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Clean energy for a sustainable future: Analysis of a PV system and LED bulbs in a hotel

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ABSTRACT

Scholars are increasingly prioritising sustainability as the driving force behind their research efforts, and many businesses are placing the customer at the centre of their agendas. Hospitality facilities, such as hotels, are also making concerted efforts to mitigate climate change. The present study proposed a sustainability analysis of the installation of a photovoltaic (PV) system and the replacement of conventional lighting with light emitting diode (LED) bulbs in a hotel, considering economic, environmental and social sustainability dimensions.

The results showed that NPV varied between 967 and 3624 €/kW for the PV system, with a 100 % probability of achieving a positive NPV in a high market scenario and a 79–84 % probability of the same in a low market scenario. Concerning energy efficiency, the adoption of LED bulbs determined a NPV in the range of 105–216 €/bulb. These figures were highly dependent on the percentage of self-consumed energy and the purchase price of electricity. Environmental analyses indicated that the installation of a PV system could lead to an emissions reduction of 422 gCO_2eq/kWh, translating to 61 $tCO_2eq/year$. In addition, social analyses underscored the significance of renewable installations and energy-efficiency interventions to support the ecological transition. However, consumer choices within hotels did not consistently align with sustainable models. Notably, a green premium of 13.2 €/day was recognised for hotels using renewable systems, and 8.3 €/day for those using smart lighting. The results advocate for a pragmatic sustainability model that sees green investments enhancing a hotel's sustainability. However, a shift in consumer attitudes is necessary to fully realise this potential.

Nomenclature

ACbyLB	avoided cost by LED bulbs
BEP	break-even point
BP_U	bulb power unitary
CI_B	investment cost bulb
CI_{UB}	unit investment cost bulbs
CO	Coal
CO_B	bulb operative cost
CR_b	bulb replacement cost
DCI	discounted cash inflow
DCO	discounted cash outflow
DDNC-1	discounted do nothing cost 1 year
DPBT	discounted payback time
ECbyB	energy consumed by bulbs
ECD	carbon dioxide emission
FF	fossil fuels
GD	gas derivate
Inv	investment cost
IRR	internal rate of return
LED	light emitting diodes
MS	high market scenario
N_B	number of bulbs
NG	natural gas
N_H	number of hours
NPV	net present value
OI	oil
OT	other
Pc	purchase cost of electricity
PEM	percentage energy mix
P_{RC}	percentage of replacement cost

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(*continued*)

ps	selling price
PV	photovoltaic
r	opportunity cost of capital
RECD	reducing carbon dioxide emission
SDG	sustainable development goals
TaxD	tax deduction
WTP	willingness-to-pay

1. Introduction

The role of policy makers is critical in the energy transition to a low-carbon society. Product diversification and increased knowledge can reduce the use of natural resources [1], environmental taxes directly affect carbon emissions and encourage renewable energy consumption [2], and some analyses show that the use of subsidies increases investment in renewable energy [3]. In this context, appropriate policy regulations are crucial [4]. Economic growth is more supported by renewables than non-renewables [5], which also mitigate environmental degradation problems [6,7]. At the same time, also energy efficiency practices play a strategic role for economic growth [8]. It is emphasized by some studies that renewables reduce volatility in energy markets [9] and the prosumer figure suffers less from energy price volatility and related speculative phenomena [10].

The advantages of renewable energy are linked to energy security [11] and economic growth [12]. Initiatives to drive renewable energy should start with school curricula promoting the use of green products [13] and the cultivation of energy-efficient practices [14]. However, a key role must also be played by demand response, which is expected to be critical for future electricity systems [15]. In addition, electricity prices have been identified as the most crucial factor in reducing total energy consumption [16]. Energy communities and energy independence represent the future, and they must be driven by policy choices rooted in sustainable education and youth involvement. A pragmatic approach, extending beyond a pure ideological view, is essential to ensure the equitable distribution of benefits among different categories of stakeholders [17].

The tourism sector is not exempt from these changes [18], and it stands to benefit from individuals' sustainable use of natural resources [19] and circular strategies [20]. Central issues for the tourism industry include food waste and water and energy consumption, for which circular economy practices may be vital to support economic and sustainable development [21]. The hotel sector is also actively involved in this paradigm shift [22], for which a multi-stakeholder approach is suggested [23]. Specifically, green hotel practices may significantly contribute to achieving several sustainable development goals (SDGs), such as SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), SDG 12 (responsible consumption and production) and SDG 13 (climate action) [24].

The theme of sustainability is very relevant to the hotel industry, and particularly aspects of hospitality such as management, energy conservation and training [25]. Sustainable improvements may encompass the optimisation of water use [26], food waste [27] and waste management [28]. However, special attention should be paid to the energy component, considering that hotels demonstrate excessive consumption [29]. This necessitates a comprehensive assessment of their carbon footprint [30]. Despite efforts in this direction, some studies have shown that energy and carbon intensity remain unacceptably high in this sector [31].

Given the high electricity consumption within hotels, there is a pressing need for the adoption of renewable energy technologies. One of the obstacles in this regard is that hotel owners tend to be cost-oriented and to operate with short time horizons [32]. Analyses have underlined that the promotion of renewable technologies occurs most effectively under favourable market conditions, which include the availability of subsidies, continuous technological improvement, positive responses from tourists and recognition of the benefits by hoteliers [33]. Notably, the sustained success of a hotel is contingent on the reinvestment of economic returns in sustainability initiatives that involve the entire organisation and foster customer relationships [34].

Businesses, including hotels, must reassess existing technologies or develop innovative new technologies to meet emerging environmental demands and pursue green competitiveness [35]. Previous studies have explored integrated renewable plants [36], identifying economic benefits [37]. Other research has focused on storage integration [38] to overcome the intermittency challenges associated with certain renewable sources [39].

In the literature, studies have approached this subject through techno-economic [40], techno-economic-environmental [41] and environmental [42] lenses. In this context, hotels have been identified as playing a crucial role in fostering sustainable tourism, based on environmental, economic, political and sociocultural criteria [43]. Notably, social issues are gaining prominence in investigations of sustainability, with consumers reporting a higher willingness-to-pay (WTP) for hotels demonstrating corporate social responsibility [44]. In addition, pro-environmental attitudes may positively influence booking intention, WTP and word-of-mouth [45]. Understanding the role played by ecological hotel design [46] and green certification [47] is also crucial in this context.

Green human resource practices have been identified as contributing factors to improved hotel environmental performance [48]. The overall positive image of green hotels is driven by the interaction of two core variables – environmental values and cognitive image – alongside the peripheral condition of low-carbon knowledge [49,50]. A recent review highlighted that hotels in tropical regions tend to consume more energy than those located in temperate zones, with four- and five-star hotels exhibiting the highest consumption [51]. The potential of light emitting diode (LED) bulbs appears very promising [52]. Moreover, among renewable technologies, the highest preference is for rooftop solar panels [53].

