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Introducing waste generation as a factor affecting carbon footprint in hotel operation and assessment of reduction practices

Athanasia Orfanou [a], Eleftheria Klontza [a,*], Stergios Vakalis [b], Irene Voukkali [c], Antonis A. Zorpas [c], Demetris F. Lekkas [a]

[a] Waste Management Laboratory, Department of the Environment, University of the Aegean, 81100, Mytilene, Greece

[b] Thermodynamics and Transport Phenomena Laboratory, School of Chemical Engineering, National Technical University of Athens, 9 Heroon Polytechniou, GR-15780, Athens, Greece

[c] Open University of Cyprus, Faculty of Pure and Applied Sciences, Laboratory of Chemical Engineering and Engineering Sustainability, Giannou Kranidioti 89, Latsia, 2231, Nicosia, Cyprus

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ABSTRACT

Hospitality sector is a crucial industry for Greek and global economy which applies environmental pressure through services such as accommodation, food and waste management. This study proposes a methodology for the calculation of the carbon footprint during hotel operation by considering four main domains: energy consumption, propane gas consumption (used for meal preparation), hotel waste and food waste. A 5-star resort hotel in Northern Greece was used as a pilot study. Reports on energy consumption were provided through electricity meters installed in the hotel, while data on the quantities of waste and the existing management practices were collected through staff interviews and questionnaires. Emissions (CO_2eq) were calculated using RETScreen, the average-data method and emission factors. The results demonstrate that energy consumption is responsible for the 81 % of CO_2eq emissions/ guest night, followed by emissions from food waste (11 %), waste (5 %), and propane gas used in the kitchen which contributes the least (3 %) in total emissions. Different scenarios were analysed to evaluate sustainable practices such as Renewable Energy Sources penetration, food waste composting and increasing recycling and their contribution to the reduction of total emissions. Scenario analysis showed that solar energy use could reduce total emissions by 36 %, while it is underlined that the application of sustainable waste management practices, which are often easier and less costly than energy efficiency improvements, could lead up to 15 % reduction of overall emissions, reducing them to 25.79 kgCO_2eq/guest-night. The combination of all the proposed scenarios could lead to a total reduction of 47.45 % of hotel emissions.

1. Introduction

In recent years, there has been a growing interest in sustainability within the tourism industry, along with an increasing focus on adopting practices with low environmental impact [1,2]. The tourism industry plays a crucial role in global greenhouse gas (GHG) emissions and previous studies mention that is contributing 5 % to worldwide emissions [3,4], while more recent studies estimate that tourism is responsible for the 8 % of the worldwide GHG emissions which corresponds to 4.5 Gt CO_2eq annually [5,6]. In the case of some popular touristic destinations, such as Spain, the impact of tourism is even higher, accounting for the 11 % of total GHG emissions [7]. Transportation plays a major role, causing 75 % of these emissions [8]. In general, tourism creates environmental pressure via various services, including accommodation, nutrition, recreational activities, and transportation. At the same time, it remains highly prone to the effects of global warming, since climate plays a key role in shaping the appeal of travel destinations [9].

A recent study by Gössling et al. [10] indicates that tourism sector could alone consume 40 % of the world's remaining carbon budget designated for a 1.5 °C temperature increase, if no action that could reduce its impact is taken. To this direction, the European Green Deal aims to establish the EU's commitment to new growth models and achieve climate neutrality by 2050, with a target to reduce emissions by at least 55 % by 2030 [11]. A key component of this initiative is the greening of European tourism, which seeks to adopt a more sustainable and responsible ecosystem approach. This effort involves collaboration

* Corresponding author.
E-mail address: eleftheria.klontza@aegean.gr (E. Klontza).

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among various stakeholders as well as tourists themselves [12].

Hotels can contribute significantly to the carbon footprint of the hospitality sector with reported values from 0.32 – 749 kg $CO_{2\text{-eq}}$/tourist/day [9]. Within this context, several studies deal with the carbon footprint of hotels. Some refer to the calculation of their emissions [13], across different tourist accommodations types in top tourist destinations such as Peru and Brazil [14], and in Global South countries like South Western Nigeria [15] and others refer specifically to the carbon footprint of luxury hotels [16,17]. Some suggest using tools such as carbon tracking apps, to understand and influence the behaviour of hotel's guests to offset their emissions [18]. Additionally, studies propose specific practices for waste management in the hospitality industry such as choosing suppliers who collect packaging waste or reducing packaging of food products [19], while others present hotel's staff and guests as the main responsible parties in their waste management practice [20,21]. Recent publications investigate solutions to achieve net zero carbon emissions, starting by questioning if it is feasible [22], others by studying which is the best hybrid renewable system that could be implemented in a hotel to reach zero emissions [23] or which are the optimal tourism practices that will help hotels to achieve that goal [24].

An interesting outcome from studying the impact of hospitality sector is the disproportionate environmental impact in the case of luxury accommodation. Puig et al. [17], showed that emissions from luxury hotels can be triple to those from average hotels and up to five times higher than those from one-star hotels. Energy consumption in luxury and five-star hotels is a main contributor, accounting for more than half of the total emissions [17]. These findings underline the need for accessible carbon footprint estimation methods, especially for accommodations with high emissions and quantifiable, measurable data that will lead to more sustainable tourism practices [25].

Emissions are related to energy consumption which ranges from less than a 150 kWh/m^2 year for hotels rated with 2 to 4 stars to >500 kWh/m^2 per year in the case of luxury and five-star hotels [26,27]. Another factor that affects hotel's environmental impact significantly, is waste generation since it accounts for 1.7 to 2.5 kg/guest night [28]. The type of waste that is considered of high importance and still ends up in landfills in a great extent within the tourist sector is food waste [29]. Amicarelli et al. [30], mentioned that the hospitality sector (hotels, restaurants, and catering services) is responsible for 10 million t of food waste annually, out of 85 million t which are generated in total within European Union; the corresponding annual production is 170 kg per capita [30]. According to Poore and Nemecek [31], food waste accounts for around 6 % of global greenhouse gas emissions. This contradicts Sustainable Development Goal (SDG) 12, which aims to ensure sustainable consumption and production patterns. Specifically, Target 12.3 calls for halving global per capita food waste by 2030 at both retail and consumer levels, while also reducing food losses throughout production and supply chains, including post-harvest losses [32].

In Greece, tourism plays a catalytic role in the country's economy. In 2023, Greece's inbound tourism exceeded pre-pandemic levels, marking a significant milestone in the recovery of this sector. It witnessed the highest tourism performance ever recorded since the inception of the Border Survey, with arrivals increasing by 4.4 %, from 31.3 million in 2019 to 32.7 million in 2023 [33]. Given the ever-increasing number of tourists and the prolongation of the tourist season, which increases the demand for energy needs and consequently the sector's environmental footprint, Greece's National Climate Law prioritizes establishing rules to control and mitigate these impacts [34].

Several studies have been conducted in Greece, focusing on hotels' environmental impact. Some of them study the environmental footprint of seaside hotels in areas in Greece such as Chalkidiki [35] and Crete [27], while others study the hotels' efforts to adopt practices for its reduction. Khodaiji and Christopoulou [36], aim to identify and analyze sustainable development in the Greek hospitality industry by evaluating two of Greece's leading hotel groups. Parpairi [37] examined energy consumption in small Greek hotels and the use of renewable energy sources (RES) as an energy-saving and carbon-footprint reducing strategy. Other studies examine guests' positive behavior toward hotels' green practices in Crete [38] and their willingness to choose Greek hotels that have adopted sustainable practices [39].

