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Material flows and operational carbon emissions in full- service tourist accommodation across comfort categories

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Research Article

Keywords: Hotel carbon footprint, Scope 3 emissions, Hotel Food procurement, Life cycle assessment, Mixed-methods case study

Posted Date: June 28th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9800896/v1

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Additional Declarations: No competing interests reported.

Abstract

This paper presents the first peer-reviewed operational life-cycle carbon footprint of tourist accommodation in Ireland, using a qualitatively-informed, embedded multiple-case study of four hotels spanning the 3-, 4- and 5-star segments as the empirical vehicle for a full Scope 1–3 inventory. Primary data from procurement ledgers, utility records and on-site field visits are triangulated with two semi-structured manager interviews covering all four properties, and converted to emissions using a transparent factor-selection hierarchy combining Irish-specific peer-reviewed data for supplier-verified categories (beef, dairy), Sustainable Energy Authority of Ireland national factors for energy, DEFRA [1] for waste, and Agribalyse v3.2, Ecoinvent v3.9 and CONCITO for all remaining items. Food and beverage procurement constitutes 40–58% of total annual carbon footprints the single largest emission category at every property and the inclusion of food in the system boundary alters the relative performance ranking that emerges under Scope 1 and Scope 2 alone. Per-room-night intensities span 15.87–56.14 kg CO_2e (mean 39.87); findings are robust to ± 20% factor perturbation and to alternative national-priority factor scenarios. The paper reframes hospitality carbon footprinting as a resource-productivity and material-flow problem, contributes the first Irish benchmarks for the sector, and provides a directly replicable methodology for CSRD-compliant Scope 3 disclosure.

1. Introduction

The persistent divergence between current mitigation trajectories and the 1.5°C pathway documented in the UNEP [2] Emissions Gap Report has intensified demand for sector-specific, operationally grounded emissions evidence in consumer-facing industries where disclosure obligations are outpacing the supply of primary data. In the hospitality sector, this mitigation challenge intersects directly with the United Nations Sustainable Development Goals (SDGs) specifically SDG 13 (Climate Action) and SDG 12 (Responsible Consumption and Production). However, the industry’s ability to meaningfully contribute to SDG 12 is currently compromised by structural deficits in how environmental impact is measured. Specifically, the widespread exclusion of Scope 3 supply chain emissions from standard reporting frameworks creates a blind spot that hides the true environmental cost of food procurement, masking the areas where mitigation leverage is highest. The IPCC [3] AR6 Working Group III assessment identifies demand-side mitigation in buildings and food systems as carrying among the highest near-term abatement potential of any sectoral cluster. Tourism is a material and rapidly growing contributor to this challenge: Lenzen, Sun [4] estimated the global tourism carbon footprint at 8% of total anthropogenic emissions, and Sun, Faturay [5] document continued consumption-based growth concentrated in high-income markets, where aviation in particular generates a disproportionate share of climate impact [6]. Tourist accommodation accounts for approximately 21% of sector-level emissions [7] and is among the most energy-intensive categories of commercial building globally [8].

Viewed through a resource-productivity lens, tourist accommodation is better understood as a node in a concentrated material-and-energy flow procured food, water, energy carriers and consumables entering the property, and service delivery, waste streams and greenhouse gas emissions leaving it [3]. Extending operational carbon foot printing to include Scope 3 procurement is therefore not merely an accounting refinement; it realigns the emissions perimeter with the actual material-flow perimeter of the hotel, enabling the resource-efficiency interventions that the European Union's Corporate Sustainability Reporting Directive [9] and the World Sustainable Hospitality Alliance [10] Net Positive Hospitality Pathway now require.

Despite two decades of hotel carbon footprint research, the evidence base remains structurally constrained. The dominant measurement framework the Hotel Carbon Measurement Initiative (HCMI), deployed across more than 30,000 hotels worldwide restricts its system boundary to Scope 1 direct combustion, Scope 2 purchased electricity, and a single Scope 3 stream of outsourced laundry [Sustainable Hospitality 10]. Food and beverage procurement, the most carbon-intensive supply-chain activity of full-service hotels [11], is explicitly absent. The consequence is a body of per-room-night benchmarks that are internally inconsistent across studies and, as this paper demonstrates empirically, capable of producing incorrect relative performance rankings when food-dominated Scope 3 emissions are excluded.

Geographically, hotel carbon research has concentrated on Mediterranean Europe, East Asia and developed Anglophone markets. Ireland is a mid-sized European tourism economy with a rapidly decarbonising national electricity grid, peer-reviewed grass-based agri-food LCA infrastructure [12, 13], and an accommodation sector dominated by independently operated full-service hotels has received no peer-reviewed hotel-level carbon footprint assessment, and is absent from international hotel benchmarking datasets [14]. This is particularly consequential given Ireland's legally binding 51% GHG reduction target by 2030 and its EPA-projected trajectory of only 23% [15] and given that Coelho [16] tourism environmental accounts depend for their calibration on precisely the kind of bottom-up inventory data that Irish accommodation currently lacks.

To address these compounding deficiencies, this paper employs a qualitatively informed, embedded multiple-case study of four Irish hotels across three comfort categories. It explicitly extends the system boundary to include Scope 3 food and beverage procurement, pairing quantitative Life Cycle Assessment (O-LCA) with qualitative supplier and management interviews.

Specifically, this study is guided by three main research questions (RQs):

RQ1

To what extent does Scope 3 food procurement contribute to the total operational carbon footprint of full-service hotels compared to standard operational (Scope 1 and 2) emissions?

RQ2

How does the inclusion of full-scope food procurement emissions alter the relative environmental performance rankings and intra-category variability of hotels?

RQ3

What are the practical enablers and structural barriers facing hotel operators when attempting to implement procurement-led (Scope 3) decarbonisation strategies?

By answering these questions, this study makes three major contributions. First, it provides the first peer-reviewed operational life-cycle carbon footprint of tourist accommodations in Ireland, establishing a primary-data benchmark (RQ1). Second, it empirically illustrates that conventional Scope 1 and 2 benchmarking systematically misallocates environmental-performance rankings, demonstrating a "ranking reversal" effect (RQ2). Third, through management and supplier interviews, it identifies the structural constraints and

collaborative supply-chain mechanics required to operationalize Scope 3 reductions, demonstrating that measurement alone cannot drive decarbonization without supplier integration (RQ3).

Section 2 reviews the literature; Section 3 describes the mixed-methods design and methodology; Section 4 presents quantitative results; Section 5 integrates quantitative and qualitative findings in discussion; Section 6 concludes.

2. Literature Review

2.1 The Evolution of Hotel Carbon Footprint Assessment

Hotel carbon footprint research has historically been anchored in two diverging paradigms: the activity-accounting approach and more holistic life-cycle models. The activity-accounting approach, typified by the Hotel Carbon Measurement Initiative (HCMI), focuses almost exclusively on Scope 1 direct combustion and Scope 2 operational energy. This narrow focus initially gained traction because energy metrics are easily monitored through onsite utility billing, making the methodology highly accessible for hospitality managers [17]. However, environmental scientists quickly recognized that treating hotels as closed energetic systems ignores the massive environmental load embodied in their upstream supply chains.

To correct this fundamental accounting flaw, Filimonau, Dickinson [18] introduced the Life Cycle Energy Analysis (LCEA) paradigm. By applying ISO 14040/14044 logic to the hospitality sector, LCEA enables broader resource-flow accounting for tourist accommodations. Subsequent applications of comprehensive Life Cycle Assessment (LCA) and Ecological Footprint (EF) methodologies demonstrated that adopting a full value-chain perspective drastically alters our understanding of hotel impacts [19]. Recent comparative studies confirm that while direct energy consumption is a critical driver of environmental harm, indirect emissions from the supply chain, particularly food procurement, consumer goods, and waste management, frequently represent the largest portion of a hotel's total footprint. Despite this consensus in the critical LCA literature, the broader industry continues to rely on truncated benchmarks that fail to support reliable cross-study comparison without explicit boundary harmonization [20].

2.2The Scope 3 Blind Spot and Methodological Truncation

The systematic omission of Scope 3 emissions, particularly food, reflects interlocking structural barriers rather than a lack of awareness or industry effort. In fact, the hospitality sector has made remarkable strides in environmental transparency regarding direct operations. The most prominent example is the Cornell Hotel Sustainability Benchmarking Index (CHSB) [21]. As the industry's largest global data collection initiative, the CHSB successfully harmonizes data from tens of thousands of hotels worldwide, providing an invaluable, publicly accessible dataset for energy, water, and Scope 1 and 2 carbon emissions [21]. Initiatives like the CHSB have revolutionized hotel benchmarking by creating robust, standardized baselines that help operators optimize energy efficiency and track decarbonization progress over time.