The European case has been extensively analysed in the literature [54,55]. Here, the proactive role of the prosumer has been identified as significant for the realisation of a new social model based on the production and self-consumption of renewable energy [56]. Green innovations, such as LED lamps and photovoltaic (PV) panels, have also been recognised for their potential to improve financial and operational performance [57]. Thus, the issue of sustainability in hotels has become crucial for the different categories of stakeholders involved [58,59]. This work aims to support this research objective because hotels, in responding to competitiveness challenges and the imperative of combating climate change, can identify green solutions. This work analyses a mix of two technologies (PV panels and LED bulbs) to support the transformation of hotels into sustainable projects. To this end, a sustainability analysis, encompassing economic, environmental and social dimensions, was conducted to evaluate the benefits of integrating renewable energy and energy efficiency within a hotel in the Italian context.

2. Methods

The methodology section outlines the economic (Section 2.1) and environmental (Section 2.2) elements used to evaluate the PV system. Subsequently, the data for energy efficiency related to LED bulbs are described (Section 2.3), followed by those related to the social analysis (Section 2.4). The methodological approach of the study involved a mix of quantitative methods, including a discounted cash flow (DCF), the calculation of carbon dioxide emissions reductions and energy consumption reductions, and an online survey, with the aim of generating a comprehensive assessment of sustainability.

2.1. Economic data and PV systems

Solar systems have a significant installed capacity within the European context. However, over recent years, they have shown only modest growth [60]. The political landscape plays an important role in determining these trends, and the present study aimed at evaluating the impact of a 50 % subsidised tax deduction compared to the basic 36 % tax deduction. A DCF was employed to evaluate project profitability, considering the time flow of money and the various cash flows during the project's useful life. This method is widely recognised in the literature for evaluating sustainability projects and provides strategic information to decision makers [56,61].

Several indicators were proposed to assess profitability [62]: (i) net present value (NPV), indicating the wealth generated by a project; (ii) internal rate of return (IRR), indicating the percentage economic return of a project; (iii) discounted do nothing cost 1 year (DDNC-1), indicating the economic wealth lost by delaying project realisation by 1 year, and (iv) discounted payback time (DPBT), indicating the length of time needed to recover the initial investment.

The cash inflows of a PV system include: (i) avoided costs in the bill, representing a profit for the prosumer; (ii) the cost of selling the energy produced and not self-consumed; and (iii) the subsidised tax deduction. Investment costs significantly outweigh operating costs, and the inverter is expected to be replaced after 10 years. The proposed economic model adheres to the structure presented in the literature [62]. Equations (1)–(4) present the economic indicators.

$$NPV = \sum_{t=0}^{N} (I_t - O_t) / (1 + r)^t = DCI - DCO \quad (1)$$

$$\sum_{t=0}^{DPBT} (I_t - O_t) / (1 + r)^t = 0 \quad (2)$$

$$\sum_{t=0}^{N} (I_t - O_t) / (1 + IRR)^t = 0 \quad (3)$$

$$DDNC - 1 = \sum_{t=0}^{N} (I_t - O_t) / (1 + r)^t - \sum_{t=1}^{N+1} (I_t - O_t) / (1 + r)^t \quad (4)$$

whereby DCI is the discounted cash inflow, DCO is the discounted cash outflow, N is the lifetime of the project and r is the opportunity cost of capital. Table 1 presents the economic input data used in this work.

Given the dynamic energy context, characterised by significant variation in energy prices, two market scenarios (MS) were considered:.

- a high MS with a purchase price of 45 cent€/kWh and a selling price of 23 cent€/kWh; and
- a low MS with a purchase price of 25 cent€/kWh and a selling price of 13 cent€/kWh.

Table 1
Economic input data [10,56,63–65]

Variable	Value
Administrative/electrical connection cost	1300 €
Decreased efficiency of a system	0.70 %
Electricity purchase price	25–45 cent€/kWh
Electricity selling price	13–23 cent€/kWh
Interest rate on a loan	3 %
Lifetime of a PV system	20 y
Opportunity cost of capital	5 %
Percentage of insurance cost	1 %
Percentage of inverter cost	15 %
Percentage of maintenance cost	2 %
Percentage of self-consumption	50 %
Percentage of taxes cost	40 %
Period of loan	10 y
Period of tax deduction	10 y
Plant size	100 kW
Rate of energy inflation	1.5 %
Rate of inflation	2 %
Solar productivity	1450 kWh/(kW*y)
Unitary investment cost	1800 €/kW
Unitary subsidised tax deduction	50 %
Value-added tax	10 %

Fig. 1 illustrates the energy consumption. Energy produced was calculated using PVGIS software, as 145,000 kWh in the first year. It was assumed that, based on daily/monthly consumption patterns, the installation of a PV system could achieve 50 % self-consumption.

2.2. Environmental data and PV systems

Among the myriad of available technologies, PV systems stand out as promising solutions for clean and sustainable energy generation [66,67]. The present assessment of the environmental impact of a new PV system was based on the assumption that one kWh of energy produced from renewable sources would replace one kWh of energy produced from fossil sources, resulting in a reduction of CO_2eq emissions [62]. In the literature, new approaches have been proposed to improve environmental performance [67].

The reduction in carbon dioxide emissions (RECD) was quantified by substituting a mix of energy sources (excluding renewables) for that produced by a PV system.

$$RECD = ECD_{FF} - ECD_{PV} \quad (5)$$

$$ECD_{FF} = ECD_{OI} \times PEM_{OI} + ECD_{CO} \times PEM_{CO} + ECD_{NG} \times PEM_{NG} + ECD_{GD} \times PEM_{GD} + ECD_{OT} \times PEM_{OT} \quad (6)$$

In equations (5) and (6), ECD represents the carbon dioxide emitted from specific resources and PEM indicates the percentage in the energy mix of these specific resources. The subscripts refer to the resource concerned: fossil fuels (FF), photovoltaic (PV), oil (OI), coal (CO), natural gas (NG), gas derivatives (GD) and other (OT) (Table 2).

2.3. Energy efficiency data and LED bulbs

LEDs have transformed the energy industry, serving as an ecologically sound alternative to conventional lighting solutions. Notably, compact fluorescent or conventional incandescent lights emit significantly higher levels of greenhouse gases compared to LED bulbs. For example, an LED bulb uses 80 % less greenhouse gas while delivering the same brightness as an incandescent bulb. As a result, carbon emissions are decreased and energy resources are preserved [73,74].

An additional environmental advantage of LED lights is their lack of mercury or other harmful materials, which are often found in other kinds of bulbs. This minimises the risk of pollution associated with LED lights, thereby safeguarding the environment. Furthermore, LED lights can last up to six times longer than other types of lights, representing an additional environmental benefit. They can also save energy and reduce the environmental impact associated with the production of new products. However, studies have also revealed some negative effects of LED lights, such as the disruption of the natural light-dark cycle that has evolved over thousands of years, and to which animals and plants have adapted [75]. This concerns scientists, because light pollution may significantly affect ecosystem health [76].