Carbon footprint (CF) studies use a variety of data sources [40–42]. Primary data collection often focuses on emissions from operational activities in the accommodation sector related to energy consumption. Typically, the data are collected from invoices, and on transport-related details of tourists' trips from origin to destination and their modes of transport while on vacation. In many cases, CF studies focus exclusively on either accommodation or transportation components. In the Miralles et al. review paper [9] regarding the CF studies, most consider both direct and indirect emissions and used a bottom-up approach based on the ISO 14,040/ISO 14,044 methodology, and only a few referred to the GHG Protocol guidelines to outline their scope [9], which divides emissions into Scope 1 (direct GHG emissions), Scope 2 (electricity-related GHG emissions), and Scope 3 (indirect) categories [43].

While tourism's effect on the environment has gained significant attention, measures to limit emissions are still relatively few. According to the UNWTO only 20.7 % of hospitality accommodations currently measure their emissions and even among those, there is a lack of standardisation and consensus. Most current methodologies and tools are not easily accessible, are not designed specifically for small and medium-sized enterprises (SMEs), or are not appropriate for widespread application [44]. Especially in the case of food waste, the lack of available data prompted some researchers to review the available measuring tools for food waste quantification [45], to introduce easier approaches for analysing and separating food waste [46], and others to quantify food waste [47]. The latter showed that the hospitality sector accounts for around 12 % of total food waste in the EU-27, the third largest share after households (53 %) and the food processing industry (19 %).

Based on the above, this paper develops a methodology for the calculation of the environmental footprint during hotel operation by investigating the carbon footprint and integrating waste management in the emissions. The parameters considered are *energy consumption, propane gas consumption* which is used in the hotel's kitchen, *generated mixed waste*, and *food waste*. A thorough understanding of the distribution of carbon footprint across different hotel domains is essential for formulating sustainable scenarios and practices aim to reduce the environmental impact of the hotel industry. Furthermore, several scenarios are presented to increase hotel sustainability and reduce CO_2 emissions. The proposed scenarios can be considered as a valuable resource for hotel managers and policymakers, providing a framework for developing strategies that effectively mitigate CO_2 emissions and prioritize the mitigation of the most significant contributors.

2. Methodology

The aim of this study is to calculate the carbon footprint of four main domains in a hotel (Fig. 1), energy consumption, propane gas (PG) consumption in the kitchen, waste generation and management and food waste generation. In the following sections the data collection, the scope of emissions under investigation and the methodology developed and used for each domain are presented. The emissions derived from the energy consumption are calculated by using RETScreen, the propane gas consumption from the kitchen operation is estimated by using the emission factor that is produced during propane gas combustion, waste generation is calculated with an average-data method, and food waste generation by using the emission factor of one kilo of food waste that is retrieved from the literature. Also, three scenarios regarding green practices for reducing the hotel's carbon footprint are suggested and analysed.

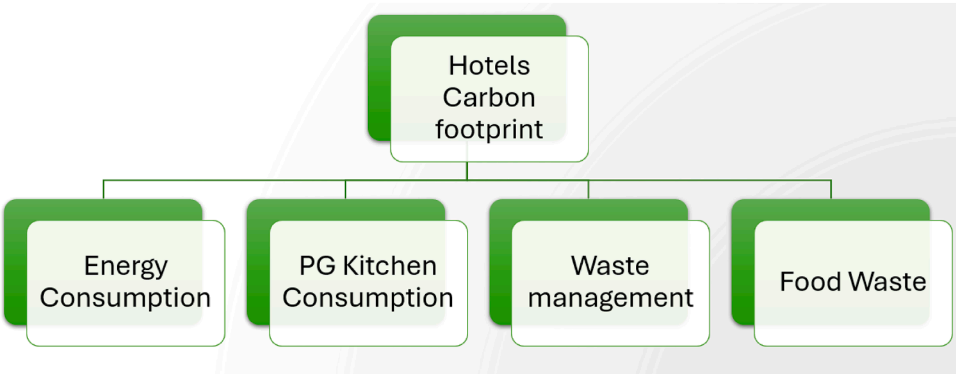

Fig. 1. Domains of hotels carbon footprint.

2.1. Data collection

To collect primary data of the domains studied two types of questionnaires are used. Questionnaire 1 is filled out by the Technical Director and Technical Manager and gathers information on total energy and propane gas (PG) consumption and guest nights. Questionnaire 2 is filled out by hotel staff and gathers more detailed data regarding waste composition and management and supplemented by on-site visits to measure food waste.

Two types of data are identified, Category A for the initial distinction of data classification based on usage (energy, waste production etc.) and Category B for data quantification (electricity, natural gas, propane gas consumption per month, recyclables, etc.). The data collected for each category are presented in Table 1.

The total CO_2 emissions of the hotel based on collected data are calculated by aggregating emissions from energy consumption, propane gas consumption used in the kitchen, waste management and food waste. The different methodologies for these calculations are presented in the following sub sections.

2.2. Parameters of analysis

2.2.1. Scopes of emissions

In accordance to the GHG Protocol, this study examines emissions of all three scopes: Scope 1, which includes direct emissions derived from the hotel (natural and propane gas consumption), Scope 2, which refers to indirect emissions of the hotel derived from energy obtained and use (electricity and gas consumption), and Scope 3, emissions that are not produced by the hotel itself and are not the result of activities from assets owned or being controlled, but that the hotel indirectly affects in its value chain, are examined (CH_4 gas generation at landfill produced by the disposal of hotel's waste and food waste) [43] (Table 2). Scope 3 emissions from supply chains are significant in hospitality (e.g., food procurement) as well as emissions related to travelling. Those attributes introduce 2 more dimensions; even though present the entire carbon footprint assessments, are beyond the scope of this paper. This study focuses only on the operation of the hotel - not the origin of the visitors or the source of food, since this is the proposed methodology for creating a comparative assessment between hotels located in different areas. In the case of incorporating supply chain emissions, hotels located on islands and/or remote locations (e.g. ski resorts) would be presenting significant differences if compared with hotels in city centers.

After gathering the information on the energy consumption of the hotel from the questionnaires, electricity consumption, natural gas and use of renewable energy sources (if there is any use of RES), the carbon footprint of the hotel's energy consumption is estimated.

2.2.2. Energy emissions

The hotel's energy consumption is analyzed by using RETScreen, a tool designed to assess the energy output of prospective renewable energy projects [48]. It also offers insights into the project's emissions, economic performance, and associated risks [49]. It is a valuable tool for decision-making and for evaluating the feasibility of prospective renewable energy projects, as well as for identifying supplementary strategies for profitable energy generation [49]. The energy analysis assesses the energy produced by the proposed energy system. The cost analysis estimates the initial and annual costs of the proposed project. The analysis of the emissions evaluates the reduction of the GHG emissions achieved through the implementation of renewable energy sources (RES). The financial analysis calculates the net present value of the project and assesses the overall economic sustainability of the project. To calculate the emissions that are produced by using natural gas, a conversion factor of 0.18 kg of CO_2eq/kWh is used [50].

Table 1
Type of data collected from the hotel.