However, despite these monumental achievements in operational transparency, the industry still faces a profound structural barrier regarding Scope 3 emissions. Data availability remains the primary obstacle for upstream impacts. Calculating food procurement footprints requires reconstructing purchase ledgers

covering hundreds of commodity items, each requiring a corresponding life-cycle emission factor. As Heidrich and Tiwary [22] note, small and medium-sized tourism businesses generally lack the financial resources, life-cycle engineering knowledge, and expertise to monitor carbon emissions from their complex webs of suppliers.

Into this methodological vacuum, frameworks like the Hotel Carbon Measurement Initiative (HCMI) were designed for operational simplicity, which naturally supported the success of large-scale indices like the CHSB. By scoping its boundary strictly to Scope 1, Scope 2, and outsourced laundry, the industry utilized the most reliable and readily available primary data. Yet, the widespread adoption of this energy-centric boundary has inadvertently institutionalized the exclusion of broader supply chains in hotel reporting. The quantitative consequences of this truncation are severe. Filimonau [23] estimated that excluding supply-chain emissions can understate a hotel's true carbon footprint by 30 to 75%. Environmentally extended input-output analyses further demonstrate that Scope 3 emissions can account for between 54% and 94% of total emissions in the hospitality context. Consequently, while current industry benchmarks excel at reflecting operational energy impacts, they represent only a fraction of a hotel’s true climate burden, masking the areas where mitigation leverage is highest.

2.3 Tourism's Carbon 'Foodprint'

When supply chain boundaries are properly extended, food emerges as the dominant driver of hospitality emissions. Gössling, Garrod [24] fundamentally challenged the sector to address tourism’s carbon "foodprint", noting that food production and consumption carry massive, yet largely unmanaged, greenhouse gas implications. The carbon intensity of food is driven deeply by production systems rather than just transport distances. Poore and Nemecek (2018), synthesizing data across 38,700 farms, demonstrated profound variances in emission factors across food categories, showing that ruminant livestock drastically outweighs plant-based proteins in climate impact. Clune, Crossin [25] confirmed this dynamic, concluding that commodity type is a far stronger predictor of emission intensity than origin distance or food miles.

In hospitality-adjacent contexts, food production has been shown to account for up to 78% of institutional catering’s climate-change potential [26], and 50 to 60% of total emissions in US restaurants [27]. Furthermore, research by [28] identifies procurement substitution, waste reduction, and menu redesign as the highest-leverage demand-side interventions available to hotel operators. Yet, because these Scope 3 emissions sit outside the boundaries of conventional hotel carbon accounting, the relationship between a hotel's comfort category and its true emissions intensity remains largely unquantified. Luxury and full-service hotels inherently feature extensive food and beverage operations, but conventional energy-only benchmarks fail to capture the climate penalty of these services.

2.4 The Imperative for Supplier Integration and Mixed Methods

Recognizing the dominance of Scope 3 emissions necessitates a fundamental shift in how hotels approach decarbonization. Because these emissions arise from upstream supplier activities, they represent the least internally governed share of a hotel's carbon footprint. Consequently, their reduction is entirely dependent on

external stakeholder collaboration. Stakeholder Theory posits that managing these indirect impacts requires moving beyond simple internal eco-efficiency to active, structural supply-chain governance [29].

Quantitative LCA can successfully identify emission hotspots, but it cannot explain or resolve the friction inherent in the supply chain. Studies on responsible tourism practice consistently find that a lack of information, inadequate external guidelines, financial constraints, and poor alignment between hotels and their suppliers derail the implementation of environmentally responsible practices [30, 31]. To effectively reduce a hotel's carbon footprint, management must engage directly with vendors to alter procurement practices, a process fraught with operational resistance. Therefore, pairing LCA with qualitative interviews bridges a critical gap in the literature. It connects the mathematical reality of Scope 3 emission hotspots with the operational reality of supply chain management, deeply exploring how hotel managers and suppliers negotiate sustainable procurement barriers in real-world environments.

2.5 The Compound Research Gap

Ultimately, hotel carbon footprint research is characterized by compounding deficiencies: restricted system boundaries that institutionalize the Scope 3 blind spot and the systematic exclusion of food procurement dynamics. To date, no peer-reviewed study has demonstrated empirically how the inclusion of food alters the rank ordering of hotel carbon intensities across different comfort categories. This "ranking reversal" effect was theorized by Laurent, Olsen [32] and Lenzen [33], who argued that truncation errors do not just systematically lower emission totals, but actively distort which subjects appear most efficient. However, this reversal has never been proven at the hotel property level. By deploying a mixed-methods approach that combines full-scope O-LCA with qualitative stakeholder interviews, this study directly addresses these interconnected gaps and advances the use of life-cycle assessment as a practical tool for sustainable system transformation in the commercial built environment.

3. Methods

3.1 Study design: a qualitatively informed, embedded multiple-case study

This research adopts a qualitatively informed, mixed-methods, embedded multiple-case study design [34, 35], in which four Irish hotels are treated as primary cases and their operational departments energy systems, housekeeping, food-and-beverage procurement, waste streams and guest services as embedded sub-units of analysis. The multiple-case architecture follows replication rather than sampling logic: cases were selected to produce literal replication within the Irish accommodation segment, while the deliberate inclusion of 3-, 4- and 5-star tiers and an LPG-only fossil-fuel configuration at H004 introduces controlled theoretical replication in which contrasting results are anticipated for theoretically specified reasons. Generalisation is claimed analytically to the propositions articulated in Section 1 concerning the bias introduced by Scope-1-and-2-only benchmarking and transferable [36] to comparable contexts, not statistically to the Irish hotel population.

The sample size of four is consistent with the established norm in peer-reviewed hospitality life cycle assessment, in which studies typically examine one to six properties because of the labour intensity of primary inventory data collection [18, 37–39]. Because primary-data operational LCA requires reconstructing

inventory from raw procurement ledgers, utility invoices, and waste manifests, large-N statistical sampling is physically impossible. Consequently, this study rejects statistical sampling logic in favour of Yin's (2009) replication logic. The sample size of four was purposively selected to represent the three dominant comfort categories (3, 4, and 5-star) and differing energy configurations. This ensures that the depth of the primary inventory compensates for the breadth of the sample, aligning with the established norm in hospitality LCA where peer-reviewed studies typically examine one to six properties [23, 37, 38].

Purposive sampling [40] prioritised analytical leverage over representativeness. Properties were selected under the Categories, Union framework to span the three principal comfort categories present in the Irish market: one three-star property (H001, Connacht), two four-star properties (H002, Leinster; H003, Leinster), and one five-star property (H004, Leinster). The sample includes both independent (H001) and group-operated (H002, H003 and H004) ownership structures and includes one property (H004) with an LPG-only energy configuration that is atypical of most of the Irish estate and therefore theoretically informative about energy-carrier-driven footprint variation. Ireland was selected as the empirical context because Ireland's nationally specific characteristics a partially decarbonised grid managed by SEAI, a grass-fed livestock system with peer-reviewed national emission factors, and a tourism sector dominated by independent full-service hotels create a carbon profile that European averages cannot approximate without empirical verification. Hotel characteristics are presented in Table 1.

Table 1
Characteristics of tourist accommodation properties under study.

Feature / Category	H001 (3★)	H002 (4★)	H003 (4★)	H004 (5★)
LOCATION AND CLASSIFICATION				
Country	Ireland	Ireland	Ireland	Ireland
Province	Connacht	Leinster	Leinster	Leinster
Location type	Regional	City centre	Riverside / rural	Rural / woodland
Hotel Stars classification	3-star	4-star	4-star	5-star
Ownership structure	Independent	Hotel Group	Hotel Group	Hotel Group
OPERATION				
Year business opened	1963	1985	1991	2005
Operational season	Year-round (closed 2 months, ref. year)	Year-round	Year-round	Year-round
CAPACITY AND OCCUPANCY				
Number of rooms	50–60	130–140	100–110	60–70
Guest capacity (per night)	108	314	233	156
Annual occupancy rate (%)	59.1	70.0	80.0	73.0
Annual room-nights	11,670	35,258	29,786	18,119
Annual guest-nights	21,012	67,648	49,981	33,371
ENERGY SYSTEMS AND SERVICES				
Primary heating fuel	Natural gas (centralised)	Natural gas (centralised)	Natural gas (centralised)	LPG (on-site tank; no mains gas)
Electricity source	National grid	National grid	National grid	National grid
Food service	Full service on-site (B/L/D)	Full service on-site (B/L/D)	Full service on-site (B/L/D)	Full service on-site (B/L/D)
Leisure facilities	None	Gym	Pool, gym	Spa, pool, gym

As summarized in Table 1, this purposive selection ensures the study captures the operational diversity of the Irish hospitality sector. By including variations in location type, star classification, and ownership structure, the subsequent analysis can isolate whether carbon intensity is driven by fundamental facility characteristics or

by specific procurement choices. This operational baseline directly informs the resource consumption inventory detailed in the following section.

