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Energy Consumption and Carbon Emissions in Three Small-Size Hotels in The Island of Crete, Greece. Achieving Net-Zero Carbon Emissions

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ABSTRACT: Hotels utilize large amounts of energy for meeting their energy requirements. They mainly use conventional energy sources while the use of zero-carbon energies is rather limited. The necessity to mitigate climate change and the efforts to achieve net-zero carbon economies in the next decades require the clean energy transition in hotel industry. An energy analysis of three small-size hotels located in the island of Crete, Greece has been realized combined with evaluation of their carbon emissions. It has been found that all of them use several benign energy technologies such as solar thermal, solar photovoltaic, solid biomass burning and high efficiency heat pumps. One hotel has negative carbon emissions, one zero-carbon emissions while the third has substantially reduced its carbon emissions and it could zero them with the use of solar energy technologies. Our work indicates that the achievement of net-zero carbon emission small-size hotels, due to energy use, in Crete is technically feasible, economically viable while the current legal framework allows the use of clean energy technologies in them. It is useful since it indicates that the clean energy transition in small-size hotels in Crete is easily achievable and it should be promoted. Their clean energy transition improves the environmental sustainability of the local hotel industry and it helps in the achievement of the national and EU target for net-zero emission societies by 2050.

KEYWORDS: carbon emissions, Crete-Greece, energy, hotels, net-zero, renewable energies

1. INTRODUCTION

Hotel buildings are large energy consumers compared with other commercial buildings [1], [2]. They mainly utilize fossil fuels while the use of renewable energies in them is limited so far [3], [4], [5], [6]. However, mitigation of climate change requires the reduction of energy consumption and carbon emissions in their premises [7], [8], [9], [10], [11]. Solar energy is abundant in Crete, Greece while the technologies of solar thermal energy for hot water production and of solar photovoltaic (solar-PV) energy for electricity generation are mature, reliable and cost-efficient. Additionally, the use of high efficiency heat pumps for heat and cooling generation is broadly used in several buildings including hotel buildings.

The aim of the current work is to investigate the use of several benign energy technologies in small-size hotels located in the island of Crete, Greece which can reduce of completely eliminate their net-carbon emissions due to energy use.

The text is structured as follows: After the literature survey the energy use and the carbon emissions in hotels are mentioned. Next, the use of several renewable energies and low carbon energy technologies in hotels are stated as well as the use of energy saving measures in them. After that the requirements for achieving net-zero carbon emission hotels are mentioned followed by energy analysis and estimation of carbon emissions in three small-size hotels located in Crete, Greece. The text ends with discussion of the findings, the conclusions drawn and the citation of the references used.

The text is innovative since there are not many published studies related with the energy consumption and carbon emissions of small-size hotels in Crete while it covers an existing gap regarding the development of net-zero emission hotels in Crete. It could be useful to hotel owners, to policy makers who promote the transition to low-carbon economy, to several stakeholders of the tourism industry in the island and to energy companies which design and construct benign energy systems.

2. LITERATURE SURVEY

The energy consumption and the use of renewable energies in hotels in Crete, Greece have been examined [1]. The author studied the energy behavior of five summer operating hotels in Crete stating that their average annual energy consumption was at 149 kWh/m^2 and 19.4 kWh/p.n.s. while their average annual CO_2 emissions due to energy use were 12.1 kgCO_2/p.n.s. The application of renewable energies in Mediterranean hotels focused on Balearic Islands' hotels has been explored [2]. The authors stated that the average annual energy consumption in the Balearic hotels is 150 kWh/m^2 at season hotels operating six months per year and 250 kWh/m^2 at the rest operating all over the year. They also mentioned that solar thermal systems used for domestic hot water production can reduce significantly the use of fossil fuels in seasonal hotels. The use of renewable energies in hotels has been reviewed [3]. The authors stated that renewable energies