Data	Category A (Data classification based on usage)	Category B (Data quantification)
Guest nights		
Energy Consumption	Energy use (2019)	Electricity (2019)
		Natural Gas (2019)
		Renewable energy sources
Kitchen Propane Gas Consumption		Kitchen Propane Gas Consumption (2019)
Waste	Mixed municipal waste	Landfilling
		Composting
	Recycling	Paper
		Glass
		Plastic
		Lead batteries
		Edible oils and fats
	Food waste	Meal preparation waste
		Plate waste

Table 2
Scopes of emissions under investigation in this study.

Scope	Emission activities	Examples
1	Consumption of natural and propane gas	Natural gas consumption for heating and propane gas consumption in kitchen
2	Consumption of electricity	Electricity consumption of the hotel
3	CH_4 gas generation at landfill from the disposal of the hotel's waste	Produced mixed waste
3	CH_4 gas generation at landfill from the disposal of the hotel's waste	Food waste that is derived from the hotel

2.2.3. Propane gas emissions

Propane gas is used in the kitchen for meal preparation. The monthly consumption data for propane gas use is collected through the questionnaire. To calculate its carbon footprint, a conversion factor of 0.21 – 0.23 kg of CO_2eq/kWh is used, which refers to the emissions produced during propane gas combustion [50].

2.2.4. Waste management emissions

Regarding the measurement of waste generation, data is collected from the hotel staff by using Questionnaire 2. The emissions from waste generated in the hotel, are calculated by using the average-data method [51]. This method is useful when hotels can collect data based on the total waste diversion rates. For this method, hotel staff collect data regarding the total mass of waste generated in the hotel and the percentage of the waste being landfilled, recycled etc. The average emission factor of landfilling used for the purpose of this work, is 300 kg CO_2 e/t [51,52] for conventional landfilling, instead of 1000 kg CO2eq/t for open dump since it is forbidden in Greece. Other emission factors reported in the literature include 328 kg CO_2eq/t for 100 % landfilling [53], 497 kg CO_2eq/t based on UK data [54] and up to 580 kg CO_2eq/t [55]. For recycling, the emission factor is 10 kg CO_2 e/t [51]. These emission factors can vary depending on the region and waste composition. However, site-specific or Greek national emission factors for individual waste streams are not currently available. For this reason, the value of 300 kg CO_2eq per tonne of waste is selected as a representative average, as this is a commonly used value in the literature. In addition, a sensitivity analysis is conducted to evaluate the influence of emission factor variability on waste footprint estimates.

Total emissions from waste management are calculated by taking into account the emission factor of the waste treatment method used each time and can be described by the following equation:

$$\boldsymbol{CO_2eq_{WM}} = \boldsymbol{\Sigma} \left(\boldsymbol{TW} \ (\boldsymbol{t}) \ \times \boldsymbol{PW} \times \boldsymbol{EF} \right)$$

CO_2 eq $_{WM}$: emissions from waste management, TW: total waste (t), PW: proportion of total waste treated by waste treatment method, EF: emission factor of waste treated method (kgCO_2EQ/t).

The average emission factor sourced by GHG Protocol is calculated considering waste composition with the biodegradable part being from 35 to 40 % of the total (EU average value). This assumption is valid for Greece as well, since the biodegradable portion of the MSW, which is responsible for the emissions 300 kg CO_2eq/t, is similar to EU average: 35–40 % of MSW. Therefore, we can accept the same factor for our Greek case study which is representative for the waste composition in Greece as well.

2.2.5. Food waste emissions

For the purpose of this study, food waste refers to any discarded food that is created during the food service process in the hospitality sector. Food waste can be categorized based on the phases of waste generation, for example pre-consumer (production level) and post-consumer food waste [56]. Pre-consumer waste refers to the waste that is collected from the kitchen, and is mainly composed of meal preparation waste, such as peels, shells, and other parts of raw materials that are not consumed, but also includes food that hasn't been served, or food that has been expired or spoiled. Post-consumer waste (often mentioned as plate waste) contains food that has been served but not consumed. It is found on the consumers' plate and ends up in waste, due to an excessive quantity of food or inadequate quality [57–59].

Data collection and quantification of food waste flows is accomplished by separation and measurement of the waste by hotel staff. Food waste is separated and collected in two bins, one for the waste generated in the kitchen and one for the waste generated in the restaurant.

The emissions of food waste are estimated separately from the emissions of waste management. According to literature [60,61], one kilogram of food waste is equivalent to approximately 2 - 2.1 kg CO_2eq. More specifically, in terms of hotel emissions, a recent study showed that hotel emissions range from 2.5 to 25 kg of CO_2eq per 1 to 10 kg respectively of food waste per day [62,63]. Other studies report values as high as 3 kg CO_2eq per kilogram of food waste [64]. As a reference factor, the average of the values found in the literature is used.

A sensitivity analysis was performed using Monte Carlo simulation [65] to address uncertainty of the emission factors related to natural gas, propane gas, landfilling, recycling and food waste. To complement the emission factor (EF) Monte Carlo analysis, we model variability in activity data that can affect annual intensity results. Monthly bed-occupancy was computed from monthly guest-nights and hotel capacity (312 beds). In 2019, occupancy ranged from 39.4 to 76.5 % (with an average number of 54.7). Data for the monthly energy intensity of kWh/guest-night (or monthly energy per guest-night) are retrieved from Table 3, which is presented in the Results section, and varied from 95.8 to 240.4 kWh/guest-night. Regressing monthly energy intensity on occupancy gives: $Eg = 291.5 - 267.9\ O + \varepsilon$, with O being the occupancy, ε being equal to the residual standard deviation, which was modeled as ε: [0, σεˆ2], with ε equal to the residual RMSE which is equal to 24 kWh/guest night. The electricity emissions produced by RETScreen were held at the year-specific value used in the base case.

2.3. Proposed scenarios

The tourism industry is currently under significant pressures related to mass tourism, which places considerable stress on both the environment and local communities and creates issues such as excessive greenhouse gas emissions, overuse of land and water resources, as well as unsustainable food consumption and food waste [66]. In response, the hospitality sector is facing growing pressure from consumers to adopt sustainable practices and eco-friendly initiatives [67]. In this study, three scenarios are recommended as sustainable solutions for the reduction of the hotel environmental footprint which derives from energy consumption and food waste.

2.3.1. Scenario 1: integration of renewable energy sources (RES) in hotel electricity consumption

This study analyzed and compared two different scenarios for energy production in the hotel: the baseline case (hotels' current state) and a recommended scenario which aims to reduce the hotel's carbon footprint. Both scenarios utilize Greece's current energy mix, as illustrated in Fig. 2.

In the baseline case, energy is supplied by the central grid and internal load. The baseline scenario incorporates energy from renewable energy sources, as the Greece energy mix has been used in RETScreen (Fig. 2). This means that the 26 % of the Total Energy Consumption (kWh), comes from renewable energy sources. In the proposed scenario, the penetration of renewable energy sources and more specifically a photovoltaic (PV) system with a total rated power of 2400 kW is introduced. The system consists of 10,000 monocrystalline photovoltaic units from the manufacturer Canadian Solar, model Mono-Si CS6P 240 W, providing a total electric power of 2400 kW. The PV station will cover a total area of 16,107 m^2, within the range that is reported in literature [68] and with a system efficiency of 14.9 %. The software RETSCREEN utilizes the F-CHART algorithm that takes into account the fluctuation of the solar radiation, while the angle of the panels has been adjusted from the maximum possible performance for the area of study. The efficiency relates to the conversion of the solar radiation into electricity, which is also influenced by parameters like temperature, which are also considered from the software.

