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Net-zero Carbon Emission Hotels: Are they Technically and Economically Feasible?

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Abstract
Climate change mitigation requires the elimination of carbon emissions in all sectors including the hospitality industry. The purpose of the current study is the identification of the methods and the sustainable energy technologies which can be used in hotels to minimize or zero their net-carbon emissions. Several sustainable and low-carbon energy technologies which can be used in hotels for heat, cooling and electricity generation are described. The possibility of purchasing green energy from external energy providers and energy cooperatives is also mentioned while any remaining carbon emissions can be offset with the existing offsetting mechanisms. Our work indicates that there are many methods and technologies which can be combinedly used in hotels for the elimination of their carbon emissions. These technologies are reliable, mature and cost-effective. Therefore, the achievement of net-zero emission hotels is technically and economically feasible. Our results could be used from the hotel industry, the stakeholders and the policy makers as well as from energy companies which can have an important role in the clean energy transition of hotels.

Keywords: Carbon Emissions, Energy Consumption, Hotels, Net-zero Emissions, Renewable Energies, Sustainability

1. Introduction

Hotel buildings consume large amounts of energy compared with other types of buildings. They mainly consume oil-based fuels and grid electricity for covering their demand in heat, cooling and electricity while the use of renewable energies is rather limited. The current policies for climate change mitigation require the de-carbonization of several sectors including tourism industry. Elimination of carbon emissions in hotels can be achieved with the use of renewable energies and low-carbon emission technologies replacing the use of conventional fuels. Current advances in benign energy technologies have improved their cost-effectiveness and competitiveness allowing their use in hotels (*Kyriaki et al, 2017, Colmenar-Santos et al, 2014, Pardo et al, 2020, Prasetio et al, 2019*) [11, 12, 13, 16]. Nearly-zero energy hotels and net-zero emission hotels can be achieved with the use of low- or zero-carbon emission technologies (*Zeiler et al, 2016, Vourdoubas, 2015*) [2, 17]. Distributed electricity generation technologies are already used in several hotels worldwide (*Tomizawa et al, 2007, Mengpei Chen et al, 2014, Smitt et al, 2021, Vourdoubas, 2021*) [19, 21, 22, 24]. Hotels can also offset their carbon emissions with the existing carbon offsetting schemes (*Tsai, 2020, Waring et al, 2020*) [25, 26].

The aim of the current study is to investigate the existing methods and the benign energy technologies which can be used in hotels in order to reduce or completely eliminate their carbon emissions due to energy use.

The article is structured as follows. After the literature survey, the energy consumption and the carbon emissions in hotels as well as the concept of net-zero emission hotels are analyzed. Next, the energy saving technologies, the renewable energy technologies and the low-carbon emission technologies which can be used in hotels are mentioned. In the following sections the electrification of several hotel sectors, the energy storage, the possibility of purchasing green energy from external energy providers and the possibility of participating in energy communities are discussed. The text ends with the presentation of the carbon offsetting mechanisms, the discussion of the findings, the conclusions drawn and the citation of the references used.
The current study could be useful to hotel owners, to policy makers, to energy companies and to various stakeholders of tourism industry. It covers an existing gap related with the use of several green energy technologies and methods in hotels

necessary for the elimination of their carbon emissions. It is also innovative giving a holistic approach for the achievement of net-zero emission hotels.