Energy efficiency stands out as one of the most important solutions for reducing energy consumption and related costs [77]. In this vein, use of LEB bulbs has been identified as an effective measure for lowering energy consumption in hotels [78]. Furthermore, the adoption of energy-efficient technologies may not only reduce overall costs, but also enhance a hotel's brand and increase its attractiveness to customers seeking sustainable solutions.

Use of LED bulbs concerns the fundamental sustainability issue of energy efficiency. The present study did not aim at quantitatively

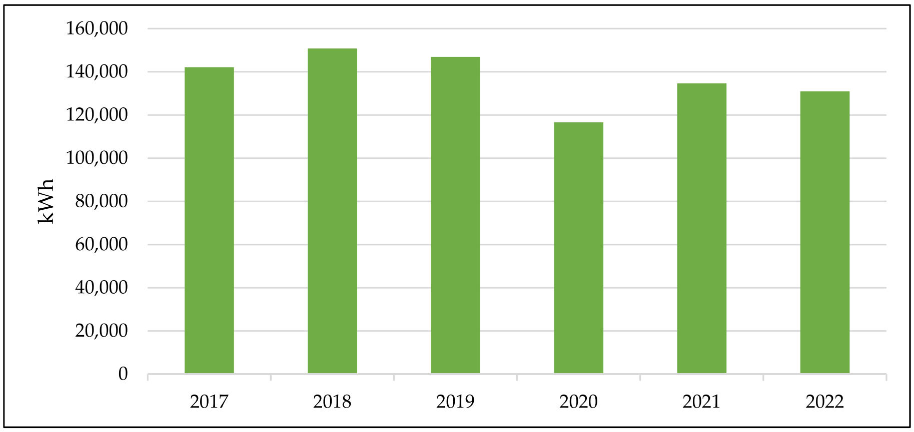

Fig. 1. Hotel energy consumption.

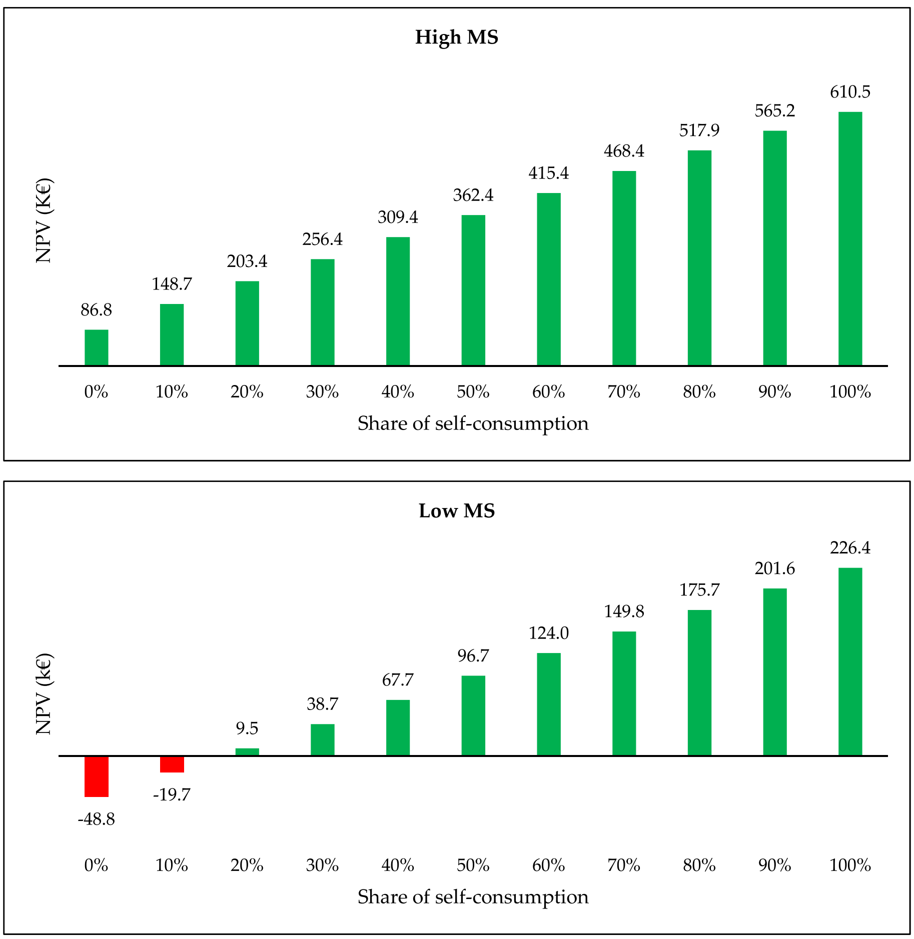

Fig. 2. NPV as a function of the percentage of self-consumption.

Table 2
Environmental input data [62,68–72].

Environmental data	Value	Energy mix	Value
ECD_{PV}	42 gCO_2eq/kWh		
ECD_{OI}	518 gCO_2eq/kWh	PEM_{OI}	5.5 %
ECD_{CO}	927 gCO_2eq/kWh	PEM_{CO}	7.4 %
ECD_{NG}	372 gCO_2eq/kWh	PEM_{NG}	73.9 %
ECD_{GD}	1382 gCO_2eq/kWh	PEM_{GD}	1.0 %
ECD_{OT}	644 gCO_2eq/kWh	PEM_{OT}	12.2 %

assessing the environmental impact of reduced carbon emissions. Instead, the focus was on highlighting how LED bulbs perform with respect to conventional lighting sources in terms of energy consumption [78].

The study data refer to a hotel located in Rome, in which the number of halogen, fluorescent and LED bulbs in different areas of the hotel were counted in the AS IS scenario. The complete dataset is provided in Table 3, and the following model was used to calculate the amount of energy consumed by these bulbs (equation (7)) and the associated costs (equation (8)). From a cost perspective, equation (9) describes the initial

Table 3
Energy efficiency data.

Hotel area	Number of bulbs (halogen)	Number of bulbs (fluorescent)	Number of bulbs (LED)	Annual hours
Rooms	80	200	0	2016
Corridors	0	20	10	4032
Food court and bar	12	0	0	1680
Reception and hall	0	16	12	3360
Outdoor area	18	18	8	4032
Bulb power	100	25	16	

investment costs, while equation (10) proposes the operating costs.

$$ECbyB = BP_U * N_B * N_H \quad (7)$$

$$ACbyLB = ECbyB * p_C \quad (8)$$

$$CI_B]CI_{UB} * N_B + CR_B \quad (9)$$

$$CO_B]CR_B * P_{RC} \quad (10)$$

In which ECbyB represents the energy consumed by bulbs, BP_U represents bulb power in unitary terms, N_B represents the number of bulbs, N_H represents the number of hours, ACbyLB represents the avoided costs by LED bulbs, pc represents the purchase cost of electricity, CI_B represents the investment cost of bulbs, CI_{UB} represents the unit investment cost of bulbs, CR_B represents the bulb replacement cost, CO_B represents the bulb operative cost and P_{RC} represents the percentage of the replacement cost.