3.2 Methodological framing: O-LCA and scope definition

This study employs an Operational Life Cycle Assessment (O-LCA), building upon the methodological frameworks established by Filimonau, Dickinson [18], Puig, Kiliç [38], and Filimonau, Rosa [37]. O-LCA applies ISO 14040/14044 system-boundary logic specifically to the operational phase of a building's life, explicitly excluding the manufacturing, construction, and end-of-life phases. This scoping decision is methodologically justified by two primary factors. First, the majority of the Irish hotel stock under study pre-dates 1990, meaning accurate construction records and embodied carbon data are largely unavailable [18, 41]. Second, O-LCA has demonstrated exceptional effectiveness in the literature for isolating and identifying actionable operational emission hotspots [37].

Greenhouse gas (GHG) emissions within this operational boundary are organized according to the GHG Protocol's three-scope framework [42]. Scope 1 covers the direct combustion of natural gas and LPG on-site. Scope 2 accounts for the emissions associated with purchased grid electricity. Scope 3 is rigorously extended to capture upstream and downstream supply-chain impacts, specifically including food and beverage procurement (from cradle to hotel delivery gate), food waste disposal, general solid waste to landfill, and dry recyclable waste processing. The complete system boundary is illustrated in Fig. 1.

Following established O-LCA protocols in the hospitality sector [18, 37, 38, 43], several categories remain outside the system boundary: building construction, guest transportation, consumer goods, cleaning products, and capital refurbishments. In accordance with ISO 14040/14044 guidelines for comparative Life Cycle Assessments, the system boundary must remain identical across all cases to ensure comparative validity. Consequently, staff commuting and municipal water consumption were excluded. While sub-metered water data and commuting records were available for one property (H001), they were unavailable for the remaining three, and incorporating asymmetrical data would violate the principle of equivalent boundary definition. Furthermore, preliminary calculations for H001 confirmed that staff commuting and water combined contributed less than 1% to the property's total carbon footprint. Applying standard LCA cut-off criteria, these categories were excluded as their inclusion would be immaterial to the final inventory and would not alter the study's central ranking-reversal findings., fundamentally compromising cross-property comparability. This exclusion is analytically sound, as both categories consistently contribute less than 1% to the total carbon footprint of full-service hotels in comparable LCEA literature [37–39].

*Dashed border indicates categories excluded from the system boundary. Scope 1 = direct combustion of natural gas and LPG on-site. Scope 2 = purchased grid electricity. Scope 3 = food and beverage procurement (cradle to hotel delivery gate), food waste disposal, landfill waste and dry recyclable waste. *Water supply and staff commuting data were available for one hotel only and are excluded to preserve cross-property comparability.*

As illustrated in Fig. 1, this expanded operational boundary deliberately bridges the gap between traditional energy management and supply-chain reality. By bringing food and beverage procurement inside the carbon accounting perimeter, the study aligns the measurement framework with the actual material flows required to

service a guest-night. The following sections detail how the raw inventory data traversing these boundaries was collected, validated, and converted into carbon equivalents.

3.3 Functional unit

The primary functional unit is one occupied room-night, defined as one guest bedroom occupied for one night inclusive of all services consumed during that stay. This is the established metric for hotel carbon footprint assessment [37, 38, 44] and enables direct cross-property and cross-study comparison. Annual room-nights are calculated as total rooms × 365 × occupancy rate. Results are also reported as annual absolute totals (kg CO_2e per year) and per guest-night to facilitate comparison with studies using the alternative functional unit, following the dual-reporting recommendation of [37].

3.4 Data collection: three triangulated evidentiary streams

Primary data were collected across three triangulated streams between September 2024 and December 2025, following the mixed-methods case-study protocol of Creswell and Poth [35].

The quantitative inventory stream comprised a full procurement-ledger review at each property, covering food-and-beverage invoices, supplier delivery dockets, waste manifests, and twelve rolling months of energy billing (electricity, mains gas where applicable, LPG at H004). Ledger data were cross validated against monthly utility bills and kitchen stock records. The field-validation stream comprised on-site visits to each property during which energy systems, kitchen and housekeeping workflows, and waste-segregation arrangements were walked through and photographed, and anomalies identified in the ledger review were resolved in situ. Of methodological importance, H004's exclusive reliance on LPG from an on-site storage tank confirmed against utility invoices and observed physically during site visits was established during this phase as an operational characteristic of the property rather than a data artefact, reflecting the absence of mains natural-gas connection at its rural Leinster location.

The qualitative stream comprised two semi-structured interviews with senior management with operational responsibility for the four properties. Because H002, H003 and H004 are operated by a single hospitality group (Hotel Group) under one group general manager, two interviews one with the independent proprietor-manager of H001 and one with the group general manager responsible for H002, H003 and H004 were sufficient to cover managerial accountabilities for all four properties. This ownership structure is a methodologically consequential feature of the case: it naturally controls for managerial-practice variance across H002–H004, allowing observed between-property differences in emissions intensity in that sub-sample to be attributed with higher confidence to property-level physical and operational characteristics (building fabric, energy carrier, occupancy profile, food-and-beverage mix) rather than to managerial style or procurement preference.

Interviews followed a protocol organised around five themes measurement and monitoring infrastructure, investment and payback logic, supply-chain and Scope 3 engagement, perceived barriers including policy and certification, and local sourcing practice. Both interviews were audio-recorded, transcribed verbatim, and analysed thematically following Braun and Clarke [45] using a two-analyst open-coding process. Thematic saturation with respect to the five protocol themes was reached within the two interviews, a consequence both concentrated ownership structure and of the managers' detailed operational knowledge; no new first-

order themes emerged in the second half of either transcript. Interview material is used in this paper to contextualise the quantitative inventory, to validate ledger-derived assumptions (notably food-category shares used to allocate procurement to emission factors), and to surface practitioner-level barriers to Scope 3 visibility that inform the policy discussion in Section 5.5. The resulting thematic framework is presented in Section 5.6 (Table 7) and summarised visually in Fig. 2.

3.5 Emission factors and their justification

All GHG emissions are expressed in kg CO_2e by multiplying inventory quantities by appropriate conversion factors (Table 2). Factor selection followed three principles: national specificity where validated Irish data exist and supplier origin is verifiable from interview evidence; European regional averages where origin cannot be verified; and the most recently published edition of each source.

Energy factors are sourced from SEAI for the reference year: grid electricity at 0.226 kg CO_2e/kWh (reflecting Ireland's 36% renewable mix, substantially below the European average of 0.276 kg CO_2e/kWh); natural gas at 0.183 kg CO_2e/kWh (gross calorific value basis, consistent with EPA, 2024); and LPG at 1.568 kg CO_2e/litre. Solid waste factors are drawn from UK DEFRA (2023) as proxies in the absence of published Irish-specific lifecycle waste factors: landfill 0.87 kg CO_2e/kg, food waste via biological treatment 0.396 kg CO_2e/kg, and dry recyclables 0.021 kg CO_2e/kg. For food and beverage procurement, Irish beef and dairy confirmed as domestically sourced at all four properties through manager interview and verified against supplier records are assigned Irish-specific peer-reviewed factors: 16.0 kg CO_2e/kg beef (O'Brien et al., 2012, grass-based suckler system) and 1.05 kg CO_2e/kg fat-and-protein-corrected milk (Buckley et al., 2020, national pasture-based average). All remaining categories reflect mixed EU-origin sourcing and are assigned European regional averages from Agribalyse v3.2 (ADEME, 2024), supplemented by Ecoinvent v3.9 for processed commodities and the CONCITO/2 – 0 LCA database for beverages, consistent with GHG Protocol Scope 3 guidance (GHG Protocol, 2011) and ISO 14044 (ISO, 2006).

Given that food-related emission factors in the peer-reviewed literature span a factor of two to three across major syntheses (Poore and Nemecek, 2018; Clune et al., 2017), a univariate ± 20% sensitivity test alone would understate epistemic uncertainty in the Scope 3 food inventory. We therefore supplement the ± 20% perturbation with a structured alternative-factor scenario using the "national-priority" configuration applying O’Brien, Shalloo [12] and Buckley, Krol [13] to all bovine and dairy items and removing the European-average blending for these categories to test whether findings depend on the choice of factor architecture. Results are reported in Section 4.5 (Table 6); the qualitative findings that food procurement dominates the footprint at every property and that food inclusion reshapes the Scope 1-and-2 ranking are preserved under all scenarios. Additionally, cradle-to-hotel-gate food-procurement factors are bounded at the point of delivery: they do not include end-of-life waste-treatment emissions, which are accounted for separately through the DEFRA food-waste factor. There is therefore no double-counting between the food-procurement and food-waste categories.

Table 2
Greenhouse gas emission conversion factors used in this study.

