improve the completeness and accuracy of emission estimates while supporting effective carbon management.

With this background, the development of a tiered carbon accounting framework specifically designed for small-scale hotels represents an important methodological advancement for hospitality carbon assessment. Such a framework enables consistent GHG accounting under data-scarce conditions while facilitating the identification of operational emission hotspots and practical emission reduction opportunities. This approach provides a scalable methodology that can be adopted by similar accommodation establishments seeking to improve environmental performance and transition towards low-carbon hospitality. Kithulkanda Tourist Hotel, located within the Seethawaka Divisional Secretariat, was selected as the case study site. It represents a typical small-scale hotel operating in a region recognized for its natural attractions and sustainable tourism potential. Assessing the carbon footprint of such establishments provides valuable baseline information to improve operational efficiency. It also supports broader policy initiatives aimed at promoting low-carbon tourism development in Sri Lanka.

Thus, this study aims to quantify the carbon footprint of Kithulkanda Tourist Hotel, identify the major sources of GHG emissions across its operations, evaluate existing environmental management practices, and propose practical strategies for emission reduction (Maitra, 2024). By addressing the existing knowledge gap in carbon footprint assessment of small-scale hotels in Sri Lanka, this study provides evidence-based insights into their environmental impacts. The findings support sustainable hospitality management, inform policy development, and contribute to national climate change mitigation efforts.

2. Methodology

2.1. Study Site

Kithulkanda Hotel, located in Padukka, Colombo District, was selected as the study site (Figure 1). The main characteristics of the building are included in Table 1.

Figure 1. Location map of the Kithulkanda Hotel study site.

Table 1. Descriptive Characteristics of Kithulkanda Hotel

Characteristics	Description
Hotel grade	Restaurant
Building age (years)	15 Years
No. of floors	Main Hall – 2 floors Guest Rooms 01 – 3 Floors Guest Rooms 02 – 03 Floors Guest House 03 – 02 Floors
Total floor area (m^2)	8,093.71 m^2
No. of guest rooms	20
Occupancy rate (%)	50 – 75%
No. of regular employees	55

2.2. Study Boundary

The carbon footprint assessment was conducted for a small-scale hotel using an operational boundary defined according to the GHG Protocol. The study covered direct emissions (Scope 1), indirect energy-related emissions (Scope 2), and other indirect emissions (Scope 3) over the reference inventory year from January 2025 to December 2025 (Figure 2 and Table 2).

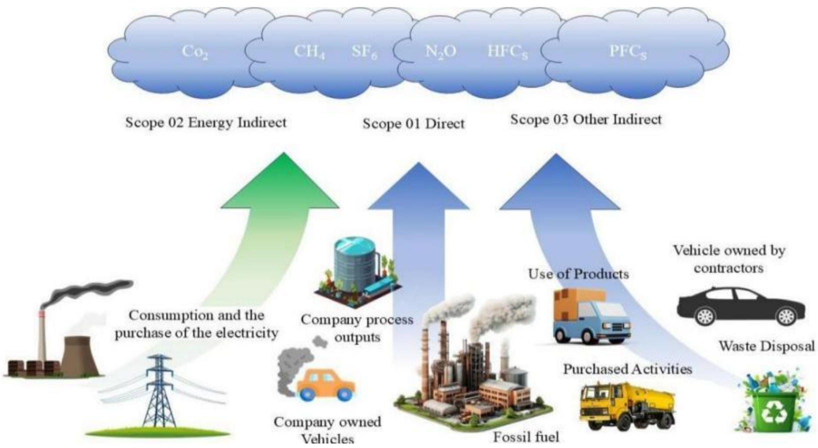

Figure 2. Scopes of emissions of the Kithulkanda Hote

Table 2. Emission sources of the Kithulkanda Hotel

Classification	Description	Emission activities
Scope 01	Direct emissions are the emissions that originate from sources owned or controlled directly by an individual or business.	Gas cooking stoves, refrigerant emissions during the use of refrigeration, air conditioning machines, and food waste storage rooms, paper waste(burning), plastic waste (open burning), garden waste(composting), fire extinguishers, staff transportation (company-owned vehicles), temporary storage of sewage in septic tanks, grass cutters, and generators
Scope 02	Indirect emissions are generated from purchasing and consuming electricity, heating, cooling, or steam by an individual or business. These emissions are not directly owned or controlled by the hotel.	Purchased grid electricity
Scope 03	The emissions arise from sources that are not owned or directly controlled by the individual or business, except for Scope 2 emissions.	Transportation of food waste(piggery), transportation of sewage, transportation of sewage by gully browsers, management of sewage, staff transportation (personal vehicles), pruning trees, transportation of key ingredients

Scope 1 included direct emissions from sources under the operational control of the hotel, while Scope 2 covered emissions from purchased grid electricity. Scope 3 included all other indirect emissions occurring outside the hotel's direct control but associated with its activities, as detailed in Table 2. Specific boundary considerations were applied for waste, wastewater, and water use to ensure consistency in emission allocation. Sewage generated on-site is temporarily stored in septic tanks, and associated emissions during this stage were included under Scope 1. Subsequent transportation and treatment of sewage at external facilities were classified under Scope 3, consistent with downstream emission accounting principles (Menegaki, 2025). For solid waste, only transportation of food waste to external facilities was included in Scope 3, while downstream processing at receiving facilities was excluded due to a lack of operational control. Water consumption was not treated as a separate emission source, as groundwater extraction is powered by electricity, which is already accounted for under Scope 2 emissions (Zambrana-Vasquez et al., 2015).

