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Quantitative Assessment of the Carbon Footprint of a Four-Star Hotel in Türkiye over the Period 2022–2024

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Abstract

This study provides a comprehensive quantitative assessment of the carbon footprint of a four-star hotel in Istanbul, Türkiye, spanning the period from 2022 to 2024, to identify critical operational emission drivers. Methodologically grounded in ISO 14064-1 and the Greenhouse Gas Protocol, the research integrates direct (Scope 1), indirect energy (Scope 2), and selected value-chain (Scope 3) emissions. The operational data underwent rigorous uncertainty and sensitivity analyses, alongside multi-tier benchmarking against global, climatic, and regional datasets. Findings reveal that total emissions increased from 1444.93 tCO_2e in 2022 to 1592.61 tCO_2e in 2024, predominantly driven by grid-connected electricity, which accounted for approximately 47.1% of the total footprint in 2024. Key operational hotspots include the continuous baseload energy demands of mechanical rooms and lifts, fugitive R-404A refrigerant leakage, and Scope 3 impacts from red meat procurement and organic waste. Furthermore, sensitivity analyses confirmed the footprint's high elasticity to the national grid's carbon intensity. Despite the facility outperforming benchmarked peers in overall eco-efficiency, the study concludes with actionable, stratified recommendations for facility engineers, hotel operators, and tourism policymakers to overcome technical, supply-chain, and grid-level barriers to decarbonization.

Keywords: carbon footprint; emission calculation; hotel; scope 1–3 emissions; ISO 14064-1; tourism sector; benchmarking; sustainability

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1. Introduction

Energy is an indispensable foundation of modern societies and has been growing in importance since the invention of the electrical generator in the 19th century [1]. In the context of Industry 4.0, it remains as essential as water and food. However, its production through conversion processes causes GHG emissions, with CO_2 standing out as a key driver of climate change. Global CO_2 emissions have been rising steadily since 1980. In 2022, the concentration increased by 2.13 ppm to 417.06 ppm, the eleventh year above +2 ppm, putting it 50% above pre-industrial levels [2].

In the wake of growing demands for environmental awareness and sustainability, companies are increasingly focusing on their CF. In this study, CF is understood as the sum of direct and indirect GHG emissions and removals attributable to an activity, organization, or product life cycle, expressed as carbon dioxide equivalent (CO_2e). This definition is methodologically consistent with the later inclusion of CO_2, CH_4, N_2O, and refrigerant-

related emissions in the inventory. Emissions are expressed in $kgCO_2e$ or tCO_2e to maintain comparability and to avoid uncertain land-area conversions [3].

The tourism sector, responsible for around 8% of global GHG emissions, will continue to grow in importance as international travel activities increase [4]. For Türkiye, the tourism industry is a central pillar of the Turkish economy, generating around 60% of total service exports [5]. In 2022, Türkiye ranked fourth worldwide with 50.5 million visitors. The resulting revenue amounted to US$41.2 billion, placing Türkiye sixth internationally [6]. According to the World Tourism Organization, accommodation accounts for 21% of CO_2 emissions within this sector [7]. Hotels, as a key segment, have particularly high energy requirements [8] and thus cause a variety of negative environmental effects.

In scientific research, the examination of CF is becoming increasingly relevant. Life cycle assessments (LCA) across diverse global contexts consistently show that the operational phase accounts for the vast majority of a hotel's environmental footprint. In a 50-year cradle-to-grave study of Chines buildings, ref. [9] calculated an embodied CF of 701.42 $kgCO_2e$ and revealed that over 85% of total lifecycle emissions stem directly from daily operations, placing hotel impact profiles higher than residential structures but lower than commercial office buildings.

A similar dynamic exists in remote environments: Ref. [10] evaluated lodges in Nepal's Sagarmatha National Park, finding that operational energy use—particularly inefficient biomass heating in traditional structures—drives both lifecycle emissions and overall costs. To capture these dynamics accurately, ref. [11] emphasize combining traditional CF assessment with comprehensive LCA frameworks. While standard CF assessment tracks direct GHG output, full LCA provides the multi-dimensional value-chain tracking needed for effective decarbonization policies.

Ref. [12] applied the Hotel Carbon Measurement Initiative model in Mauritius and found that 3-star hotels frequently exceeded international emission benchmarks. Conversely, 5-star hotels achieved lower emission intensity than global peers due to sustainability certifications and advanced energy-water management systems—though ultra-luxury resorts spiked in emissions due to expansive, resource-heavy guest services. Ref. [13] demonstrated that two large-scale hotel generated significantly more total CO_2 emissions than twelve family-run bed-and-breakfasts combined, driven by operational complexity and shared space heating/cooling.

Analyzing 28 Nigerian hotels, ref. [14] found strong positive correlations between energy consumption and total floor area, guest room count, and staffing levels, whereas building age and occupancy rates had surprisingly weak statistical impacts. Ref. [15] showed that over 99.9% of catering emissions in high-end Chinese hotels originate directly from thermal gas consumption during cooking, with luxury dining concepts generating substantially higher per-guest emissions than standard service options.

Ref. [16] confirmed that electricity consumption is the primary emission driver in Hong Kong hotels, establishing a strong positive correlation between outdoor temperatures and CO_2 output due to HVAC demands. In mainland China, ref. [17] modeled 310 5-star hotels across three climate zones using DeST simulation software. They established dynamic energy intensity baselines and found that up to 54% of hotels exceeded upper performance thresholds due to poor thermal insulation, excessive glass facades, and inefficient climate control systems. Ref. [18] revealed that luxury hotel in Iran exhibit energy intensities 3–4 times higher and carbon emissions up to 7 times higher than international norms, driven by state fossil fuel subsidies and economic isolation.

At a macro scale, ref. [19] projected that expanding the FIFA World Cup host format increases tournament lodging demand by 75%, making the total CF hyper-sensitive to the carbon intensity of the host nation's primary energy grid. Ref. [20] used CCalC software

to analyze interior furnishings across 15 Turkish 5-star hotels, empirically proving that medium-density fiberboard furniture is the most carbon-disadvantaged material choice compared to alternative interior elements.

Using data envelopment analysis on resort hotels in Antalya, ref. [21] revealed that 24 out of 32 analyzed facilities operated inefficiently across electricity, water, and gas usage, allowing researchers to model optimized consumption targets. Ref. [22] identified a distinct gap between international hotel chains and national independent properties. International chains successfully deploy holistic circular business models—such as renewable energy micro-grids, interactive "Earth Labs" and zero-wase initiatives—whereas national operators remain largely constrained to localized measures due to high capital requirements and regulatory gaps.

Although the academic environment offers a wide range of studies in various disciplines, research conducted using a publication database and search engine has revealed a considerable need for research into the systematic recording of CF, particularly in Türkiye. Against this background, the present study aims to comprehensively quantify the CF of a hotel in Istanbul. The selection of a hotel in Istanbul proves to be particularly relevant in this respect, as the metropolis has developed into one of the most frequently visited international travel destinations in recent years [23].

2. Materials and Methods

Methodologically, the study is based on a combined research approach that integrates the Scope 1, Scope 2, and Scope 3 emission categories into the ISO 14064-1 standard [24] and is guided by the specifications of Ref. [25]. The combined approach is illustrated in Figure 1.

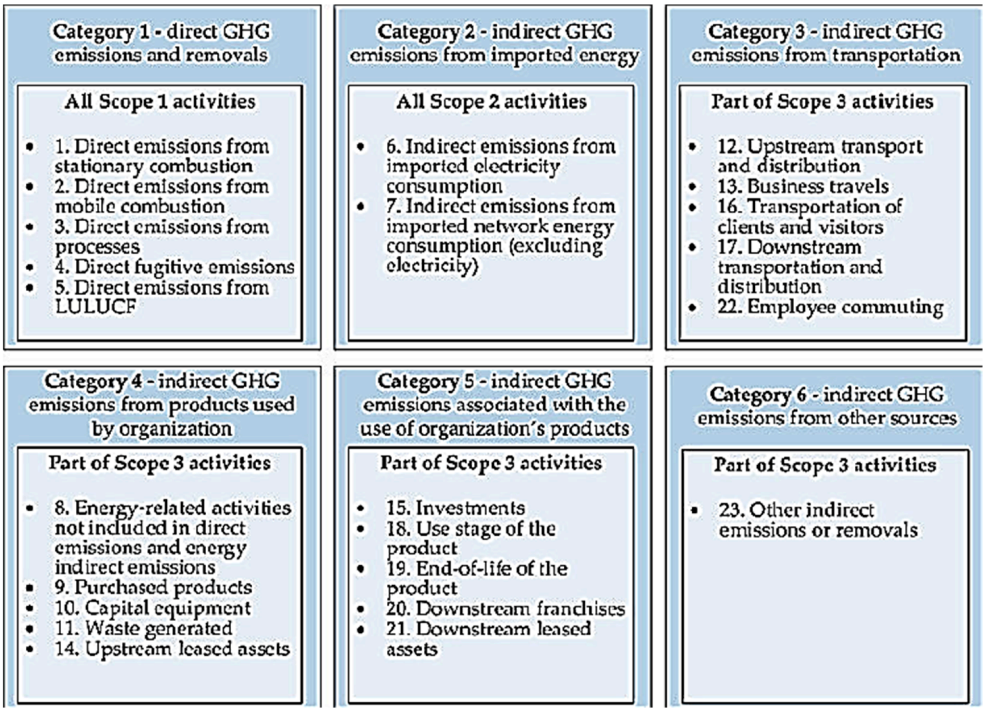


Figure 1. Classification of GHG-P emission areas according to the corresponding categories of ISO 14064-1 [25].

Category 1 (C1) covers direct emissions from stationary and mobile combustion processes, process-related emissions, and fugitive emissions, as well as Land Use, Land Use-Change and Forestry (LULUCF) where relevant. Category 2 (C2) refers to indirect

emissions from imported energy sources. Category 3 (C3) covers transport emissions, including distribution, business travel, and employee transportation. Category 4 (C4) considers emissions from waste treatment and raw material use, while Category 5 (C5) covers emissions from the use of company-owned products. Category 6 (C6) summarizes other indirect emissions or removals and, in this study, is used to report tree-related CO_2 removals separately from gross emissions. These categories define the reporting boundaries in accordance with the GHG Protocol and ISO 14064-1.

An exploratory single-case study approach has been chosen as the research strategy, as this is particularly suitable for topics with a limited knowledge base [26]. Although primarily classified as qualitative [27], it allows for the integration of quantitative elements to increase its significance [28]. The state of research on CF in the Turkish tourism sector, especially in hotels, is underdeveloped [29]. The approach enables an initial scientific exploration, creates theoretical foundations, and supports the methodological development of sustainable hotel management [30].

2.1. Formula Creation

The calculations were performed in an Excel-based (Version 2607) inventory model, considering the Intergovernmental Panel on Climate Change (IPCC) [31], GHG Protocol [32], and the guidelines of the United States Environmental Protection Agency (USEPA) [33]. Total GHG emissions are recorded in tCO_2e. and is calculated as follows:

$$TE_{(total)} = TE_{(C1)} + TE_{(C2)} + TE_{(C3)} + TE_{(C4)} + TE_{(C5)} \quad (1)$$

The TE is calculated by adding all CF values in the individual categories. Because Category 6 represents a static, multi-year accumulation of stored carbon rather than an annual emission reduction, it is explicitly excluded from this total annual operational balance and reported separately. For example, the CF for C1 is calculated as follows:

$$TE_{(C1)} = E_{(SMC)} + E_{(P)} + E_{(WwT)} + E_{(F)} + E_{(LULUCF)} \quad (2)$$

In this context:

- $TE_{(C1)}$ = Total emissions in category 1,
- $E_{(SMC)}$ = Direct emissions from stationary and mobile combustion,
- $E_{(P)}$ = Direct emissions from processes,
- $E_{(WwT)}$ = Direct emissions from chemical use in wastewater treatment,
- $E_{(F)}$ = Direct emissions from fugitive emissions,
- $E_{(LULUCF)}$ = Direct emissions from LULUCF

The USEPA [33] guidelines are used to determine emissions from stationary and mobile combustion. The specific calculation form depends on the level of information available. If calorific value or carbon-content data are missing, fuel consumption is combined with corresponding emission factors. If net calorific value is available, fuel use is first converted into an energy basis and then multiplied by fuel-specific emission factors. If carbon-content data are available, CO_2 emissions are derived from fuel mass, carbon content, and the molecular-weight ratio of CO_2 to carbon. If carbon content is stated as a percentage by mass, the calculation is:

$$CO_{2(SMC)} = AC \times (CC/100) \times 44/12 \times 1/1000 \quad (3)$$

where

- $CO_{2(SMC)}$ = CO_2 emissions from stationary and mobile combustion in tCO_2,
- AC = Amount of converted fuel or material consumption in kg,

- CC = Carbon content of the fuel or material as percentage by mass,
- 44/12 = Ratio of the molecular weights of CO_2 and carbon.