The two electricity purchase prices remained consistent with those proposed in the previous phase of the work (i.e., 0.25 and 0.45 €/kWh), considering a unitary bulb price of 25 €/unit with a 600 € replacement cost related to labour hours. Operating costs were considered 50 % of those incurred in the initial phase (300 €/year). Additionally, a useful lifetime of 9 years, a 5 % opportunity cost of capital and inflation rates (i.e., 1.5 % for energy, 2 % for capital) (Table 1) were considered.

2.4. Online survey

Researchers are increasingly focusing on energy and social science, and a behavioural, transdisciplinary approach is useful in this regard, integrating various fields, from economics to psychology according to literature [79]. The online survey serves as a useful research method in this area, particularly in the form of a structured questionnaire distributed to a sample of citizens [80]. In the present study, a survey was developed with the aim of collecting attitudes on sustainability, with a particular focus on hotels.

The survey was distributed via different social media platforms (e.g., Instagram, LinkedIn) and Google forms, to obtain an optimal number of participants and thereby reduce the bias that is typically observed in online surveys. The survey, consisting of 20 items that had been pre-validated by two European academic experts with at least 10 years of experience, covered sociodemographic factors, the green transition, sustainable choices within a hotel and an economic assessment of WTP. A total of 286 valid responses were obtained during March 2023, in alignment with the literature [81]. The purpose of the study was presented at the survey outset, and respondent anonymity was guaranteed.

Relationships among variables were assessed using descriptive statistics and various analytical methods (e.g., ANOVA, Kruskal-Wallis test).

The average age of the sample was 28 years. This represents a limitation, since the results pertained mostly to the behaviour of younger individuals. However, the educational profile aligned with expectations, since only 34 % held a master's degree. Geographically, the sample was predominantly based in central Italy, in line with the study's origin in Rome. Regarding the gender distribution, more males responded than females (62 % vs. 37 %), and just under half identified as a student (43 %). Significant values were also observed for workers (29 %) and student-workers (24 %).

3. Results and discussion

This section is divided into three analyses, each focused on a single sustainability dimension. Initially, an economic analysis of PV plants in the baseline scenario is presented (Section 3.1), with a specific focus on the role played by self-consumption (Section 3.2). Alternative scenarios are subsequently explored (Section 3.3). The section then proceeds to assess the environmental impact of PV systems (Section 3.4), followed by the economic impact associated with the use of LED bulbs, in terms of energy efficiency (Section 3.5). In addition, the results of a social analysis related to consumer perceptions of renewables and energy efficiency are proposed (Section 3.6). Finally, Section 3.7 proposes a discussion with respect to the existing literature.

3.1. Profitability analysis of a PV plant – baseline scenario

The first aim of the present study was to quantify the potential profits generated by the installation of a PV system in a hotel. Table 4 presents the results for the indicators proposed in the previous section, according to the two market scenarios defined in equations (1)–(4).

The profitability of the PV system was tested in both market scenarios with the assumption of a fixed percentage of self-consumption at 50 %. In the high MS, the profitability of this investment was evident. As the cost of electricity rose, the bill for those lacking a PV system increased, representing an avoided cost for the prosumer. NPV ranged from approximately 967–3624 €/kW, demonstrating significant benefits for the business. The costs of not installing a PV system following a 1 year delay (i.e., DDNC-1) were also considered, revealing potential prosumer losses of approximately 4.6 k€ in the low MS and 17.3 k€ in the high MS. Of note, this value solely captured the economic dimension, without incorporating the economic externalities that could arise from the environmental benefits of such a system.

Unsurprisingly, DDNC-1 was higher when the project was more profitable. The subsequent step involved measuring the discounted payback time of the investment, with DPBT offering insight into the value of money over time. Although no cut-off period was proposed, a return from the initial investment during the second year (precisely, 1 year and 2 months) proved attractive. The DPBT value of 8 years and 9 months may seem less attractive, but it fell before the middle of the project life. In addition, the IRR, in the absence of any traps, exceeded the opportunity cost of capital in both cases, thus aligning with the NPV. In particular, the IRR value of 91 % is interesting and significant, signifying a compelling incentive for a hotel to promote such a green initiative.

3.2. The role of self-consumption in PV systems

The economic analyses proposed thus far were based on an assumption of 50 % self-consumption. To generalise these findings to alternative hotel contexts, NPV was made to vary as a function of the percentage of self-consumption, ranging from 0 % (i.e., total energy sale) and 100 % (i.e., total energy self-consumption) [56]. While the

Table 4
Profitability indicators of a PV plant.

Indicator	High MS	Low MS
NPV	362,363 €	96,714 €
DDNC-1	17,255 €	4605 €
DPBT	1 year 2 months	8 years 9 months
IRR	91 %	20 %

lower extreme is mathematically valid, it is realistically unlikely. The upper extreme could be attainable with suitable consumption models, but it is also contingent on other factors and does not necessarily guarantee the total energy autonomy of a hotel (Fig. 2).

The analyses in the previous section demonstrated that the NPV of a PV system is strongly dependent on avoided costs in the bill. These new analyses confirmed another significant finding that is well-documented in the literature, underlining the key role played by the rate of self-consumption [10], [82]. Thus, the adoption of more virtuous behaviour rewarded the prosumer with greater economic returns. For a plant operating in the high MS, a change from 50 % to 60 % self-consumption resulted in a NPV increase of approximately 530 €/kW. Profitability was verified for all scenarios, ranging between 86.8 and 610.5 k€.

Conversely, in the low MS, the change from 50 % to 60 % yielded an increase of 290 €/kW. In this context, profitability was not always verified, since the scenarios with 0 % and 10 % self-consumption exhibited negative NPV. Therefore, the break-even point (BEP) analysis, which identified 17 % self-consumption, was useful. The profitability scenarios ranged from 9.5 to 226.4 k€, demonstrating significantly lower profitability than the previous range. This difference was determined by the change in both key variables: self-consumption price and self-consumption percentage. The higher the percentage of self-consumption, the lower the percentage of energy taken from the grid and, consequently, the lower the energy costs. This translated into an increase in profitability for the hotel owner.

3.3. *Profitability analysis of a PV plant – alternative scenarios*

The subsequent objective was to assess how profitability was influenced by changes in the critical variables. In this regard, sensitivity, scenario and risk analyses were conducted, as described below.

3.3.1. *Sensitivity analysis*

The sensitivity analyses encompassed as many possible self-consumption values as possible, chosen in accordance with the literature [56], [83]. A range of 30–60 % was considered, and both optimistic and pessimistic scenarios were evaluated for the different case studies. Critical variables were selected based on the results of the baseline scenario and in accordance with the literature. Among these, insolation level was not considered, since the work evaluated a hotel in a specific area (Rome) in which this critical variable remained relatively constant. The first critical variable made to vary was the one that most significantly affected costs: investment costs. Its variation delta was ± 200 €/kW (Fig. 3).