Emission Source	Unit	Factor	Factor Unit	Source	Year	Notes / Assumptions
ENERGY						
Grid electricity	kWh	0.226	kg CO_2e/kWh	(SEAI) [46]	2023	Irish national grid; 36% renewable mix; nationally specific
Natural gas	kWh	0.183	kg CO_2e/kWh	(SEAI) [46]	2023	Gross calorific value basis; consistent with EPA NIR 2024
LPG	litre	1.568	kg CO_2e/L	(SEAI) [46]	2023	Heating / stationary combustion; H004 only
WASTE						
Landfill waste (MSW)	kg	0.870	kg CO_2e/kg	DEFRA [1]	2023	UK proxy; managed landfill with gas recovery
Food waste (bio-treatment)	kg	0.396	kg CO_2e/kg	DEFRA [1]	2023	Composting/AD pathway; dominant Irish route (EPA targets)
Dry recyclable waste	kg	0.021	kg CO_2e/kg	DEFRA [1]	2023	Net factor with material recovery credits
FOOD AND BEVERAGE IRISH-SOURCED (supplier-verified in interviews)						
Irish beef (carcass weight)	kg	16.0	kg CO_2e/kg	Buckley, Krol [13]	2020	Grass-based suckler system; liveweight adjusted
Irish dairy (FPCM equivalent)	kg	1.05	kg CO_2e/kg	Buckley, Krol [13]	2020	Fat- and protein-corrected milk; national average
FOOD AND BEVERAGE EUROPEAN AVERAGE (Agribalyse v3.2 / Ecoinvent v3.9 / CONCITO)						
Poultry (chicken)	kg	4.40	kg CO_2e/kg	Agribalyse v3.2 [47]	2024	Broiler; farm to hotel gate; EU average
Pork	kg	3.83	kg CO_2e/kg	Agribalyse v3.2 [47]	2024	Farm to gate; EU average
Lamb / sheep	kg	19.50	kg CO_2e/kg	Agribalyse v3.2 [47]	2024	Farm to gate; EU average
Fish (wild, mixed)	kg	3.00	kg CO_2e/kg	Agribalyse v3.2 [47]	2024	Mixed species weighted; EU fleet
Fish (farmed salmon)	kg	5.10	kg CO_2e/kg	Agribalyse v3.2 [47]	2024	Atlantic salmon; farm to gate
Eggs	kg	2.20	kg CO_2e/kg	Agribalyse v3.2 [47]	2024	Free-range average; EU

Emission Source	Unit	Factor	Factor Unit	Source	Year	Notes / Assumptions
ENERGY						
Fresh vegetables	kg	0.53	kg CO_2e/kg	Agribalyse v3.2 [47]	2024	Weighted seasonal market basket
Fresh fruit	kg	0.62	kg CO_2e/kg	Agribalyse v3.2 [47]	2024	Weighted seasonal market basket
Cereals and bread	kg	0.83	kg CO_2e/kg	Agribalyse v3.2 [47]	2024	Mixed grain/processed; EU average
Oils and fats	kg	3.00	kg CO_2e/kg	Agribalyse v3.2 [47]	2024	Mixed vegetable oils; palm excluded
Processed ingredients	kg	2.10	kg CO_2e/kg	Agribalyse v3.2 [47]	2024	EU market average; used for gaps in Agribalyse
BEVERAGES						
Wine	litre	1.79	kg CO_2e/L	CONCITO and 2 – 0 LCA [48]	2024	EU vineyard avg; glass packaging included
Beer (lager)	litre	0.74	kg CO_2e/L	Agribalyse v3.2 [47]	2024	EU average: packaging included
Spirits	litre	2.10	kg CO_2e/L	CONCITO and 2 – 0 LCA [48]	2024	EU distillery avg; glass included
Soft drinks / juices	litre	0.35	kg CO_2e/L	Agribalyse v3.2 [47]	2024	Mixed carbonated/non-carbonated

The factor hierarchy detailed in Table 2 establishes a transparent, replicable foundation for the subsequent footprint calculations. By anchoring the most carbon-intensive commodity categories (beef and dairy) to peer-reviewed, Irish-specific agricultural data, the methodology minimizes the geographic distortion often present in European-average databases. This hybrid factor architecture ensures that the resulting Scope 3 inventory reflects the genuine emissions profile of local procurement practices, providing a robust baseline for the sensitivity analysis conducted in Section 4.5.

4. Results

4.1 Resource consumption inventory

Table 3 presents the annual resource inventory. Annual room-nights ranged from 11,670 at H001 to 35,258 at H002, and annual guest-nights from 21,012 to 67,648, implying average occupancies of 1.80–1.92 guests per room across the sample.

Energy profiles diverge substantially. H001 consumed 334,886 kWh gas and 146,012 kWh electricity the most modest profile. H002 and H003 are gas-dominated at 2,790,876 kWh and 2,672,029 kWh respectively, approximately eight times H001's volume, consistent with conference and banqueting heating demands. H004 relies exclusively on 150,367 litres of LPG and 1,474,502 kWh of electricity, the latter approximately ten times

H002's (143,790 kWh), reflecting the continuous HVAC and spa load of a residential wellness property. Food waste is the highest-volume waste stream at all four properties, ranging from 12,913 kg (H001) to 64,140 kg (H003). Recycling diversion rates vary independently of star category 34.1% at H001, 22.0% at H002, 37.5% at H003, and 45.3% at H004 indicating that recycling practice reflects management priorities rather than comfort classification.

Table 3
Annual resource consumption inventory for all four hotel properties.

Resource	Unit	H001 (3★)	H002 (4★)	H003 (4★)	H004 (5★)
ENERGY					
Natural gas	kWh	334,886	2,790,876	2,672,029	—
LPG	litres	—	—	—	150,367
Electricity	kWh	146,012	143,790	1,106,003	1,474,502
SOLID WASTE					
Food waste	kg	12,913	40,430	64,140	61,430
Landfill waste	kg	6,042	48,080	38,850	21,810
Recycling waste	kg	6,194	24,510	37,280	26,200
WATER					
Water consumption	m³	2,481	n/a (unmetered)	n/a (unmetered)	n/a (unmetered)
OCCUPANCY AND SCALE					
Number of rooms	n	50–60	130–140	100–110	60–70
Occupancy rate	%	59	70	80	73
Annual room-nights	n	11,670	35,258	29,786	18,119
Annual guest-nights	n	21,012	67,648	49,981	33,371

n/a (unmetered) = municipal water supply not sub-metered during the reference year. Water-related emissions are included for H001 only. Dashes indicate resource category not used at that property.

The resource consumption data in Table 3 reveals significant divergence in operational intensity, largely driven by the physical infrastructure of the properties. Notably, H004's reliance on LPG rather than natural gas, combined with the heavy electrical loads of its spa facilities, creates a distinct primary energy profile compared to the urban and regional hotels. However, these raw consumption metrics only tell the operational side of the story; as the subsequent carbon footprint analysis demonstrates, translating this consumption into GHG emissions fundamentally alters how these properties compare.

4.2 Carbon footprint by scope and source

Annual carbon footprints ranged from 185,145 kg CO_2e at H001 to 1,421,081 kg CO_2e at H002, with H003 at 1,404,420 and H004 at 1,017,164 (Table 4). The seven-fold range reflects differences in scale, operational intensity and food-service throughput rather than star category: both highest-emission properties are 4-star.

Scope 1 natural gas combustion dominates at H001 (61,284 kg CO_2e; 33.1%), H003 (488,981; 34.8%) and H002 (510,730; 35.9%). H004's Scope 1 derives entirely from LPG at 235,775 kg CO_2e (23.2%). Scope 2 variation is widest: H004's electricity emissions (333,237 kg CO_2e; 32.8%) are ten times H002's (32,497; 2.3%), reflecting spa infrastructure versus an older gas-heated city-centre building with limited air-conditioning. Scope 3 food and beverage procurement is the single largest emission category at every property, ranging from 79,923 kg CO_2e (H001) to 819,500 kg CO_2e (H002) and constituting 43.2%, 57.7%, 43.1% and 39.7% of total annual emissions at H001, H002, H003 and H004 respectively. At every property, food procurement generated more CO_2e than any individual energy category, including natural gas at the two most gas-intensive hotels. Waste-related Scope 3 emissions were minor at all properties, contributing 4.1–5.9% of totals.

Table 4
Annual carbon emissions by emission source, GHG Protocol scope and hotel (kg CO_2e), with per-room-night and per-guest-night intensity metrics.