2.3. Activity Data Collection

Activity data for the carbon footprint assessment was collected over 12 months using documentary evidence and primary data collection methods. Electricity consumption data were obtained from monthly utility bills and internal electricity meter records. Diesel consumption for backup power generation was determined from fuel purchase receipts and generator operation logs. Liquefied petroleum gas (LPG) consumption data were extracted from procurement records and kitchen inventory documentation.

Data on refrigerant replenishment and estimated leakage during equipment servicing were obtained from maintenance logs and service reports. Information on food ingredients and other materials included within the study boundary was collected from purchasing records and inventory registers. Waste generation data–was compiled from previous waste audits and supplemented through interviews with hotel personnel responsible for waste management. Records of wastewater management practices were obtained from the hotel's operational documentation.

Employee commuting data were collected through structured questionnaires to determine transportation modes and travel distances. Information on fire extinguisher servicing and tree pruning activities was obtained from routine maintenance records (Naderipour et al., 2021). To ensure the reliability and completeness of the greenhouse gas (GHG) inventory, all activity data were cross-checked against multiple internal sources. These included utility invoices, procurement records, maintenance logs, inventory registers, generator operation records, waste management documentation, and service reports. This verification process improved data consistency and ensured that the compiled inventory accurately represented the hotel's operational activities throughout the study period.

2.4. Emission factors

GHG emissions associated with the identified emission sources were quantified by applying appropriate emission factors to the corresponding activity data. The emission factors used in this study were obtained from internationally recognized sources, including the Intergovernmental Panel on Climate Change (IPCC) Guidelines, Department for Environment, Food and Rural Affairs (DEFRA) conversion factors, Climatiq emission factor databases, and annual emission reports published by the Ceylon Electricity Board. The selected emission factors represent the quantity of GHG emissions generated per unit of activity and were expressed as kilograms of carbon dioxide equivalents (kg CO_2-eq). The emission factors applied for estimating the carbon footprint of the hotel are summarized in Table 3.

Table 3. Summary of the carbon emission factors

Source	Emission factor	Units of the emission factor
Garden waste(composting)	0.1756	kg CO_2 eq/kg
Paper waste (Burning)	21.29	kg CO_2 eq/kg
Generator (Diesel)	2.2144	kg CO_2 eq/L
LPG gas	1.56	kg CO_2 eq/L
Electricity	0.4062	kg CO_2 eq/L/-kWh
Diesel	2.2144	kg CO_2 eq/L
Petrol	2.3104	kg CO_2 eq/L

2.5. Carbon Footprint Calculation

GHG emissions from each activity were calculated using the standard emission-based approach.

2.5.1. Scope 1

The carbon emissions of the use of LPG gas cylinders, grass cutters, generators, open burning of paper and plastic waste, and transportation of staff (by company vehicles) were estimated as per the equation.

$$GHG\ emissions\ \left(kgCO_2\ e\right) = \ Activity\ Data\ \left(unit\right)\ x\ Emission\ Factor \tag{1}$$

Emissions associated with refrigerant gases used in the air conditioning (AC) machines installed in guest rooms, dining areas, the lobby, the food waste temporary storage room, and ballrooms were quantified using the direct leakage approach (Equation 2).

$$GHG\ emissions\ \left(kgCO_2e\right) = Refrigerant\ lost\ \left(kg\right) \times GWP \tag{2}$$

Leak data were obtained from routine maintenance and service records, and all quantities were expressed in kilograms.

The 100-year Global Warming Potential (GWP_{100}) values of 1,810 kg CO_2-eq kg^{-1} for R22 (Rewlay-ngoen and Papong, 2020) and 675 kg CO_2-eq kg^{-1} for R32 (Pal et al., 2018) were applied to estimate the carbon emissions associated with refrigerant leakage.

Emissions associated with the temporary storage of sewage in the septic tank were estimated based on the following equation.

$$CH_4\ Emissions = \left[\left(TOW_j - S_j\right) \cdot EF_j - R_j\right] \tag{3}$$

$CH_4\ Emissions\ \ j = CH_4$ emissions from treatment/discharge pathway or system, j, in inventory year, $kg\ CH_4 / yr$.

TOW_j = Organics in wastewater of treatment/discharge pathway or system, j, in inventory year, $kg\ BOD / yr$.

S_j = organic component removed from wastewater (in the form of sludge) from treatment or discharge pathway or system, j, in inventory year, $kg\ BOD / yr$.

j = Each treatment/discharge pathway or system

For wastewater discharged to aquatic environments, there is no sludge removal (S_j = 0) and no CH_4 recovery (R_j = 0) (Crone et al., 2016).

EF_j = Emission factor for treatment/discharge pathway or system, j , $kg\ CH_4 / kg\ BOD$.