NPV was consistently positive, with values in the range 8.1–445.9 k€. Self-consumption price and percentage had no impact on investment costs, so its variation resulted in a change in NPV of approximately 30.5 k€. This variation was possible due to the historical declining trend in PV market investment costs, which was recently reversed due to policies such as a 110 % tax deduction [84]. Moving to the revenues, the variable with the greatest impact was the purchase cost in the bill, which showed a variation of ± 10 cent€/kWh (Fig. 4).

The results for the high MS indicated consistent profitability, varying from 198.6 to 530.9 k€. Higher percentages of self-consumption yielded more significant increases in profitability: approximately 58 k€, 77 k€, 96 k€ and 115 k€ for self-consumption percentages of 30 %, 40 %, 50 % and 60 %, respectively. In contrast, in the low MS, conditions of no profitability were again recorded, particularly for self-consumption percentages exceeding those of the baseline case. In fact, for both 30 % and 40 % self-consumption, NPV was negative. Positive NPV, when present, ranged from 0.5 to 239.4 k€. Of note, two scenarios with a bill cost of 35 cent€/kWh generated different NPVs, due to distinct selling prices for the energy produced and not self-consumed. Thus, a market scenario with a bill cost of 15 cent€/kWh would likely be unprofitable without sufficient self-consumption.

While the avoided cost in the bill was already considered in the differentiation of the two market scenarios, further analysis was strongly indicated by current geopolitical risks, the moderate energy production in Italy, and speculative effects, which have led to significant fluctuations in price. Another relevant revenue component was the selling price. The model, which was designed to promote decentralised models driving prosumer development, necessitated that the energy selling price be lower than the purchase price on the bill. Its variation was set at ± 5 cent€/kWh (Fig. 5).

The results for this variable were less significant than those found for the previous variable, due to the smaller range considered and the lower starting value. NPV ranged between 205.2 and 444.6 k€ in the high MS and 20.9–155.2 k€ in the low MS. Additionally, in this analysis, a scenario with a negative NPV emerged. In this instance, the change in NPV was smaller, corresponding to an increase in the percentage of self-consumption. The changes recorded were 51 k€, 44 k€, 37 k€ and 29 k€ for self-consumption percentages of 30 %, 40 %, 50 % and 60 %, respectively. Variations in this variable were also plausible, given the randomness that characterises the energy market.

Policy choices and incentive policies exerted a significant influence on the results. For this reason, it was assumed that the 50 % subsidised tax deduction scenario would not be considered, and the 36 % scenario would instead be taken into account (Fig. 6).

A higher tax deduction resulted in greater potential revenue, provided tax capacity on the part of the prosumer. Moreover, the tax deduction had a limited impact on the profitability of the investment, when comparing the alternative scenario (36 %) with the baseline

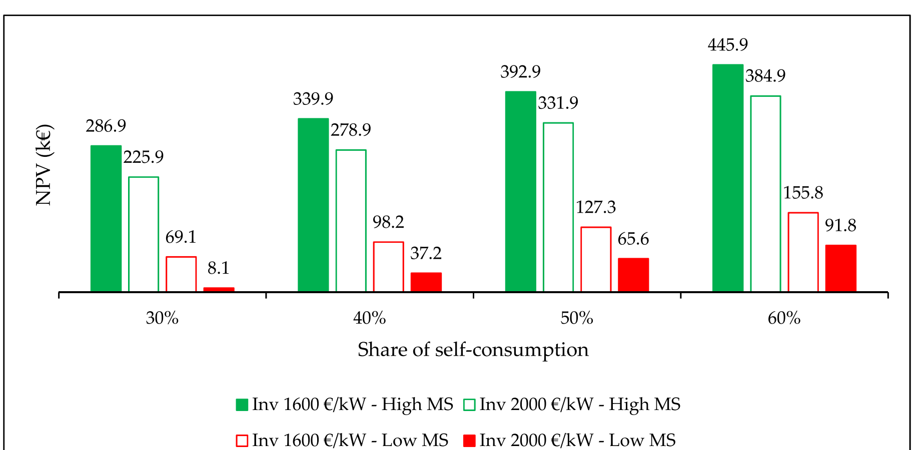

Fig. 3. NPV – Variation in investment costs.

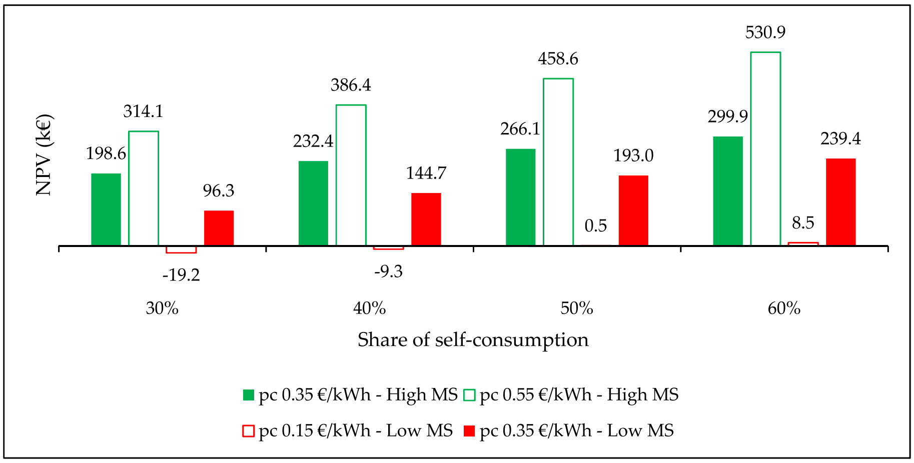

Fig. 4. NPV – Variation in purchase price.

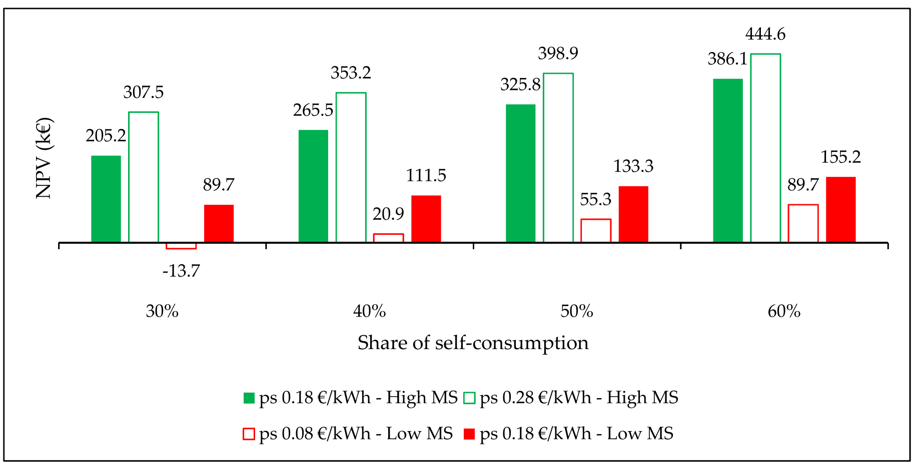

Fig. 5. NPV – Variation in energy selling price.