Emission Source	Scope	H001 (3★) kg CO_2e	H002 (4★) kg CO_2e	H003 (4★) kg CO_2e	H004 (5★) kg CO_2e
SCOPE 1 DIRECT ON-SITE COMBUSTION					
Natural gas	1	61,284	510,730	488,981	—
LPG (H004 only)	1	—	—	—	235,775
Scope 1 subtotal	1	**61,284**	**510,730**	**488,981**	**235,775**
SCOPE 2 PURCHASED GRID ELECTRICITY					
Grid electricity	2	32,999	32,497	249,957	333,237
SCOPE 3 SUPPLY CHAIN AND WASTE					
Food and beverage procurement	3	79,923	819,500	605,500	404,300
Food waste disposal	3	5,114	16,010	25,399	24,326
Landfill waste	3	5,257	41,830	33,800	18,975
Dry recycling	3	130	515	783	550
Scope 3 subtotal	3	**90,424**	**877,855**	**665,482**	**448,151**
ANNUAL TOTALS AND INTENSITY METRICS					
Annual total (kg CO_2e)	All	**185,145**	**1,421,081**	**1,404,420**	**1,017,164**
Per room-night (kg CO_2e)	—	**15.87**	**40.30**	**47.15**	**56.14**
Per guest-night (kg CO_2e)	—	**8.81**	**17.71**	**20.64**	**24.47**
Scope 1 share (%)	—	33.1%	35.9%	34.8%	23.2%
Scope 2 share (%)	—	17.8%	2.3%	17.8%	32.8%
Scope 3 share (%)	—	49.1%	61.8%	47.4%	44.0%
Food procurement share (%)	—	43.2%	57.7%	43.1%	39.7%

Scope 3 subtotal includes food procurement, food waste disposal, landfill waste and dry recycling. Food procurement share reported separately as the primary analytical variable. Percentage shares may not sum to exactly 100% due to rounding.

The emission breakdown in Table 4 confirms the overwhelming dominance of Scope 3 emissions specifically food procurement across all comfort categories. Even at highly energy-intensive properties like H002 and H004, the carbon load of the supply chain surpasses direct onsite combustion and purchased electricity. This

finding establishes the empirical foundation for the ranking-reversal effect explored in Section 4.4, proving that operational energy metrics are insufficient for benchmarking hotel climate impact

4.3 Carbon intensity per room-night and per guest-night

Per room-night, carbon footprints ranged from 15.87 kg CO_2e (H001) to 56.14 kg CO_2e (H004), with H003 at 47.15 and H002 at 40.30 a 3.54-fold difference and a sample mean of 39.87 kg CO_2e. Ranking broadly follows comfort category, although the two 4-star properties diverge by a factor of 1.17 due to differences in gas consumption efficiency and occupancy distribution. Per guest-night, the range narrows to 8.81–24.47 kg CO_2e (mean 17.91). H004's apparent disadvantage per room-night (56.14) is substantially attenuated per guest-night (24.47), reflecting higher average room occupancy from couples and spa groups. This metric sensitivity confirms the importance of dual reporting: a hotel presenting only per-guest-night figures may project a more favourable profile without any reduction in absolute environmental impact.

4.4 Ranking reversal when food procurement is included

Comparing hotel rankings under two boundary specifications reveals the paper's methodologically most consequential finding. Under Scope 1 and 2 only, the per-room-night rank order is H001 (9.40 kg CO_2e) < H002 (16.59) < H003 (25.10) < H004 (32.32), positioning H004 as the most carbon-intensive property consistent with its electricity and LPG-intensive spa configuration. Under full Scope 1–3, the order becomes H001 (15.87) < H002 (40.30) < H003 (47.15) < H004 (56.14). H002 which appeared comparatively efficient under energy-only metrics rises sharply when its large food-procurement volume, driven by 67,648 annual guest-nights, is accounted for; H002 and H003 exchange positions relative to the energy-only ranking, and the magnitude of separation across the sample changes substantially. The finding confirms that system boundary choice does not merely affect the magnitude of reported carbon footprints but can alter which hotels appear sustainable relative to one another a consequence of excluding what is empirically the largest single emission source at every property.

4.5 Sensitivity analysis

To assess the robustness of findings to uncertainty in European average food emission factors, total carbon footprints were recalculated under three scenarios: (i) all non-Irish food emission factors reduced by 20%; (ii) all non-Irish food emission factors increased by 20%; and (iii) a national-priority scenario using O'Brien et al. (2012) and Buckley et al. (2020) factors for all bovine and dairy items, removing European-average blending for these categories. The ± 20% range encompasses documented inter-study variability for key European commodity categories [25, 49]. Under all three scenarios, food procurement remains the single largest emission category at all four hotels, and the per-room-night ranking of hotels is unchanged. Food shares range from a minimum of 34.5% (H004, − 20% scenario) to a maximum of 62.1% (H002, + 20% scenario). These results confirm that the qualitative findings food procurement dominance and the ranking reversal effect are robust to emission-factor uncertainty (Table 5).

Table 5
Sensitivity analysis: total annual carbon footprint and ranking stability under ± 20% food-factor variation and under a national-priority scenario using Irish-specific factors for all bovine and dairy categories.

Hotel	Base (Table 4)	−20% food factors	+ 20% food factors	National-priority scenario	Ranking
H001 (3★)	185,145	169,161	201,130	168,200	Unchanged
H002 (4★)	1,421,081	1,257,181	1,584,981	1,252,400	Unchanged
H003 (4★)	1,404,420	1,283,320	1,525,520	1,268,100	Unchanged
H004 (5★)	1,017,164	936,304	1,098,024	940,800	Unchanged
Key finding	*Food procurement remains the single largest emission source at all four hotels under all scenarios. The per-room-night ranking of hotels is unchanged. Food dominance (> 34% of total) is robust to emission-factor uncertainty, confirming that the paper's central empirical claims are not artefacts of particular factor databases.*				

Scenarios vary only non-Irish food and beverage emission factors. Irish beef and Irish dairy retain their verified national factors in the base and ± 20% scenarios; the national-priority scenario additionally applies O'Brien et al. (2012) and Buckley et al. (2020) to all bovine and dairy items. Rankings defined by per-room-night intensity

The sensitivity analysis presented in Table 5 confirms the structural resilience of the study's central finding. Even when subjected to extreme ± 20% factor perturbation, food procurement remains the dominant emissions source across all scenarios, and the per-room-night ranking of the four properties remains entirely stable. This robustness demonstrates that the 'ranking-reversal' effect is a fundamental characteristic of full-scope hotel operations, rather than an artefact of the specific emission factor databases selected. The implications of this structural shift are discussed in the following section.

5. Discussion

5.1 Food procurement as the dominant Scope 3 emission source

This section addresses the second study contribution the empirical quantification of food procurement as the dominant Scope 3 emission source in full-service hotels. Food and beverage procurement constitutes the single largest emission category at all four hotels: 43.2%, 57.7%, 43.1% and 39.7% of total annual carbon footprints at H001, H002, H003 and H004 respectively. This empirically extends the theoretical case of Gössling, Garrod [24], who estimated food at 15–25% of total tourism emissions, and aligns with Baldwin et al. (2011) (50–60% of US restaurant LCA) and Cerutti et al. (2016) (78% of Italian institutional catering). Lower shares here reflect full-service hotels' substantial non-food energy loads, consistent with Hu et al. (2015) and [50] [51]. Hotels directing decarbonisation exclusively toward energy efficiency address at most 42–60% of their actual carbon footprint.

The qualitative evidence converges on this quantitative finding in a particularly instructive way. The Hotel Group CEO described, unprompted, the precise methodological problem the paper addresses when recalling the moment his organization moved from spend-based to direct-data Scope 3 modelling:

"When we wanted to change the methodology from modelling our Scope 3 from spend to actual raw data like food, drink, general categories to actually specifically beef, poultry, dairy, and the direct carbon load associated with beef, poultry, dairy it almost doubled our carbon load for food, which was a bit of a shock." (Hotel Group CEO)

This practitioner observation, reached independently in a live operational context, provides in vivo validation of the boundary-effect thesis the paper quantifies across the four-case sample. The finding establishes food procurement as the primary carbon lever in full-service hotels, fundamentally reframing the analysis of variability patterns examined in the following section.

5.2 Convergence and intra-category variability

This section extends the second and third contributions by examining two structural patterns in the food-emission data. A near-identical food-procurement intensity across the three upper-tier properties 21.72 kg CO_2e per room-night at H004, 21.68 at H003 and 21.67 at H002 persists despite different energy configurations and a threefold difference in room count, suggesting that full-service hotel food provision at 4- and 5-star level is governed by a common service standard of meal frequency, protein-heavy menus and national agri-food procurement. Bohdanowicz and Martinac [8] observed analogous convergence in energy intensity across European chain hotels attributable to service-level standardisation. If confirmed at scale, this convergence would support the construction of service-category food emission benchmarks applicable to sustainability certification frameworks where food procurement is currently absent.