2.3.2. Scenario 2: composting as an alternative to landfilling for food waste management

Unless there is a significant improvement in existing waste management processes, the growing volumes of waste generated by hotels could cause an important increase in the environmental footprint of the hospitality sector [69]. Additionally, Directive 99/31/EC regarding

Table 3
Hotel's energy consumption (2019).

Months	Electricity (kWh)	Natural Gas (kWh)	Total Energy Consumption (kWh)	Guest nights	Energy consumption (kWh)/ guest night	Power gross average load (kw)
Jan-19	340,581	576,164	916,745	3814	240.36	458
Feb-19	269,775	407,096	676,871	3717	182.10	363
Mar-19	310,179	347,170	657,349	4633	141.88	417
Apr-19	339,029	315,530	654,559	5217	125.47	456
May-19	428,015	343,696	771,711	4923	156.76	575
Jun-19	556,711	300,513	857,224	6015	142.51	748
Jul-19	510,065	199,065	709,130	7403	95.79	686
Aug-19	544,872	197,173	742,045	6967	106.51	732
Sep-19	447,269	210,143	657,412	5408	121.56	601
Oct-19	374,609	235,325	609,934	5225	116.73	504
Nov-19	317,404	261,118	578,522	4266	135.61	427
Dec-19	331,796	508,763	840,559	4823	174.28	446

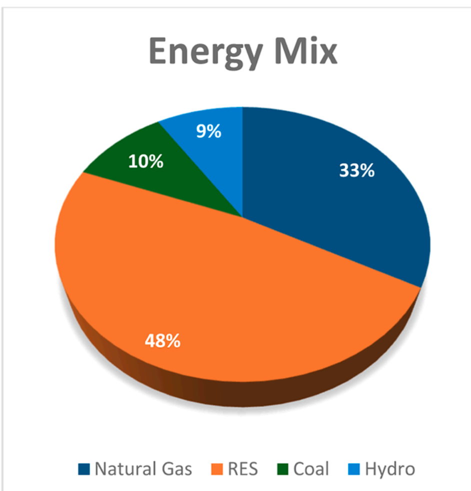

Fig. 2. National energy mix (2023).

waste landfilling, sets limitations on the amount of organic waste that could be sent to landfills [70]. For this reason, the second scenario that is proposed is relevant to the disposal method of food waste which affects the generated emissions. Owusu et al. [63], found that food waste disposal in landfills generates CO_2eq emissions of 1.38 kg per kilogram of wasted food, while composting reduces the emissions to 0.11 kg per kilogram of food waste. In that case, the scenario suggests shifting from landfilling to composting considering food waste management. On-site composting could also lead to a reduction of transportation and landfill disposal costs, due to the reduced amount of waste disposed to the landfill [71].

2.3.3. Scenario 3: increase recycling in waste management

The hospitality industry tends to consume significant amounts of natural resources in terms of energy and water and therefore often chooses disposable single use materials [72]. In the study by Díaz-Farina [73], the high amount of waste generated by guests and the low recycling rates are highlighted as some of the issues that hinder the implementation of more sustainable policies in the hospitality sector. In addition, although recent studies have also presented a lot of difficulties regarding hotels' sustainable operation [18,24], the 3Rs principle (Reduce, Reuse, Recycle) is not highly stated as a firm practice [74]. For this reason, the third scenario, is proposing to increase the third R (Recycling), since it is already implemented in some amount.

The average emission factor for recycling is 10 kg CO_2 e/t [51], significantly lower than the emissions during landfill (300 kg CO2 e/t). An increase in recycling of 20 % could be achieved by educating hotel staff on how to separate recyclable waste during collection from the different parts of the hotel.

3. Results and discussion

In this section the pilot case (resort hotel) is presented along with the results and outcomes of the carbon footprint calculations carried out to evaluate the environmental impact from energy consumption, propane gas consumption used in the kitchen, waste management and food waste. The results of the three proposed scenarios, to enhance the hotel's green transition of the hotel, are also discussed.

Pilot presentation: Five star - resort Hotel in Northern Greece

The case study selected for the analysis is a five-star resort hotel located in the North of Greece. The hotel operates on a year-round basis and offers 152 rooms, with an average size of 42 square meters. Of the total number of rooms, 34 are suites and 118 are double rooms, resulting in a total capacity of 312 beds.

The hotel is situated on a plot of land comprising 98.5 acres, of which 86 acres constitute the total area of the building unit, 45.4 acres are designated as green areas, 24.9 acres are allocated to the outdoor parking area, and 1.1 acres are occupied by the large outdoor swimming pool. Additionally, the property features outdoor recreational facilities, an internal road system, and a watercourse. The complex was built in 1990, and since then no building renovation or energy upgrade has been done, except of changes in the decoration and the wallpaper.

Data collection

Two types of questionnaires are used, a short questionnaire, which is filled in by the Technical Director and Technical Manager, for energy consumption, guest nights and propane gas (PG) use, and a detailed questionnaire, filled out by the hotel staff. Some data were provided during on-site visits. During these visits, interviews were conducted with managers, technical director or manager, general manager, room cleaning staff and kitchen staff to collect information regarding the energy usage and waste management practices. Most of the data on energy consumption were obtained from electricity bills and on waste generation from the hotel reports. Annual averages were used due to the limited seasonal data available for all the domains being studied.

Energy meters are installed within the facility to record energy consumption values and generate reports (AS Automation System Hellas), which were provided by the hotel management for this study making data collection even more robust and accurate.

3.1. Carbon footprint of hotel's energy consumption

From the energy consumption data provided by the hotel, the year 2019 was chosen as the most representative (before the COVID pandemic), since it presents a typical year regarding to tourism activity. The years 2020 and 2021 were excluded due to restrictions that were imposed by the World Health Organization and affected the number of guest arrivals.

The hotel's energy consumption relies on electricity and natural gas. Electricity is used for most of the hotel's operations and is distributed by the Public Power Corporation S.A. (PPC), which is the largest electricity company in the Greek network. There are no private or on-site sources of renewable energy. Natural gas is used mainly for heating, hot water (and the indoor pool) and steam production (for laundry), while the kitchen (i.e. the non-electric equipment) relies on propane (LPG) and therefore is analysed as a separate domain.

Based on the data provided, electricity consumption of the hotel can be considered stable for the last 10 years and proportional to the number of visitors. Higher values per quest night are observed during June and January, despite January having 37 % fewer guests. Regarding the natural gas consumption per guest night, it is higher during the winter months.

In a typical year such as 2019, the hotel's annual energy consumption (electricity and natural gas) is 8.6 GWh and the average energy consumption per m^2 is 1008 kWh/m^2. This is in agreement with the values reported in the literature for luxury and five-star hotels, which range from 564 to 1004 kWh/m^2 per year with non-hosting operation of the hotels (pools, spa, fitness centers, saunas) requiring more energy than the hosting operations [26,27,75]. The hotel's high energy consumption values and the lack of building renovations or energy upgrades were of the main reasons to choose this hotel for the pilot case.

As shown in Table 3, the winter months have the highest energy consumption per guest night. This indicates that the hotel's operations require significant energy consumption even when it is not operating at its full capacity.