R_j = Amount of CH_4 recovered or flared from treatment/discharge pathway or system, j , in inventory year, $kg\ CH_4 / yr$. The default value is zero.

$$EF_j = B_0 \cdot MCF_j \tag{4}$$

EF_j = emission factor, $kg\ CH_4 / kg$

j = Each treatment/discharge pathway or system

MCF_j = Methane correction factor (fraction)

BO = maximum CH_4 producing capacity, $kg\ CH_4 / kg\ BOD$

$$TOW = P \cdot BOD \cdot 0.001 \cdot 365 \tag{5}$$

TOW = total organics in wastewater in the inventory year, kg BOD/yr
P = country population in the inventory year (persons)
BOD = country-specific per capita BOD5 in inventory year, g/person/day.
0.001 = conversion from grams BOD to kg BOD

The estimated methane emissions were converted into carbon dioxide equivalents (CO_2-eq) using the 100-year Global Warming Potential (GWP100) value of methane. A GWP value of 28 kg CO_2-eq/kg CH_4 was applied according to the IPCC Fifth Assessment Report (Alexander et al., 2013).

$$GHG\ emissions\ (kgCO_2\ e) = CH_4\ emissions\ (kgCH_4\ ) \times 28 \tag{6}$$

Emissions from fire extinguishers were estimated based on the equation.

$$CO_2\ emissions (kg) = Mass\ of\ CO_2\ discharged\ (kg) \tag{7}$$

2.5.2. Scope 2

Scope 2 emissions mainly come from purchased electricity used for guest room lighting and HVAC, common area lighting, kitchen and laundry equipment, pool and spa facilities, office operations, building systems like centralized air conditioning, and outdoor lighting. Additionally, electricity usage in office operations and maintenance activities is also considered in this analysis.

$$CO_2\ Emissions (Total) tCO_2 = Emission\ Factors\ for\ electricity\ units\ in\ Sri\ Lanka\ x\ Electric\ consumption\ (kWh) \tag{8}$$

Thermal power plants accounted for 46% of the total electricity generation, according to the Ministry of Power and Energy Progress Report (2022).

2.5.3. Scope 3

Carbon emissions associated with indirect activities, such as wastewater management by gully browsers (both transportation and management), staff transportation (personal vehicles), transportation of key ingredients, transportation of solid waste to the piggery, and tree maintenance (pruning and thinning), were estimated based on the following equation.

$$kg\ CO_2\ eq\ = Activity\ Data\ (unit)\ x\ Emission\ Factor \tag{9}$$

2.6. Sensitivity Assessment

A sensitivity analysis was conducted to evaluate the influence of variations in refrigerant consumption on the total carbon footprint. This analysis focused on the two refrigerants used in the study site, R22 and R32, which were identified as significant contributors to Scope 1 emissions. The baseline scenario was developed using actual recorded refrigerant consumption data. Subsequently, alternative scenarios were generated by varying refrigerant quantities by ±20% to assess the robustness of the emission estimates

(Table 4). Specifically, individual and combined changes in R32 and R22 consumption were considered to capture different operational uncertainty conditions.

Table 4. Baseline refrigerant inventory and GHG emissions used in the sensitivity analysis

Refrigerant	**Quantity (kg)**	**Emission factor** ($kg\ CO_2e / kg$)	**Baseline emissions** ($kg\ CO_2e$)
R32	112.53	675	75,960.45
R22	200.00	1,810	362,000.00
Total refrigerant emissions	–	–	437,960.45

For each scenario, emissions were recalculated using the same emission estimation approach applied in the baseline case, where refrigerant emissions were determined by multiplying the quantity of refrigerant lost (kg) by the corresponding global warming potential (GWP). The total carbon footprint was then compared across all scenarios, including contributions from other emission sources, which were kept constant to isolate the effect of refrigerant variability. This sensitivity assessment enabled the evaluation of how uncertainties in refrigerant leakage and usage patterns may influence overall GHG emissions and provided a range of possible emission outcomes for the study system.

2.7. Assumptions and Limitations

This study is based on several methodological assumptions inherent to activity-based GHG accounting. It was assumed that annual refrigerant recharge quantities adequately represent actual refrigerant leakage over the study period. All activity data obtained from hotel operational records were considered complete, consistent, and representative of routine operational conditions. Emission factors were assumed to remain constant throughout the study period and to be representative of the local and global conditions relevant to the assessed activities. This includes the assumption that internationally sourced emission factors appropriately reflect the emissions intensity of the processes within the defined system boundary.

Recyclable waste streams (e.g., glass and PET bottles) were excluded from the assessment due to the lack of reliable downstream treatment data and associated emission factors, as well as their expected marginal contribution to the overall carbon footprint. Similar exclusion approaches have been reported in previous studies where data limitations and negligible influence on total emissions were identified (Ingrao and Wojnarowska, 2023). For the sensitivity analysis, only refrigerant quantities were varied (±20%), while all other activity data and emission factors were held constant. Accordingly, the uncertainty analysis captures only the influence of refrigerant-related variability and does not account for uncertainties associated with other emission sources, data quality, or emission factors. Therefore, the results of the sensitivity analysis should be interpreted as indicative of the relative influence of refrigerant leakage rather than a comprehensive quantification of total model uncertainty.

3. Results and discussion

The total carbon emissions of the hotel were estimated at 630.89 t CO_2-eq, as shown in Table 5. The study indicated that Scope 1 emissions constituted the largest share of the hotel's total carbon footprint, accounting for 77.22% of total emissions (Figure 3).

Table 5. Percentage contribution of emission sources to the carbon footprint of Kithulkanda Hotel.