In addition to CO_2, CH_4 and N_2O are also released during stationary combustion processes and must be considered in emissions accounting. Equation (3) only calculates CO_2 emissions; therefore, CH_4 and N_2O are calculated separately and converted into CO_2e using their GWP values [33]. To accurately quantify the activity data for these calculations, the following specific unit conversion factors were applied to standardize the raw consumption metrics for each fuel type: 0.123 m^3 per 1 kWh for natural gas, 0.84 kg per 1 L for diesel, 13.98 kWh per 1 kg for LPG, and 0.735 kg per 1 L for gasoline:

$$E_{i(tCO_2e)} = AC \times NCV \times ECF \times EF_i \times GWP_i \times UCF,\ i \in \{CH_4, N_2O\} \quad (4)$$

In this context:

- AC = Amount of converted fuel consumption,
- NCV = Net calorific value,
- ECF = Energy conversion factor,
- EF_i = Emission factor for gas i,
- GWP_i = Global Warming Potential of gas i, and
- UCF = unit conversion factor required by the units of AC, NCV, ECF, and EF_i.

The recording of CF in the remaining categories is differentiated. C2, which is assigned to Scope 2, is based on electricity consumption multiplied by a corresponding electricity emission factor. If electricity consumption is expressed in kWh and the emission factor is expressed in $kgCO_2e/kWh$, the result is divided by 1000 to obtain tCO_2e. If the emission factor is expressed in tCO_2e/MWh, electricity must first be converted into MWh. For C3, the relevant transport activity data are converted into the units required by the respective transport emission factor before conversion to tCO_2e.

C4 to C6 fall within the broader Scope 3-related accounting boundary in this study. C4 plays a central role because it covers indirect GHG emissions resulting from the procurement of goods and services and from subsequent disposal. For the hotel context examined, these emission sources can be divided into two sub-segments: emissions generated during the purchase and use of external products and services, and emissions from the disposal of the resulting waste streams. Spend-based emission factors are used for quantification, determining average GHG emissions in $kgCO_2e$ per US Dollar or another explicitly defined currency unit invested for specific product groups and services [34]. The methodological approach can be represented as follows:

$$E_{(Pr)} = Pr_{(TP)} \times EF_{(UP)} \times 1/1000 \quad (5)$$

where:

- $E_{(Pr)}$ = Indirect CO_2e emissions of the purchased product or service in tCO_2e,
- $Pr_{(TP)}$ = Total purchase price in the currency basis used by the emission factor,
- $EF_{(UP)}$ = Spend-based emission factor in $kgCO_2e$ per US Dollars.

The emissions resulting from the disposal phase of the products can be quantified using the following equation, provided that the waste quantity and emission factor use matching units:

$$E_{(W)} = A_{(W)} \times EF_{(W)} \times 1/1000 \quad (6)$$

In this context:

- $E_{(W)}$ = Indirect emissions from generated waste in tCO_2e,

- $A_{(W)}$ = Amount of generated waste, for example in kg or m^3 depending on the waste stream,
- $EF_{(W)}$ = Emission factor of the generated waste in $kgCO_2e$ per unit of $A_{(W)}$.

Equation (6) is applied to all individual waste types, with the sum of the individual results being used to determine the total emissions for this sector. Regarding the Scope 3 boundary definition, Category 5 (C5) emissions were explicitly excluded. Because a four-star hotel primarily provides on-site hospitality services rather than manufacturing physical goods that generate downstream use-phase emissions, C5 is considered immaterial to the facility's operational boundary. However, it is acknowledged that due to the exclusion of certain complex Scope 3 sub-categories, the reported total emissions represent a conservative baseline and likely underestimate the absolute, comprehensive life cycle carbon footprint of the hotel.

Category 6 (C6), on the other hand, is interpreted not as an emission source but as a supplementary carbon storage category, accounting for the existing tree populations on the hotel premises. To ensure methodological validity, the tree-related carbon sink was calculated strictly as a stored carbon stock rather than an annual emission reduction. The original equation was methodologically incomplete because it used carbon density and the CO_2/C conversion factor without explicitly including total tree volume, biomass expansion, or below-ground biomass. Therefore, the revised calculation explicitly strictly quantifies the static stored carbon stock. Tree carbon stock was estimated from species-specific dry wood density, measured total wood volume, biomass expansion factors, root-to-shoot ratio, carbon fraction of dry matter, and the molecular conversion factor 44/12:

$$ER_{(tCO_2e)} = V_{total} \times \rho dry \times fC \times 44/12 \times 1/1000 \quad (7)$$

where

- $ER_{(tCO_2e)}$ = Stored carbon stock in tCO_2e,
- V_{total} = Total standing wood volume in m^3 (representing total volume, not annual increment)
- ρdry = dry wood density in kg/m^3
- fC = carbon fraction of dry biomass,
- 44/12 = Conversion factor from carbon to CO_2.

2.2. Basic Information About the Hotel

The study is based on a four-star hotel built in Istanbul with a total area of 19,400 m^2, of which 11,520 m^2 is enclosed operating space and 5500 m^2 is green space. The building has 13 floors with 164 guest rooms, six lifts, and 92 parking spaces. In addition to the restaurant, bar, swimming pool, and garden area, it has a laundry and medical facilities. In accordance with [27], the study period was clearly limited to the years 2022–2024 to ensure consistent emissions development. The data collection covers only the hotel's operational activities, including energy, water, and waste flows. External or organizationally independent units, such as integrated retail stores, were excluded from the analysis. Based on this data, a graphical representation of resource consumption and waste volumes is provided.

The hotel's total electricity consumption rose from 834,969.36 kWh in 2022 to 1162,614.97 kWh in 2024, with peaks in the summer months and minimum consumption in February. Gas consumption increased from approximately 5359 m^3 (2022) to approximately 6526 m^3 (2024), with monthly fluctuations between 300 m^3 and 600 m^3 and a marked peak in November 2024. Water consumption reached approximately 14,507 L in 2022, rose slightly in 2023, and fell to approximately 13,638 L in 2024. The highest values oc-

curred between April and September, illustrating the temperature-dependent influence on water demand.

Figure 2 shows that during the period under review, the areas "corridors and lifts" and "mechanical rooms" had the highest electricity consumption, with both categories exceeding the 200,000 kWh mark in 2024. The "guest rooms" and "kitchen and restaurant" segments also recorded significant consumption value, meaning that these four sub-areas together account for most of the hotel's total electricity requirements. In contrast, the "management office room" and "medical services" areas have the lowest electricity consumption. Overall, electricity demand in 2024 is significantly higher than in previous years.

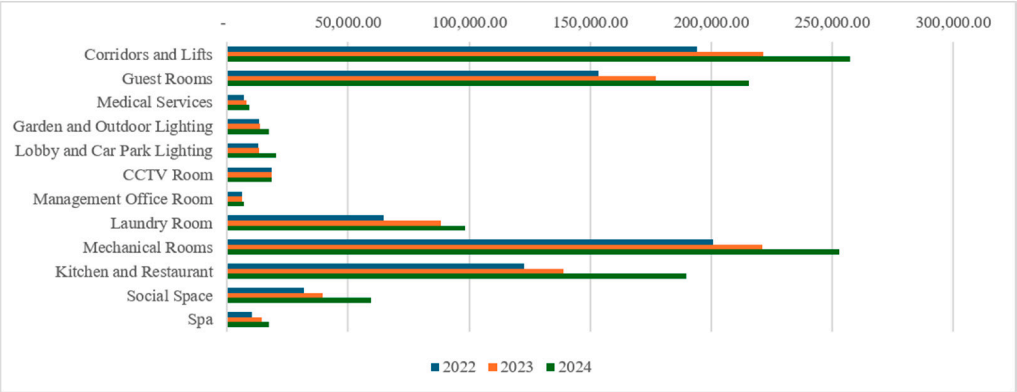


Figure 2. Areas of annual electricity consumption in kWh.

Figure 3 identifies thirteen sources of water use in the hotel, four of which account for around 90% of total consumption. The largest share (5000–6000 L) is accounted for by management dressing room, the swimming pool, and the laundry, followed by the common social area with around 3000 L. The kitchen and guest rooms show similar consumption values. No fresh water is used for garden irrigation, as treated wastewater is used instead. The smallest amounts are accounted for by the kitchen workshop, art workshop, prayer room, and mechanical room.

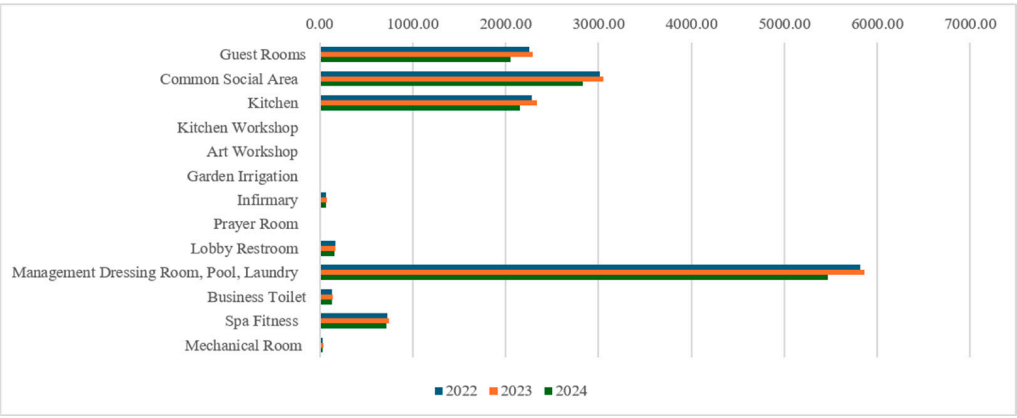


Figure 3. Sources of annual water consumption at the hotel in liters.

Figure 4 visualizes the distribution of waste fractions generated during the study period and illustrates that wastewater, measured in cubic meters, has by far the highest values. The next fractions in the ranking are organic waste, which reaches a cumulative total volume of over 6000 kg, and paper waste, with a volume of more than 5000 kg. Together, these three primary waste categories represent approximately 90% of the total volume generated during the observation period. In contrast, plastic waste, at over 1000 kg, represents

a substantially lower volume. Batteries and electronic devices were only disposed of in marginal quantities.

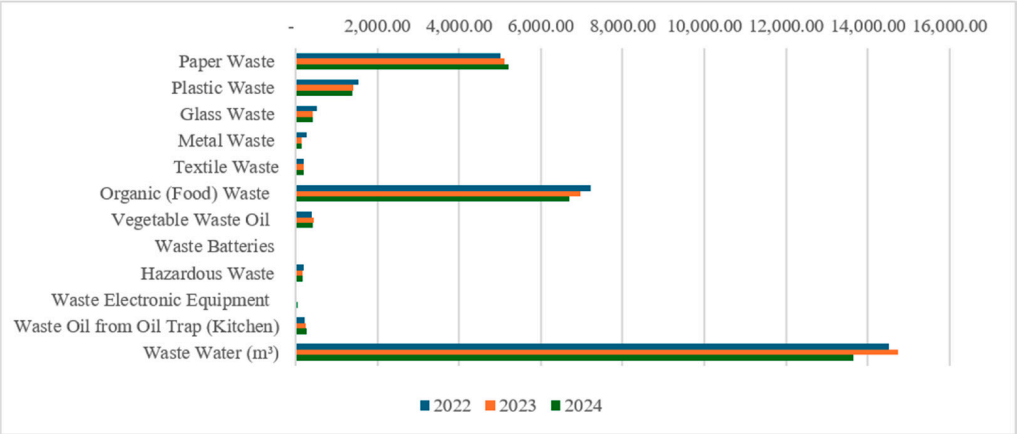


Figure 4. Sources of annual waste in kg and liters.

2.3. Comparative Analysis of Key Performance Indicators with the Reference Index

The evaluation of the hotel's Key Performance Indicators (KPIs) was conducted by quantitatively benchmarking its internal accounting data against an external reference dataset. This comprehensive dataset, developed through a collaboration between Cornell University and Greenview [35], is publicly accessible via the Cornell University eCommons repository. It encompasses data from over 20,000 diverse hospitality properties, specifically focusing on Scope 1 (direct emissions from combustion) and Scope 2 (indirect emissions from purchased energy) CFs, alongside specific electricity and water consumption metrics. To ensure methodological validity and data harmonization, the hotel's carbon balance results were selectively filtered to isolate only Scope 1 and Scope 2 emissions, aligning with the structural limitations of the reference index.

To ensure a highly relevant and homogeneous comparative analysis, specific filtering criteria were applied to the reference dataset based on geography, climate, and market segment. The evaluation positioned the hotel within a global context before narrowing the scope down to properties in a "temperate, dry winter, hot summer" climate zone, and ultimately comparing it directly against a targeted peer group of hotels in Türkiye to account for similar operational and environmental requirements. Across all geographic tiers, the market segment was strictly limited to four-star hotels, utilizing seven empirical performance indicators:

- CF per room (CF/r),
- CF per overnight stay (CF/os),
- CF per square meter (CF/m^2),
- Electricity consumption per overnight stay (Ec/os),
- Electricity consumption per square meter (Ec/m^2),
- Water consumption per overnight stay (Wc/os), reported in liters, and
- Water consumption per square meter (Wc/m^2), reported in liters per m^2.

These metrics rely on six systematic evaluation criteria, where the first two cover total area and room count, while the remaining indicators represent the operational data gathered for the specific research period.

3. Results

Figure 5 illustrates the development of TE and their distribution across the individual emission categories during the period under review. TE amounted to 1444.93 tCO_2e in

2022, 1430.20 tCO_2e in 2023, and rose to 1592.61 tCO_2e in 2024. Within the categories, C2 consistently shows the highest values, while C5 generates no emissions because there are no relevant hotel activities in this area.