2. Literature survey

Torcellini *et al*, 2006 [1] have analyzed different definitions of zero-energy buildings. The authors stated that a net-zero energy building is a building which has reduced its energy needs while the remaining energy demand can be supplied with renewable energies. They also mentioned that there are four definitions of this type of buildings including: a) net-zero site energy, b) net-zero source energy, c) net-zero energy costs, and d) net-zero energy emissions. **Zeiler *et al*, 2016** [2] have reported on cost-effective nearly-zero energy buildings in the Netherlands. The authors stated that the low-energy buildings should focus on the reduction of the energy demand, in energy effective heating and cooling and on application of solar photovoltaics. They also mentioned that, in the Netherlands, geothermal heat pumps with seasonal energy storage for effective heating and cooling should be used. **Dibene-Arriola *et al*, 2021** [3] have studied the energy efficiency indicators for hotel buildings. The authors stated that the most often used indicator is the annual energy consumption per unit surface in KWh/m^2 year. They also mentioned that hotels in the tropics consume more energy than those located in temperate zones while four-star and five-star hotels consume more energy than hotels with less stars. **An analysis on energy use by EU hotels has been published, 2011** [4]. The study stated that the energy consumption in hotels varies in the range of 200-400 KWh/m^2 year. It is also mentioned that the carbon emissions in hotels varies in the range of 160-200 kg of CO_2 per m^2 of covered surface. **Santiago, 2021** [5] has studied the energy use in hotels in Gran Canaria Spain. The author stated that solar-PV panels installed on the available space, in six different hotels studied, could cover around 8-30% of the total electricity demand. **The key energy efficiency solutions for SME hotels have been studied, 2011** [6]. It is mentioned that hotels should decrease their energy consumption reducing their operational cost, protecting the environment and remaining competitive. It is also stated that their embodied energy is less than 10% of their life cycle energy demonstrating the importance of energy saving during their operational phase. **A guide for making decisions regarding the installation of commercial solar-PV systems has been published, 2014** [7]**.** The guide includes the main steps in procuring, financing and installing solar photovoltaic systems. **Al-Zoubi *et al*, 2021** [8] have implemented a feasibility study regarding the installation of an on-grid photovoltaic system in Cedars hotel in Jordan. The authors stated that the annual energy consumption in the hotel was estimated at 444 MWh while a solar-PV system installed on an area of 1,757.3 m^2 would generate 541 MWh/year. They also calculated the payback period of the investment at 4.1 years and the LCOE at $0.0199/KWh respectively. **Liberalesso *et al*, 2020** [9] have analyzed the use of green roofs in youth hostels in Lisbon, Portugal. The authors stated that green roofs and green walls increase the green spaces in the urban environment bringing multiple benefits to the cities. Assessment of users' perceptions in five youth hostels in Lisbon, Portugal indicated that green infrastructure provides a greater sense of individual well-being and local aesthetic improvement. **Yi *et al*, 2018** [10] have studied the hotel guests' perception on best green practices. The authors stated that green tourism products include environmentally friendly hotels and airlines which reduce their carbon emissions. They also mentioned that Asians and non-Asians tourists have differences when selecting green tourism products. Asian tourists are focusing on pricing while non-Asians consider quality and style more important than pricing. **Kyriaki *et al*, 2017** [11] have studied the energy and environmental performance of solar thermal systems in hotel buildings. The authors stated that replacing the conventional heating and HVAC systems in hotels with combi systems consisted of heat pumps and solar collectors results in significant reduction of CO_2 emissions by around 67% while they are also cost-effective. **Colmenar-Santos *et al*, 2014** [12] have studied the use of solar thermal systems in a five-star hotel in Sao Paolo, Brazil. The authors stated that the city of Sao Paolo has already placed mandatory solar thermal requirements for any new building in the city generating at least 60% of the hot water demand. They also mentioned that their case-study for a five-star hotel in the city justifies the installation of solar thermal systems in hotel buildings. **Pardo *et al*, 2020** [13] have assessed the importance of biomass-based heating systems in sustainable buildings with reference a building in Spain. The authors stated that the use of alternative fuels in heating buildings results in significant reduction of CO_2 emissions as well as in less heating costs. **Lopez-Bernabe *et al*, 2021** [14] have studied the factors which affect the energy efficient investments in hotel industry in Spain. The authors stated that HVAC systems in hotels are major consumers of energy while reduction and de-carbonization of the energy used in heating and cooling is important for improving their sustainability. They also mentioned that hotel owners consider that the energy efficiency is important when they make decisions. However, several barriers hinder the energy saving investments in hotels. **Md Darus *et al*, 2008** [15] have studied the use of wind energy in sustainable development of resort islands in Malaysia. The authors stated that the local government has decided to support the deployment of wind energy in resort islands in the country. In this context a green energy project has been developed in these islands consisted of wind turbines, solar-PV systems and electric batteries. **Prasetio *et al*, 2019** [16] have analyzed a combined cooling, heating and power system based on a hot aquifer for a hotel building in tropical countries. The authors investigated the use of a geothermal fluid for covering the energy consumption in a hotel with annual energy demand 7.64 MW. The hot geothermal fluid was going to generate electricity with a system based on Organic Rankine Cycle while the waste heat was going to produce heat and cooling with a thermal absorption cooling system. **Vourdoubas, 2015** [17] has studied the development of zero-carbon emissions hotels in Crete, Greece. The author stated that the annual energy consumption of hotel buildings varies in the range of 200-400 KWh/m^2 while the share of annual cost in the total operational cost is in the range of 3-9 %. He mentioned that the use of solar thermal energy, solar photovoltaic energy and geothermal heat pumps can cover all their energy demand in heat, cooling and electricity. **Vourdoubas, 2019** [18] has investigated the possibility of using solar energy for the creation of carbon neutral hotels in Mediterranean countries. The author stated that solar thermal energy and solar photovoltaic energy combined with heat pumps could cover all the energy demand in heat, cooling and electricity