	Source	Quantity	Units (kg/L)	Emission factor	Units of the emission factor	CO_2kgeq	Percentage %
Scope 1	Garden waste(composting)	2,184	kg	0.1756	kg CO_2 eq/kg	383.51	0.06
	Paper waste (Burning)	12.48	kg	21.29	kg CO_2 eq/kg	265.70	0.04
	Refrigerant gas used in AC machines(R32)	112.54	kg	675	kg CO_2 eq/kg	75,960	11.69
	Refrigerant gas used in AC machines(R22)	200	kg	1,810	kg CO_2 eq/kg	362,000	55.69
	Generator (Diesel)	5,200	L	2.2144	kg CO_2 eq/L	11,514.88	1.77
	LPG gas	14,352	L	1.56	kg CO_2 eq/L	22,389.12	3.44
	Waste water (soakage pit)	156,000	L			28,148.40	4.33
	Fire Extinguisher	22	kg			412.00	0.06
	Company vehicles	539.76	L	2.2144	kg CO_2 eq/L	1,195.24	0.18
Scope 2	Electricity	169,188	kWh			68,724.17	10.57
Scope 3	Food waste (Piggery)-transport	260	L	2.2144	Total kg CO e	575.74	0.09
	Waste water (gully browser)-transport	1872	L	2.2144	Total kg CO e	4,145.36	0.64
	Waste water (gully barrow) management	156,000	L			47,289.20	7.28
	Staff (personal vehicle)					17,358.73	2.67
	Pruning trees (chainsaw)	4.5	L	2.3104	Total kg CO e	10.40	0.00
	Transportation of the main food ingredients					9,606.58	1.48
Total						649,979.02	

Scope 3 emissions were the second-largest contributor, representing 12.55% of the hotel's total carbon footprint. In contrast, Scope 2 emissions, which were primarily associated with purchased grid electricity, constituted the smallest share, accounting for 10.57% of the hotel's total carbon footprint.

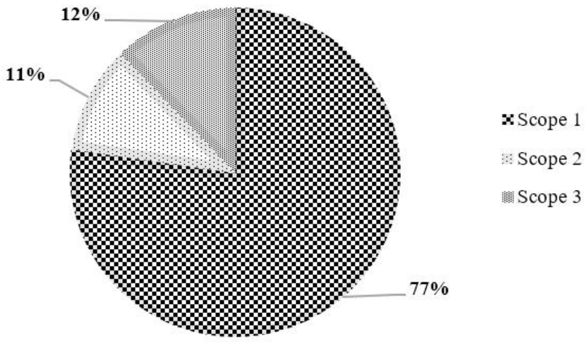

Figure 3. Percentage contribution of Scope 1, Scope 2, and Scope 3 emissions to the total carbon footprint of Kithulkanda Hotel.

When normalized for an occupancy rate of 50–75%, the per-room carbon emissions of Kithulkanda Hotel ranged from 45.6 to 68.3 t CO_2-eq per room per year, substantially exceeding the 16.6–26.5 t CO_2-eq per room per year reported for five benchmark star-class hotels, each with more than 200 rooms (Abeydeera and Karunasena, 2019). Both the present study and the benchmark assessment included Scope 1 and Scope 2 emissions, together with selected Scope 3 emissions (waste disposal, water consumption, and wastewater treatment). However, the present study additionally accounted for minor emission sources, such as main ingredient transportation, garden maintenance, and fire extinguisher use. Despite having only 19 rooms, Kithulkanda Hotel exhibited considerably higher per-room emissions than the benchmark hotels, highlighting the need for targeted mitigation strategies to reduce its carbon footprint.

The carbon footprint assessment further revealed that refrigerants, which were used in the hotel's air-conditioning system, were the largest contributors to total emissions. Among these, R-32 accounted for the highest share (55.69%), followed by R-22 (11.69%). This finding is consistent with previous studies showing that hydrofluorocarbons (HFCs), such as R-32, possess high GWPs because of their relatively long atmospheric lifetimes and high radiative efficiency, enabling them to trap infrared radiation more effectively than chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), or natural refrigerants, despite having negligible ozone-depleting potential (Pal et al., 2018). Refrigerant leakage is a common issue in poorly maintained cooling systems and is often caused by defective seals, improper servicing, or accidental releases during equipment disposal. The exceptionally high refrigerant-related emissions observed in this study may indicate substantial leakage or incomplete recovery of refrigerants during the replacement or disposal of older air-conditioning units. These findings underscore the importance of effective refrigerant management as a key mitigation strategy for reducing the hotel's overall carbon footprint (Teng et al., 2012). R-22, an HCFC with both ozone-depleting potential (ODP) and a high GWP, is phased out under the Montreal Protocol. Although R-32 has zero ozone depletion potential, it still has a relatively high GWP of approximately 675. Among the transitional alternatives, the R-410A blend of R-32 and R-125 has been widely adopted as a substitute for R-22 because it offers improved energy efficiency and zero ODP. However, its high GWP (approximately 2,088) limits its long-term sustainability. Natural refrigerants such as R-290 (propane) and R-717 (ammonia) represent more environmentally sustainable alternatives due to their near-zero GWP and high thermodynamic efficiency, although safety concerns related to flammability and toxicity require appropriate system design and handling. Similarly, R-744 (carbon dioxide) is a promising refrigerant with a GWP of 1 and zero ODP, making it suitable for trans-critical systems in large-scale applications despite its higher operating pressures. In addition, the emerging class of hydrofluoroolefins (HFOs), including HFO-1234yf and HFO-1234ze, offers ultra-low GWP values (<10) and high energy efficiency, making them attractive options for modern air-conditioning systems, although they exhibit mild flammability. Hotels and other commercial establishments can further reduce the environmental impacts of cooling systems by adopting these low-GWP refrigerants, improving energy efficiency through passive cooling and natural ventilation strategies, and implementing refrigerant recovery and recycling programs. Collectively, these measures reduce dependence on conventional air-conditioning systems and mitigate GHG emissions associated with refrigeration and cooling operations (Park, 2019).