play an important role in the concept of green hotels. They also mentioned that there are external barriers such as consumer attitudes, legislation etc. and internal barriers such as lack of knowledge, finance etc. hindering the adoption of renewable energies in hotel industry. The adoption of renewable energies in Portuguese hotels has been studied [4]. The authors stated that despite of positive perceptions of renewable energies by hotel owners and managers their adoption in hotels is low. They also mentioned that market factors have a statistically significant influence on their adoption. The evolution of energy research in hospitality industry has been investigated [5]. The authors stated that interdisciplinary research combining natural science and social science is essential for advancing the field of hotel energy consumption. The role of renewable energies in the development of the tourism sector focusing in Egypt, Kenya and Ethiopia has been examined [6]. The author stated that there is a positive and significant relationship between the tourists visiting Egypt and the consumption of renewable energy in the country. On the contrary, similar relation in Kenya and Ethiopia was not observed. The transformation of existing hotels to net-zero carbon enterprises has been analyzed [7]. The authors prioritized the reduction of operational energy to achieve net-zero carbon hotels. They also proposed the balancing of the operational cost savings with the cost of interventions. The achievement of net-zero emissions in the global tourism industry has been studied [8]. The author was focused on several issues for achieving net-zero emission hotels such as: a) the role of natural capital solutions and offsetting, b) the technological solutions, and c) the relationship between the net-zero transition, growth and sustainability. The decarburization of hotels has been analyzed [9]. It is stated that energy costs correspond at 3-6% of hotel budgets and create around 60% of their carbon footprint while embodied emissions account for 30-70% of their entire lifecycle carbon footprint. It is also mentioned that hotels account at around 1% in the global CO_2 emissions. According to their estimations the annual carbon efficiency in hotels is in the range 60-70 $kgCO_2/m^2$. It is also mentioned that achieving net-zero carbon hotels requires a holistic approach. The feasibility of achieving net-zero carbon hotels in Mediterranean region has been examined [10]. The author stated that solar thermal energy, solar-PV energy and high efficiency heat pumps can have combined zero the net carbon emissions in hotels. Additionally, he mentioned, solid biomass can be used for meeting their heating needs. A net-zero carbon methodology for hotels has been developed [11]. It is stated that several different initiatives have been proposed so far to support the achievement of the net-zero carbon target in hotels. The proposed methodology provides specific guidance in hotels to eliminate their carbon emissions achieving the net-zero carbon target. The adoption of renewable energy technologies by hotels in Malawi has been examined [12]. The authors stated that the adoption of renewable energies in hotels addresses environmental challenges and reduces their energy cost. They mentioned that hotels do not adopt sustainable energy technologies due to lack of technological awareness by hotel managers. The use of renewable energies in hotels has been studied [13]. The authors examined the use of five types of renewable energies in them including solar thermal, solar passive, solar-PV, biomass and geothermal energy in five EU regions including East Attica, Sicily, Alpes-Maritimes, Andalusia and Madeira. They stated that hotels were more interested in solar thermal, solar-PV and geothermal energy. The development of sustainable energies in five star hotels in Egypt has been explored [14]. The authors stated that five-star hotels are required to continuously adopt energy saving strategies in an integrated manner to achieve their optimum performance. An analysis on energy use by European hotels has been realized [15]. The analysis indicated that the average energy use by hotels was in the range 305-330 kWh/m^2 year. It was also mentioned that the annual CO_2 release was in the range of 160-200 $kgCO_2/m^2$. The nexus between tourism and renewable energies in Crete, Greece has been analyzed [16]. The author stated that solar energy is the most widely used benign energy source in Cretan hotel industry. Additionally, he mentioned, heat pumps are also used extensively for air-conditioning. The concept of nearly-zero energy hotels has been studied [17]. The authors explored the definition of nearly-zero energy hotels in large complex buildings. They stated that it is important to demonstrate to hoteliers that achieving a nearly-zero energy hotel is cost-effective. They also mentioned that some EU countries have already developed definitions for nearly-zero energy hotels. The stakeholders' perceptions of the possible energy sustainability solutions in hotels in Canary Islands questioning thirty-one experts in the field has been investigated [18]. The authors stated that the priority for energy transition in hotels in Canary Islands includes self-consumption using renewable energies together with storage systems. A study regarding the factors affecting the use of renewable energies in the hotel industry has been published [19]. The report stated that hotel facilities are the most energy consuming in the tertiary building sector. It is also mentioned that many EU hotels have substantially reduced their energy consumption becoming partly or completely independent from conventional energy sources. The technical and economic feasibility of developing net-carbon emission hotels has been explored [20]. The author stated that there are many methods and sustainable energy technologies which can be used combined in hotels reducing or eliminating their carbon footprint. These clean energy technologies are reliable, mature and cost-effective while they can be easily used in the hotel sector. The carbon emissions in the tourism industry in Crete have been evaluated [21]. The author stated that the tourism-related carbon intensity in Crete is similar to the carbon intensity of other popular tourism destinations. He