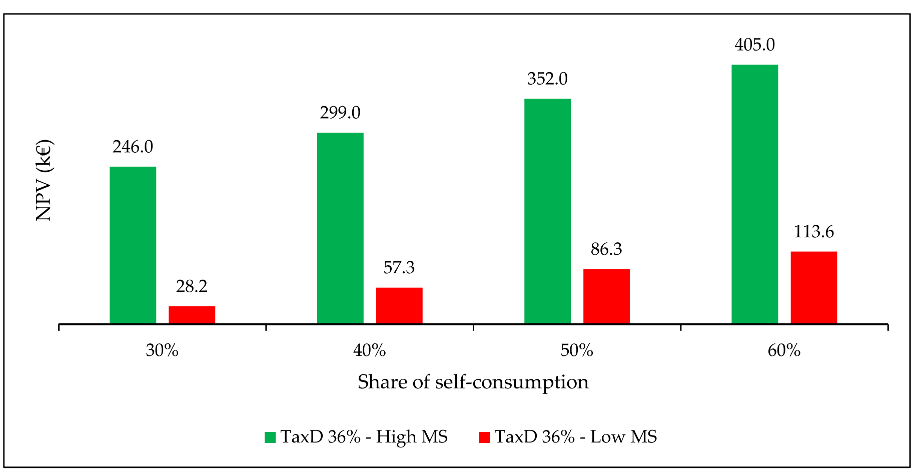

Fig. 6. NPV – Variation in the tax deduction.

scenario (50 %). In fact, there was an increase of approximately 10.3 k€, motivated by the constraint on the maximum allowable expenditure of 96 k€. NPV was consistently positive, ranging from 28.2 to 405 k€. In addition, a BEP analysis confirmed profitability in the high MS in a total energy sales context, while registering only 20 % for the low MS (thus showing an increase from the previously calculated 17 %).

The final critical variable that was made to vary was the opportunity cost of capital, representing a key parameter of the DCF. In this regard, an alternative value of 7.5 was considered (Fig. 7).

The results of this pessimistic scenario, in which the opportunity cost of capital most significantly reduced cash flows over the years, confirmed a positive NPV. NPV ranged from 18.5 to 325 k€, contingent

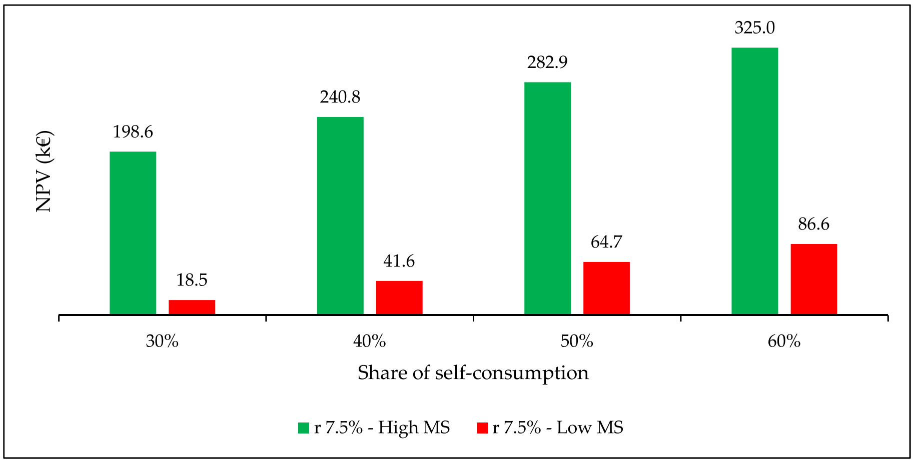

Fig. 7. NPV – Variation in the opportunity cost of capital.

on the percentage of self-consumption and the different market scenarios. In the extreme cases, considering 30 % and 60 % self-consumption, NPV was reduced by approximately 57.8 k€ and 90.4 k€ in the high MS and 20.1 k€ and 37.4 k€ in the low MS, respectively.

3.3.2. Scenario analysis

The subsequent phase in the analysis of alternative scenarios involved the assessment of simultaneous change in the variables. Evaluations were once again conducted for percentages of self-consumption ranging from 30 to 60 %, with a pessimistic scenario considered. On the revenue side, the purchase cost varied by 10 cent€/kWh, and the selling price varied by 5 cent€/kWh (with the same delta as the sensitivity analysis) (Fig. 8).

The simultaneous effect resulted in a reduction of NPV, determining that NPV remained positive in the high MS, while it turned negative in the low MS. In the high MS, NPV varied from 147.5 to 270.6 k€. The reduction was more significant as the percentage of self-consumption increased, with values of 109 k€, 121 k€, 133 k€ and 145 k€ registered for 30 %, 40 %, 50 % and 60 % self-consumption, respectively. On the cost side, investment costs varied with an increase of 200 €/kW, to which increases of 20 % were added for maintenance and insurance costs (to consider more than one variable) (Fig. 9).

This analysis showed that NPV remained positive in the high MS, ranging from 209.8 to 368.8 k€, with a reduction of 46.6 k€. In the low MS, NPV was not positive in the context of 30 % self-consumption. With a higher self-consumption percentage, it ranged from 20.2 to 72.4 k€. Thus, these analyses confirmed that profitability in energy contexts with high market prices generated more profitability for the prosumer in multiple scenarios, even if the prosumer failed to synchronise energy consumption with production patterns. In contrast, some contexts of economic loss occurred in the low-market MS.

3.3.3. Risk analysis

The final tool was a risk analysis, which, in addition to changing variables, also assigned a probability of occurrence to the events. The variables subjected to change were consistent with those of the sensitivity analysis (i.e., investment cost, purchase cost, selling price, opportunity cost of capital), and the analyses were proposed for both 50 % and 36 % tax deductions. The starting scenario considered 50 % self-consumption. Fig. 10 proposes two examples related to the high and low MS with the 50 % deduction, while Fig. 11 aggregates the four case studies.

The results of this analysis were consistent with those generated for the previous analyses. Profitable business outcomes were verified for the high MS, while in the low MS, some contexts emerged in which NPV was negative. Though only the pessimistic scenario was proposed in the scenario analyses, both positive and negative changes in NPV were considered in the risk analyses. These results, applied to 50 % self-consumption, showed significant NPV profitability in the range of 79–84 %.