Wastewater management emerged as a significant source of GHG emissions, including temporary onsite storage of sewage in septic tanks (Scope 1) and transportation and offsite sewage treatment (Scope 3), accounting for 12.24% of the hotel's total emissions. The establishment of an on-site wastewater treatment facility could reduce emissions associated with sewage from 11.35% to 7.4% of the hotel's total GHG footprint. Several Scope 1 (e.g., generator operation, LPG use, and waste management) and

Scope 3 activities (e.g., staff commuting, food waste transport, tree pruning, and food ingredient transportation) were minor emission sources, collectively accounting for only 9.8% of the hotel's total GHG emissions (Deswal and Deswal, 2025).

LPG consumption accounted for 35.14% of emissions within this category, highlighting it as a major emission source. Emissions can be reduced by improving fuel-use efficiency, adopting energy-efficient cooking equipment, and transitioning to lower-carbon alternatives such as electricity, induction systems, or biogas where feasible. Staff training on efficient LPG use and regular maintenance of appliances to prevent leaks and inefficiencies can further minimize emissions. Implementing these strategies could potentially reduce LPG-related GHG emissions by 20–30%, contributing to a measurable decrease in the hotel's overall carbon footprint (Streimikiene et al., 2024).

For staff commuting, which currently contributes 2.67% of the hotel's total GHG emissions (≈17,345 kg CO_2-eq/yr), several mitigation measures can be implemented. Carpooling among employees who live near each other could reduce emissions by approximately 50% (≈8,672 kg CO_2-eq/yr). Electric vehicles (EVs) for commuting staff could potentially eliminate up to 100% of tailpipe emissions (≈17,345 kg CO_2-eq/yr). Additionally, a shuttle service using a three-wheeler or small van could be arranged for groups of employees living close to each other, providing a partial reduction depending on route efficiency. Hiring staff who live closer to the hotel can further minimize commuting distances and associate GHG emissions. Implementing these strategies in combination can significantly lower the hotel's overall carbon footprint from staff commuting (Tarek and Paran, 2024).

Transportation of main food ingredients contributes 9,606.58 kg CO_2-eq to the hotel's total GHG emissions, with meat items (51.95%), rice (22.31%), and edible oil (13.74%) as the largest contributors (Table 6). Implementing local sourcing can substantially reduce these emissions by shortening travel distances (National Research Council, 2010). For example, sourcing meat, rice, and oil from suppliers located closer to the hotel could reduce their transport-related emissions by approximately 4,226 kg CO_2-eq, nearly 44% of total ingredient transport emissions. Additional measures, such as switching from diesel lorries to electric or hybrid vehicles, consolidating deliveries, and optimizing routes, can further lower emissions.

Table 6. Summary of greenhouse gas (GHG) emissions associated with the transportation of major ingredients.

Material	Vehicle type	Fuel type	Fuel volume(L)	Distance from source to hotel(km)	Weight(kg)	Emission factor	Units of the emission factor	CO_2eq
Rice	Lorry	Disel	7.57	53	100	2.6705	Total kg CO e	2,142.86
Edible oil	Lorry	Disel	5.94	41.6	60	2.6705	Total kg CO e	1,319.78
Meat items	Lorry	Disel	11.55	80.9	120	2.6705	Total kg CO e	4,990.60
Eggs	Three wheels	Petrol	0.54	16.8	900	2.3104	Total kg CO e	41.92
Fish and seafood	Lorry	Disel	5.28	37	60	2.6705	Total kg CO e	1,043.42
Vegetables	Lorry	Disel	0.95	6.7	250	2.6705	Total kg CO e	34.00
Fruits	Lorry	Disel	0.95	6.7	200	2.6705	Total kg CO e	34.00
Total								9,606.58

Generator emissions were estimated at 11,171 kg CO_2-eq per year, accounting for 18.07% of the hotel's Scope 1 emissions. To evaluate potential mitigation strategies, several scenarios were considered. Installing a rooftop solar photovoltaic (PV) system could offset approximately 50% of the current electricity demand from generators, reducing emissions by an estimated 5,586 kg CO_2-eq per year. Additional reductions could be achieved by replacing existing generators with more fuel-efficient models, implementing regular maintenance and optimal load management practices, and transitioning to biodiesel blends such as B20.

Although paper waste burning contributed to 265.70 kg CO_2-eq, it still represents an opportunity for further emission reduction. Open waste burning (OWB) releases carbon dioxide (CO_2), methane (CH_4), and black carbon (BC), all of which are important short-lived climate pollutants (SLCPs) (Ramadan, Fajar and Puspita, 2024). In addition to contributing to climate change, OWB poses significant public health risks, including respiratory diseases and cancer, while also imposing substantial economic costs through environmental degradation and increased healthcare expenditures (Ramadan, Fajar and Puspita, 2024). The hotel can minimize paper waste and associated emissions by replacing paper-based systems with digital documentation, e-receipts, and cloud storage. Implementing double-sided printing, reusing partially printed sheets, and directing segregated paper to certified recycling facilities can further reduce waste generation. Moreover, repurposing paper for decorative or craft purposes enhances resource efficiency and supports sustainable, low-emission hotel operations.