also mentioned that the carbon emissions related with transport of tourists to and from Crete had the highest share in their total emissions. A report related to sustainable tourism in Greece has been published [22]. The report proposed 21 recommendations and 4 key areas including: a) diversification of the tourism product, b) collaboration and dissemination of good practices, c) alignment of tourism strategy with net-positive tourism, and d) monitoring and evaluation of Greece's pathway to net-positive tourism. The development of sustainable tourism using renewable energies in Mediterranean islands has been explored [23]. The authors stated that energy and water sufficiency are important in Mediterranean islands. They mentioned that the strategies related to renewable energy technologies' implementation in these islands are classified into four groups including institutional, process, competence and technology. The use of renewable energies as a tool to achieve tourism sustainability in Mediterranean islands which are vulnerable to climate change has been examined [24]. The author stated that apart from solar-PV systems additional energy technologies using renewable energies can be used in tourism facilities. She also mentioned that the use of renewable energies in tourism enterprises promotes the mitigation of climate change which consists a major global environmental problem. A report related to low carbon travel and tourism sector has been published [25]. The report stated that travel and tourism including aviation are responsible for about 5% of the global greenhouse gas emissions. Several measures mitigating carbon emissions in the transport and hotel sectors were mentioned. The carbon emissions generated by energy use in hotels in Taiwan have been estimated [26]. The authors studied the CO_2 emissions in different categories of hotels evaluating them in the range of 6.3-28.9 $kgCO_2$/p.n.s. They stated that hotels of higher categories (4 and 5 stars) emit more CO_2 per guest-night compared to lower hotel categories. The energy efficiency in tropical coastal hotels and the use of agro-voltaic has been studied [27]. The authors stated that luxury hotels in tropical climate can reduce their carbon footprint by improving their energy efficiency and using clean energy technologies. They evaluated the annual carbon emissions in the range of 4.4-14.5 $tonCO_2$/room. However, they mentioned, the integration of renewable energy technologies in their premises is limited due to lack of space. They proposed the development of agro-voltaic farms in adjacent to hotels areas to meet their power requirements reducing their environmental impacts. The adoption of renewable energy renovations in the Portuguese rural tourism enterprises has been examined [28]. The author stated that there is a substantial gap between the positive perception of renewable energies and the adoption of renewable energy technologies among agro-tourism enterprises. He also mentioned that the reasons for that were the unfavorable market factors as well as regulatory, legal and institutional problems. The reduction of carbon emissions during the green transformation of traditional hotel design in China has been evaluated [29]. The authors stated that: a) the construction process is the stage with the most carbon emissions, b) high star hotels have larger emissions than low star hotels, and c) hotel emissions vary greatly among different provinces. They estimated that the operational annual carbon emissions are in the range of 59.67-137.12 $kgCO_2/m^2$. The factors affecting carbon emissions in hotels in the island of Mauritius have been analyzed [30]. The authors assessed the use of land, the energy consumption and emissions, the refrigerant use, the water consumption and the wastes production as major contributors in greenhouse gas (GHG) emissions. They stated that the carbon footprint in 4-star and 5-star hotels in Mauritius island was lower than the average carbon footprint in similar hotels' categories worldwide. The carbon footprint of tourists accommodated in several hotels located in the prefecture of Attica, Greece has been evaluated [31]. The authors demonstrated the importance of hotel location on the carbon footprint of tourists. Their results indicated that hotels located in the suburbs of Athens, Greece had up to five times higher carbon footprint per guest-night compared to hotels located in the city center. The carbon emissions and the energy efficiency in hotels in China have been explored [32]. The authors stated that the implementation of energy saving technologies can enhance the carbon efficiency in hotels. They also mentioned that while direct carbon emissions from hotels are increasing their indirect emissions are decreasing. The reduction of GHG emissions from the hotel sector in Greece, Cyprus, Germany and the EU has been reported [33]. The report provides an overview of the basic principles of energy management and describes how it can be implemented effectively by the hospitality sector in order to promote energy savings and reduction of GHG emissions. The carbon footprint in different categories of French hotels has been reported [34]. The carbon emissions in several hotels in various countries are presented in table 1.