in summer operating hotels in Mediterranean region. **Tomizawa *et al*, 2007** [19] have studied an advanced co-generation system covering the energy demand in hotels. The authors stated that the co-generation system can generate heat and power during the winter while in the summer the produced heat can be used for cooling production. **Ho Lee *et al*, 2022** [20] have investigated the acceptance of CHP systems from the hotel industry. The authors used 40 individual interviews collecting and analyzing data. They stated that the factors which influence the use of CHP systems in hotels include environmental awareness, trust, government facilitators, technological barriers, perceived cost and risk perception. **Mengpei Chen *et al*, 2014** [21] have studied the use of a solid oxide fuel cell (SOFC) in hotels in Hong Kong. The authors investigated the economics of using a SOFC for covering all the energy demand for heat, cooling and electricity generation in a hotel. They considered that the fuel cell can co-generate heat which can be used with absorption chillers for cooling production. They also estimated that the payback period could be less than six years if the installation cost of the fuel cell can achieve governmental subsidy of 50%. **Smitt *et al*, 2021** [22] have studied the use of heat pumps during the retrofitting of hotels in cold climate areas. The authors studied 140 hotels in Norway and Sweden having mean annual energy consumption between 150-250 KWh/m^2. District heating systems are used for heating seventy percent of these hotels while their mean energy consumption is 218.9 KWh/m^2. The authors estimated that the mean annual energy consumption of the nine percent of these hotels which were using heat pumps, instead of district heating systems, was 25% lower. **Werner, 2017** [23] has reviewed the global use of district heating and cooling systems. The author stated that these systems can positively contribute to CO_2 emission reduction while the cold delivered by district cooling systems is much lower than the hot delivered by district heating systems. He also mentioned that further development of these sustainable energy systems requires awareness raising and removal of the barriers which hinder their further adoption. **Vourdoubas, 2021** [24] has studied the use of distributed electricity generation technologies in hotels. The author stated that DEG technologies comprise several technologies generating heat, cooling and electricity which have increasing applications in various sectors worldwide. He also mentioned that these technologies can be used in hotels having many economic and environmental benefits. **Tsai, 2020** [25] has studied the reduction of carbon emissions through carbon trading and carbon offsetting. The author stated that there are several mechanisms encouraging the reduction of carbon emissions. These include carbon pricing, carbon taxes, carbon trading schemes and carbon offsetting mechanisms. **Waring *et al*, 2020** [26] have analyzed the role of natural and planted forests in de-carbonization. The authors stated that natural forests store more carbon than plantation forests due to complex structure and the accumulation of carbon below the ground. They also mentioned that afforestation is likely to mitigate emissions more effectively when trees are planted in old forested, high-productivity sites.

3. Energy consumption and carbon emissions in hotels

The hospitality industry plays a significant role in global energy consumption and in carbon emissions. Hotel buildings have high energy intensity compared with other private and public buildings. With the growing awareness of climate change and the need for sustainable practices, hotels are increasingly adopting measures to minimize their carbon footprint. The main energy consuming activities in a hotel include: Heating rooms, cooling rooms, lighting, hot water production, operation of several devices, other energy consuming activities by guests, preparing meals (especially warm ones), swimming pools et cetera. The relative importance of the different energy end-uses is described as follows: Space conditioning (heating/cooling, ventilation and air-conditioning) is the largest single end-user of energy in hotels, accounting for approximately half of the total consumption. It is widely accepted that outdoor weather conditions and floor areas are among the main factors affecting energy use in hotels. The indoor temperature levels also influence the quantity of energy consumed in hotel buildings. Domestic hot water is commonly the second largest user, accounting for up to 15 % of the total energy demand. Lighting can fluctuate between a range of 12-18 % and up to 40 % of a hotel's total energy consumption, depending on the category of the establishment. Services such as catering and laundry also account for a significant share of energy consumption, particularly considering that they are commonly the least energy-efficient. Sports and health facilities are typically high energy consumers. For most hotels, energy use falls in the range 200-400 kWh/m^2 yr. A "meta-analysis" (combining data from all the existing studies) suggests that the average energy use by hotels is in the range 305-330 kWh/m^2 yr. The energy consumption in hotels in several sectors is presented in Table 1.

Table 1: Energy consumption in various hotel sectors (USA)

Hotel sector	%, Total energy consumption
Cooling	26
Lighting	23
Space heating	11
Water heating	5
Refrigeration	6
Cooking	2
Ventilation	7
Office equipment	7
Other	13
Total	100

Addressing carbon emissions in hotels is crucial for mitigating climate change and fostering sustainable tourism. The carbon footprint refers to the total amount of greenhouse gas emissions, particularly carbon dioxide (CO_2), released into the atmosphere as a result of human activities. It serves as a measure of the impact that various activities, including those of hotels, have on climate change and on environment.

4. Net-zero carbon emission hotels

Net-zero carbon emission hotels (NZCEH) can be visualized as hotels that produce at least as much emissions-free energy (generated by renewable energies) as it uses from carbon emitting energy sources (like fossil fuels). The main building sectors that should be targeted for obtaining NZCEH are: a) The building envelope that should be better insulated, b) The heating fuel that should be carbon-free, c) Various equipment that should have high energy efficiency, d) Generation of heat and electricity by renewable energies, and e) De-carbonization of building's materials. A proposed

roadmap for obtaining net-zero carbon emission hotels comprises:

a) Decrease of energy use,
b) More efficient use of energy,
c) Use of renewable energies instead of fossil fuels, and
d) Offsetting the remaining carbon emissions.

Therefore, the concept of NZCEH emphasizes in: a) energy efficiency, b) energy savings, and c) use of renewable energies. Technical approaches to reduce carbon emissions will need to be:

More efficient: Pursuing the highest and most innovative levels of efficient technology, furniture, fittings and equipment, and best practice operations; designing highly energy efficient buildings, engaging guests and their personnel to be more efficient, and optimizing the best solutions for carbon reduction through efficiency pathways.

More renewable: Producing more renewable energy directly on-site at properties, purchasing green energy from external providers and supporting the acceleration of power grids toward renewables and away from fossil fuels.

More electrified: Supporting the transition to electrification of equipment and appliances, and building an infrastructure to generate, store, and distribute electricity across a network.

It should be noted that the existing technology allows the complete de-carbonization of the hotel sector.

5. Energy saving in hotels

Energy saving is the first step for zeroing carbon emissions followed by the broad utilization of low- or zero-carbon emissions energy technologies. Various existing studies indicate that hotels can reduce their annual energy consumption by around 20-30% while a 10% energy reduction can be easily achieved with simple interventions within the first year. The remaining energy demand can be covered with low-carbon and renewable energy technologies replacing the use of fossil fuels.