In the present study, the hotel stores food waste in a cooled storage room before it is collected once a week and delivered to a piggery farm. In this study, only the emissions from food waste transportation were considered, amounting to 575.74 kg CO_2-eq, representing 0.09% of the hotel's total emissions. Although diverting food waste to pig feed supports resource recovery and generally results in lower emissions, the energy used for cooling and weekly transport may partially offset these benefits. According to Kim and Kim (2010), diverting food waste to pigs through dry feeding (storage and feeding without adding water) produces approximately 200 kg CO_2-eq per unit of food waste, while wet feeding results in only 61 kg CO_2-eq, composting in 123 kg CO_2-eq, and land-filling in 1,010 kg CO_2-eq (Kim and Kim, 2010). The hotel has implemented several preventive measures in line with the European Union (EU) food waste hierarchy, which prioritizes disposal options according to their environmental impact (Figure 4) (Voukkali et al., 2023).

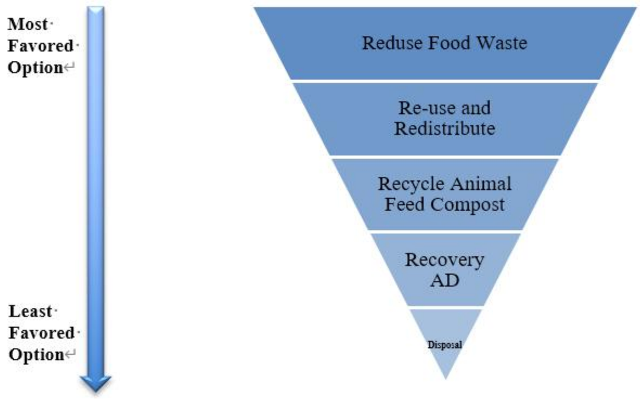

Figure 4. The Food Waste Hierarchy Adopted by the EU (Zu Ermgassen et al., 2016)

These include limiting buffet arrangements to events with more than twenty guests and offering an à la carte menu for smaller groups, thereby reducing waste generation at the source. Surplus edible food is redistributed by allowing staff to take home leftover buffet items. Where prevention or redistribution is not feasible, food waste is supplied to a local pig farmer for use as animal feed, representing a low-emission alternative to composting, bio-char production, or landfilling. Overall, these practices reflect the adoption of higher-priority strategies within the hierarchy, contributing to lower environmental impacts and promoting circular food waste management.

Despite these measures, further emission reductions can be achieved through improved operational practices. The GHG reduction potential of using food waste as pig feed could be enhanced if the pig farmer collected food waste daily using fuel-efficient vehicles, thereby eliminating the need for long-term cold storage and reducing transport-related emissions. This highlights that both hotel-side waste handling and transport logistics are crucial in maximizing the climate benefits of food waste management through livestock feeding. It has been estimated that adopting energy-efficient cooking practices (Lipinski et al., 2013), increasing the proportion of plant-based dishes, preparing meals upon order, and implementing measures such as portion size reduction, offering vegetarian alternatives, and eliminating single-use packaging can significantly reduce food waste and contribute to a 50–80% reduction in associated GHG emissions (Gössling et al., 2011).

In addition, pruning trees using a chainsaw and consuming 4.5 L of petrol generated 0.01 tCO_2e, which is negligible in the overall footprint (Figure 5). Although minor in magnitude, this activity reflects landscaping and aesthetic management practices within the restaurant. While the associated emissions are small, such operational practices contribute to the overall environmental profile of the facility. Eco-friendly landscaping approaches, such as the use of electric chainsaws or manual tools powered by renewable electricity, can further reduce emissions. Therefore, although not significant in quantitative terms, switching to cleaner equipment may enhance the restaurant's sustainability image and align with broader low-carbon tourism practices (Tan et al., 2019).

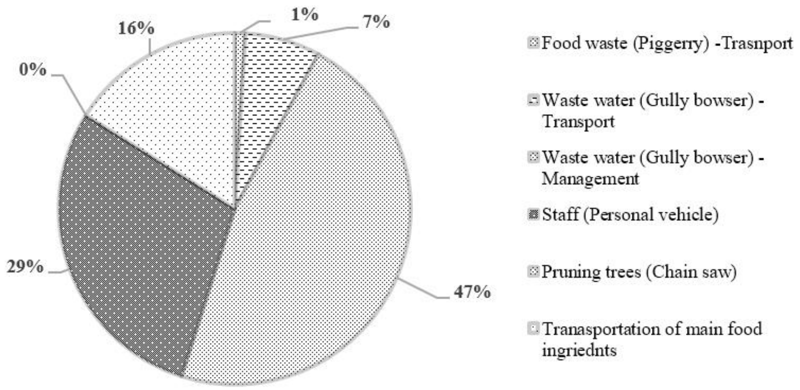

Figure 5. Composition of Scope 3 indirect emissions sources associated with Kithulkanda Hotel