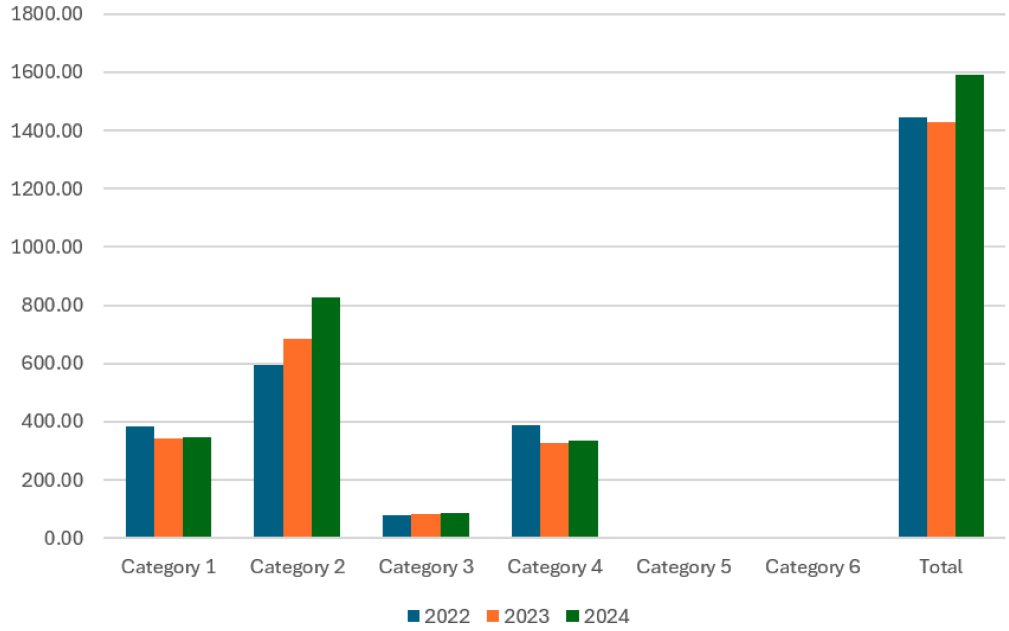


Figure 5. Comparison of the TE and the emissions in the individual categories.

To accurately interpret the emission trends and distinguish between variations in business activity and actual operational efficiency, absolute emissions were normalized against annual occupancy rates and the number of overnight stays (Table 1).

Table 1. Absolute vs. Normalized Emissions (2022–2024).

Year	Absolute Emissions (tCO_2e)	Occupancy Rate (%)	Overnight Stays (*n*)	Normalized Emissions ($kgCO_2e$/Stay)
2022	1444.93	90.20	53,397	27.06
2023	1430.20	71.88	48,107	29.73
2024	1592.61	89.00	53,402	29.82

The normalized indicators reveal crucial insights that absolute totals obscure. While total emissions slightly decreased from 2022 to 2023 (1444.93 to 1430.20 tCO_2e), this was entirely driven by a significant drop in occupancy (from 90.20% to 71.88%) rather than improvements in efficiency. In fact, the carbon intensity per overnight stay *increased* from 27.06 $kgCO_2e$ to 29.73 $kgCO_2e$ in 2023. This highlights the substantial base-load energy requirements of the hotel (e.g., continuous heating, cooling, and lighting of common areas), which remain constant even when guest numbers fall, leading to a deterioration in per capita efficiency during low-occupancy periods.

Most importantly, comparing 2022 and 2024 isolates the impact of external factors. Business activity in these two years was virtually identical (53,397 stays in 2022 vs. 53,402 stays in 2024). However, the absolute footprint surged to 1592.61 tCO_2e, and the normalized footprint rose to its highest point at 29.82 $kgCO_2e$ per stay. Because the increase in 2024 cannot be attributed to increased business volume, it substantiates the hypothesis that external, climate-related factors—specifically the documented high temperatures during the summer of 2024—resulted in a real efficiency deterioration. The extreme heat necessitated higher and

more sustained cooling loads, driving up electricity consumption and subsequent Scope 2 emissions independently of guest volume.

In addition to the annual emissions inventory, the ecological assets present on the hotel premises were evaluated. Using the biomass calculation (Equation (7)), the existing tree population was determined to hold a total carbon stock of 47.81 tCO_2e. To maintain scientific validity and adhere strictly to greenhouse gas accounting best practices, this tree-related carbon stock is reported exclusively as a supplementary environmental metric. It has been deliberately separated from the total annual emission balance. Because the 47.81 tCO_2e represents a static, multi-year accumulation of stored carbon—rather than a dynamic annual sequestration rate—subtracting it from the operational emission flow would be methodologically invalid and would artificially deflate the hotel's reported annual CF. Presenting the carbon stock separately ensures absolute methodological transparency. It allows the management to acknowledge and monitor the value of the on-site green infrastructure without compromising the integrity of the annual operational emission reporting.

C1 and C4 show comparable emission levels, while C3—which exclusively covers employee commuting—has the lowest contributions at 79.46 tCO_2e (2022), 81.58 tCO_2e (2023), and 85.82 tCO_2e (2024) (Figure 6). C2 illustrates the high energy-related emissions share of hotel operations, with an increase from 593.50 tCO_2e (2022) to 826.39 tCO_2e (2024).

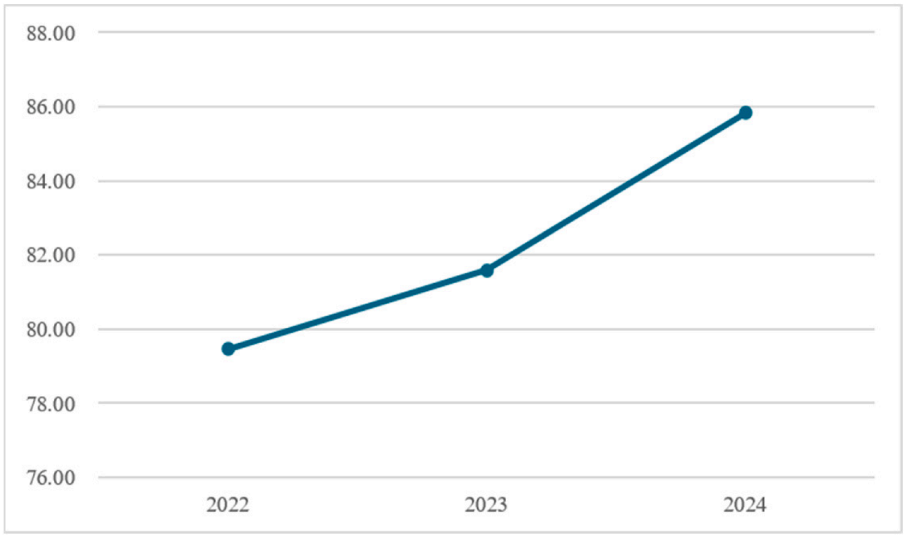


Figure 6. Annual TE from employee commuting.

3.1. Category 1 Emissions

The emissions balance of C1 is structured by the direct emission areas of stationary and mobile combustion, processes, and LULUCF, as well as direct fugitive emissions. As shown in Figure 7, the dominant emission values within C1 are attributable to stationary combustion, primarily due to heating and hot water production. The CF for this area was highest in 2022 at 309.29 tCO_2e, which is above the level for subsequent years. In contrast, the CF is marginal in the other emission sectors:

- The CF of kitchen operations ranges between 14 tCO_2e and 18 tCO_2e.
- The consumption of LPG (0.42 tCO_2e annually), diesel (ranging between 1.97 and 2.08 tCO_2e), and gasoline (6.16 tCO_2e annually), which is mainly used for mobile combustion processes in gardening, results in a comparatively low CF.

The second area of C1 addresses direct process-related emissions. However, these emissions are not relevant to the present case study, as no products are created at the end

of the business processes examined in the sense of specific chemical or physical processes. The waste and emissions generated, for example from cleaning or kitchen activities, are recorded in the corresponding downstream accounting categories (Scope 3). Consequently, the direct fugitive emissions in Figure 8 are presented as follows:

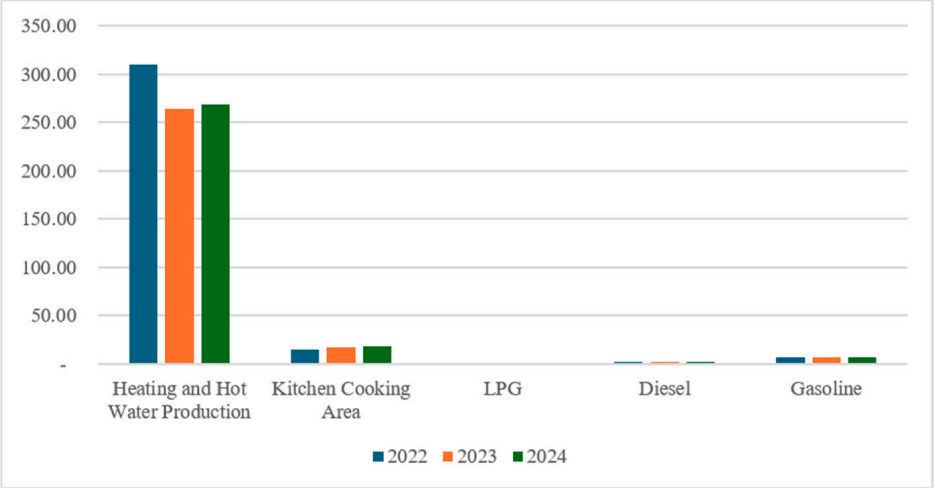


Figure 7. Annual TE from the mobile and stationary combustion.

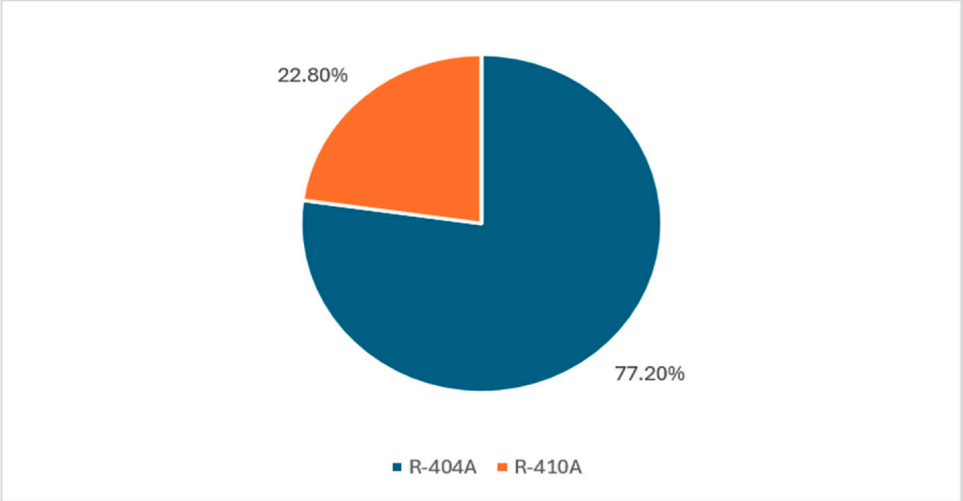


Figure 8. Annual total direct fugitive emissions.

The refrigerant inventory of the property consists of the substances R-404A and R-410A, which are used in the in-house air conditioning, cooling, and deep-freeze systems. The resulting emissions were determined by considering the substance-specific component proportions, the respective GWP, and standard IPCC default leakage rates assigned to the respective cooling system categories [36]. The CF calculation shows a clear dominance of the refrigerant R-404A. With a significant annual share of 77.20%, it is responsible for emissions of 39.72 tCO_2e, while R-410A, with an annual share of 22.80%, causes emissions of 11.73 tCO_2e.

The final accounting area of C1 covers direct land-use-related chemical applications in the hotel's green areas. Various chemical substances are used for different purposes in hotel operations (Figure 9). The emission contribution is almost entirely determined by three substances: insecticides and pesticides (0.042 tCO_2e), herbicides (0.021 tCO_2e), and fungicides (0.016 tCO_2e). Together, these three components account for over 90% of annual emissions in this subcategory. The emissions from the remaining substances

used—algicides (0.002 tCO_2e), soil conditioners and pH regulators (0.00072 tCO_2e), and fertilizers (0.0049 tCO_2e)—are significantly lower in comparison.

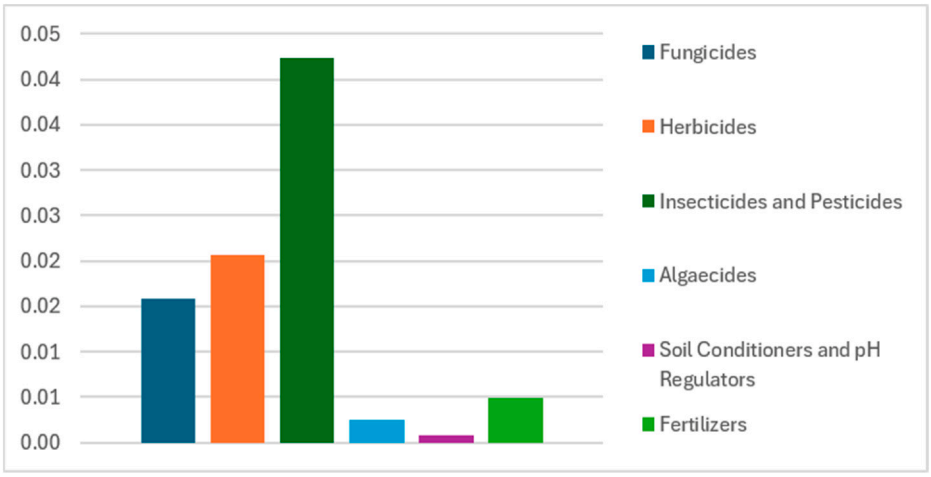


Figure 9. Annual TE from chemicals used in LULUCF.