3.4. Environmental analysis of a PV plant

The second objective of this work was to assess the environmental

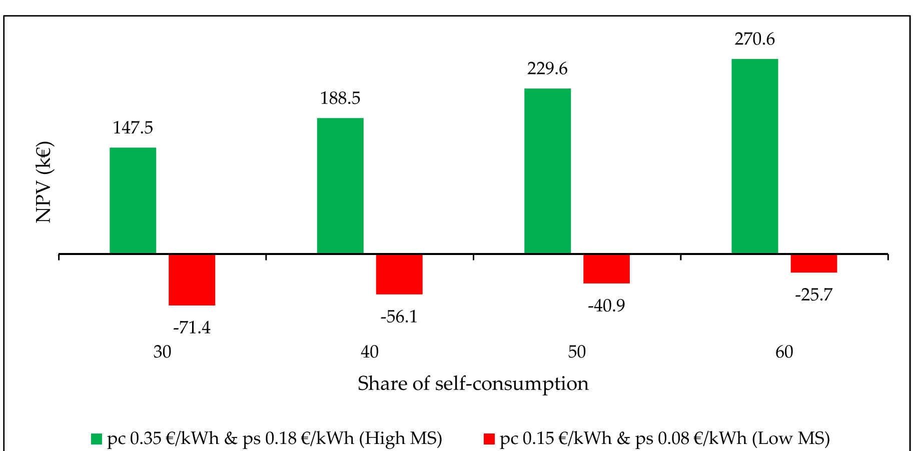

Fig. 8. NPV – Variation in the scenario analysis (revenue side).

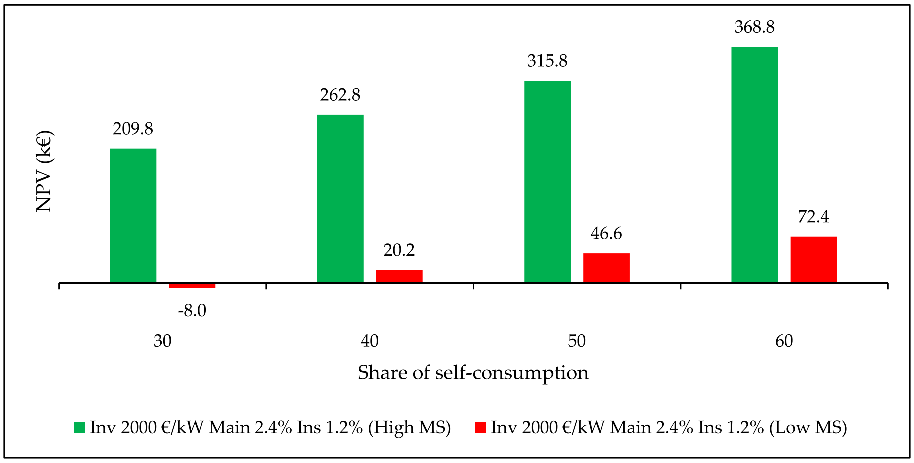

Fig. 9. NPV – Variation in the scenario analysis (cost side).

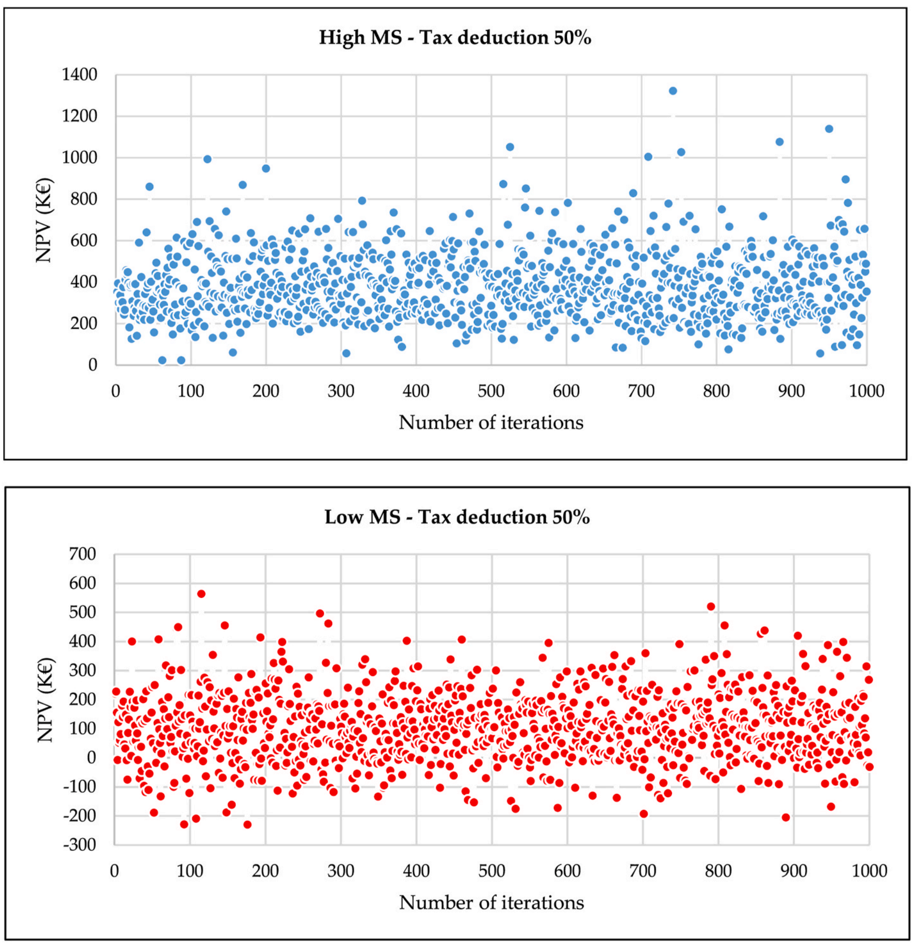

Fig. 10. NPV – Risk analysis with a 50 % tax deduction.

benefits resulting from the implementation of the PV plant. In light of the data proposed in Table 2 and applying equations (5) and (6), it emerged that the emissions associated with fossil sources was 464 gCO_2eq/kWh (ECD_{FF}). Thus, the environmental savings associated with the reduction in emissions per kWh produced by the PV plant, compared to fossil sources, amounted to 422 gCO_2eq/kWh (RECD), obtained as the difference between 464 and 42 gCO_2eq/kWh (ECD_{PV}).