Table 1. Carbon emissions in several hotels

Source, year	Country/region	Carbon emissions
Vourdoubas, 2016 [1]	Crete, Greece	12.1 $kgCO_2$/p.n.s.
Tsai et al, 2014 [26]	Taiwan	6.3-28.9 $kgCO_2$/p.n.s.
Report, 2011 [15]	Worldwide	160-200 $kgCO_2/m^2$ year
Report, 2024 [9]	Worldwide	60-70 $kgCO_2/m^2$ year
Hotel footprint per night spent [34]	France	4.73-17.11 kg of CO_2/p.n.s.
Qiu et al, 2022 [29]	China	59.67-137.12 $kgCO_2/m^2$ year
Arriola et al, 2025 [27]	Tropical coastal hotels	4.4-14.5 $tonCO_2$/room year

Source: several authors

3. ENERGY USE AND CARBON EMISSIONS IN HOTELS

As tourism continues to be a significant economic driver, the environmental impact of hospitality establishments, particularly hotels, has come under scrutiny. Energy consumption and carbon emissions are central concerns, prompting many hotels in Crete to adopt sustainable practices and invest in renewable energy sources. Hotels in Crete exhibit varying energy consumption patterns, influenced by factors such as size, operational duration, and implemented technologies. A study analyzing five summer-operating hotels in Crete estimated an average annual energy consumption of 149 kWh/m² and 19.4 kWh/p.n.s. [1]. The influence of regional factors such as climate, building design, and energy infrastructure is essential on hotel energy use. Carbon emissions from hotel operations are closely tied to energy consumption and the carbon intensity of the energy mix. According to existing studies in Crete [1], the average CO_2 emissions in hotels are estimated at 12.1 kg CO_2/p.n.s.

4. THE USE OF RENEWABLE ENERGIES AND LOW CARBON ENERGY TECHNOLOGIES IN HOTELS IN CRETE

As the global community grapples with the consequences of climate change, industries across the board are being urged to reduce their environmental footprint. The hospitality sector, and hotels in particular, face increasing pressure to adopt sustainable practices due to their intensive energy consumption and high carbon emissions. In response, the integration of renewable energy sources into hotel operations is gaining momentum worldwide. This shift not only supports environmental stewardship but also delivers long-term economic and reputational benefits. Hotels are among the most energy-demanding commercial buildings, consuming large amounts of electricity and thermal energy for lighting, heating, air conditioning, water heating, and laundry services. Renewable energies offer a viable solution. By leveraging solar, wind, geothermal, and biomass energy, hotels can reduce their dependence on conventional energy sources and significantly lower greenhouse gas emissions.

4.1 Types of Renewable Energy Use in Hotels

Solar Energy: The most commonly adopted renewable source in hotels is solar energy. Solar thermal systems are frequently used to provide hot water, particularly in sunny regions. For example, hotels in Mediterranean countries like Greece and Spain use solar panels to heat water for guest rooms and pools. Solar photovoltaic panels, meanwhile, generate electricity that can power lighting, HVAC systems, and appliances. Many hotels offset a large portion of their electricity consumption this way.

Wind Energy: Although less common due to space and zoning restrictions, some hotels utilize small-scale wind turbines. These are especially viable in coastal or remote locations with consistent wind patterns. In areas with sufficient wind resources, such as northern Europe or island nations, wind turbines can provide a meaningful share of a hotel's electricity needs.

Geothermal Energy: Hotels in regions with geothermal activity, like Iceland, the western United States, and parts of Italy and Turkey, can use this source for heating and even cooling. Geothermal heat pumps are highly efficient and can reduce both energy costs and emissions substantially over time.

Biomass and Bioenergy: Some rural and eco-resort hotels adopt biomass boilers to meet heating needs using organic waste or wood pellets. This not only makes use of local resources but also closes the loop on organic waste disposal.

In recent years, hotels in Crete have increasingly adopted advanced energy technologies to improve efficiency and reduce environmental impact. Among these innovations, heat pumps and power storage systems play a growing role in transforming how energy is used and managed.

Heat pumps are becoming popular in Cretan hotels due to their ability to provide both heating and cooling using significantly less energy than conventional systems. By transferring heat from the air or ground, they efficiently maintain indoor comfort with minimal electricity consumption. Many hotels use air-source heat pumps for space heating and water heating, especially during the cooler months. These systems are often integrated with building automation to optimize energy use based on occupancy and outdoor temperatures.

Power storage systems, typically involving lithium-ion batteries, are also being introduced to complement solar photovoltaic installations. With Crete's abundant sunshine, hotels can generate renewable electricity during the day and store excess energy for use at night or during peak demand. This reduces reliance on the grid, lowers energy bills, and enhances resilience during power outages.

Together, heat pumps and power storage technologies are helping Cretan hotels transition toward a more sustainable and energy-efficient future, aligning with broader environmental goals and tourism trends.