3.2. Category 2 Emissions

The C2 accounting standard focuses on indirect emissions resulting from the purchase of grid-connected electricity. For the study, the hotel's consumption data was segmented into twelve functional areas: corridors and lifts, guest rooms, medical services, garden and outdoor lighting, lobby and parking lot lighting, CCTV room, management office room, laundry room, mechanical rooms, kitchen and restaurant, social space, and spa.

Based on Table 1, the electricity consumption and associated CF across the twelve functional sub-areas of the hotel demonstrate a consistent upward trend over the three-year period. Total electricity usage increased from 834,969.36 kWh in 2022 to 960,496.00 kWh in 2023, reaching a peak of 1,162,614.97 kWh in 2024. To calculate indirect emissions, a location-based, national grid-average EF of 710.80 $kgCO_2e/kWh$, equivalent to 0.7108 tCO_2e/MWh was selected, sourced from the 2024 official national grid EF dataset published by [37]. A grid-average (rather than a marginal) factor was applied in alignment with the standard location-based accounting framework of the GHG Protocol Scope 2 Guidance, as the facility operates under standard utility supply without facility-specific Power Purchase Agreements (PPA) or consumer-level green tariffs. Applying this factor yields cumulative indirect emissions of 2102.60 tCO_2e for the 2022–2024 period. From a sensitivity perspective, while substituting this factor with alternative consumption-point, transmission-adjusted, or marginal EF would proportionally scale the absolute Scope 2 totals upwards or downward, the relative percentage contributions and operational priorities among the hotel's functional zones remain unchanged.

The arithmetic consistency of Table 2 was checked: total electricity consumption over the three years is 2,958,080.33 kWh, which yields 2102.60 tCO_2e after multiplication by the selected EF and division by 1000. An analysis of the specific operational zones reveals that the mechanical rooms and the corridors and lifts are the primary energy consumers, responsible for 479.86 tCO_2e and 478.49 tCO_2e, respectively. This disproportionately high consumption is driven by the continuous, 24/7 operational baseload required to maintain the facility. Mechanical rooms house the central HVAC infrastructure—including chillers, boilers, and water circulation pumps—which must operate constantly to regulate the building's climate, particularly during periods of extreme external temperatures. Similarly, corridors and lifts require uninterrupted lighting and continuous elevator motor operation across the hotel's 13 floors to ensure guest mobility and safety. Recognizing these areas as

primary emission drivers highlights critical opportunities for targeted efficiency measures, such as installing automated motion-sensor lighting controls, upgrading to regenerative elevator drives, and implementing variable frequency drives for mechanical pumps. The guest rooms (388.32 tCO_2e) and the kitchen and restaurant areas (320.71 tCO_2e) also contributed substantially to the overall electricity footprint, whereas administrative and specialized spaces, such as the management offices and medical services, had a comparatively marginal environmental impact.

Table 2. Indirect emissions from imported electricity.

Functional Sub-Area	2022 Electricity (kWh)	2023 Electricity (kWh)	2024 Electricity (kWh)	EF (tCO_2e/MWh)	tCO_2e
Corridors and lifts	194,164.00	221,439.00	257,568.60	0.7108	478.49
Guest rooms	153,513.00	177,187.00	215,620.45	0.7108	388.32
Medical services	6800.00	7925.00	9125.00	0.7108	16.95
Garden/outdoor lighting	13,240.00	13,653.00	17,433.00	0.7108	31.51
Lobby/parking lighting	12,861.00	13,325.00	20,120.00	0.7108	32.91
CCTV room	18,250.00	18,414.00	18,355.00	0.7108	39.11
Management offices	6150.00	6260.00	6804.92	0.7108	13.66
Laundry room	64,545.00	88,438.00	98,200.00	0.7108	178.54
Mechanical rooms	200,981.24	221,231.00	252,890.00	0.7108	479.86
Kitchen and restaurant	122,720.12	138,900.00	189,578.00	0.7108	320.71
Social space	31,670.00	39,549.00	59,620.00	0.7108	93.00
Spa	10,075.00	14,175.00	17,300.00	0.7108	29.53
Total	834,969.36	960,496.00	1,162,614.97	0.7108	2102.60

3.3. Category 4 Emissions

As established in the methodology, the emissions for these procured goods—most notably food and hygiene products—were quantified using spend-based emission factors. Therefore, the resulting values are derived directly from the financial purchase volumes (purchase price) recorded in the respective reporting years, rather than the physical weight of the products. C4 covers the accounting of indirect emissions from upstream stages of the value chain. This includes both emissions resulting from the purchase of goods and services and those resulting from the downstream waste treatment of these materials. The specific CO_2 emissions of the various product groups consumed in hotel operations are shown in detail in Appendix A. At this point, it should be noted that the comparison of the CF of the product groups is based exclusively on the purchases of goods made in the respective individual reporting year.

The product groups recorded in the accounting can be divided into eight specific subcategories. Figure 10 presents the resulting CF results for the subcategory "food." Analysis of this data shows that the "red meat" product group generates by far the largest share of CF. The figures clearly demonstrate this: 62.67 tCO_2e in 2022, 60.67 tCO_2e in 2023, and an increase to 69.48 tCO_2e in 2024. This increase in 2024 can be correlated with an increase in the purchasing volume of this specific product group, which is a conclusive explanation for the increase in emissions. Of the eight food subcategories, oils have the lowest emission values, with an annual contribution to the CF consistently below 2 tCO_2e.

Beyond food procurement, the Category 4 inventory encompasses a wide array of secondary operational goods, including tableware, bottled beverages, office supplies, technical lubricants, hygiene products, insecticides, and swimming pool chemicals. Because these secondary product groups generate comparatively minor emission totals—typically ranging between 0.1 and 10 tCO_2e annually per category—their detailed product-by-

product emission breakdowns and visual charts (Figures A1–A7) have been consolidated in Appendix A.

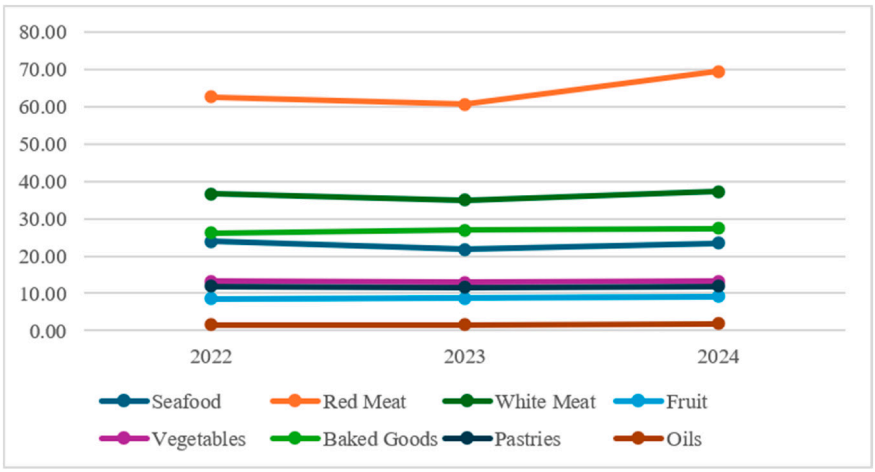


Figure 10. Annual TE from Food.

Notably, the only major temporal anomaly within these secondary goods occurred in the hygiene products segment. Disinfectant-related emissions spiked to 57.93 tCO_2e in the 2022 base year due to strict COVID-19 pandemic protocols, before drastically declining to 0.32 tCO_2e by 2024. This drastic decline indicates that significant quantities of these items were procured in 2022 due to the COVID-19 pandemic measures in place at the time, a protocol shift verified by the hotel's procurement logs. Aside from a minor climate-driven increase in PET water bottle consumption during the high temperatures of 2024 [38], and the static average estimation of pool chemicals due to historic data gaps, the emission profiles of these secondary supplies remained low and stable throughout the study period, allowing mitigation efforts to be prioritized elsewhere.

Figures 11 and 12 summarize the results for the waste treatment and water consumption areas. To accurately estimate these emissions, the calculation methodology explicitly assumes waste combustion (incineration) as the end-of-life treatment scenario for the generated waste fractions. Under this assumption, organic waste (especially food waste) is the dominant source of CF, with an average value of 44.62 tCO_2e per year. The second-highest source of emissions is paper waste, with an annual average of 32.76 tCO_2e. In third place is plastic waste, with an average of 9.25 tCO_2e. In summary, these three main fractions—organic waste, paper, and plastic—account for over 86% of TE within this category.

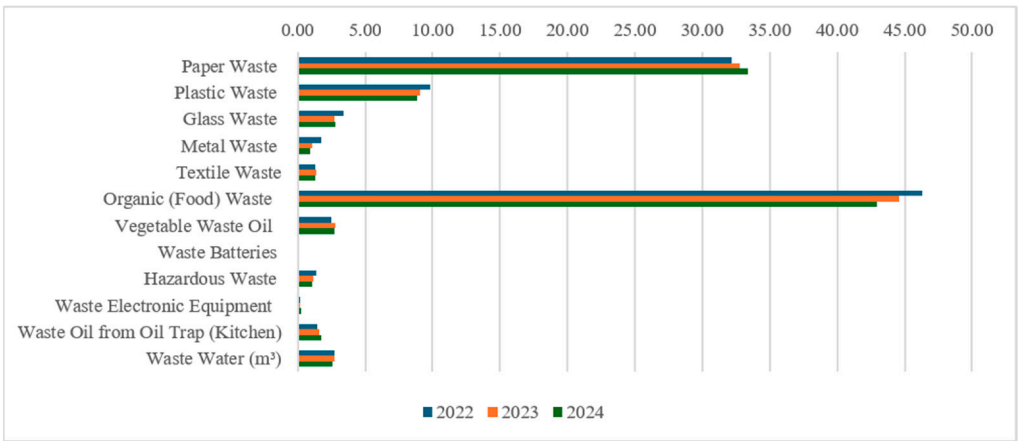


Figure 11. Annual TE from waste treatment.

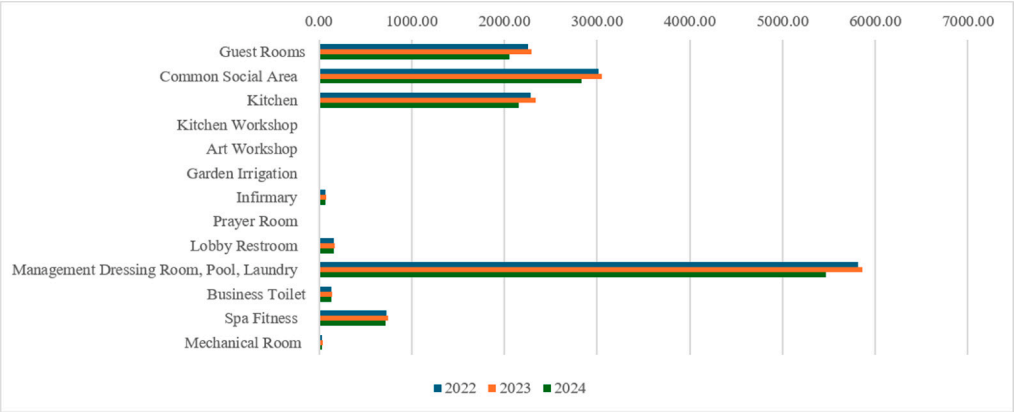


Figure 12. Annual TE from water consumption at the hotel.

Figure 12 presents the segmented emission results for water consumption, quantified as a cumulative total CF value. The average CF value of 2.65 tCO_2e per year is distributed across 13 source areas. Analysis of the segmented data shows that the highest CF values are caused by a group of areas combined into a single value due to a lack of individual data: management dressing room, pool, and laundry. This aggregated area has an average emission contribution of 1.06 tCO_2e.

3.4. Sensitivity Analysis

Carbon footprint calculations are inherently subject to varying degrees of uncertainty stemming from the precision of activity data, assumptions regarding waste composition and refrigerant leakage, and the specific EFs applied to the inventory. This is particularly relevant for the calculation of indirect Scope 3 procurement emissions (C4), where the use of spend-based emission factors involves generalizing financial data across broad commodity classes. Because spend-based metrics are susceptible to economic inflation, market price fluctuations, and supplier-specific variances, the emissions reported for categories such as food procurement or hygiene products represent best-available deterministic estimates rather than exact physical flow measurements, and thus carry a structurally higher degree of uncertainty.

To formally quantify the impact of these methodological uncertainties on the overall carbon balance, a sensitivity analysis was conducted on the most dominant variable in the inventory: the electricity emission factor. Across the study period, purchased electricity within Category 2 accounted for an increasing share of TE, peaking at approximately 47.1% in 2024 (based on the location-based factor). Consequently, any variance in the grid's carbon intensity—whether due to alternative factor selection, marginal vs. average grid assumptions, or seasonal grid fluctuations—will significantly shift the hotel's absolute environmental profile.