Electricity consumption contributes 68,724.17 kg CO_2-eq, representing approximately 10.57% of the hotel's total GHG emissions. To mitigate this impact, the hotel has implemented several energy conservation initiatives, including green roofs and vertical gardens that act as natural insulation systems, reducing ambient temperatures and minimizing air-conditioning demand. In addition, the hotel is surrounded by a small patch of forest, which provides shade and cools the surrounding air, helping reduce indoor temperatures and complementing the artificial cooling measures. Studies indicate that a 1 °C reduction in ambient temperature can lower building energy consumption by around 5% (Jia et al., 2024). Green roofs, consisting of layers such as vegetation, substrate, drainage, and waterproofing, enhance roof insulation by limiting heat transfer from solar radiation, while plant evapotranspiration further cools the building by converting absorbed solar energy into water vapor (Morakinyo et al., 2017). To further improve cooling efficiency, the application of reflective coatings to the existing roof surfaces is recommended, as cool roofs with an albedo greater than 0.70 can reduce peak daytime temperatures by up to 3 °C and achieve direct energy savings of 20–70% (Macintyre and Heaviside, 2019).

The hotel has replaced conventional lighting with energy-efficient LED bulbs, adopted zigzag lighting patterns in corridors to avoid unnecessary full illumination, and ensured that lighting and cooling systems in the restaurant and common areas are switched off when unoccupied. In addition, the construction of cooling ponds adjacent to the premises contributes to passive temperature regulation, thereby reducing electricity demand for air conditioning (Salata et al., 2016). Building on these existing initiatives, it is recommended that the hotel transition its rooftop solar photovoltaic (SPV) system from the current Net Plus scheme to the Net Metering scheme (Zublie, Hasanuzzaman and Rahim, 2023). Under the current arrangement, all electricity generated by the SPV system is exported to the national grid, and the hotel receives financial compensation from the Ceylon Electricity Board (CEB). Although this provides an additional revenue stream, it does not directly reduce the hotel's operational carbon footprint because all on-site electricity demand continues to be met by grid electricity. By shifting to a Net Metering scheme, the hotel could directly utilize the electricity generated by its SPV system during daytime operations, particularly for air-conditioning, laundry, and kitchen facilities, thereby substantially reducing its reliance on grid electricity and the associated GHG emissions. Such a transition would increase the share of renewable energy in the hotel's energy mix while supporting national renewable energy policies and carbon neutrality targets. When combined with the hotel's existing energy-efficiency measures, self-consumption of solar-generated electricity would provide a robust strategy for achieving significant GHG emission reductions and enhancing long-term operational sustainability (Aljović, 2025). Similar findings have been reported recently by Menegaki (2024), who proved that integrating energy-efficient measures, including LED lighting, smart HVAC systems, and renewable energy technologies, in a hotel in Greece can reduce energy consumption by 10–20% (Menegaki, 2024).

The adoption of advanced energy conservation and efficiency strategies in hotel operations presents a significant opportunity to reduce electricity consumption and associate GHG emissions. A foundational approach involves the deployment of Building Energy Management Systems (BEMS) or smart metering, which enables continuous monitoring of energy use and facilitates data-driven identification of inefficiencies. This allows for the optimization of energy-intensive activities, particularly during off-peak periods, thereby improving overall operational efficiency. By building monitoring systems, significant reductions in energy demand can be achieved through improvements in building design and infrastructure. Upgrading to high-efficiency HVAC systems, enhancing building envelope insulation, and installing low-emissivity glazing effectively reduce thermal loads and cooling requirements (Alassaf, 2024). These passive and active design interventions directly address the major sources of energy consumption in hotel buildings. Further reductions can be achieved through the adoption of energy-efficient equipment and system-level optimization. The integration of solar thermal water heating systems, along with energy-efficient kitchen and refrigeration equipment, reduces dependence on grid electricity (Dilini et al., 2023). In addition, operational strategies such as demand-side load management, the use of variable frequency drives in water circulation systems, and systematic preventive maintenance enhance system performance and minimize energy losses. Complementing these technical and operational measures, behavioral interventions play a critical role in sustaining energy efficiency outcomes. Staff training programs and guest awareness initiatives encourage energy-conscious practices and foster a culture of shared responsibility for energy conservation (Belaïd and Fikru, 2025).

Evidence from previous studies further supports the effectiveness of integrated approaches. Ayoub et al. (2014) revealed that applying an Energy Conservation Matrix in a hotel in Qatar, combining envelope redesign, occupant behavior change, and renewable energy integration, resulted in a reduction of site energy use by up to 24.12% and a decrease in CO_2 emissions by approximately 27%, with 30% renewable energy adoption (Ayoub et al.,2014). This highlights the strong mitigation potential of combining technological and behavioral interventions in commercial buildings. Finally, the incorporation of on-site renewable energy systems further strengthens the sustainability profile of hotel operations. Expanding photovoltaic installations and utilizing biogas generation from organic waste significantly reduce reliance on grid electricity. Collectively, these interventions can reduce grid electricity consumption by 20–40%, leading to substantial decreases in Scope 2 emissions while also providing long-term economic benefits. Supporting this integrated approach, Orfanou et al. (2025) reported that combining renewable energy sources, food waste composting, and enhanced recycling practices reduced total hotel GHG emissions by 47.45%, emphasizing that the greatest mitigation potential is achieved through multiple complementary interventions rather than isolated measures (Orfanou et al.,2025).