5. ENERGY-SAVING MEASURES IN HOTELS IN CRETE

Many hotels in Crete are increasingly adopting energy-saving measures that promote sustainability and efficiency. Energy-efficient lighting is another widely adopted measure. Hotels have replaced traditional incandescent bulbs with LED lighting**,** which consumes up to 80% less energy and lasts much longer. In many cases, lighting is controlled by motion sensors and daylight sensors**,** ensuring that lights are only used when necessary, further reducing waste. To optimize

climate control, hotels are increasingly investing in smart heat, ventilation, air-conditioning (HVAC) systems. These systems regulate heating and cooling based on occupancy and external weather conditions, avoiding unnecessary energy use. Some properties also use key card systems that automatically switch off air conditioning and lights when guests leave their rooms. Building insulation and design improvements are also central to energy efficiency. Many hotels have upgraded windows, roofs, and wall insulation to reduce heat loss in winter and minimize cooling needs in summer. The use of double-glazed windows**,** shading systems**,** and natural ventilation techniques helps to maintain indoor comfort without overreliance on mechanical systems. Several larger or eco-conscious hotels are also incorporating building energy management systems (BEMS)**.** These allow hotel operators to monitor, analyze, and control energy use in real time, identifying inefficiencies and optimizing performance across lighting, heating, and ventilation systems. Water-saving technologies indirectly contribute to energy savings as well. Low-flow fixtures**,** water-efficient laundry systems**,** and greywater recycling reduce hot water consumption, thus lowering the energy required to heat water.

6. REQUIREMENTS AND METHODS FOR ACHIEVING NET-ZERO CARBON EMISSION HOTELS DUE TO ENERGY USE

As the urgency to address climate change grows, the hospitality industry is under increasing pressure to reduce its environmental footprint. One of the most ambitious goals for hotels is to achieve net-zero carbon emissions**,** meaning the total greenhouse gases produced are balanced by actions that remove or offset an equivalent amount from the atmosphere. Achieving this goal requires a comprehensive and multi-layered approach, involving changes in design, operations, energy sourcing, and waste management. The first and most fundamental requirement is energy efficiency**.** Hotels must reduce their overall energy demand through high-performance building envelopes, including insulation, double or triple-glazed windows, and air-tight construction. Efficient HVAC systems, LED lighting**,** and smart energy management systems are essential for minimizing unnecessary energy use.

The next critical step is the use of renewable energy sources. Hotels must transition away from fossil fuels and instead use solar photovoltaic panels**,** solar thermal systems**,** geothermal heat pumps, or wind power depending on regional availability. On-site generation combined with battery storage systems ensures reliability and reduces reliance on carbon-intensive electricity grids. To ensure a stable energy supply, especially when using intermittent sources like solar and wind energy, battery storage systems are increasingly used. These systems store excess renewable energy generated during the day for use at night or during peak demand, reducing reliance on the grid. Energy management systems (EMS) and smart controls are also critical. These technologies allow hotels to monitor, control, and optimize energy consumption in real time, adjusting lighting, HVAC, and other systems based on usage patterns, occupancy, and weather forecasts.

Furthermore, grid decarbonization plays a supportive role. By purchasing electricity from certified green energy suppliers or participating in renewable energy purchasing agreements (PPAs)**,** hotels can further reduce the carbon intensity of the electricity they consume. Participation of hotels in energy cooperatives facilitates their decarbonization. Their participation offsets their grid electricity consumption with green electricity generated from the energy cooperatives using renewable energies. Achieving net-zero also often involves carbon offsetting**,** at least in the short term. Hotels may invest in certified offset projects such as reforestation or renewable energy in other regions to balance out unavoidable emissions. Importantly, certification and monitoring systems play a vital role. Ongoing measurement, reporting, and verification of emissions are necessary to ensure transparency and continuous improvement. Achieving net-zero carbon emissions in hotels is a complex but increasingly attainable goal. It requires a combination of energy-efficient design, renewable energy use, smart operations, sustainable procurement, and carbon management. As technology advances and climate regulations tighten, net-zero emission hotels are likely to become the new standard in sustainable tourism. The factors affecting the development of net-zero carbon emission hotels in Crete are presented in table 2.

Table 2. Factors affecting the development of net-zero carbon emission hotels in Crete

Factor	Current status
Legal	The legal framework in Greece allows the use of on-site or off-site solar-PV systems with the net-billing regulations in hotels. It also allows their participation in energy cooperatives or the purchase of zero-carbon electricity from green energy providers.
Technological	The green energy technologies required for the development of net-zero emission hotels are mature, reliable and they are used in many applications in Crete. These technologies include the solar thermal, the solar-PV, the solid biomass burning and the heat pumps.
Economical	The abovementioned technologies are economically viable and they are currently used without subsidies.