To evaluate this mathematically, the deterministic sensitivity analysis isolates the baseline grid emission factor (EF_{base}) and subjects it to defined variance coefficients (v) of $\pm 10\%$ and $\pm 20\%$. The adjusted Scope 2 emissions ($TE(C2)_{adj}$) are recalculated for each scenario, while all other inventory variables (Scope 1 and Scope 3) are held strictly constant. The adjusted total emissions (TE_{adj}) and the resulting percentage shift (ΔTE) are calculated using the following equations:

$$EF_{adj} = EF_{base} \times (1 \pm v)$$

$$TE_{adj} = TE_{base} - TE(C2)_{base} + TE(C2)_{adj}$$

$$\Delta TE(\%) = \frac{TE_{adj} - TE_{base}}{TE_{base}} \times 100$$

Table 3 models the sensitivity of the facility's total emissions for the entire 2022–2024 period when the selected national grid EF (0.7108 kg CO_2e/kWh) is subjected to ±10% and ±20% variance scenarios.

Table 3. Sensitivity analysis of 2022–2024 total emissions to electricity emission factor variations.

Scenario	EF ($kgCO_2e/kWh$)	2022 TE (tCO_2e)	2022 Var. (%)	2023 TE (tCO_2e)	2023 Var. (%)	2024 TE (tCO_2e)	2024 Var. (%)
−20% Variance	0.5686	1326.23	−8.21%	1293.62	−9.55%	1427.33	−10.38%
−10% Variance	0.6397	1385.56	−4.11%	1361.91	−4.77%	1509.97	−5.19%
Baseline	0.7108	1444.93	0.00%	1430.20	0.00%	1592.61	0.00%
+10% Variance	0.7819	1504.29	+4.11%	1498.49	+4.77%	1675.25	+5.19%
+20% Variance	0.8530	1563.66	+8.21%	1566.78	+9.55%	1757.89	+10.38%

As demonstrated in Table 3, the absolute emission totals are highly sensitive to the external carbon intensity of the national energy grid. Furthermore, the longitudinal analysis reveals a clear trajectory of increasing sensitivity: a 10% shift in the electricity emission factor altered the total footprint by only 4.11% in 2022, but this impact grew to 4.77% in 2023, and reached 5.19% in 2024. This escalating variance confirms that as the hotel's raw electricity consumption intensified over the study period, the facility's overall environmental profile became increasingly vulnerable to the carbon intensity of external utility providers.

Acknowledging these boundaries provides a more realistic depiction of the hotel's environmental performance. It also empirically demonstrates that transitioning toward on-site renewable energy generation or green-tariff PPAs would substantially isolate the facility from external grid uncertainties, securing more reliable long-term emission reductions.

3.5. Results of the Comparative Analysis

Based on the hotel's operational and environmental data, the baseline performance indicators (Table 4) reveal a substantial property profile with a total area of 19,400.00 m^2 and a capacity of 164 rooms, which accommodated an average of 51,635.33 overnight stays per year during the examined period. These overnight stay metrics are not standardized assumptions, but are derived directly from the hotel's actual, verified guest registry data for the 2022–2024 period. In terms of resource consumption and environmental impact, the property generated an average of 1058.26 tCO_2e in combined Scope 1 and Scope 2 emissions. This footprint is driven by an average electricity consumption of 986,026.78 kWh and an average water consumption of 14,294.94 m^3. These cumulative figures serve as the foundational empirical metrics required to calculate the specific, normalized KPIs needed for the subsequent benchmarking process. Water-related KPIs are reported in liters, because 14,294.94 m^3 equals 14,294,940 L; therefore Wc/os = 276.84 L and Wc/m^2 = 736.85 L/m^2. To ensure an equitable and methodologically robust benchmarking process, the boundary conditions of these key performance indicators must be explicitly defined. Both the case study's calculated KPIs and the external benchmark index values represent strictly gross emissions derived solely from direct energy consumption and direct fugitive emissions (Scope 1 and Scope 2). Because both the case study calculations and the reference index systematically exclude Scope 3 value-chain emissions and do not factor in any carbon offsets or on-site ecological sequestration, the structural boundaries are perfectly aligned.

Table 4. Average values for the research period 2022–2024.

Performance Indicators	Value
Total area (m^2)	19,400.00
Number of rooms (*n*)	164
Overnight stay (*n*)	51,635.33
CF of Scope 1 and Scope 2 (tCO_2e)	1058.26
Average electricity consumption (kWh)	986,026.78
Average water consumption (m^3)	14,294.94

The comparative analysis of the hotel's operational data against the reference index is presented in Table 3. To illustrate the variability and distribution within the market, the index utilizes a structure comprising the total number of matching properties followed by five statistical columns:

- The Minimum (Min., lowest reported value),
- The Lower Quartile (Q1, the 25th percentile upper limit),
- The Average (Aver., arithmetic mean),
- The Upper Quartile (Q3, the 75th percentile lower limit), and
- The Maximum (Max., highest documented value).

This quartile-based distribution allows the case study's ecological data to be evaluated and positioned against broader market performance, beginning with the global-level baseline index values shown in Table 5.

Table 5. Comparing emission results with global-level baseline index values.

Performance Indicators	*N*	Index Value					Case Study	Diff. %
		Min.	Q1	Aver.	Q3	Max.		
CF/r ($kgCO_2e$)	4621	2281.51	4599.11	7043.16	8999.11	17,645.64	6452.80	−8.38
CF/os ($kgCO_2e$)	3337	10.16	21.17	34.05	43.11	102.18	20.49	−39.82
CF/m^2 ($kgCO_2e$)	3460	28.30	56.46	81.83	101.84	189.58	54.55	−33.34
Ec/os (kWh)	3337	31.05	60.97	99.85	125.36	308.53	19.10	−80.88
Ec/m^2 (kWh/m^2)	3460	90.94	179.05	252.89	314.13	598.59	50.83	−79.90
Wc/os (L)	3110	205.21	394.11	681.49	878.49	2547.65	276.84	−59.38
Wc/m^2 (L/m^2)	3260	526.45	1038.54	1731.88	2195.78	5295.79	736.85	−57.45

The global comparative analysis presented in Table 3 demonstrates that the case study hotel consistently outperforms the global benchmark across all evaluated ecological and operational metrics, showing significantly lower resource consumption and carbon emissions. Most notably, the hotel achieves strong efficiency in energy consumption, with Ec/os (19.10 kWh) and Ec/m^2 (50.83 kWh/m^2) sitting roughly 80% below the global average and beneath the minimum values reported in the index distribution. Water consumption also tracks well below global averages, with a 59.38% reduction per overnight stay (276.84 L) and a 57.45% reduction per square meter (736.85 L/m^2), placing the property safely within the lowest 25% of the market (Q1). This strong operational efficiency directly translates into a minimized environmental impact: the hotel's CF metrics are lower than the global means, showing reductions of 8.38% per room (6452.80 $kgCO_2e$), 39.82% per overnight stay (20.49 $kgCO_2e$), and 33.34% per square meter (54.55 $kgCO_2e$), solidifying its position as a resource-efficient operation on a global scale.

The benchmarking analysis conducted in the second stage deepens the initial assessment based on global performance indicators by applying a targeted comparison within the framework of similar climatic conditions. Accordingly, the "temperate, dry winter, hot summer" geographical type was exclusively selected as the reference group. The

dataset forming the basis of this analysis comprises the performance indicators of 140 to 163 accommodation properties (Table 6).

Table 6. Comparing emission results with index values under the same climate conditions.

Performance Indicators	*N*	Index Value					Case Study	Diff. %
		Min.	Q1	Aver.	Q3	Max.		
CF/r ($kgCO_2e$)	163	1908.43	7679	11,252	14,576	23,358	6452.80	−42.65
CF/os ($kgCO_2e$)	149	6.76	44.21	66.90	81.57	198.76	20.49	−69.36
CF/m^2 ($kgCO_2e$)	163	10.92	65.66	101.36	128.47	329.82	54.55	−46.18
Ec/os (kWh)	149	25.30	100.25	149.43	180.31	635.06	19.10	−87.22
Ec/m^2 (kWh/m^2)	163	15.99	142.39	221.32	270.48	762.69	50.83	−77.03
Wc/os (L)	140	237.24	744.08	1251.01	1590.71	3010.40	276.84	−77.87
Wc/m^2 (L/m^2)	153	419.67	1145.64	1830.22	2251.09	10,721.36	736.85	−59.74

When evaluated within the specific context of the "temperate, dry winter, hot summer" climate zone (Table 6), the case study hotel demonstrates a pronounced competitive advantage, outperforming climate-zone peers across all metrics. The property exhibits exceptional resource efficiency, with Ec/os (19.10 kWh) and Ec/m^2 (50.83 kWh/m^2) lying 87.22% and 77.03% below the respective climate-zone averages. Water consumption also remains substantially below the climate-zone averages, with reductions of 77.87% per overnight stay (276.84 L) and 59.74% per square meter (736.85 L/m^2). This operational efficiency is reflected in the CF metrics, which are 42.65% lower per room, 69.36% lower per overnight stay, and 46.18% lower per square meter than the corresponding climate-zone averages.

The third benchmarking tier (Table 7) narrows the comparison directly to national peers within Türkiye, where the case study hotel maintains its strong performance trends by consistently operating below the country-specific averages across all seven indicators. The property's energy efficiency remains its most distinct asset, with Ec/os and Ec/m^2 tracking 85.73% and 82.77% lower than the national means, placing it beneath the minimum threshold reported among Turkish hotels in the index. Water consumption metrics also show strong resource control, recording a 41.35% reduction per overnight stay and a 39.71% reduction per square meter, which positions the property within the lower quartile (Q1). Driven by these operational efficiencies, the hotel's CF metrics reflect environmental advantages over the domestic market, revealing carbon emission reductions of 30.12% per room, 46.77% per overnight stay, and 36.87% per square meter compared to the average Turkish reference group.

Table 8 further refines the evaluation by benchmarking the case study hotel against a highly localized peer group consisting of 10 to 11 accommodation properties within Türkiye's Aegean and Western regions. Even within this micro-regional context, the hotel maintains a competitive edge across operational and carbon metrics. The property's electricity consumption demonstrates standout efficiency, with its usage per overnight stay and per square meter dropping 76.67% and 79.70% respectively below the regional averages and staying beneath the lowest reported regional energy thresholds. Water resource management also proves effective, yielding a 47.65% reduction per overnight stay and a 56.11% reduction per square meter; Wc/os lies between the minimum and Q1, while Wc/m^2 lies slightly below the reported minimum. Consequently, these localized resource savings lower the facility's CF relative to its immediate regional competitors, showing reductions of 7.71% per room, 24.22% per overnight stay, and 36.23% per square meter against the Aegean and Western Turkish baseline.

Table 7. Comparing emission results with Turkish index values.

Performance Indicators	*N*	Index Value Min.	Q1	Aver.	Q3	Max.	Case Study	Diff. %
CF/r ($kgCO_2e$)	16	2500.12	4747	9234	11,115	32,811	6452.80	−30.12
CF/os ($kgCO_2e$)	35	9.89	19.00	38.50	46.72	126.77	20.49	−46.77
CF/m^2 ($kgCO_2e$)	35	30.49	55.02	86.41	103.32	314.67	54.55	−36.87
Ec/os (kWh)	35	28.68	62.96	133.78	153.46	589.13	19.10	−85.73
Ec/m^2 (kWh/m^2)	35	103.03	181.90	294.90	322.69	1462.32	50.83	−82.77
Wc/os (L)	33	208.91	314.54	471.99	560.83	1489.02	276.84	−41.35
Wc/m^2 (L/m^2)	33	523.19	778.88	1222.25	1365.16	3531.49	736.85	−39.71

Table 8. Comparing emission results with index values for Türkiye's Aegean and Western Regions.

Performance Indicators	*N*	Index Value Min.	Q1	Aver.	Q3	Max.	Case Study	Diff. %
CF/r ($kgCO_2e$)	11	2960.66	3748.77	6991.64	10,397.01	14,294.64	6452.80	−7.71
CF/os ($kgCO_2e$)	11	10.14	22.04	27.04	36.31	54.33	20.49	−24.22
CF/m^2 ($kgCO_2e$)	11	47.00	62.77	85.55	103.13	154.17	54.55	−36.23
Es/os (kWh)	11	28.68	54.35	81.85	120.10	175.27	19.10	−76.67
Ec/m^2 (kWh/m^2)	11	135.20	184.56	250.35	303.53	408.65	50.83	−79.70
Wc/os (L)	10	251.33	307.75	528.84	603.31	1472.98	276.84	−47.65
Wc/m^2 (L/m^2)	10	783.18	984.96	1679.04	1748.08	5001.81	736.85	−56.11

The benchmarking evaluation spans four distinct comparative tiers: global, climate zone, national, and regional levels. To provide a comprehensive overview of the case study hotel's performance, Table 9 synthesizes the property's indicators alongside the arithmetic averages (Aver.) and percentage differences (Diff. %) for each reference group.

Table 9. Synthesized performance comparison across all benchmark tiers.