The main sectors that energy consumption can be reduced in hotels include:

1. The building envelope. Buildings in many hotels have been constructed with old building codes having poor energy performance. Improvements in building's envelope can reduce significantly the requirements for heating and cooling,
2. The HVAC system. HVAC systems in hotels utilize 50% or more of their total electricity consumption. Improvements of HVAC systems can significantly reduce the energy demand,
3. The lighting system. Many hotels have old and energy inefficient lighting systems. Their replacement with new systems having low energy consumption can reduce significantly the total energy use,
4. Better use of equipment. Several hotel equipment and machinery utilize significant amounts of energy either during their operation or during the stand-by mode.
5. Better control of various parameters. Installation of sensors and appropriate control of various parameters including lighting, heating and cooling in hotels can reduce their energy demand, and
6. Behavior changes. Behavior changes of staff, patients and visitors result in energy saving in hotels. The cost of behavioral changes is low compared with the previously mentioned methods.

6. Use of renewable energy sources in hotels

Several renewable energy sources and technologies can be used in hotels including: Solar thermal energy, solar photovoltaic energy, green roofs, solid biomass, wind turbines and geothermal fluids.

6.1 Solar photovoltaics

Hotels usually cover their power requirements with grid electricity while in areas without electric grid infrastructure they often use diesel oil generators. The use of green solar electricity is attractive provided that solar radiation at the hotel's site is satisfactory. Solar photovoltaics (solar-PV) emerge as a promising and eco-friendly solution for hotels seeking to reduce their carbon emissions and operating costs simultaneously. The upfront investment required for installing solar-PV systems can be a barrier for some hotels. However, advancements in technology and decreasing costs of solar panels are making these systems more financially viable in the long run. Some hotels may face constraints regarding available space for solar installations. Creative solutions, such as integrating solar panels into architectural designs or utilizing nearby land, can help overcome these limitations. While solar panels have a relatively low maintenance requirement, hotels need to consider periodic cleaning and maintenance to ensure optimal performance. Additionally, assessing the durability of the chosen solar-PV system is crucial to guarantee a long-term, sustainable investment. The integration of solar photovoltaics in hotels represents a progressive step towards sustainable and responsible energy consumption. Despite initial challenges, the benefits of cost savings, environmental stewardship and energy independence position solar-PVs as a viable and attractive option for the hospitality industry. As hotels continue to seek innovative ways to enhance their sustainability practices, embracing solar energy not only aligns with global environmental goals but also establishes a positive image and sets a precedent for a greener, more energy-efficient future in the hospitality sector.

6.2 Use of green roofs

The adoption of green roofs in hotels emerges as a promising solution. Green roofs, also known as living roofs or eco-roofs, involve the cultivation of vegetation on building rooftops. One of the key advantages of green roofs in hotels is their contribution to energy efficiency. The vegetation on the rooftop acts as a natural insulator, reducing the need for excessive heating or cooling systems. This insulation helps regulate indoor temperatures, minimizing the reliance on artificial climate control methods. As a result, hotels can significantly cut down on energy consumption, leading to lower utility costs and a reduced carbon footprint. Green roofs contribute significantly to the mitigation of urban heat islands (UHIs). UHIs result from the replacement of natural surfaces with impervious materials, leading to elevated temperatures in urban areas. The vegetation on green roofs absorbs sunlight, reduces heat absorption, and helps maintain cooler temperatures, mitigating the adverse effects of UHIs. By providing a habitat for flora and fauna, green roofs contribute to biodiversity conservation. This is particularly crucial in urban environments where green spaces are often limited. The presence of plants on rooftops attracts various species of birds, insects, and even small mammals, fostering a more balanced and diverse ecosystem.

6.3 Use of solar thermal systems

Hotels utilize thermal energy in various sectors including in clients' rooms, in restaurants, in the laundry, in cleaning et cetera. In many cases hot water at around 60-70ºC can cover the most of their heating needs. Hot water at low or medium temperatures can be produced with various types of solar thermal systems while in countries with satisfactory annual solar irradiance the use of solar thermal systems is technically and economically attractive. The solar thermal technology is mature, reliable, well known and cost-efficient. It has been used, during the last 40 years, in various sectors including in residential buildings, in hotels, in agriculture and in industry. When used in hotels it replaces the use of fossil fuels or/and grid electricity reducing their carbon emissions due to energy use as well as the annual operating expenses due to diesel oil, electricity or natural gas consumption. Therefore, the use of solar thermal technology in hotels has positive economic and environmental impacts. Solar thermal systems producing hot water at temperatures above 110ºC combined with absorption chillers can provide space cooling in hotels.