Simultaneously, the two 4-star properties diverge by a factor of 1.17 in per-room-night intensity (47.15 versus 40.30 kg CO_2e), extending Puig, Kiliç [38] finding that intra-category differences can equal inter-category ones. When food is included, H003's higher figure reflects gas consumption per room-night output, while H002's higher food share (57.7%) reflects large guest throughput relative to its energy load a cross-substitution invisible under HCMI Scope 1 and 2 reporting. Styles, Schönberger [52], Huang, Wang [53], Tsai, Lin [54] each confirm that management practice, building age and facility mix explain more variance in hotel carbon intensity than star rating alone. The qualitative interview evidence supports this: Manager A described over 20 years of utility monitoring at H001 while acknowledging that smaller properties "shy away" from the numbers game, while the hotel group CEO documented a €350,000 boiler-connection investment at H003 that was justifiable only because the group had ten years of sub-metered sensor data. These patterns together reveal that a hotel's carbon profile is shaped as much by its food-service configuration and management culture as by its energy system.

5.3 The ranking reversal effect and its methodological implications

This section addresses the third study contribution the empirical demonstration that including food procurement reshapes hotel performance rankings. Under Scope 1 and 2, H002 appears the most energy-efficient 4-star property; under full Scope 1–3 it rises sharply, and H002 and H003 exchange positions.

Laurent, Olsen [32] demonstrated that single-indicator comparisons produce incorrect environmental rankings in approximately 30% of pairwise cases because excluded categories carry material environmental loads; Lenzen [33] showed truncation errors from narrow boundaries can exceed 50% of true impacts for supply-chain-intensive activities. This study provides the first property-level empirical demonstration of this reversal in a hotel context, confirming that HCMI-compliant benchmarks are incomparable with full-scope assessments without explicit boundary harmonisation a systematic blind spot Chan [55] identified in hotel management carbon reporting and which Filimonau and Delysia [51] identify as the field's most consequential unresolved methodological issue.

In terms of scholarly contribution, the paper advances the hotel LCA literature by demonstrating that system-boundary choice can reverse, not merely rescale, performance rankings, and by delivering the first full-scope Irish hotel benchmarks replicable for CSRD compliance. Boundary transparency is consequently a prerequisite for comparative hotel carbon assessment, shifting the decarbonisation agenda toward the supply-chain interventions addressed in the following section.

5.4 Decarbonisation implications for hotel operators and policy

This section addresses the practical implications of the ranking-reversal effect for hotel decarbonisation. Because the qualitative evidence reveals that external, audit-grade Scope 3 certification is currently absent (Theme 4), hoteliers cannot wait for top-down regulatory frameworks to act. Based on the quantitative inventory and qualitative barrier analysis, we propose a stepped, actionable approach for operators:

Step 1: Pivot capital from passive energy retrofits to active menu engineering.

As national grids decarbonise (e.g., Ireland's trajectory toward 80% renewable electricity by 2030), the carbon mitigation value of Scope 2 efficiency investments will passively diminish. However, food procurement emissions will not benefit from grid decarbonisation. Operators must recognize that menu engineering and green procurement now represent the most accessible, highest-impact levers for carbon reduction, particularly for independent hotels with constrained capital budgets.

Step 2: Implement immediate protein substitution.

Procurement-led decarbonisation does not require waiting for perfect supplier data. Substituting ruminant protein (beef and lamb) with poultry, fish, or plant-based alternatives is an immediate, actionable step. As demonstrated by the 4.1:1 emission-factor ratio between beef and chicken in this study, this single procurement shift yields material Scope 3 reductions without requiring capital-intensive infrastructure investment.

Step 3: Establish transitional supplier-engagement metrics.

In the absence of EU-wide certification (the "greenwashing risk" identified by management), hotels must establish transitional, internal supplier-engagement metrics. Rather than demanding full life cycle assessments from small, local producers which is operationally unrealistic hotels should prioritize sourcing from suppliers verified by existing, credible national programs (such as Ireland's Origin Green). By embedding

these specific verification requirements into supplier contracts today, hotels can build the data architecture they will need for mandatory CSRD reporting tomorrow.

Third, the EU CSRD [56] will require hotels above applicable thresholds to disclose full Scope 3 emissions; this study's methodology and emission-factor table provide a directly replicable compliance template, addressing the preparedness gap documented by Apolloni, Volgger [57]. The qualitative evidence underscores the urgency: the Hotel Group is committed via the Science-Based Targets initiative to a 35% Scope 3 reduction by 2033, but as of the reference year had "pretty much zero" active supplier engagement, with formal strategy launch planned for 2026. This temporal lag between target-setting and implementation typical of the Irish hospitality sector is precisely the gap that CSRD-ready methodology, of the kind presented here, can close.

5.5 Contextual comparison with the international literature

The Irish sample (8.81–24.47 kg CO_2e per guest-night) is consistent with mid-range to upper full-service hotel values once boundary differences are acknowledged: Thai homestays averaged 0.32 kg CO_2e [37]; New Zealand budget properties fell below 4 kg CO_2e [58]; UK three-star hotels reported 14–25 kg CO_2e under operational-only LCEA [18]; Balearic Islands hotels reached 20–31 kg CO_2e [59]; Brazilian and Peruvian full-service properties reported 10–30 kg CO_2e under partial Scope 3 [37]; and Spanish coastal hotels' 9–14 kg CO_2e [38] would likely exceed 20 kg CO_2e with food included (Table 6). The Irish hotels are neither outliers nor exceptional. What distinguishes this study is boundary completeness, revealing carbon intensities approximately 70–130% higher than operational-only assessments would suggest consistent with Filimonau [23] estimate that excluding supply-chain emissions understates hotel footprints by 30–75%.

Table 6
Comparative carbon-intensity benchmarks from published hotel LCA studies.

Study	Location	Hotel Category	Per guest-night (kg CO_2e)	Per room-night (kg CO_2e)	System Boundary	Year	Notes
[58]	New Zealand	Budget / hostels	4–6.2		Energy only	2001	No food; energy-based
[8]	Europe (Hilton/Scandic)	Full-service chain	~ 10–22*		Energy only	2007	kWh × EU av. EF; no food
[59]	Balearic Islands	Mixed	20–31		Lifecycle energy	2010	Mediterranean resort; no food
[18]	UK (Dorset)	3-star	14–25		O-LCA; excl. food	2011	First LCEA UK hotels
[60]	Taiwan	4–5 star	29	50	Energy only	2015	
[38]	Spain (coastal)	2–4 star	9–14		Full LCA; excl. food	2017	Operational phase only
[61]	Netherland	All	22-49.5 (Average)			2019	Dutch holidaymakers; domestic vs. outbound daily footprint
[37]	Brazil / Peru	2–5 star	10–30		Hybrid; partial Scope 3	2021	Some Scope 3; food excluded
[39]	Thailand	Homestays	0.32		O-LCA; excl. food	2021	Basic accommodation
[62]	Brazil	Hotel Chains		42.9	Water and energy	2022	No food and waste
[63]							
[64]	China	2–5 star	18.47		Energy	2023	Scope 1 and Scope 2
[65]	Greece	5 stars	37.19		Operational (incl. waste & LPG)	2023	Food waste = 11%, Energy = 81%
This study	**Ireland**	**3–5 full-service**	**8.81–24.47**		Full Scope 1–3 incl. food	2026	First Irish benchmarks; food = 40–58% of total

**Derived from reported kWh per guest-night converted at European-average emission factors. Dashes in the food procurement column indicate explicit exclusion. This study's full Scope 1–3 figures are not directly comparable with Scope 1 and 2-only studies.*

As Table 6 illustrates, the apparent high carbon intensity of the Irish sample is not a reflection of poor operational efficiency, but rather an artefact of boundary completeness. When food procurement is excluded, the properties align closely with European and global averages. By making the supply chain visible, this study highlights the severe truncation error embedded in the current literature, reinforcing the necessity for standardized, full-scope reporting frameworks under the incoming CSRD regulations.

5.6 Integrating qualitative evidence: thematic framework

Thematic analysis of the two manager interviews yielded five saturated themes, presented in Table 7 and visualised in Fig. 2. Each theme is triangulated against the quantitative findings and against the international literature. The themes monitoring and data culture; investment and payback logic; supply-chain visibility and Scope 3 emissions; policy and certification gap; and local sourcing reality together describe a sector where leading operators have the measurement infrastructure and strategic commitment to engage with Scope 3 but lack the methodological consensus, audit-grade certification framework, and supplier-level data architecture to execute at scale. The paper's primary-data inventory and transparent factor-selection hierarchy directly address the second of these deficits; the first and third will require sector-level, not study-level, response.

Table 7
Thematic framework derived from semi-structured manager interviews, with illustrative quotations and connection to quantitative findings.