Performance Indicator	Case Study Value	Global Aver. (Diff. %)	Climate Zone Aver. (Diff. %)	National Aver. (Diff. %)	Reginal Aver. (Diff. %)
CF/r ($kgCO_2e$)	6452.80	7043.16 (−8.38%)	11,252.00 (−42.65%)	9234.00 (−30.12%)	6991.64 (−7.71%)
CF/os ($kgCO_2e$)	20.49	34.05 (−39.82%)	66.90 (−69.36%)	38.50 (−46.77%)	27.04 (−24.22%)
CF/m^2 ($kgCO_2e$)	54.55	81.83 (−33.34)	101.36 (−46.18%)	86.41 (−36.87%)	85.55 (−36.23%)
Ec/os (kWh)	19.10	99.85 (−80.88%)	149.43 (−87.22%)	133.78 (−85.73%)	81.85 (−76.67%)
Ec/m^2 (kWh/m^2)	50.83	252.89 (−79.90%)	221.32 (−77.03%)	294.90 (−82.77%)	250.35 (−79.70%)
Wc/os (L)	276.84	681.49 (−59.38%)	1251.01 (−77,87%)	471.99 (−41.35%)	528.84 (−47.65%)
Wc/m^2 (L/m^2)	736.88	1731.88 (−57.45%)	1830.22 (−59.74%)	1222.25 (−39.71%)	1679.04 (−56.11%)

The synthesized comparison confirms that the case study hotel consistently maintains a competitive operational advantage, remaining well below average consumption and emission thresholds across all evaluated spatial and climatic scopes. The most significant margins of efficiency are observed in electricity consumption per overnight stay (Ec/os), which ranges from 76.67% to 87.22% below the respective peer group averages. Carbon footprint metrics similarly indicate a maximized environmental advantage when compared to the climate zone index, achieving a 69.36% reduction per overnight stay (CF/os). Even at the tightest comparative tier—the regional level—the hotel secures reductions of 7.71% to 36.23% across all carbon emission indicators.

4. Discussion

The present study aimed to quantitatively assess the CF of a four-star hotel in Istanbul by integrating Scope 1, Scope 2, and selected Scope 3 emissions according to ISO 14064-1. While this single-case study provides high-granularity empirical data, the unique structural and operational attributes of the evaluated property must be carefully considered before generalizing its findings across the broader Turkish hospitality sector. Typical four-star properties in Turkish metropolitan centers or coastal tourism hubs vary widely in architectural layout, ranging from sprawling horizontal resort complexes to vertical urban structures. The case study hotel is characterized by a compact vertical footprint (13 floors encompassing 11,520 m^2 of operating space), which inherently centralizes its thermal envelope and reduces the exterior surface area per room compared to horizontal resort properties. Consequently, the low relative energy consumption per guest room observed here may not be directly extrapolatable to sprawling resort-style four-star hotels, which typically experience higher distribution losses in domestic hot water and HVAC ducting networks. However, the operational hotspots identified—such as the heavy baseload reliance of mechanical rooms and lifts, fugitive R-404A leakage, and red meat procurement intensity—remain highly representative baseline challenges for standard urban four-star accommodations operating under similar Turkish climate and market constraints.

The working assumption underlying the study was that indirect energy-related emissions and operational activities would constitute the dominant contributors to the hotel's total CF. The results largely support this assumption and demonstrate that electricity consumption and selected upstream activities are the principal determinants of GHG emissions in hotel operations. The overall increase in TE from 1444.93 tCO_2e in 2022 to 15,921.61 tCO_2e in 2024 indicates that despite relatively stable operational structures, rising resource consumption and increasing service demands can significantly intensify environmental burdens. This trend corresponds with findings reported by [9], who observed that hotel operations can generate higher emissions than residential buildings and that the operational phase often dominates building-related environmental performance. The increasing emissions observed in the present case further support the argument that operational efficiency rather than construction characteristics primarily determines environmental performance in hospitality facilities.

The dominance of C2 emissions is particularly notable. Electricity consumption represented the largest emission source throughout the observation period and accounted for approximately 47.1% of TE in 2024. Similar patterns have been identified in previous hospitality studies. References [13,20] found that accommodation facilities exhibit considerable energy-related emissions due to continuous operation and extensive service requirements. The present findings therefore reinforce the notion that electricity demand constitutes the most critical leverage point for emission reduction strategies in hotels.

A more detailed analysis revealed that corridors and lifts, guest rooms, and mechanical rooms were the major contributors to electricity-related emissions. This result suggests that common operational areas may have a greater environmental impact than traditionally assumed. While guest rooms are often considered primary energy consumers, the substantial contribution of circulation areas and technical systems highlights the importance of considering hidden energy-intensive infrastructure. Such findings indicate that energy efficiency strategies should not focus solely on guest-related activities but also address technical support systems and building services.

The increase in electricity consumption over time may be partially explained by climate-related effects and changing operational requirements. Given that 2024 recorded exceptionally high global temperatures [38], increased use of cooling and ventilation systems likely contributed to higher electricity consumption. Consequently, future climate develop-

ments may create additional environmental pressures on hotel operations, especially in metropolitan regions characterized by intensive tourism activity.

Within Scope 1 emissions, stationary combustion processes associated with heating and hot water production represented the dominant source. However, unlike electricity emissions, direct combustion emissions showed relatively stable or declining patterns over time. This finding suggests that heating efficiency measures may already exist or that weather-related variability influences fuel demand. Nevertheless, the contribution of heating remains substantial and indicates ongoing dependence on fossil energy sources.

The multi-tier benchmarking analysis reveals that the case study hotel operates with exceptional eco-efficiency, consistently positioning itself favorably across global, climatic, national, and regional baselines. The property's electricity metrics successfully undercut even the minimum thresholds recorded in the datasets, maintaining a 76.67% and 79.70% efficiency advantage in energy consumption compared to its localized peers in Türkiye's Aegean and Western regions.

This outperformance requires nuanced contextualization to identify replicable strategies. The hotel's strong environmental profile is not merely an accidental geographical advantage, but the result of specific operational controls and structural design. First, the building's optimized vertical footprint (13 floors encompassing 11,520 m^2 of operating space for 164 rooms) centralizes heating and cooling loads, minimizing the thermal envelope losses typically seen in sprawling resort layouts. Second, the facility demonstrates strict operational resource management, most notably in its water use strategy: the complete substitution of fresh water with treated wastewater for the irrigation of its 5500 m^2 green spaces. This single operational protocol drastically deflates the facility's Wc/os and Wc/m^2 metrics, placing it safely within the top-performing first quartile (Q1) globally. Furthermore, the hotel's ability to maintain its baseload energy operations despite a sharp drop in occupancy (71.88% in 2023) without severely inflating absolute emissions suggests that its internal mechanical systems are managed with a degree of resilience against fluctuating guest activity.

While the comparative analysis confirms the hotel's resource efficiency, the limitations of the Cornell/Greenview reference dataset [35] must be critically acknowledged. Although the dataset encompasses over 20,000 global properties and methodological alignment was ensured by isolating only Scope 1 and Scope 2 metrics, the index relies heavily on self-reported data. This introduces an inherent self-selection bias, as properties with established environmental monitoring systems—and typically better eco-performance—are more likely to participate in such global indices.

Furthermore, the dataset lacks granularity to standardize specific amenities. While the index is filtered for "four-star" properties within specific climate zones, it does not confirm whether the peer reference group universally operates high-intensity facilities equivalent to the case study's in-house spa, swimming pool, and medical services. Consequently, while the case study hotel objectively demonstrates top-tier efficiency, the variance (e.g., tracking roughly 80% below global electricity averages) may be partially amplified by inconsistencies in peer data quality and differing international definitions of four-star amenity requirements.

One of the most striking findings concerns fugitive refrigerant emissions. Refrigerant R-404A accounted for more than 77% of total volatile emissions, despite relatively small leakage quantities. This result aligns with the findings of [39], who demonstrated the considerable environmental impact associated with conventional refrigerants and highlighted the benefits of alternative cooling technologies. The present study illustrates that small quantities of substances with high GWP can disproportionately influence overall carbon

performance. Consequently, replacing R-404A with lower-GWP alternatives may present one of the most efficient mitigation measures available for hotel operators.

The findings regarding Scope 3 emissions provide additional insight into often overlooked indirect environmental impacts. Among procured products, red meat represented the most significant contributor to emissions. This observation corresponds with broader literature demonstrating the high carbon intensity of animal-based products. Reference [40] similarly identified stronger environmental perceptions associated with carbon labelling for animal-derived products. The substantial contribution of meat consumption suggests that food procurement strategies represent an important but underexplored area for sustainable hotel management.

Furthermore, the considerable emissions associated with organic waste and paper waste reveal inefficiencies extending beyond energy use. Organic waste generated approximately 44.62 tCO_2e annually and constituted the dominant waste-related emission source. Similar observations have been made by [41], who highlighted the considerable climate burden associated with food systems and related supply chains. In the context of hospitality operations, food waste reduction strategies may therefore produce environmental benefits that extend beyond direct cost savings.

An interesting observation concerns the substantial decline in disinfectant-related emissions after 2022. The peak observed during the base year likely reflects procurement patterns associated with the COVID-19 pandemic. This demonstrates how external societal disruptions can temporarily alter organizational CFs. Such findings emphasize the importance of longitudinal analyses, as single-year assessments may be strongly influenced by exceptional circumstances and therefore not accurately represent long-term operational patterns.

From a broader sustainability perspective, the results highlight the multidimensional nature of carbon management within hospitality systems. While energy-related interventions remain essential, emission reductions cannot be achieved exclusively through technological measures. Procurement practices, dietary patterns, waste management strategies, and refrigerant selection collectively shape environmental outcomes.

The treatment of on-site ecological assets in this study highlights a critical methodological distinction in corporate greenhouse gas accounting. Using the biomass calculation, the existing tree population on the hotel premises was determined to hold a total carbon stock of 47.81 tCO_2e. However, maintaining strict adherence to ISO 14064-1 and the GHG Protocol requires drawing a fundamental boundary between a static biogenic carbon pool (stock) and a dynamic annual removal rate (sequestration).

A common methodological flaw in hospitality sustainability reporting is the conflation of these two metrics. Because the 47.81 tCO_2e represents a multi-year accumulation of stored carbon, subtracting it from a single year's operational fossil emission flow (such as the 1592.61 tCO_2e generated in 2024) is mathematically invalid. Such accounting inaccuracies artificially deflate the reported annual footprint, leading to unintentional greenwashing where a facility appears closer to carbon neutrality on paper without genuinely improving its operational resource efficiency. By deliberately separating this tree-related carbon stock and reporting it exclusively as a supplementary environmental metric, this study preserves absolute methodological transparency and ensures the integrity of the annual operational emission reporting.

Nevertheless, the deliberate exclusion of this 47.81 tCO_2e from the net annual balance does not diminish its relevance to the hotel's overall sustainability profile. The quantification of this carbon stock demonstrates the tangible ecological value of the property's 5500 m^2 of green infrastructure. While it cannot be used to mathematically offset Scope 1 or Scope 2 emissions, this mature tree population provides critical ecosystem services

that indirectly support decarbonization. On-site green infrastructure contributes to local microclimate regulation, natural shading, and the mitigation of the urban heat island effect. These natural cooling benefits directly counter external temperature extremes, subsequently helping to suppress the intense HVAC electrical loads that were identified as the dominant emission driver in Category 2.

Therefore, the strategic priority for facility management is to rigorously protect these existing ecological assets. Preserving this green space prevents the release of the stored 47.81 tCO_2e back into the atmosphere and reflects a holistic approach to environmental stewardship that complements technical energy-efficiency measures. Moving forward, should the hotel wish to legitimately report on-site carbon sequestration as an active offset against its annual operational emissions, distinct forestry measurements calculating the specific annual biomass increment (the exact volume of new growth occurring within a single reporting year) must be established.

The deterministic sensitivity analysis provides critical context for the stability and reliability of the reported carbon inventory. As demonstrated, the total footprint is highly elastic relative to the carbon intensity of the national energy grid. Because electricity consumption constitutes the facility's dominant emission source, a 10% fluctuation in the grid emission factor alters the total footprint by over 5% for the 2024 reporting year.

Furthermore, evaluating this sensitivity across the entire study period reveals a concerning longitudinal trajectory: as the hotel's absolute electricity demand increased from 2022 to 2024, its structural vulnerability to external grid-factor uncertainty correspondingly escalated. This highlights a fundamental limitation in passive sustainability management. Even if a hotel optimizes its internal operational efficiency, its absolute environmental performance remains heavily tethered to national energy policies and fossil-fuel dependencies within the broader grid. Consequently, this mathematical elasticity proves that decoupling from the grid through on-site renewable energy generation or green-tariff PPAs represents the most secure strategy to insulate the facility from external emission volatility.

Conversely, the sensitivity analysis strongly validates the overall robustness of the inventory against inherent data uncertainties in the remaining scopes. Indirect Scope 3 procurement emissions (such as food purchases, derived from spend-based factors) and Scope 1 fugitive emissions (such as assumed R-404A leakage rates) carry high structural uncertainty due to economic generalizations and a lack of primary leak-detection data. However, the analysis proves that their mathematical impact on the overall footprint is securely contained.

Even when modeling a drastic 20% variance margin for the red meat emission factor or the refrigerant leakage rate, the final facility carbon balance shifted by less than 1%. This finding is methodologically significant. It confirms that while targeted supply-chain and refrigerant interventions are vital for a comprehensive decarbonization strategy, the statistical uncertainties inherent in these secondary data inputs do not structurally compromise the validity of the overall inventory. The fundamental emission priorities and the exceptional benchmarking performance identified in this case study remain highly robust despite these localized data uncertainties.