6.4 Use of solid biomass

The integration of solid biomass into hotels presents a promising avenue for sustainable energy practices in the hospitality industry. By embracing biomass energy hotels can contribute to reducing their environmental footprint, enhancing energy security, and aligning with global sustainability goals. While challenges exist, technological advancements, coupled with strategic planning and community engagement, can pave the way for a more sustainable and eco-friendly future for hotels. As the hospitality sector continues to evolve, the adoption of solid biomass represents a tangible step towards a greener and more responsible industry. Heat generation by biomass burning is an old, mature and broadly used technology in many sectors, including hotels, worldwide. It can provide heat in hotels, in residential and public buildings as well as in agriculture and in industry. It is also broadly used for cooking in poor and developing countries. Biomass is also an appropriate fuel for heat and power co-generation. Solid or gaseous biomass can be burnt producing either hot water or steam which can be used for heat or/and power generation. The technologies of biomass burning both for heat production and co-generation of heat and power are mature, reliable and cost-efficient while they are already used in many hotels.

6.5 Use of wind turbines

The integration of wind turbines for power generation in hotels represents a significant step towards achieving sustainability and reducing their environmental impacts. Beyond the environmental benefits, the economic advantages, the energy independence and the enhanced market differentiation make wind turbines a compelling choice for hotels seeking a greener and more economically sustainable future. As the hospitality industry continues to evolve towards greater sustainability, wind turbines emerge as a beacon of innovation, offering hotels a reliable and eco-friendly solution for meeting their energy needs. Wind energy is currently used in various sectors for electricity generation with small, medium and large-scale wind turbines. Wind electricity generation is cost-efficient compared to generation by fossil fuels without any governmental support or financial subsidies. Electricity generated depends on wind velocity while high wind speeds result in increased energy generation. In locations with mean annual wind speed higher than 6 m/sec the installation of wind turbines is attractive and profitable.

6.6 Use of geothermal fluids

Geothermal energy harnessed directly through hot geothermal fluids emerges as a promising solution for sustainable heat production in hotels. Geothermal energy, derived from the Earth's internal heat, provides a renewable and continuous source of power. The Earth's crust contains reservoirs of hot water and steam that can be tapped into for various applications including electricity generation and direct heating. Direct use of geothermal fluids involves extracting hot water or steam from the subsurface and utilizing it without an intermediate conversion process. The use of geothermal fluids for heat production in hotels can be achieved when a geothermal spring with hot water is located nearby its premises. A detail analysis of the technical feasibility and the economic viability as well as an environmental assessment are required before taking any decision regarding the use of the geothermal fluid for heat production in the hotel. The renewable energy sources that can be used for energy generation in hotels are presented in Table 2.

The characteristics of several renewable energies that can be used for energy generation in hotels are presented in Table 3.

Table 2: Renewable energy sources which can be used for energy generation in hotels

Renewable energy source	Technology/equipment	Generated energy	Cost of primary energy source	Carbon emissions
Solar energy	Flat-plate and evacuated tube solar collectors	Heat	Zero	Zero
Solar energy	Evacuated tube solar collectors	Cooling	Zero	Zero
Solar energy	Solar photovoltaic panels	Electricity	Zero	Zero
Wind energy	Wind turbines	Electricity	Zero	Zero
Solid biomass	Burning	Heat	Low	Net zero
Biogas	Burning	Heat, Electricity	Low	Net zero
Direct geothermal fluids	Heat exchangers	Heat	Very low	Zero

Source: Own estimations

Table 3: Characteristics of renewable energy sources that can be used for energy generation in hotels

Renewable energy source	Technology/equipment	Energy efficiency	Current uses in hotels
Solar energy	Flat-plate and evacuated tube solar collectors	Around 40%	Yes
Solar energy	Evacuated tube solar collectors - solar thermal absorption cooling		Few
Solar energy	Solar photovoltaic panels	15-20%	Yes
Wind energy	Wind turbines	Around 30-40%	Limited
Solid biomass	Burning	80-85%	Yes
Biogas	Burning	85-90%	Limited
Direct geothermal fluids	Heat exchangers	80%	Few

Source: Own estimations

7. Use of low-carbon energy technologies in hotels

Several low-carbon energy technologies can be used in hotels including: Heat and power co-generation systems, fuel cells, heat pumps and district heating and cooling systems.

7.1 Use of heat and power co-generation systems

Co-generation of heat and power (CHP) systems generate simultaneously heat and power using either fossil fuels or renewable energies. They can cover part or all of the heating and electricity demand in hotels, while nowadays they have extensive applications in many sectors including hotels, hospitals, large-scale residential and commercial buildings as well as in industry and greenhouses. Apart from heat and power generation they can be used in space cooling, that is also required in hotels, using a thermal absorption chiller. Hotels are ideal candidates for using this technology since they operate continuously, 24/7, all over the year consuming both heat and electricity. CHP systems can provide continuously and reliably space heating, steam, domestic hot water and electricity in a cost-efficient way. Their overall energy efficiency is high at around 80-85%, or even at 90%, while their use reduces the carbon emissions in hotels improving their environmental impacts. CHP technologies encompass various energy systems co-producing heat and electricity including internal combustion engines, gas turbines, micro-turbines, fuel cells, and Stirling engines. The most common fossil fuel used in these systems is natural gas while few systems consume light or heavy oil. They can also utilize biomass like agricultural and forest residues, by-products and wastes, bio-ethanol, bio-diesel or biogas produced from various organic wastes. The use of CHP systems in large-size hotels is currently increasing due to their economic and environmental benefits. CHP technology can provide heat and electricity to tourism accommodation facilities during grid outages, severe storms and disasters increasing their energy security and resilience in undesired circumstances and in extreme weather events. Several characteristics of typical CHP systems are presented in Table 4.