Theme	Summary of evidence	Illustrative quotations	Connection to quantitative findings
T1. Monitoring and data culture	Both managers treat continuous emissions monitoring as operational infrastructure, not a reporting obligation. Manager A has tracked utility data for over 20 years; the hotel group CEO deployed IoT sensor arrays across 30 + sub-metered zones with Ultan Technologies from 2016 onwards.	"Without understanding your usage... you can't make positive impacts, or you don't know if you do what the results are." (Manager A) “We have about, I don't know, 30 electrical meters inside the buildings all looking at who's consuming what energy and when." (Hotel group CEO)	Directly validates the study's decision to construct primary-data inventories from ledger-level records rather than estimation. Explains why the "measurement-first" barrier identified in the literature [23] persists at sector level while leading operators have moved past it.
T2. Investment and payback logic	Capital decisions are justified by payback calculations derived from monitoring data, not by carbon abstractions. The hotel group CEO uses measurement to hold suppliers accountable to promised efficiency (e.g., boiler commissioning rectified by German engineer) and to make predictive asset-replacement decisions (98.9% efficiency gain on well-water pumps).	"The monitoring helps you justify the investment and it allows you to have a strong dialogue with suppliers." (hotel group CEO) "If you don't know what your measurements are before you start... you can't understand anything after that." (Manager A)	Frames the study's emission-factor transparency not as academic formality but as operational necessity: hotel-level decision support requires factor-level auditability. Supports the argument (Section 3.5) for a structured factor-selection hierarchy.
T3. Supply-chain visibility and Scope 3	Both managers describe Scope 3 as an unresolved frontier. Hotel group is SBTi-committed to 35% Scope 3 reduction by 2033; its 2023 spend-based model nearly doubled the estimated food carbon load when reconfigured using direct-data emission factors confirming the study's central methodological argument.	"When we wanted to change the methodology from modelling our scope three from spend to actual the raw data... it almost doubled our carbon load for food, which was a bit of a shock." (hotel group CEO) “[Supplier engagement] is probably a step that we haven't gone to." (Manager A)	Provides direct empirical confirmation of the ranking reversal thesis (Section 5.3). A national industry leader has independently discovered, in live data, the same boundary-effect phenomenon the study quantifies across the four-case sample.
T4. Policy and certification gap	Both managers identify the absence of credible, audit-grade sustainability certification as the structural barrier to procurement-led decarbonisation enabling greenwashing and preventing premium pricing for verified sustainable products.	"There's no certification for Green Hotels; there's nothing in Europe at the moment... there's a lot of greenwashing out there." (Manager A) “There needs to be a bit of certainty in [the Scope 3 model] ... international best practice." (hotel group CEO)	Contextualises the paper's CSRD discussion (Section 5.5): operators are preparing for regulated disclosure while lacking the methodological consensus that would make disclosure comparable across properties. The study partially closes that gap.

Theme	Summary of evidence	Illustrative quotations	Connection to quantitative findings
T5. Local sourcing reality	Both managers resist the assumption that "local = sustainable". Seasonality, production scale and quality consistency constrain how much of a hotel's food basket can be locally sourced. Hotel group estimates 40–45% local; Manager A notes that onions come from Spain and tomatoes from Holland.	"Sometimes the onions have to come from Spain, and sometimes the tomatoes have to come from Holland." (Manager A) “You could be local and terrible for sustainability depending on your practices." (hotel group CEO)	Informs the study's factor-selection hierarchy (Section 3.5): Irish-specific emission factors are applied only where origin is supplier-verified (beef, dairy), not assumed from "local" rhetoric. Strengthens the defensibility of the mixed Irish-EU emission-factor architecture.

Themes identified through two-analyst open coding of verbatim transcripts following Braun and Clarke (2006). Manager A = independent proprietor-manager of H001; hotel group CEO = group general manager covering H002, H003 and H004.

Beyond the substantive content of each theme summarised in Table 7, the spatial relationships among the five themes carry an analytical message that is not visible in the tabular form. Figure 2 visualises this thematic structure, organising the framework into five vertical pillars that together describe the operational decarbonisation logic articulated by the two managers. Read from left to right, the framework moves from the most immediate operational concern, what gets measured, through the financial reasoning that determines whether measurement leads to action, into the upstream supply-chain horizon where the largest unaddressed emissions reside, then outward to the policy and certification environment that constrains what action is possible, and finally to the practical reality of local sourcing as it is encountered rather than imagined. The horizontal flow is not incidental: each theme depends on the one preceding it. Without monitoring infrastructure (T1), investment cases cannot be built (T2); without internal investment maturity, supply-chain engagement (T3) remains aspirational; without standardised certification (T4), supplier engagement cannot be verified or rewarded; and without operational realism about what local sourcing can and cannot deliver (T5), procurement-led decarbonisation collapses into greenwashing.

Read together, the five themes describe a sector at a transitional moment. Both managers have already constructed the measurement architecture and operational discipline that the literature identifies as preconditions for credible Scope 3 engagement [23, 51], and the Hotel Group has gone further, committing through the Science-Based Targets initiative to a 35% Scope 3 reduction by 2033 and discovering through its own data that spend-based modelling materially understates food-related emissions. What both managers lack and what no individual operator can supply is a sector-level infrastructure of audit-grade certification, harmonised emission factors, and supplier-level data architecture that would make procurement-led decarbonisation comparable, defensible, and rewardable in the marketplace. The paper's primary-data inventory and transparent factor-selection hierarchy address the second of these deficits directly; the first and the third require coordinated sector-level response from regulators, industry bodies, and supply-chain certification schemes. The thematic framework therefore positions the quantitative findings of this study not as an isolated empirical contribution but as a methodological template that becomes operationally

meaningful only when paired with the institutional infrastructure that the qualitative evidence reveals to be missing.

6. Conclusion

This paper presents the first full-scope Scope 1–3 O-LCA of Irish hotel carbon footprints, executed as a qualitatively-informed, embedded multiple-case study of four independently operated properties across three comfort categories during the 2024–2025 reference year. It is the first multi-hotel study to empirically demonstrate how food-procurement inclusion reshapes both the magnitude and rank ordering of hotel carbon intensities, and the first to triangulate a primary-data carbon inventory against the thematic insights of senior operators responsible for all four properties in the sample.

Four findings emerge. Food and beverage procurement is the single largest emission source at all four hotels, constituting 40–58% of total annual carbon footprints. Upper-tier properties converge on approximately 21.7 kg CO_2e of food per room-night regardless of energy configuration. Including food in the system boundary alters relative performance rankings, confirming empirically the ranking-reversal effect theorised by Laurent, Olsen [32] and Lenzen [33]. First Irish per-room-night benchmarks range from 15.87 to 56.14 kg CO_2e, with a sample mean of 39.87 kg CO_2e. Two methodological contributions extend beyond Ireland: the empirical demonstration that HCMI-compliant benchmarks cannot be compared with full-scope assessments without boundary harmonisation, and that system-boundary choice can reverse rather than merely rescale relative performance rankings. The replicable O-LCA framework and fully documented emission-factor table provide a directly applicable CSRD Scope 3 compliance template. Substantively, the paper reframes hospitality carbon foot printing as a resource-productivity problem in which the emissions perimeter and the procurement-and-waste material-flow perimeter are realigned the editorial framing of Resources, Conservation & Recycling.

The study is based on four purposively selected hotels, a sample size consistent with, or larger than, the established norm in peer-reviewed hospitality life cycle assessment, where studies typically examine one to six properties owing to the labour-intensive nature of primary inventory data collection. Following Yin [34], the design applies replication rather than sampling logic, and generalisation is claimed analytically and transferable, not statistically. The combined procurement-ledger review, field-validation visits and manager interviews produced data saturation with respect to the operational categories identified as theoretically salient. Generalisation to larger resort properties, urban mid-scale chains or rural self-catering segments would require complementary multi-site replication. Future research should seek to automate Scope 3 supplier-level data extraction to enable the sector-level statistical estimation that manual ledger reconstruction currently precludes.; pursue longitudinal assessment of grid-decarbonisation effects on Scope 2 intensity; and investigate supplier-specific Scope 3 reporting through Origin Green food-verification infrastructure. A natural extension which we are pursuing is a sector-wide survey instrument calibrated against the present inventory to enable population-scale estimation of Scope 3 food emissions in Irish accommodation. Ultimately, this study demonstrates that the current reliance on Scope 1 and 2 benchmarking is not merely incomplete; it is actively misleading. For the hospitality sector to transition from symbolic environmental reporting to genuine alignment with SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action), it must abandon truncated methodologies. Achieving these global goals requires a structural shift toward full-scope supply chain accountability, where food procurement is managed not just as

an operational cost, but as the industry's primary climate lever. This study demonstrates that the current reliance on Scope 1 and 2 benchmarking is not merely incomplete; it is actively misleading. Achieving SDG 12 and SDG 13 in the hospitality sector requires abandoning truncated methodologies in favour of full-scope supply chain accountability.

Declarations

Funding:
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contributions
Sahar Attari: Conceptualisation, Methodology, Investigation, Formal analysis, Writing, original draft, Writing – review & editing. James Hanrahan: Supervision, Writing, review & editing.

Competing Interests
The authors declare no competing interests.

Dual Publication
This manuscript has not been previously published, nor is it under consideration for publication elsewhere.