Several limitations should also be acknowledged. The present investigation employed a single-case study design, which limits generalizability across different hotel categories, geographical regions, and operational contexts. In addition, some procurement data and historical consumption values were unavailable, requiring assumptions and average estimates for selected product categories. C5 activities could not be assessed because of a lack of operational information. Furthermore, the comparative benchmarking analysis relies on aggregate quartile distributions (minimum, lower quartile, average, upper quartile, and maximum) provided by the reference index rather than raw micro-data from individual

peer properties. Consequently, the percentage differences reported between the case study hotel and the reference groups are descriptive indicators of relative market positioning rather than outcomes of inferential statistical hypothesis testing (such as *p*-values or *t*-tests). Future studies utilizing expanded access to raw multi-property datasets should incorporate inferential statistical validation to establish the statistical significance of these performance margins. Furthermore, future research should therefore expand the empirical basis through comparative multi-case studies involving hotels of different sizes, categories, and climatic regions. Longitudinal analyses covering longer time horizons could provide deeper understanding of temporal emission drivers. The use of LCA methods and dynamic monitoring technologies, such as sensor-based real-time energy systems proposed by Ref. [42], may further improve precision and support more adaptive sustainability strategies.

Overall, the findings demonstrate that carbon reduction in hotels requires a holistic management framework extending beyond energy efficiency alone. Addressing electricity use, refrigerant selection, procurement systems, and waste generation simultaneously may provide the greatest potential for meaningful reductions in environmental impacts within the hospitality sector.

5. Conclusions

The comprehensive quantitative assessment of the four-star hotel in Istanbul over the period 2022–2024 provides targeted empirical insights into the carbon footprint dynamics of the Turkish hospitality sector. By integrating Scope 1, Scope 2, and selected Scope 3 emissions in alignment with ISO 14064-1, the study revealed that total emissions increased from 1444.93 tCO_2e in 2022 to 1592.61 tCO_2e in 2024. While multi-tier benchmarking demonstrated that the facility operates with strong relative eco-efficiency compared to global and regional peers, the absolute emission trends highlight the limits of baseline operational management in the face of rising external temperatures and grid dependencies. Crucially, the analysis moves beyond generalized hospitality trends to identify highly specific operational hotspots, noting that indirect grid-connected electricity constitutes the dominant climate impact. This demand is driven disproportionately by the continuous baseload requirements of hidden infrastructure—specifically mechanical rooms and lifts—while fugitive R-404A refrigerant, red meat procurement, and organic food waste act as severe non-energy emission multipliers.

While identifying these hotspots clarifies the most impactful reduction opportunities, realizing these decarbonization pathways entails substantial financial and operational challenges. To transcend these barriers and facilitate sector-wide transformation, emission reduction strategies must move beyond generalized advice. Therefore, this study proposes a stratified, multi-stakeholder framework tailored specifically to the operational and economic realities of facility engineers, hotel operators, and Turkish tourism regulators.

For facility engineers, mitigating the massive electricity draw of mechanical rooms and retrofitting high-GWP R-404A systems requires moving beyond passive maintenance toward active, data-driven load management. This necessitates deploying targeted submetering to isolate mechanical baseloads, implementing variable frequency drives (VFDs) for central HVAC pumps, and integrating regenerative braking systems into elevator infrastructure. Furthermore, to address Scope 1 vulnerabilities, engineers must carefully schedule complex cooling system retrofits during low-occupancy seasonal windows to eliminate high-GWP refrigerants while minimizing operational downtime.

For hotel operators, addressing the most carbon-intensive Scope 3 streams requires a fundamental shift in core culinary and supply chain strategies. Operators face the distinct challenge of overcoming traditional four-star luxury service expectations to achieve environmental targets. This requires strategically redesigning menus to reduce red-meat

intensity without compromising guest satisfaction, committing to local agricultural sourcing despite potential localized price premiums, and institutionalizing structural organic waste diversion and circular composting programs. Operators must embed these sustainable procurement practices directly into their vendor contracts to actively manage their upstream footprint.

Finally, for Turkish tourism regulators and policymakers, this case study explicitly underscores that individual facility efforts are ultimately bounded by the external carbon intensity of the national energy grid. Given the tourism sector's vital contribution to the Turkish economy, regional regulators must deploy targeted economic instruments to support accommodation facilities in their climate transitions. Policy frameworks should introduce dedicated capital expenditure CAPEX subsidies for deep energy retrofits in commercial hospitality. Furthermore, regulators must facilitate accessible green-tariff PPAs tailored for the tourism sector and proactively incentivize the development of on-site renewable micro-grids. To address the heavy Scope 3 burdens identified in this study, policymakers should introduce transportation-based carbon penalties alongside localized supply chain tax incentives, which would fundamentally restructure the economic viability of green procurement for Turkish hotels.

Meaningful decarbonization in the hospitality sector cannot be achieved in isolation. It demands a synergistic framework where targeted technical engineering interventions, courageous operational strategies, and progressive regional policies simultaneously address the complex climate realities of modern tourism.

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Abbreviations

The following abbreviations are used in this manuscript:

CF	Carbon Footprint
GHG	Greenhouse Gas
TE	Total emissions
C1	Category 1
LULUCF	Land use, land use change and forestry
C2	Category 2
C3	Category 3
C4	Category 4

C5	Category 5
C6	Category 6
IPCC	Intergovernmental Panel on Climate Change
USEPA	United States Environmental Protection Agency
GWP	Global Warming Potential
PPA	Power Purchase Agreements
KPIs	Key Performance Indicators
CF/r	Carbon Footprint per room
CF/os	Carbon Footprint per overnight stay
CF/m^2	Carbon footprint per square meter
Ec/os	Electricity consumption per overnight stay
Ec/m^2	Electricity consumption per square meter
Wc/os	Water consumption per overnight stay
Wc/m^2	Water consumption per square meter
L	Liters
L/m^2	Liters per m^2
N	Number of Hotels
Min.	Lowest reported value
Q1	The 25th percentile upper limit
Aver.	Arithmetic mean
Q3	The 75th percentile lower limit
Max.	Highest documented value
Diff.	Index difference

Appendix A. Detailed Category 4 Emission Profiles

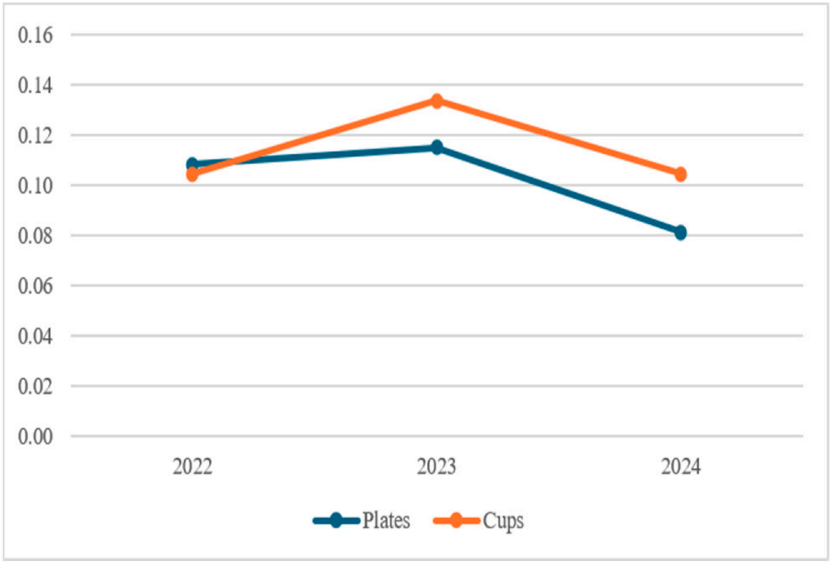


Figure A1. Annual TE from tableware.

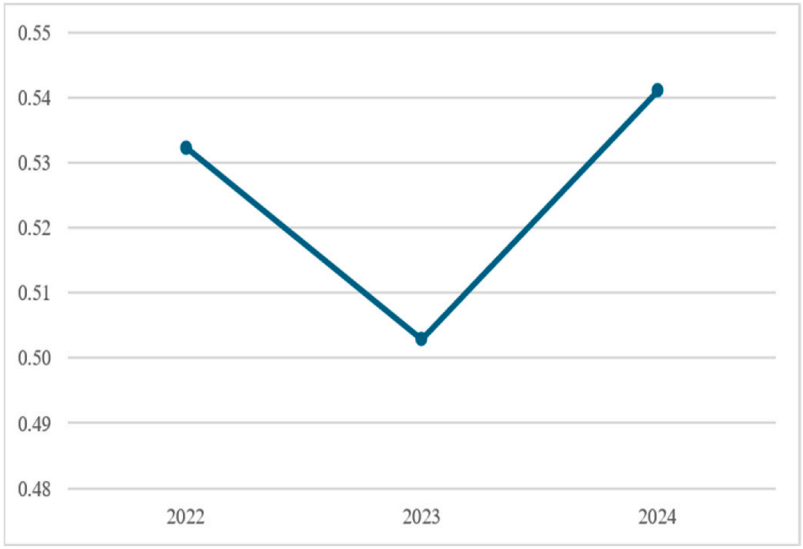


Figure A2. Annual TE from bottled beverages.

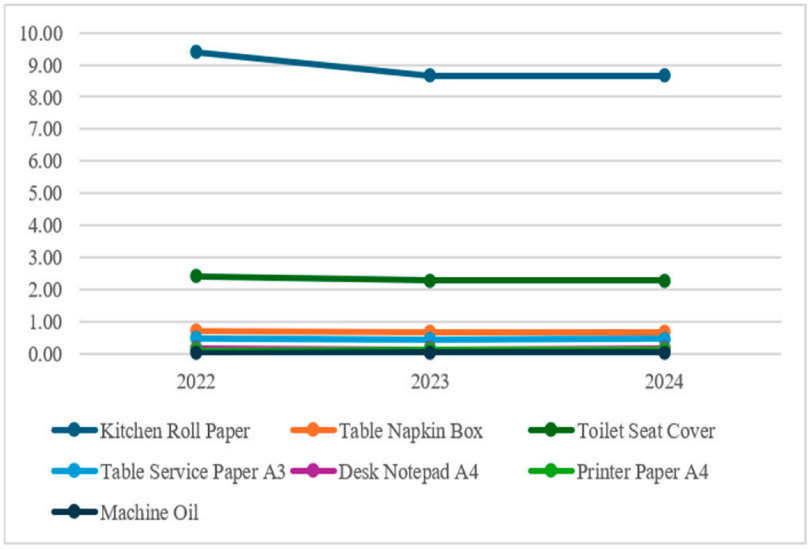


Figure A3. Annual TE from office supplies.

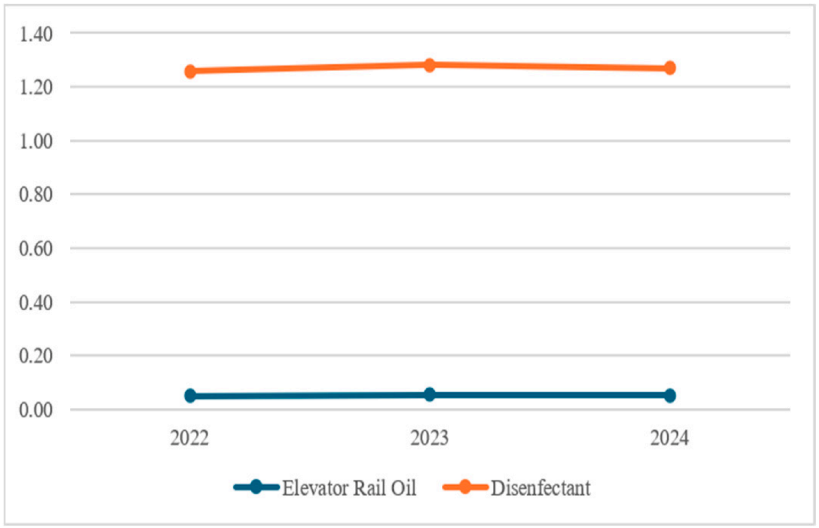


Figure A4. Annual TE from technical Lubricants.

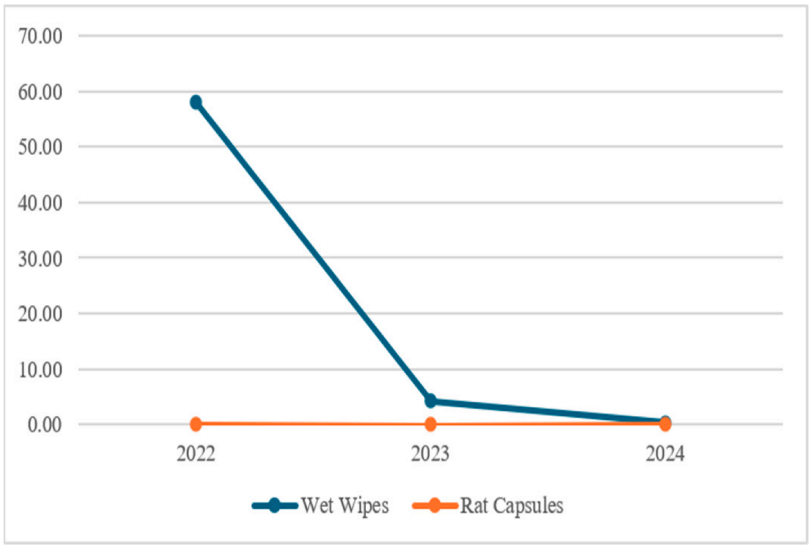


Figure A5. Annual TE from hygiene products.