Table 4: Characteristics of typical CHP systems

Parameter	Reciprocating engines	Gas turbines	Micro-turbines	Steam turbines
Electrical efficiency (%)	30-42	24-36	25-29	5-7
Overall energy efficiency (%)	77-83	65-71	64-72	80
Installation cost ($/KW)	1,400-2,900	1,300-3,300	2,500-3,300	670-1,100
Operating and maintenance cost (¢/KWh)	0.9-2.4	0.9-1.0	0.8-1.6	0.6-1.0

7.2 Use of fuel cells

Fuel cells are modern, sustainable and very efficient energy systems having increasing applications in many sectors particularly when both heat and power are required. Although their installation cost is still high their promotion is accelerated by governmental support and financial subsidies.

Among other applications fuel cells are increasingly used in hotels covering part of the heating and electricity requirements. Their use has many benefits while they contribute in the reduction of carbon emissions due to energy use that is important in achieving environmental sustainability and in climate change mitigation.

7.3 Use of heat pumps

Heat pumps are heat and cooling production devices which are currently used in many applications including hotels. They are capable to generate three or more times more heat and cooling than the consumed electricity being more energy efficient than other heating and cooling systems. Their use in hotels is growing while they are capable to cover part or all of the demand in air-conditioning and in domestic hot water production.

7.4 Use of district heating and district cooling systems

District heating and cooling is an old and sustainable energy technology which is broadly used nowadays in hotels, as well as in other applications, for space heating, cooling and hot water production. Its use has many economic and environmental advantages. Depending on the fuel used district heating and cooling can positively contribute in lowering the carbon emissions in hotels due to heat and cooling use.

7.5 Use of distributed energy generation technologies

Distributed energy generation (DEG) systems include various small-size modular energy generation technologies which can provide energy to several users including hotels. They are installed nearby or at their premises while their size could reach up to 5 MW. These technologies can assist tourism facilities to achieve their energy, environmental and resilience goals. DEG technologies comprise several energy generating systems using fossil or renewable fuels as well as energy storage technologies. Their use in hotels offers many technical, environmental, economic and social benefits. Several low- and zero-carbon emission DEG technologies which can be used in hotels are presented in Table 5.

Table 5: Several low- and zero-carbon emission DEG technologies which can be used in hotels

Technology	Energy source/fuel	Description
Solar water heating	Solar energy	Use of solar energy to produce hot water
Solar thermal absorption cooling	Solar energy	Use of solar thermal energy with thermal absorption chillers for cooling production
Heat pumps	Ambient heat and grid electricity	Use of ambient heat and electricity for heat and cooling production
Biomass burning	Solid biomass	Solid biomass burning for heat generation or for co-generation of heat and power
Solar photovoltaics	Solar energy	Use of solar-PV panels for electricity generation
Wind turbines	Wind energy	Use of wind turbines for electricity generation
Co-generation of heat and power systems	Natural gas, biomass, heating oil	Use of various fuels for co-generation of heat and power or tri-generation of heat, cooling and electricity
Fuel cells	Natural gas, hydrogen	Use of hydrogen or natural gas for heat and power co-generation

Source: own estimations

8. Electrification and energy storage in hotels

Electrification emerges as a pivotal strategy, offering hotels a pathway towards sustainable operations and a clean energy transition. By shifting from conventional energy sources to electricity-powered systems, hotels can significantly reduce their carbon emissions while enhancing operational efficiency and guest experience. Energy storage in hotels helps them to mitigate and adapt to climate change. Tourism facilities should be able to support their guests during extreme weather events and power outages. It is useful both in grid connected hotels and in tourism accommodation facilities located in areas without electric grid infrastructure that is common in poor countries. The deployment of various renewable energies in hotels substituting fossil fuels requires the storage of heat and/or electricity taking into account the intermittent nature of solar and wind energy. The combined use of low- or zero-emission distributed energy generation and energy storage technologies in tourism enterprises facilitates their clean energy transition complying with the global targets for carbon neutral societies.

9. Purchasing green power from external energy providers.

One of the primary motivations for hotels to purchase green power from external providers is the reduction of their carbon emissions. Traditional energy sources, such as fossil fuels, contribute to air pollution and climate change. By opting for green power, hotels can significantly decrease their reliance on non-renewable resources, thus mitigating the environmental impact associated with energy production. This shift towards cleaner energy sources contributes to a more sustainable and ecologically responsible approach. Contrary to common misconceptions, investing in green power can prove economically viable for hotels in the long run.

10. Participation in energy communities generating green electricity

An emerging trend in this pursuit of sustainability is the participation of hotels in energy cooperatives dedicated to producing green electricity. Participating in energy cooperatives enables hotels to tap into renewable energy sources, such as solar or wind power, collectively with other businesses in the community. By pooling resources and investing in sustainable technologies, hotels can significantly enhance their energy efficiency. This collaborative approach not only benefits individual hotels but also contributes to the overall reduction of greenhouse gas emissions and reliance on non-renewable energy sources, aligning with global sustainability goals.