Following the proposed methodology, the hotel's electricity consumption is analyzed using RETScreen. Based on Table 3 the energy consumption index is calculated 139 kWh/ guest night while in the values reported in literature range from 19.4 kWh/guest night [27] to 40.31 kWh/guest night [76], 43.4 kWh/guest night [77] and up to 120 kWh/guest night in the case of five-star hotels [78]. The basic case of a power generation system is calculated by converting the monthly energy of thermal units taken from Table 3. and the chart is available in the supplementary material (S01).

In the base case scenario (hotel's current situation), the hotel's annual emissions derived by electricity are equal to 1192 t CO_2eq. RETScreen was used for the calculation, using the Greek energy mix composition for this year (Fig. 2), [79]. This means that GHG emissions from hotel's electricity consumption only account for approximately 19.09 kg CO_2eq per guest night which is higher than the average 16.8 kg CO_2eq/guest night that is reported in the literature [77].

The emissions that are produced from natural gas, are calculated by using a conversion factor of 0.18 kg of CO_2eq/kWh and are responsible for 11.25 kg CO_2 per guest night. This value is also higher than the average 9.9 kg CO_2eq/guest night that is reported in the literature [77].

The emissions related to the hotel's energy consumption are 30.34 CO_2 /guest night in total. Electricity contributes to the 62.92 % of hotel energy emissions gas and natural gas to the 37.08 %.

3.2. *Carbon footprint of hotel's propane gas consumption in the kitchen*

Propane gas is used in the kitchen for meal preparation. The monthly consumption for 2019 is shown in Table 4, with the peak occurring in the summer, as it is the high touristic season, with an increased number of guests.

In Table 4, emissions that derive from hotel kitchen and propane gas (PG) use, as well as the emissions in terms of CO_2eq per guest night (kg CO_2eq/guest night) are presented. During high season, in the summer months, both the consumption of PG in the kitchen and the emissions reach their highest levels. However, emissions per guest night are in the lowest level during this period due to the increased number of guest nights and subsequently the reduction of the emissions/guest night ratio. To conclude, the emissions that are produced from the use of PG in the kitchen are responsible for 1.20 kg CO_2eq/ guest night.

Table 4
Hotels' kitchen PG Consumption (2019) and emissions.

Months	Kitchen PG Consumption (KWh)	Kitchen emissions (kg CO_2eq)	Guest nights	Kitchen emissions per guest night (kg CO_2eq/guest night)
1	28,597	6005	3814	1.57
2	25,105	5272	3717	1.42
3	27,354	5744	4633	1.24
4	27,192	5710	5217	1.09
5	29,387	6171	4923	1.25
6	33,552	7046	6015	1.17
7	34,904	7330	7403	0.99
8	34,918	7333	6967	1.05
9	30,460	6397	5408	1.18
10	29,350	6164	5225	1.18
11	26,794	5627	4266	1.32
12	27,736	5825	4823	1.21

Compared to other fossil fuels such as coal or oil, propane gas emits less CO_2 per unit of energy, making it a relatively lower-emission and more sustainable option for cooking [50].

3.3. *Carbon footprint of hotel's waste management*

For the calculation of the amount of generated waste, data were collected from the hotel. Data are also reported annually to the Hellenic Electronic Register on Waste, which is monitored by the Greek Ministry of Environment and Energy. For the year 2019, it has been calculated that 396.521 t of solid waste (in total) and 40.671 t of recyclable waste were generated. The detailed waste composition is available in the supplementary material (S02).

In Fig. 3, waste composition is presented. Mixed municipal waste accounts for the largest proportion of waste (89.74 %), followed by glass packaging (4.58 %), paper and cardboard packaging (3.06 %), edible oils and fats (1.52 %), plastic packaging (0.88 %) and lead batteries with 0.21 % which sum up to 10.26 % of total recyclable waste. The emissions from waste management were calculated, without taking into account the food waste.

With the use of the equation that presented in the methodology section, the CO_2 emission from waste management is calculated to be 1.71 kg⋯CO_2eq/ guest night (Table 5). This result was produced using the data for total waste and recyclable waste, waste composition data and the emission factor which corresponds to each treatment method.

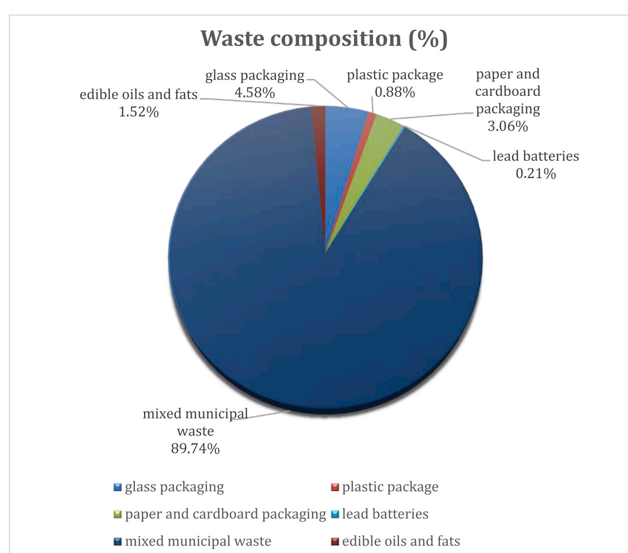

Fig. 3. Composition (%) of the waste generated in the pilot hotel.

Table 5
Emissions from hotels' waste management.

	kg	Guest nights	kg/guest night	kg CO_2eq/ guest night
Waste	396,521	62,411	6.35	1.71
Recyclable waste	40,671	62,411	0.65	0.006

3.4. *Carbon footprint of food waste management in the pilot hotel*

Food waste was collected separately and measured in the kitchen for the purpose of the study, with respect to hotel's policy. For accurate data reporting, waste was separated into two bins: one for waste generated in the kitchen (meal preparation waste) and one for the waste generated in the restaurant (plate waste). The measurements were conducted over six days and data (amount of waste generated) were provided directly by the hotel staff. It is well understood that data collection through staff interviews and questionnaires introduces potential uncertainty in the estimation of waste quantities, particularly for food waste. However, the methodology applied for the collection of data should comply with the hotel's policy as well as its quality standards and internal audits, resulting in limited access to kitchen and storage facilities. The quantities provided by the hotel staff agreed with those reported to waste collection and management authorities. As it is presented in the supplementary material (S03) the average value for food waste generation per day is 173 kg which is 5 times higher than what is presented in literature [63], which is 11–30 kg food waste daily. Considering the food covers that rise up to 260,497, the food waste/ cover is 0.24 kg, which is close to the average daily food waste/cover that is reported in the literature for a 5-star hotel, which is approximately 0.383 kg [80]. The average value for the food waste per guest night is 1.57 kg. Although the amount seems high, it is attributed to quality control management systems and audits, according to which the prepared meals for any extra demand (not served) should be disposed after 4 h.

In Table 6, the emissions from hotel food waste are presented and were estimated by using as an indicator the average value of 2.5 kg CO_2eq that was retrieved from the literature [62,63]. This approach assisted the estimation of the amount of GHG that was produced from hotel's food waste generation (Fig. 4). The estimated emissions are 3.31 kg CO_2 eq/per guest night.