Authorship
The corresponding author confirms that she has read the journal's policies and is submitting this manuscript in accordance with those policies.

Permission to Use Third-Party Material
All figures and tables in this manuscript were created by the authors and have never been previously published. No third-party material has been used.

Data Availability
The data supporting this study were collected by the authors and are not publicly available due to confidentiality agreements with participating hotels. Reasonable requests for access should be directed to the corresponding author.

Ethical Approval and accordance

The study received ethical approval from the Institute Research Ethics Committee (IREC) of Atlantic Technological University Sligo on 2 October 2024 under approval reference number 2024023. The research forms part of a doctoral programme conducted by the lead author under the supervision of the second author. All research procedures involving human participants were performed in accordance with the ethical guidelines of the Atlantic Technological University Sligo Institute Research Ethics Committee. Written informed consent was obtained from all interview participants prior to data collection. Participants were informed of their right to withdraw at any stage, and the identities of participating accommodation providers and individual interviewees have been anonymised in all published outputs.

Acknowledgments

This research is supported by Atlantic Technological University through the Postgraduate Research Training Programme in Operations and Supply Chain Research (OSCAR).

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Figures

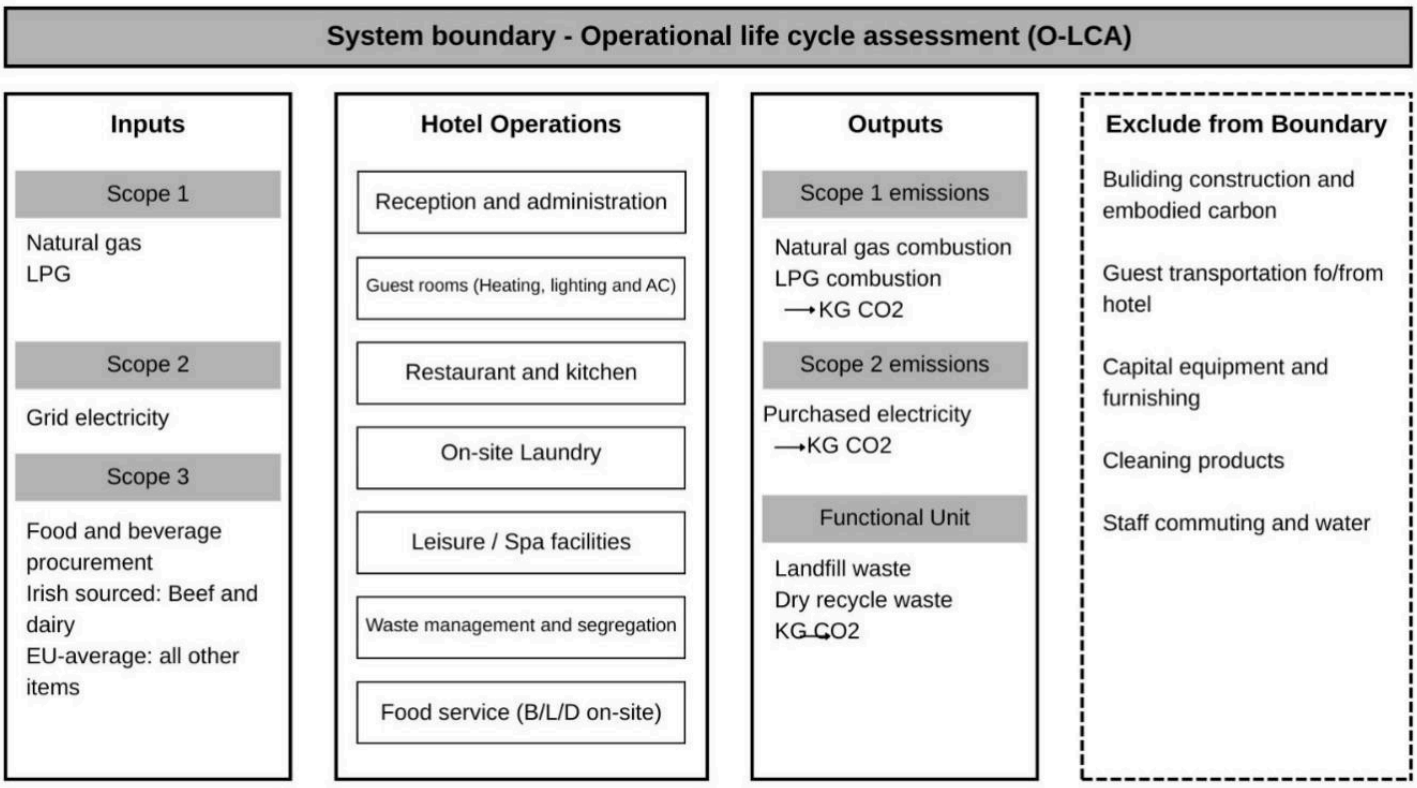


Figure 1

System boundary for the operational life cycle assessment of Irish hotels.

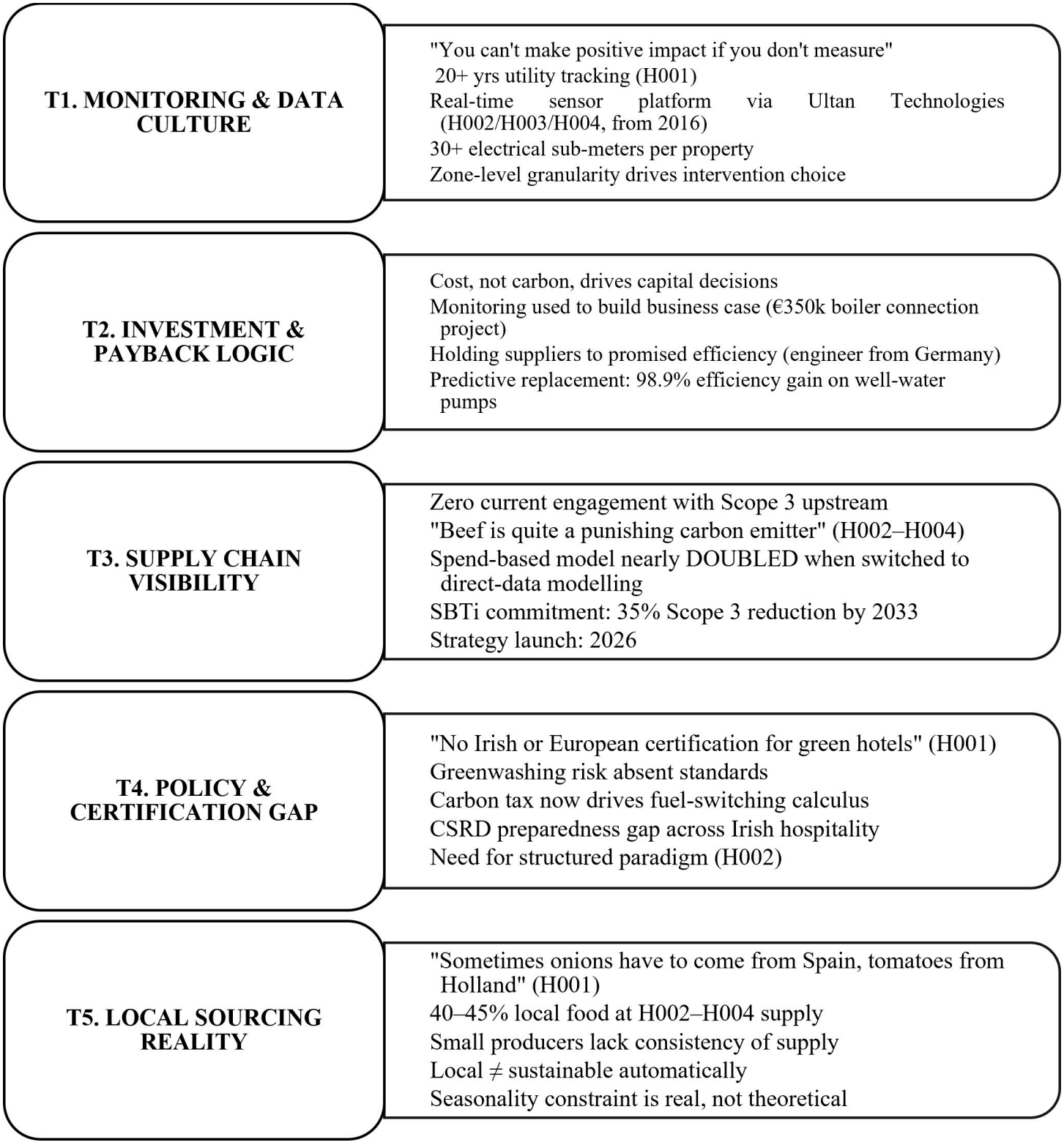


Figure 2

Thematic framework: manager-identified barriers and enablers of hotel decarbonisation.