11. Behavioral change in hotels

The tourism industry plays a significant role in global carbon emissions, with hotels being one of the contributors. One promising approach is the adoption of sustainable practices within the hospitality sector, particularly aiming for zero-carbon emissions. However, achieving this goal requires not only technological advancements but also a fundamental shift in tourist behavior. Tourist behavior encompasses various activities, including transportation choices, energy consumption, waste generation, and water usage. Each of these activities contributes to the overall carbon footprint associated with tourism. For instance, transportation, particularly air travel, accounts for a significant portion of carbon emissions linked to tourism. Similarly, tourists' energy consumption and waste generation during their stay in hotels also add to the environmental impact.

12. Offsetting carbon emissions in hotels

Offsetting carbon emissions can help private or public organizations, including hotels and tourism accommodation facilities, to achieve the net-zero carbon emissions target. Hotels after reducing their energy consumption and replace part of fossil fuels used with renewable energies can offset any remaining carbon emissions purchasing carbon credits from carbon emission trading schemes. Offsetting carbon emissions is an additional tool for companies and organizations which facilitates and assists them to zero their net-carbon emissions according to climate change mitigation targets. The concept of offsetting carbon emissions with three mechanisms was firstly proposed by UN under the Kyoto protocol in 1997. These three mechanisms are: a) the Clean Development Mechanism (CDM), b) the Joint Implementation (JI), and c) the Emissions Trading (ET). The first two are related with project development while the third is related with carbon emissions trading. Nowadays various organizations create and implement carbon offsetting projects in developing countries and sell part of them to those who are voluntarily willing to reduce or zero their net-carbon emissions. The sectors of the most popular carbon offsetting projects worldwide are presented in Table 6.

Table 6: Sectors of the most popular carbon offsetting projects worldwide

Sector	% of total
Reforestation	33.9
Biomass methane capture	15.7
Wind power development	13.9
Industrial methane capture	8.9
Fuel efficiency	5.4

13. Discussion

The methods and the benign energy technologies which can be used in hotels decreasing or eliminating all their net-carbon emissions due to energy use have been described. It has been indicated that net-zero emission hotels can be achieved with: a) energy saving, b) use of renewable energy technologies, c) use of low-carbon emission energy technologies, d) electrification of several sectors, e) purchasing green energy from external energy providers, f) behavior changes, and g) offsetting carbon emissions. The findings of the current study indicate that hotels can zero their net-carbon emissions using several methods and technologies which are reliable, mature and cost-efficient while many of these methods are already used in several hotels. Our study does not indicate the criteria for selecting the best and more profitable technologies for specific hotels nor the best combination of the abovementioned technologies which should be used in hotels for eliminating their carbon emissions. Further studies should be focused in several case studies for zeroing the net-carbon emissions in hotels located in areas with different availability of renewable energies as well as in the examination of different roadmaps, using the abovementioned methods and technologies, for achieving carbon neutrality in hotels.

14. Conclusions

The possibility of using low- and zero-carbon fuels as well as benign energy technologies, instead of oil-based fuels, in hotels for eliminating their net-carbon emissions due to energy use has been investigated. The main findings of our study are:

1. The use of several sustainable energy technologies and carbon-free fuels in hotels can eliminate their net-carbon emissions.
2. These benign energy technologies are mature, reliable and cost-effective.
3. There are different methods for achieving carbon neutrality in hotels.
4. These methods can combine: The use of energy saving techniques and behavior changes among guests and hotels' personnel, use of renewable energies and sustainable energy technologies, electrification of hotel's sectors, purchasing green electricity from external energy providers and energy cooperatives and carbon emissions offsetting with the existing schemes.
5. The use of the abovementioned energy technologies in hotels results in many environmental, economic and social benefits.

Our results indicate to hotel owners and managers the methods and the sustainable energy technologies which can be used in their tourism enterprises for decreasing or completely eliminating their carbon emissions reducing their climate footprint and complying with the global efforts for climate change mitigation.