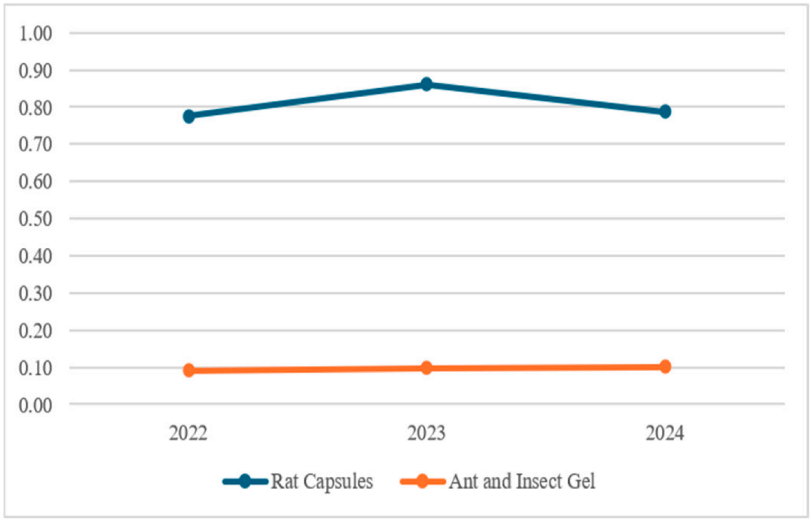


Figure A6. Annual TE from Insecticides.

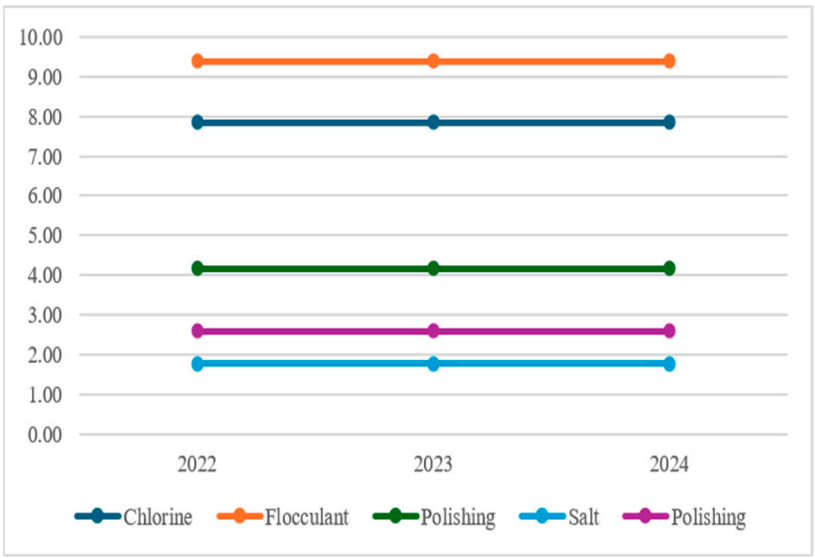


Figure A7. Annual TE from swimming pool chemicals.

References

1. Seit Wann Gibt es Strom? Available online: https://www.verivox.de/strom/themen/seit-wann-gibt-es-strom/ (accessed on 8 April 2024).
2. Greenhouse Gases Continued to Increase Rapidly in 2022. Available online: https://www.noaa.gov/news-release/greenhouse-gases-continued-to-increase-rapidly-in-2022#: :text=Atmospheric%20CO2%20is%20now,more%20had%20never%20been%20recorded (accessed on 9 January 2024).
3. Wiedmann, T.; Minx, J. A Definition of 'Carbon Footprint'. In *Ecological Economics Research Trends*; Pertsova, C.C., Ed.; Nova Science Publishers: New York, NY, USA, 2008; pp. 1–11.
4. Gössling, S.; Balas, M.; Mayer, M.; Sun, Y.-Y. A review of tourism and climate change mitigation: The scales, scopes, stakeholders and strategies of carbon management. *Tour. Manag.* **2023**, *95*, 104681. [CrossRef]
5. Hizmet Ticaret İstatistikleri. Available online: https://ticaret.gov.tr/hizmet-ticareti/hizmet-ticaret-istatistikleri (accessed on 12 July 2024).
6. Dünya Turizmi 2022 Yılında Yüzde 111 Büyüdü. Available online: https://www.tursab.org.tr/e-dergi?pdf=/assets/assets/uploads/dunya-turizm-istatistik/2022-yilsonu-degerlendirmesi.pdf (accessed on 20 June 2024).
7. Khatib, A.N. Climate Change and Travel: Harmonizing to Abate Impact. *Curr. Infect. Dis. Rep.* **2023**, *25*, 77–85. [CrossRef] [PubMed]
8. MacAskill, S.; Becken, S.; Coghlan, A. Engaging hotel guests to reduce energy and water consumption: A quantitative review of guest impact on resource use in tourist accommodation. *Clean. Responsible Consum.* **2023**, *11*, 100156. [CrossRef]
9. Pan, D.; Yu, X.; Zhou, Y. Cradle-to-grave lifecycle carbon footprint analysis and frontier decarbonization pathways of district buildings in subtropical Guangzhou, China. *J. Clean. Prod.* **2023**, *416*, 137921. [CrossRef]
10. Bhochhibhoya, S.; Pizzol, M.; Marinello, F.; Cavalli, R. Sustainability performance of hotel buildings in the Himalayan region. *J. Clean. Prod.* **2020**, *250*, 119538. [CrossRef]
11. Castellani, V.; Sala, S. Ecological Footprint and Life Cycle Assessment in the sustainability assessment of tourism activities. *Ecol. Indic.* **2012**, *16*, 135–147. [CrossRef]
12. Toshima, M.-C.; Naadir, G.; Ramasamy-Coolen, P.; Chandradeo, B.; Ravi, F. The Contributing Factors of Carbon Footprints Among Hotels on the Island of Mauritius: A Comparative Analysis. *Eur. J. Sustain. Dev.* **2021**, *10*, 9–19. [CrossRef]
13. Koiwanit, J.; Filimonau, V. Carbon footprint assessment of home-stays in Thailand. *Resour. Conserv. Recycl.* **2021**, *164*, 105123. [CrossRef]
14. Oluseyi, P.O.; Babatunde, O.M.; Babatunde, O.A. Assessment of energy consumption and carbon footprint from the hotel sector within Lagos, Nigeria. *Energy Build.* **2016**, *118*, 106–113. [CrossRef]
15. Liqin, Y. The Analysis on Carbon Footprint of Catering Products in High-star Hotels during Operation: Based on Investigation Conducted in parts of High-star Hotels in Ji'nan. *Energy Procedia* **2011**, *5*, 890–894. [CrossRef]
16. Lai, J.H.K. Carbon footprints of hotels: Analysis of three archetypes in Hong Kong. *Sustain. Cities Soc.* **2015**, *14*, 334–341. [CrossRef]
17. Sheng, Y.; Miao, Z.; Zhang, J.; Lin, X.; Ma, H. Energy consumption model and energy benchmarks of five-star hotels in China. *Energy Build.* **2018**, *165*, 286–292. [CrossRef]
18. Salehi, M.; Filimonau, V.; Asadzadeh, M.; Ghaderi, E. Strategies to improve energy and carbon efficiency of luxury hotels in Iran. *Sustain. Prod. Consum.* **2021**, *26*, 1–15. [CrossRef]
19. Tóffano Pereira, R.; Filimonau, V.; Ribeiro, G. Projecting the carbon footprint of tourist accommodation at the 2030 FIFA World CupTM. *Clean. Responsible Consum.* **2020**, *1*, 100004. [CrossRef]
20. Sipahi, S.; Tavşan, F. Otel Mobilya Tasarımlarında Yaşam Döngüsü Değerlendirmesi: Antalya Örneği Life Cycle Assessment in Hotel Furniture Designs: Example of Antalya. *Int. J. Eng. Des. Technol.* **2021**, *3*, 16–29.
21. Önüt, S.; Soner, S. Energy efficiency assessment for the Antalya Region hotels in Turkey. *Energy Build.* **2006**, *38*, 964–971. [CrossRef]
22. Aktaş, S.C.; Süer, S. Döngüsel Ekonomi Anlayışı ile Otel İşletmeciliği Uygulamaları: Bir Doküman Analizi Çalışması. *J. Acad. Tour. Stud.* **2022**, *3*, 13–31. [CrossRef]
23. Die Meistbesuchte Stadt der Welt Liegt in der Türkei. Available online: https://www.merkur.de/reise/istanbul-tuerkei-new-york-london-euromonitor-reisen-meistbesuchte-stadt-welt-2023-zr-92834751.html (accessed on 4 October 2025).
24. *DIN EN ISO 14064-1:2019-06*; Treibhausgase—Teil 1: Spezifikation mit Anleitung zur Quantitativen Bestimmung und Berichterstattung von Treibhausgasemissionen und Entzug von Treibhausgasen auf Organisationsebene (ISO 14064-1:2018); Deutsche und Englische Fassung EN ISO 14064-1:2018. Beuth Verlag GmbH: Berlin, Germany, 2019.
25. Jurić, Ž.; Ljubas, D. Comparative Assessment of Carbon Footprints of Selected Organizations: The Application of the Enhanced Bilan Carbone Model. *Sustainability* **2020**, *12*, 9618. [CrossRef]
26. Explorative Forschung: Definition, Arten, Beispiele. Available online: https://www.appinio.com/de/blog/marktforschung/explorative-forschung (accessed on 5 April 2025).

27. Crowe, S.; Cresswell, K.; Robertson, A.; Huby, G.; Avery, A.; Sheikh, A. The case study approach. *BMC Med. Res. Methodol.* **2011**, *11*, 100. [CrossRef] [PubMed]
28. Shareia, B.F. Qualitative and Quantitative Case Study Research Method on Social Science: Accounting Perspective. *Int. J. Econ. Manag. Eng.* **2016**, *10*, 3839–3844. [CrossRef]
29. Sancaklı, E. Türkiye'de Karbon Ayak İzi Konulu Lisansüstü Tezlerinin İncelenmesi. *Peyzaj* **2024**, *6*, 50–60. [CrossRef]
30. Exploratory Research | Definition, Guide, & Examples. Available online: https://www.scribbr.com/methodology/exploratory-research/ (accessed on 6 April 2025).
31. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available online: https://www.ipcc-nggip.iges.or.jp/public/2006gl/ (accessed on 26 March 2025).
32. The Greenhouse Gas Protocol—A Corporate Accounting and Reporting Standard. Available online: https://ghgprotocol.org/corporate-standard#supporting-documents (accessed on 10 October 2024).
33. Greenhouse Gas Inventory Guidance: Direct Emissions from Mobile Combustion Source. Available online: https://www.epa.gov/sites/default/files/2020-12/documents/mobileemissions.pdf (accessed on 17 May 2025).
34. Supply Chain Greenhouse Gas Emission Factors for US Industries and Commodities. Available online: https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=CESER&dirEntryId=349324 (accessed on 17 May 2025).
35. Wie viel Kohlendioxid (CO_2) speichert der Baum bzw. der Wald. Available online: https://www.wald.de/waldwissen/wie-viel-kohlendioxid-co2-speichert-der-wald-bzw-ein-baum/ (accessed on 26 March 2025).
36. Ricaurte, E.; Jagarajan, R. Hotel Sustainability Benchmarking Index 2024. 2024. Available online: https://ecommons.cornell.edu/items/85eddae3-2b5b-41fb-88ad-75a0b53f8424 (accessed on 21 June 2025).
37. Forster, P.; Storelvmo, T.; Armour, K.; Collins, W.; Dufresne, J.-L.; Frame, D.; Lunt, D.J.; Mauritsen, T.; Palmer, M.D.; Watanabe, M.; et al. The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In *Climate Change (2021): The Physical Science Basis*; Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2023; pp. 923–1054. [CrossRef]
38. T.C. Enerji ve Tabii Kaynaklar Bakanlığı. Türkiye Ulusal Elektrik Şebekesi Emisyon Faktörü Bilgi Formu. 2025. Available online: https://enerji.gov.tr//Media/Dizin/EVCED/tr/%C3%87evreVe%C4%B0klim/%C4%B0klimDe%C4%9Fi%C5%9Fikli%C4%9Fi/TUESEmisyonFktr/Belgeler/Sebeke_EF_Bilgi_Formu_2022.pdf (accessed on 8 July 2025).
39. C3S Seasonal Lookback: Summer 2024. Available online: https://climate.copernicus.eu/c3s-seasonal-lookback-summer-2024 (accessed on 3 June 2025).
40. Gong, L.; Zhang, Z.; Chen, M.; Taylor, S.; Wang, X. Study on the carbon footprint of cold storage units using low-GWP alternative refrigerants. *J. Clean. Prod.* **2023**, *430*, 139589. [CrossRef]
41. Ang, M.Y.A.; Pontes, N.; France, C. Unsustainable burgers? Deploying carbon footprint labels to enhance sustainability perceptions of animal-based food products. *J. Retail. Consum. Serv.* **2023**, *76*, 103567. [CrossRef]
42. Shabir, I.; Dash, K.K.; Dar, A.H.; Pandey, V.K.; Fayaz, U.; Srivastava, S.; Nisha, R. Carbon footprints evaluation for sustainable food processing system development: A comprehensive review. *Future Foods* **2023**, *7*, 100215. [CrossRef]

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