Social	The use of green energy technologies is socially accepted by all stakeholders of the tourism industry in the island.
Environmental	The current policies in Greece and in EU regarding the achievement of net-zero emission societies by 2050 favor the development of net-zero emission hotels in Crete

Source: own estimations

7. ENERGY CONSUMPTION AND CARBON EMISSIONS IN A SMALL-SIZE HOTEL LOCATED IN SOUTH-WEST CRETE (HOTEL A)

A grid-connected small-size hotel operating seven months every year with capacity 34 beds located in south-west Crete has planned to minimize their CO_2 emissions due to energy use. Its covered area is 660 m^2. The hotel is new and during 2024 has hosted 617 tourists who stayed 4,320 nights. The energy rating of the hotel is "A" while its building envelope is well insulated with external wall insulation and it has double glazed windows and doors. Solar energy systems generating solar heat and solar electricity have been installed in the hotel. During the operation in 2024 the hotel did not use fossil fuels such as heating oil, diesel oil, Natural gas and LPG. The hotel has installed in its premises several sustainable energy systems including:

a) A Solar-PV system with nominal power at 17 kW_p generating 17 kW_p X 1,550 kWh/kW_p = 21,700 kWh_{el}/year. An additional solar-PV system at 4 kW_p, with potential generation of 6,200 kWh/year is going to be installed in the future. The electricity generated by the additional solar-PV system is going to be used in recharging the batteries of the guests' electric vehicles and meeting the power demand in new electric apparatus. The annual electricity generation by the solar-PV modules at 17 kW_p exceeds the grid electricity consumption in 2024 in the hotel by 2,751 kWh.

b) A solar-thermal system with solar collector area 20 m^2 (14 kW_{th}). The potential solar heat production is estimated at 20 m^2 X 300 kWh_{th}/m^2 = 6,000 kWh_{th}/year.

c) Two heat pumps for space cooling (and heating if needed) which can produce hot water additionally to hot water produced by the solar thermal system.

The abovementioned hotel can be considered as a positive energy hotel since it does not use fossil fuels and produces annually more carbon-free solar electricity than the grid electricity consumed. In the following estimations it has been assumed that all the heat produced by the solar thermal system is consumed within the hotel while the ambient heat used in heat pumps is not included. The characteristics of the hotel are presented in table 3.

Table 3. Energy production and consumption in a small-size hotel located in South-west Crete (2024) (Hotel A)

Number of beds	34
Covered area	660 m^2
Number of tourists	617
Bed-nights	4,320
Energy sources used	Grid electricity, solar energy and ambient heat
Power storage system use	Yes
Grid connection	Yes, with net-billing
Annual grid electricity consumption	18,949 kWh_{el}/year
Potential solar electricity generation by the solar-PV system at 17 kW_p	21,700 kWh_{el}/year
Annual electricity surplus	2,751 kWh
Annual solar thermal energy consumption	6,000 kWh_{th}/year
Total annual heat and electricity consumption [the ambient heat used by the heat pumps is not included]	24,949 kWh/year
Specific energy consumption	37.80 kWh/m^2 year
Specific energy consumption	773.79 kWh/bed year
Specific energy consumption	5.78 kWh/p.n.s.

Source: Own estimations

8. ENERGY CONSUMPTION AND CARBON EMISSIONS IN A SMALL-SIZE HOTEL LOCATED IN NORTH-WEST CRETE (HOTEL B)

A small-size family-owned hotel located in Stalos village located around 7 km west of Chania (in municipality of Chania) operates 7 months annually (10,721 bed-nights in 2023). Its capacity is 52 beds and its covered area 1,000 m^2. The hotel has installed several sustainable energy systems including:

A) A solar-PV system with nominal power at 10 KW_p installed on the terrace of the building. It generates 15,000 KWh_{el} per year,

B) A solar thermal system producing domestic hot water installed on the terrace of the building. The surface of the solar thermal panels is 30 m^2 [12 panels, 2.5 m^2 each]. The total heat power is 21.72 KW_{th}. Diesel oil is additionally used for domestic hot water production,

C) The hotel uses efficient LED bulbs for lighting,

D) A modern energy system is used optimizing the production and distribution of hot water,

E) The hotel has double glazed windows and well insulated walls to reduce thermal losses,

F) LPG is used in the kitchen for cooking with energy efficient apparatus.