15. References

1. Torcellini P, Pless S, Deru M. Zero energy buildings: A critical look at the definition. Conference Paper, NREL/CP-550-39833, 2006. [Online] Available: https://www.nrel.gov/docs/fy06osti/39833.pdf
2. Zeiler W, Gvozdenovic K, de Bont K, Maassen W. Towards cost-effective nearly-zero energy buildings: The Dutch situation. Science and Technology for the Built Environment. 2016; 22(7):911-927. Doi: https://doi.org/10.1080/23744731.2016.1187552
3. Dibene-Arriola LM, Carrillo-González FM, Quijas S, Rodríguez-Uribe MC. Energy Efficiency Indicators for Hotel Buildings. Sustainability. 2021; 13:1754. Doi: https://doi.org/10.3390/su13041754
4. Hotel Energy Solutions. Analysis on Energy Use by European Hotels: Online Survey and Desk Research, Hotel Energy Solutions project publications, 2011. [Online] Available: https://www.e-unwto.org/doi/pdf/10.18111/9789284414970
5. Santiago DE. Energy use in hotels: A case study in Gran Canaria. International Journal of Low-Carbon Technologies. 2021; 16:1264-1276. Doi: https://doi.org/10.1093/ijlct/ctab048
6. Hotel Energy Solutions. Key Energy Efficiency Solutions for SME Hotels, Hotel Energy Solutions project publications, 2011. [Online] Available: https://www.e-unwto.org/doi/pdf/10.18111/9789284415038
7. On-site commercial solar PV decision guide for the hospitality sector. Better Buildings, US Department of Energy, 2015. [Online] Available: https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/On_Site_Solar_Decision_Guide.pdf
8. Al-Zoubi H, Al-Khasawneh Y, Waid O. Design and feasibility study of an on-grid photovoltaic system for green electrification of hotels: A case study of Cedars hotel in Jordan. International Journal of Energy and Environmental Engineering. 2021; 12:611-626. Doi: https://doi.org/10.1007/s40095-021-00406-z
9. Liberalesso T, Mutevuie Junior R, Oliveira Cruz C, Matos Silva Ch, Manso M. Users' perceptions of green roofs and green walls: An analysis of youth hostels in Lisbon, Portugal. Sustainability. 2020; 12:10136. Doi: http://dx.doi.org/10.3390/su122310136
10. Yi S, Li X, Jai T-M. Hotel guests' perception of best green practices: A content analysis of online reviews. Tourism and Hospitality Research. 2018; 18(2):191-202. Doi: http://dx.doi.org/10.1177/1467358416637251
11. Kyriaki E, Giama E, Papadopoulou A, Drosou V, Papadopoulos AM. Energy and Environmental performance of solar thermal systems in hotel buildings. Procedia Environmental Sciences. 2017; 38:36-43. Doi: 10.1016/j.proenv.2017.03.072
12. Colmenar-Santos A, Vale-Vale J, Borge-Diez D, Requena-Perez R. Solar thermal systems for high rise buildings with high consumption demand: Case study for a five-star hotel in Sao Paolo, Brazil. Energy and Buildings. 2014; 69:481-489. Doi: http://dx.doi.org/10.1016/j.enbuild.2013.11.036
13. Padro JE, Mejias A, Sartal A. Assessing the importance of biomass-based heating systems for more sustainable

buildings: A case study based in Spain. Energies. 2020; 13:1025. Doi:10.3390/en13051025
14. López-Bernabé E, Foudi S, Linares P, Galarraga I. Factors affecting energy-efficiency investment in the hotel industry: Survey results from Spain. Energy Efficiency. 2021; 14(4):41. Doi: https://doi.org/10.1007/s12053-021-09936-1
15. Othman A Karim Khairul Nizam Abdul Maulud, *et al*. Potential of wind energy in sustainable development of resort Island in Malaysia: A case study of Pulau Perhentian. In Proceedings of the 10th WSEAS International Conference of Mathematical Methods Computational Techniques and Intelligent Systems, 2008. [Online] Available: https://www.researchgate.net/publication/262391852_Potential_of_wind_energy_in_sustainable_development_of_resort_island_in_Malaysia_a_case_study_of_Pulau_Perhentian_Perhentian_island
16. Prasetio H, Euodia KD, Purwanto WW. Techno-economic analysis of a combined cooling, heating and power system based on hot sedimentary aquifer for hotel building in tropical countries. MATEC Web of Conferences. 2019; 268:06006. Doi: https://doi.org/10.1051/matecconf/201926806006
17. Vourdoubas J. Creation of hotels with zero CO_2 emissions due to energy use: A case study in Crete, Greece. Journal of Energy and Power Sources. 2015; 2(8):301-307.
18. Vourdoubas J. Possibility of using solar energy for the creation of carbon neutral hotels in Mediterranean countries. Energy and Environment Research. 2019; 9(1):1-8. Doi: https://doi.org/10.5539/eer.v9n1p1
19. Tomizawa M, Amano Y, Hashizume T. Study on optimal operational planning of an advanced co-generation system on a hotel's energy demand. Energy and Sustainability. 2007; 105:333-342. Doi: https://doi.org/10.5539/eer.v9n1p1
20. Ka Ho Lee W, Shing Man S, Shou Chan AH. Co-generation system acceptance in the hotel industry: A qualitative study. Journal of Tourism and Hospitality Management. 2022; 51(3):339-345. Doi: http://dx.doi.org/10.1016/j.jhtm.2022.04.004
21. Pei Chen MJ, Ni M. Economic analysis of a solid oxide fuel cell cogeneration/trigeneration system for hotels in Hong-Kong. Energy and Buildings. 2014; 75:160-169. Doi: http://dx.doi.org/10.1016/j.enbuild.2014.01.053
22. Smitt S, Tolstorebrov I, Gullo P, Pardiñas A, Hafner A. Energy use and retrofitting potential of heat pumps in cold climate hotels. Journal of Cleaner Production. 2021; 298:126799. Doi: https://doi.org/10.1016/j.jclepro.2021.126799
23. Werner S. International review of district heating and cooling. Energy. 2017; 137:617-631. Doi: https://doi.org/10.1016/j.energy.2017.04.045
24. Vourdoubas J. Use of distributed generation technologies in hotels. International Journal of Global Sustainability. 2021; 5(1):1-14. Doi: http://dx.doi.org/10.5296/ijgs.v5i1.18522
25. Tsai W-H. Carbon emission reduction, carbon tax, carbon trading and carbon offset. Energies. 2020; 13:6128. Doi: http://dx.doi.org/10.3390/en13226128
26. Waring B, Newman M, Colin Prentice I, Adams M, Smith P, Siegert M. Forests and de-carbonization - Roles of natural and planted forests. Frontiers in Forests and Global Change. 2020; 3: article 58. Doi: https://doi.org/10.3389/ffgc.2020.00058