The findings of the present study differ from those reported by Abeydeera and Karunasena (2019), who identified purchased electricity and gas (Scope 2) as the dominant sources of GHG emissions in five-star-class hotels in Sri Lanka (Abeydeera and Karunasena, 2019). In contrast, Scope 1 emissions constituted the largest share of total GHG emissions in the present study. This difference is likely due to variations in hotel characteristics, including building size, occupancy rate, and energy-use patterns. The hotels examined by Abeydeera and Karunasena were large establishments with more than 200 rooms and an average occupancy rate of approximately 50% (Abeydeera and Karunasena, 2019). Their emphasis on guest comfort, together with the widespread use of chiller-based air conditioning systems in Sri Lanka's tropical climate, resulted in high electricity consumption and consequently greater Scope 2 emissions.

In comparison, the hotel assessed in the present study has only 19 rooms and a lower operational scale, with an occupancy rate ranging from 50% to 75%. As a result, the electricity purchased made the smallest contribution to the hotel's total GHG emissions. These findings suggest that smaller hotels generally require less electricity for cooling and other operational activities, leading to lower Scope 2 emissions. They also support the previously reported relationship between occupancy rate and electricity consumption, while demonstrating how hotel size and operational characteristics influence the overall carbon footprint. A sensitivity analysis was subsequently conducted to evaluate the effect of refrigerant leakage on the hotel's total carbon footprint (Table 7).

Table 7. Sensitivity analysis of refrigerant emissions under different scenarios

Scenario	R32 change	R22 change	Total refrigerant emissions (kg CO_2e)	Total hotel emissions (kg CO_2e)	Change from baseline (%)
Baseline	0%	0%	437,960.45	649,969.48	0.00
S1	+20%	0%	447,477.79	659,486.82	+1.46
S2	−20%	0%	418,985.19	630,994.22	−2.92
S3	0%	+20%	510,360.00	722,369.03	+11.14
S4	0%	−20%	365,560.00	577,569.03	−11.14
S5	+20%	+20%	519,877.79	731,886.82	+12.60
S6	−20%	−20%	346,585.19	558,594.22	−14.06

Refrigerant quantities were varied by ±20% while other emission sources remained constant. The results showed that the carbon footprint was considerably more sensitive to changes in R22 than R32 because of its higher GWP (1810). A 20% increase in R22 increased total emissions by 11.14%, whereas a similar increase in R32 resulted in only a 1.46% increase. When both refrigerants were increased simultaneously by 20%, the total carbon footprint increased by 12.60%, while a simultaneous 20% decreased emissions by 14.06%. These findings demonstrate that refrigerant leakage, particularly from R22 systems, is the most influential source of uncertainty in the carbon footprint assessment, emphasizing the importance of leak prevention, regular maintenance, and replacement of R22 with low-GWP refrigerants.

4. Conclusion

This study quantified the greenhouse gas (GHG) emissions of a small-scale hotel in Sri Lanka using the GHG Protocol and ISO 14064 framework. It provides one of the few comprehensive carbon footprint assessments for this category of accommodation. The hotel generated a total carbon footprint of 649,979 kg CO_2-eq yr^{-1}. Scope 1 emissions accounted for 77.22% of the total, followed by Scope 3 emissions (12.55%) and Scope 2 emissions (10.57%). Refrigerant leakage from air-conditioning systems was the dominant emission source, contributing 67.38% of total emissions. Wastewater management (11.61%) and electricity purchased (10.57%) were the next largest contributors. The sensitivity analysis showed that the inventory was highly influenced by refrigerant management. A 20% increase in R22 leakage increased total hotel emissions by 11.14%. In contrast, simultaneous reductions in R22 and R32 leakage reduced total emissions by 14.06%.

The results indicate that the greatest mitigation potential lies in improving refrigerant management. Key actions include phasing out high-global-warming-potential refrigerants, implementing rigorous leak detection and maintenance programs, and adopting low-GWP refrigerants. Additional mitigation measures include expanding on-site solar photovoltaic systems under a Net Metering scheme, improving energy efficiency through passive cooling strategies and efficient HVAC systems, optimizing LPG consumption, upgrading wastewater treatment practices, promoting sustainable staff transportation, and strengthening local sourcing and food waste management. Together, these measures address the major emission hotpots identified in this study and provide a practical pathway for reducing operational emissions in small-scale hotels.

This study has several limitations. Refrigerant leakage was estimated from annual recharge records and may not fully represent actual leakage rates. Several emission factors were obtained from international databases because Sri Lanka-specific factors were unavailable. Recyclable waste streams and selected downstream life-cycle emissions were excluded due to insufficient activity data. In addition, the uncertainty analysis focused only on refrigerant-related variability. Future research should incorporate continuous refrigerant leakage monitoring, develop country-specific emission factors, expand life-cycle boundary coverage, and evaluate the long-term effectiveness and cost-effectiveness of mitigation measures across different hotel categories. Despite these limitations, this study provides a valuable baseline for carbon accounting in Sri Lanka's small-scale hospitality sector. It also offers evidence-based guidance to support low-carbon tourism development and national climate mitigation goals.

Author Contributions

For research articles, L. A. W. A. C. Liyanage, K. A. S. H. Wijayasenarathne, R. Amarasinghe, and S. Ramachandra contributed equally to all aspects of the study, including conceptualization, methodology, analysis, and manuscript preparation. All authors have read and approved the final version of the manuscript.

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Conflict of Interest Statement

No conflicts of interest.

Data Availability Statement

The data used in this study will be made available upon request.

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