Sampling was performed during low touristic season coincided with an average occupancy rate of 60 %, with no significant events held in the hotel, so it can be considered that the results show the usual situation regarding food waste generation in the hotel. The values are expected to increase significantly during the summer season given the fact that the number of overnight stays in the period May - October is two and three times higher than those of the sampling period.

3.5. *Total CO_2eq emissions of the hotel*

The total CO_2eq emissions of the hotel were calculated by aggregating emissions from energy consumption, propane gas consumption used in the kitchen, waste management and food waste. The results that are demonstrated in Table 7 show that energy consumption remains the highest contributor, followed by waste and food waste generation, with

Table 6
Emissions from hotels' food waste.

Source	Average value (kg)/ guest night	kg CO_2 eq/per guest night
Meal preparation waste (kg)/ guest night	0.34	0.71
Plate waste (kg)/ guest night	1.24	2.60
Total food waste generation (kg)/ guest night	1.57	3.31

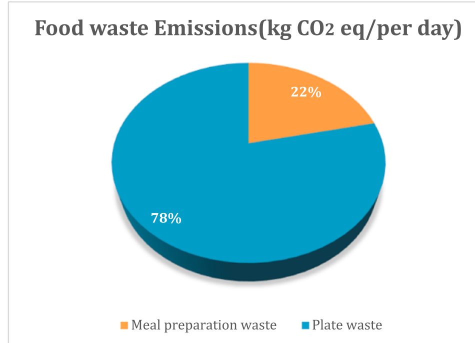

Fig. 4. Hotel's food waste CO_2 emissions.

Table 7
Emissions of hotel's different domains.

Domain	Energy consumption	PG kitchen consumption	Waste management	Food waste	Total
Emissions (kg CO_2 eq/ guest night)	30.34	1.20	1.71	3.95	37.19

the propane gas consumption in the kitchen being the factor with the lowest contribution. The total emissions of the pilot hotel account for 37.19 kg CO_2 eq/ guest night and are referring to the hotel's operational footprint. The results are slightly higher than the average value of 29 kgCO_2eq /guest-night for luxury hotels which is reported in the literature [16], and from similar Greek or Mediterranean resorts such as 27 kg CO2-eq/guest night in Chalkidiki in Greece, 28 kg CO_2e/ guest night in Crete and 23 kg CO_2e /guest night in Spain [17,35,81]. In contrast, much higher values (up to 749 kg CO_2eq/tourist/day) cited in some studies include emissions related to transportation which can account for the largest of the total carbon footprint (up to 94 %) [9].

In terms of the contribution of each sector to the total emissions, as shown in Fig. 5, energy consumption accounts for the largest percentage of CO_2eq emissions per visitor night, contributing 81 % of the total. This is followed by emissions from waste and food waste, accounting for 5 % and 11 % respectively, with PG kitchen operations producing the smallest percentage of emissions (3 %).

Although waste-related CO_2 emissions account for a smaller percentage of the overall emissions, this research aims to emphasize the importance of the food waste and waste management sectors, since they are critical factors for reducing carbon emissions. This could be attributed to the fact that sustainable waste management strategies are often easier and less costly to implement than energy efficiency improvements. Specifically, food waste management strategies are inexpensive, easily implemented in the hospitality sector and one of the most cost-

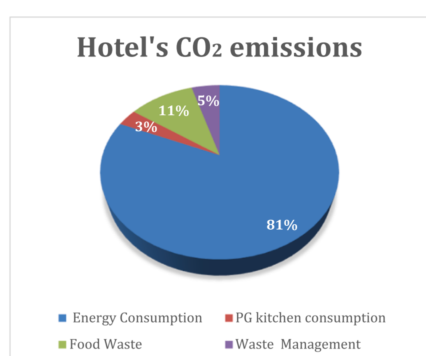

Fig. 5. Hotel's CO_2eq emissions.

effective ways to address climate change [14,82]. Hotel employees who are trained on the serious impact of food waste in the hospitality industry are more likely to engage in food waste minimization and encourage customers to follow sustainable practices [14].

3.5.1. Sensitivity analysis

The sensitivity analysis indicates that varying key emission factors by ±20 % produces only modest changes in total CO_2-equivalent emissions, with the impact unevenly distributed across sources (Fig. 6). The emission factor for natural gas (energy use) exhibits the strongest influence since this factor causes approximately $a \pm 1.25$-unit shift in total CO_2eq emissions. By contrast, the same variation in the food waste emission factor changes total emissions by only 0.40 CO_2eq units, and variations in the landfill and kitchen propane gas factors yield even smaller shifts (0.20 and 0.15 CO_2eq respectively). Collectively, these uncertainties propagate to a total output variability of ±1.33 (in CO_2eq units) on a baseline of 17.48 (emissions depended on emission factors), i.e. roughly a 7–8 % potential deviation (Table 8), and on a baseline of total emissions 37.19 a 3.57 % potential deviation. Natural gas-related emissions clearly dominate the uncertainty in the overall carbon footprint, implying that the reliability of total emissions estimates is most contingent on the accuracy of that emission factor. In contrast, uncertainties in waste-related emission factors have comparatively minor effects [83]. Targeted improvements in the most influential factor (energy emission factor) would significantly enhance confidence in the inventory's results.

The EF-only Monte Carlo (natural gas, LPG, landfilling, recycling, food-waste) yields an uncertainty of 3.6 % with 1.33 % being attributed on an EF-dependent subtotal of 17.48 kg CO_2e/ guest-night and with a total baseline of 37.19 kg CO_2e/ guest-night). To address occupancy and seasonal energy fluctuations, we added an activity-data layer, as described in the latter part of the Methods section. The annual energy intensity exhibits a 95 % interval of 129.3 - 150.5 kWh/guest-night (−7.0 % to +8.2 % around the mean of 139 kWh/ guest-night). This translates to 28.23 - 32.85 kg CO_2e/guest-night for the energy component (baseline 30.34), and 35.08 - 39.70 kg CO_2e/ guest-night in total (baseline 37.19), i.e., −5.7 % to +6.8 % from occupancy/seasonality alone. When combined with the emission factor uncertainty (assumed independent), the overall band is 6.7 - 7.5 % around the central estimate. Domain contributions remain effectively unchanged, with energy being 81 %, food waste 11 %, mixed waste 5 %, and LPG 3 %.

3.6. Proposed scenarios

The scenarios studied in the paper and are recommended for reducing the hotel's footprint by reducing energy consumption and adopting a sustainable food waste management system have produced the results described below.

Table 8
Emission factors deviations.

Domain	Emission factor	Emissions (kgCO_2eq/ guest night)	STD (±)
Energy consumption	Natural Gas (NG)	11.26	1.25
PG kitchen consumption	Propane Gas (PG)	1.20	0.15
Waste management emissions	Landfill (LG)	1.70	0.20
Waste management emissions	Recycling	0.00067	0.00008
Food waste	Food waste	3.33	0.40

3.6.1. Results from scenario 1: integration of renewable energy sources (RES) in hotel's electricity consumption

Scenario 1 suggests the use of solar energy as main energy source with the aim to decrease GHG emissions. The result is a reduction of CO_2eq emissions by 71.3 %. Specifically, in the base case 1192 t CO_2eq GHG emissions are produced, while in the proposed case a decrease was observed to 342.3 t of CO_2, resulting in a gross annual reduction of 850 t of CO_2. This reduction accounts for 36.36 % of total emissions.