It should be noted that the sustainable energy investments in the hotel were partly subsidized by the EU structural funds. The energy consumption and the carbon emissions in the hotel are presented in tables 4 and 5.

Table 4. Energy production and consumption in a small-size hotel located in North-west Crete (2023) (Hotel B)

Capacity	52 beds
Covered area	1,000 m^2
Bed-nights	10,721
Energy sources used	Grid electricity, solar energy, diesel oil, LPG
Use of power storage system	No
Grid connection	Yes, with net-metering
Grid electricity consumption	34,913 kWh
Solar-PV electricity generation	15,000 kWh
Solar thermal energy generation	8,750 kWh
Diesel oil consumption	11,000 kWh
LPG consumption	4,347 kWh
Solar-PV and solar thermal energy production	23,750 kWh
Total energy consumption (includes the produced solar heat and electricity)	74,010 kWh
Solar energy production/total energy consumption	32.09 %
Specific energy consumption	74.01 kWh/m^2 year
Specific energy consumption	1,423.27 kWh/bed year
Specific energy consumption	6.90 kWh/p.n.s.

Source: own estimations

Table 5. Carbon emissions due to energy use in a small-size hotel located in North-west Crete (2023) (Hotel B)

Carbon emissions due to grid electricity use (Carbon emission coefficient = 0.404 $kgCO_2$/kWh)	14,105 $kgCO_2$/year
Carbon emissions due to diesel oil use (Carbon emission coefficient = 0.266 $kgCO_2$/kWh)	2,926 $kgCO_2$/year
Carbon emissions due to LPG use (Carbon emission coefficient = 0.230 $kgCO_2$/kWh)	1,000 $kgCO_2$/year
Total carbon emissions due to energy use	18,031 $kgCO_2$/year
Specific CO_2 emissions	18.03 $kgCO_2/m^2$ year
Specific CO_2 emissions	346.75 $kgCO_2$/bed year
Specific CO_2 emissions	1.68 $kgCO_2$/p.n.s.

Source: own estimations

The hotel uses solar thermal and solar-PV energy meeting 32.09 % of its energy demand while it also uses grid electricity, diesel oil and LPG. The elimination of its carbon emissions can be achieved with:

a) Replacement of the old apparatus and equipment in the kitchen with electric equipment eliminating the use of LPG,
b) Meeting all its heating needs with solar thermal collectors and heat pumps eliminating the use of diesel oil, and
c) Use of on-site or off-site solar-PV systems generating green electricity equal to grid electricity use. Alternatively, with participation in an energy community generating green electricity equal to net grid electricity use. Another alternative for achieving carbon neutrality is the purchasing of green electricity from an external green electricity provider.

9. AN OFF-GRID AGRO-TOURISM FACILITY LOCATED IN SOUTH-WEST CRETE (HOTEL C)

An agro-tourism facility opened up to its guests in the early 90s, after twelve years of exhaustive works of restoration on the remnants of a medieval settlement that was abandoned in the middle of the 20th century. The off-grid agro-tourism facility operates all over the year and promotes a sustainable and long-term eco-friendly traveling model characterized by:

- Self-sufficiency of energy provision through solar panels for electricity and wood for heating & hot water,
- Organic food production in the farms and yards of the property and the nearby area,
- Systematic natural composting of organic material, including the leaves of trees that surround the area,
- Biological treatment of wastewater,
- Natural spring water supply towards the eco-lodge and the farm,
- Natural conditioning and zero electronic devices in the rooms,
- Zero food waste, into the food chain of the property, and
- Natural reforestation of the area by minimizing goat grazing.

The energy consumption in the agro-tourism facility in 2023 is presented in table 6.

Table 6. Energy consumption in an agro-tourism facility located in south-west Crete (excluding the restaurant) (Hotel C)

Number of beds	41
Covered area	450 m^2
Bed-nights	7,420
Energy sources used	Solar-PV, solid biomass
Use of power storage system	Yes
Grid connection	No
Total energy consumption	54,000 kWh/year
Total electricity consumption	6,480 kWh/year
Total heat consumption	47,520 kWh/year
Total carbon emissions	0
Specific energy consumption	120 kWh//m^2 year
Specific energy consumption	1,317.07 kWh/bed year
Specific energy consumption	7.28 kWh/p.n.s.