The total annual cost for the proposed scenario was estimated by RETScreen. It corresponds to the annual costs related to the operation, maintenance, and financing of the project and is basically the sum of the savings or operating and maintenance costs, the fuel costs for the proposed case and the debt payments. The total annual cost includes the repayment of the "capital" of the debt and in the proposed case, it was estimated by the software that the initial cost amounts to 2581081 €.

The proposed system has a remuneration time of 3.8 years and an overall lower net present value of 13.7 million €. The net present value (NPV) of the scenario and the amortisation period are presented and are available in the supplementary material (S04). Although the initial investment cost for photovoltaic (PV) systems is significant, it is gradually offset by reductions in electricity purchases. In addition, these installations generally require minimal maintenance with annual costs ranging between 1–2 % of the initial capital [84].

In Mediterranean countries, renewable energy penetration levels exceeding 50 % are technically feasible, with studies reporting that hotel profits can increase by up to 31.4 % and reduce its GHG emissions [85]. A real-world implementation is a resort hotel in Thessaloniki, where a 1 MW photovoltaic park comprising 1738 solar collectors was installed at an investment cost of €1.4 million and is expected to reduce the hotel's

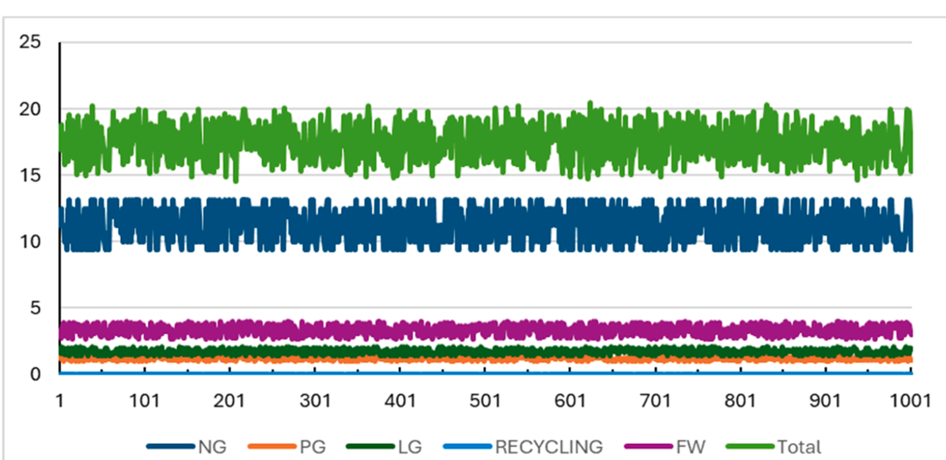

Fig. 6. Emission factor (EF-only) abased Monte Carlo sensitivity analysis.

annual CO_2 emissions by 528 tons, improving its environmental footprint by approximately 25 %. Vourdoubas et al. [86], similarly emphasized that the adoption of solar energy technologies in hotels operating during the summer throughout the Mediterranean can fully cover their energy needs while remaining technically viable, economically beneficial, and environmentally sustainable. Their study, which modeled a 3000 m^2 hotel in Crete, demonstrated that the integration of photovoltaic and thermal systems could meet all annual energy requirements, at a capital cost of €95.7/m^2. The innovation of the present study lies in the use of a PV park for the electrification of an energy-intense facility that can be considered "hard-to-abate", since there is extensive utilization of fossil fuels for heating and cooling. "Hard-to-abate" industries happen to be in the forefront of the green energy transition efforts and are included in the national plan for energy and climate. In addition, the design of the PV park ensures that the produced electricity is utilized onsite and does not take advantage of net metering schemes that would overload the grid.

3.6.2. Results from scenario 2: composting as an alternative to landfilling for food waste management

Scenario 2 proposes the use of composting instead of landfilling as a food waste management method which would decrease the GHG emissions from 1.83 kg CO_2eq per guest night to 0.15 kg CO_2eq per guest night. On a larger scale, considering an annual total of 62,411 guest nights, this change would result in a substantial reduction in emissions from 114 t CO_2eq to 9.3 t CO_2 eq. This corresponds to a decrease of nearly 92 %, which reduces the total emissions by 13.8 %. In this scenario, the feasibility of on-site composting should be discussed, and infrastructure costs and logistical challenges should be considered. Also, it should be highlighted that the new National Legislation (Greek Law 4819/2021) is pushing hotels towards that direction, separate collection and if possible on-site treatment [87]. For the hospitality sector an in-vessel composting unit could help overcome several logistical challenges and it is the most suitable solution, since it combines space efficiency, odor and insects' control, temperature regulation, it is easy to operate, and it is more efficient in processing several waste streams [88]. Since odor control is essential in environments like hotels, and although in-vessel systems are more effective at retaining odors than open composting, to secure that the use of bulking agents is proposed (e.g., biochar, straw) and microbial inoculants to further improve process stability and reduce odor [89]. Additionally, to secure the minimization of methane generation, proper system management is required, including active aeration, moisture control, and frequent turning [90]. In addition, separation at source is needed, which would require training of the hotel staff and obtaining specific bins. Finally, this option is in line with the EU Landfill Directive (99/31/EC), which imposes restrictions on the landfilling of organic waste and requires a reduction in the amount of organic waste going to landfill, thereby promoting the identification of alternative ways of managing organic waste, such as composting [91].

3.6.3. Results from scenario 3: increase recycling in waste management

Scenario 3 proposes an increase in the percentage of the waste generated in the hotel and being recycled, in which, among others, contributes to avoiding the depletion of natural resources. The fraction of recyclable waste can be increased by 20 % after training the hotel staff and standardize the waste collecting, sorting and recycling process. The implementation of this scenario will result to a waste composition of 28.21 % recyclable waste and 71.79 % mixed municipal waste.

In the case described above the introduction of new data, on total waste and recyclable waste, into the equation leads to a reduction of the CO_2 emissions due to waste management. The emissions are reduced to 1.38 kg CO_2eq/ guest night comparing to 1.71 kg CO_2eq/ guest night, which is calculated in the current state, which equals to a 19.3 % reduction of the emissions derived from waste management and a reduction of 0.97 % on total emissions.

Although reduction and reuse are the most preferred from the 3Rs on the waste management hierarchy model, the increase in recycling was chosen as the third scenario because of the hotel's existing recycling infrastructure (separate bins) and practices. In addition, Greek law 4819/2021 orders higher recycling performance in hotels, specifically those with >100 beds, by requiring separate collection of packaging waste from each guest room [87]. This scenario could be easier to achieve with minimal staff training and minor changes to existing equipment, since it is already implemented. In a luxury hotel, such as the one in the pilot study both reduction and reuse are a challenge due to the importance given to provide comfort and luxury services to visitors. Therefore, the study focuses on the overall recycling performance and how is affecting the CO_2 emissions of the hotel operation with regard to the practices that can be supported with / by the local (municipality or regional) infrastructure.

The results which occur by applying each of the Scenarios for the reduction of GHG emissions described above separately and the case of combining all of them at the same time, are summarized in Table 9. Overall, the application of RES in the energy mix, which is consumed in the hotel, results in a 36.36 % reduction on the total GHG emissions. The diversion of food waste from landfill results in a decrease of 13.8 % in the total emissions and the increase of recycling in the waste management practice of the hotel can result in a decrease of 0.97 % of the total emissions per guest night. This outcome reflects a conservative scenario aligned with current infrastructure and hotel operational constraints.

It can be concluded that by applying different scenarios including sustainable practices, individually or combined, it could lead to a noticeable reduction (47.45 %) in the total emissions of the hotel (Table 9). This value may represent a target that is not easy to achieve, but it should be considered that it corresponds to the simultaneous implementation of the three different scenarios recommended in this study. The interactions between the combined scenarios are not being presented in this study as that was not in the proposed methodology. The overall reduction of 47.45 % should be interpreted as an indicative upper limit and in line with recent studies that have shown [92,93] integrated approaches such as energy hubs or hybrid RES systems (HRESs) could lead to important synergies.

Additionally, both the financial barriers and the operational implications should be considered at policy level. For example, regional funding for CO_2 reduction in hotels could be supported by subsidies, that in these cases can go up to 60–80 % in specific regions in EU.

Future research could focus on calculating and comparing carbon footprint across different hotel categories and regions. Emphasis should be given in collecting and analysing data from luxury or all- inclusive hotels in popular Greek insular touristic destinations such as Corfu, Crete, Kos and Rhodes but also from different hotel categories such as budget hotels or one-and two-star hotels (as long as they serve at least breakfast to avoid bias in the estimation of the total footprint) to provide the results of cross-category comparison. Seasonal data, which would integrate temporal variations, could be collected and correlated to waste generation and water and energy consumption of the whole region, which could contribute to more precise quantification of the impact and provide the policymakers and hotel owners with valuable tools. Specific focus should be given on retrieving food waste data and their current waste management practices, an understudied area with significant research gaps, proposing a standardized measuring and quantification

Table 9
Performance of alternative scenarios.

	Total Emissions (kg CO_2 eq/ guest night)
Current state	30.34
Scenario 1	19.30 (−36.36 %)
Scenario 2	26.16 (−13.8 %)
Scenario 3	30.01 (−0.97 %)
Scenario 1&2&3	15.95 (−47.45 %)

method to achieve data consistency and calculating this domain carbon footprint as well as proposing sustainable practices for its reduction. It is important to implement scenarios with combined strategies in the field of waste management, such as waste prevention combined with recycling, in order to emphasize the importance of the 3Rs hierarchy. Future research should also expand carbon footprint boundaries to incorporate supply chain Scope 3 emissions, (cradle-to-gate) emissions of purchased goods and services, by using Life Cycle Assessment (LCA), which would strengthen the generalizability of the findings and offer a more comprehensive view of decarbonization strategies for tourism (Farm to Fork EU strategy). Additionally, a cost-benefit analysis should be conducted for each proposed scenario to assess economic feasibility. Touristic areas face a series of environmental issues and challenges as well as significant pressures due to tourism activity which result in seasonal variation in waste generation. It is observed quite often in these areas inadequate waste management and a lack of initiatives for the implementation of modern and alternative methods within the framework of the circular economy.

4. Conclusions

This paper presents a methodology for calculating the carbon footprint of a hotel by considering four main domains: energy consumption, propane gas use in the kitchen, hotel waste and food waste. The integration of produced waste and particularly food waste as a factor affecting carbon footprint in hotel operation is considered significant as it reflects an important dimension that needs to be considered under the European Green Deal. In addition, three different scenarios are presented which could contribute to sustainable energy and waste management and reduction of the hotel carbon footprint.

With energy consumption being the main domain contributing up to 81 % of the hotel's GHG, it is evident that reduction measures should be prioritized. A straightforward suggestion is to include RES and especially solar panels to cover the hotel's energy requirements. This action could lead to 71.3 % reduction in hotel's emissions that derive from electricity consumption, and with a relatively small payback time. The utilization of propane gas for meal preparation could be already considered a practice which contributes to a lower footprint due to lower GHG emissions compared to other alternatives.

As presented in this paper, food waste generation and waste management practices have an impact in emissions of the hospitality sector, each responsible for 11 % and 5 % respectively in pilot's hotel total emissions. By diverting food waste from landfill through composting, the related emissions may be reduced by nearly 92 %, highlighting the importance of the adoption of circular economy practices in the kitchen during meal preparation and serving by the hotel management and staff. In addition, recycling practices have a positive impact on reducing pressure to resources and align with SDG 12 for responsible consumption and production. It is therefore important for these challenges to be addressed and for specific measures towards sustainable tourism to be taken.

Resort hotels, known for their high energy consumption and often classified as challenging to decarbonize, can play a leading role in the transition towards green energy practices and have been included in the Greek national energy and climate strategy document as possible good examples. Due to their high carbon footprint, it is important to adopt sustainable practices and decrease their related emissions. This effort should include implementation of practices regarding the hotel's operational parameters, as well as the use of 3Rs principles and educating staff in the necessity of implementing these practices and engaging guests to adopt a more sustainable approach. Greek hotels are already adopting sustainable practices. Using objective and widely accepted methods and tools to measure their carbon footprint can be considered as a significant step to understand the source and the significance of their emissions. Following an evidence-based approach, policymakers can plan and introduce policies and regulations to reduce hotels' - and to a wider dimension - tourism carbon footprint. In addition, engaging and familiarizing stakeholders and particularly hotel managers, employees, and guests with the 3Rs principle and their implementation, is essential for shifting towards more sustainable practices and achieve the desired reduction of hotels' emissions related to all contributing factors including waste management. This factor should be considered especially in resort hotels where food waste generation is significant - related to the variety of catering services and the requirements of tour operators; this dimension has already been considered in EU and national legislation for accommodation units with >100 beds that are required to separate food waste.

Therefore, the implementation of environmental performance standards, measuring tools and methods for evaluating the performance of hotels - and the entire tourism activity - with regard to GHG emissions in hotels would be essential in achieving this objective.

In conclusion, more efficient strategies and policies could help in reducing the emissions in the Greek hospitality sector. These could include government subsidies or grants provided under the European Green Deal or the InvestEU Fund for sustainable infrastructure in hotels, specifically for installing on-site composting systems or collaborating with local composting facilities, monitoring and collecting food waste measurements and adopting renewable energy technologies. In addition, measures such as tax incentives for using compost in hotels gardens, and enforceable regulations implying requirements on organic waste composting in the hospitality sector could serve as economic drivers promoting composting over waste disposal. Awarding eco-labels or certificates to hotels that reduce effectively food waste through proper management and composting could be another strategy which would enhance their appeal to environmentally conscious guests. These policies align with the EU's Farm to Fork strategy about reducing food loss and waste. Finally, the key is to prioritize domains that involve both hotel employees and guests, such as waste and food waste management, which with the right cooperation and education, sustainable practices could be employed successfully.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used DeepL Write and DeepL Translate in order to translate from Greek to English and correct the syntax. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

CRediT authorship contribution statement

Athanasia Orfanou: Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Eleftheria Klontza:** Writing – review & editing, Supervision, Project administration, Investigation, Conceptualization. **Stergios Vakalis:** Writing – review & editing, Supervision, Conceptualization. **Irene Voukkali:** Writing – review & editing, Methodology, Data curation. **Antonis A. Zorpas:** Writing – review & editing, Supervision, Conceptualization. **Demetris F. Lekkas:** Writing – review & editing, Validation, Supervision, Project administration, Conceptualization.

Declaration of competing interest

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

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.nexus.2025.100615.

Data availability

The data that has been used is confidential.

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