Source: own estimations

10. DISCUSSION

The energy consumption and the carbon emissions in three small-size hotels located in the island of Crete, Greece have been evaluated. The energy consumption in these three hotels has been evaluated. It was in the range of 5.78 kWh/p.n.s. to 7.28 kWh/p.n.s. which is low compared to the average value reported at 13.6 kWh/p.n.s. The estimated energy consumption in these hotels is lower than the energy consumption reported in other studies for hotels in Crete at 19.4 kWh/p.n.s. [1]. The hotel with specific energy consumption at 5.78 kWh/p.n.s. is a new built hotel with very good thermal insulation which justifies its low energy consumption. The evaluated carbon emissions in the second hotel at 1.68 $kgCO_2$/p.n.s. are significantly lower than the carbon emissions reported in hotels in Crete at 12.1 $kgCO_2$/p.n.s. [1], in Taiwan at 6.3-28.9 $kgCO_2$/p.n.s. [26] and in France at 4.73-17.11 $kgCO_2$/p.n.s. [34]. The characteristics of these hotels are presented in table 7. All of them have installed solar-PV systems for power generation. Two of them, with seasonal operation, are using solar thermal energy for domestic hot water production while the third, which operates all over the year, is using solid biomass for heat production. Using benign energy technologies one hotel has eliminated all its carbon emissions due to energy use while the other has achieved negative carbon emissions. The third hotel has reduced its carbon emissions while it can easily eliminate all of them either with the installation of an additional on-site or off-site solar-PV system or with electricity purchase from a green energy provider. The sustainable energy technologies used in these hotels,

including the solar thermal, the solar-PV, the solid biomass burning and the use of heat pumps are broadly used in Crete nowadays in several applications. The energy analysis in these three hotels indicates that the elimination of their carbon footprint is technically feasible and economically viable. The existing legal framework in Greece allows the reduction or the complete elimination of carbon emissions in hotels. It should be noted that the accuracy of our estimations depends on the accuracy of the energy data used in the three hotels. Future work should be focused on the energy analysis of medium- or large-scale hotels in Crete exploring the possibility of using zero-carbon energy technologies, instead of fossil fuels, for covering their energy needs reducing or completely eliminating their carbon footprint.

Table 7. Characteristics of the three hotels studied

	Hotel A	Hotel B	Hotel C
Number of beds	34	52	41
Operation	Summer period, seven months	Summer period, seven months	All over the year
Energy sources and fuels used	Grid electricity, Solar-PV, solar thermal	Grid electricity, Solar-PV, solar thermal, diesel oil, LPG	Solar-PV, solid biomass
Power storage in batteries	Yes	No	Yes
Grid connection	Yes	Yes	No
Characterization of the hotel	Hotel with negative carbon emissions	Hotel with positive carbon emissions	Hotel with zero carbon emissions
Specific energy consumption	37.80 kWh/m^2 year	74.01 kWh/m^2 year	120 kWh//m^2 year
Specific energy consumption	773.79 kWh/bed year	1,423.27 kWh/bed year	1,317.07 kWh/bed year
Specific energy consumption	5.78 kWh/p.n.s.	6.90 kWh/p.n.s.	7.28 kWh/p.n.s.
Specific carbon emissions	Negative carbon emissions	1.68 kgCO_2/p.n.s.	Zero carbon emissions

Source: own estimations

11. CONCLUSIONS

The use of several benign energy technologies in three small-size hotels located in the island of Crete, Greece which can reduce of completely eliminate their net-carbon emissions due to energy use has been explored. The integration of renewable energies into hotel operations represents a critical step toward sustainability. As the hospitality industry seeks to align with global climate goals and reduce its environmental footprint, renewable energies offer a path that is both environmentally and economically sustainable. The three small-scale hotels have low specific energy consumption while all of them use sustainable energy technologies meeting their energy requirements. The benign energy technologies used in these hotels were: a) solar thermal energy, b) solar-PV energy, c) solid biomass, and d) high efficiency heat pumps. One hotel had negative carbon emissions, one had zero carbon emissions while the third had reduced its carbon emissions and it could easily achieve carbon neutrality using solar energy which is abundant in Crete. Our study indicates that small-size hotels located in the island of Crete, Greece can reduce or totally eliminate their carbon emissions, due to energy use, using local renewable energies and sustainable energy technologies which are mature, reliable and cost-efficient. The legal framework in the country allows the use of these energy technologies in hotels while their use is supported since they contribute in the achievement of the national and EU goal for net-zero carbon emissions by 2050.

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