Considering that a 100 kW plant located in Rome would generate approximately 145,000 kWh of clean energy in the first year of operation, the corresponding environmental benefit could be calculated as 61 tCO_2eq/year (i.e., an annual avoidance of up to 61 tonnes of carbon dioxide emissions). Factoring in the annual performance reduction of the PV system over 20 years, with energy production at approximately 126,900 kWh, emissions reductions would be equivalent to approximately 51.5 tCO_2eq/year. This would contribute to decreasing the demand for electricity generated from fossil fuels, thereby positively influencing the overall energy mix and encouraging greater adoption of renewable energy. This environmental achievement would also

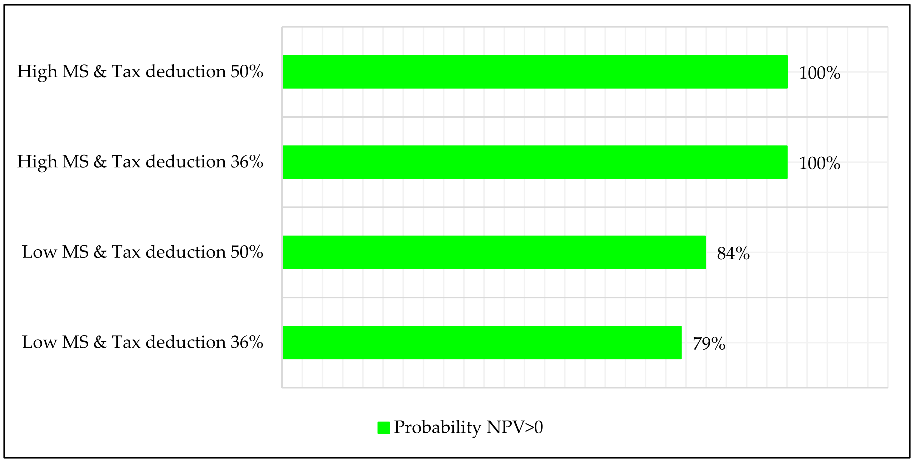

Fig. 11. NPV – Risk analysis with 50 % self-consumption.

represent an asset in the hotel's communication and marketing initiatives, showcasing its commitment to environmental sustainability and thereby increasing customer trust and attractiveness.

3.5. Economic analysis of LED bulbs

According to the model described in Section 2.3, the AS IS situation determined energy consumption of 42,462 kWh/year. In a TO BE scenario, total replacement with LED bulbs would lower this value to 15,633 kWh/year, representing a total reduction of 26,828 kWh/year. The economic valuation of this data, considering the least convenient economic scenario (i.e., the low MS with a unitary avoided cost of 0.25 €/kWh), showed a total cost reduction from 10,615 €/year to 3908 €/year, equating to savings of 6707 €/year (i.e., approximately 63 %). This value was treated as a cash inflow, representing an avoidable cost of installing LED bulbs. The calculation accounted for different areas of the hotel and their respective hours of lighting activity. In the high MS, economic savings amounted to 12,073 €/year, considering a unitary avoided cost of 0.45 €/kWh (Table 5). The results were obtained using equations (7)–(10).

The replacement of 364 bulbs yielded favourable economic outcomes, with NPV in the range of 38,396–78,710 €. Although these values were lower than those determined for the implementation of a PV system, it should be noted that the useful life of the project was approximately half as long. Discounted payback times in both market scenarios were very favourable, requiring 1 years and 7 months in the worst-case scenario and not exceeding 1 year in the best-case scenario – making it well-suited to the hotel's cut-off period.

Economic performance is naturally influenced by the price that would otherwise be paid in the bill. Thus, in a future energy scenario anticipating increased costs in the bill, consumers opting for energy efficiency interventions stand to gain more significant benefits. The IRR, not subject to traps, ranged from 67 to 123 %. However, a 1-year delay in implementation incurred significant costs (1828 € or 3748 €).

To enhance the robustness of the results, the primary variables – the cost of energy and the unit price of bulbs – were varied from the baseline scenario (Fig. 12). The choice of energy cost variation was ±0.05 €/kWh, so as to avoid similar results between the low and high MS. The purchase cost was varied by ± 5 €/unit.

Table 5
Profitability indicators of LED bulbs – Baseline scenario.

Indicator	High MS	Low MS
NPV	78,710 €	38,396 €
DDNC-1	3748 €	1828 €
DPBT	11 months	1 years 7 months
IRR	123 %	67 %

The results confirmed the profitability of this green investment project, with NPV ranging from 28,319 to 88,785 €. Price in the electricity bill remained the most significant variable influencing the results, confirming the strategic importance of this parameter in the evolving energy context moving toward sustainable development. A reduction in energy consumption also inevitably generated environmental benefits.

3.6. Social analysis

After addressing the initial five sociodemographic questions (section 2.4), the study proceeded to examine the subsequent three sections of the questionnaire.

3.6.1. Renewables and energy efficiency in support of the ecological transition

The three questions in Section 2 of the questionnaire, employing a Likert scale ranging from 1 to 5, highlighted respondents' perceptions of the relevance of renewable energy (4.3) and energy efficiency (4.2) in fostering a green transition. The previous finding regarding the important role played by subsidies in supporting renewable energy production found resonance in the results (4.4). However, the distribution of responses revealed a very small sample that appears to agree little or not with these questions (i.e., approximately 2–4 respondents per item) – (Fig. 13).

Cluster-level analyses revealed no significant differences between males and females (a statistically insignificant number of respondents indicated a preference not to indicate a gender) – (Table 6). Nevertheless, a significant difference emerged for age, with approximately 55 % of respondents aged 18–24 years. Respondents in this age bracket tended to show less 'favourable' responses regarding the importance of both renewable energy and energy efficiency for the ecological transition. This suggests a knowledge gap that sustainable education might address. Furthermore, the lower score for subsidies among younger respondents might indicate their perception that green sources can be competitive in the market even without public support.

A Kruskal-Wallis H test indicated a significant difference in the dependent variable between age groups ($\chi^2 = 15.1, p < 0.001$). A post-hoc Dunn's test, using a Bonferroni corrected alpha of 0.017, showed that the mean rank of a renewable-subsidy and energy efficiency–subsidy statistically differed.

3.6.2. Sustainable consumer behaviours in hotels

The subsequent section of the questionnaire aimed at assessing respondents' consumption choices, both sustainable and otherwise, with a specific focus on hotels. Two out of the three Likert scale items revealed

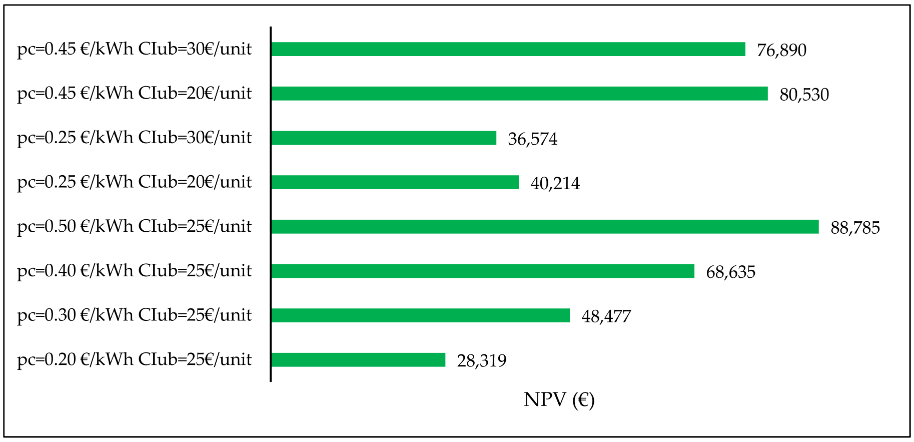

Fig. 12. NPV of LED bulbs – Alternative scenarios.

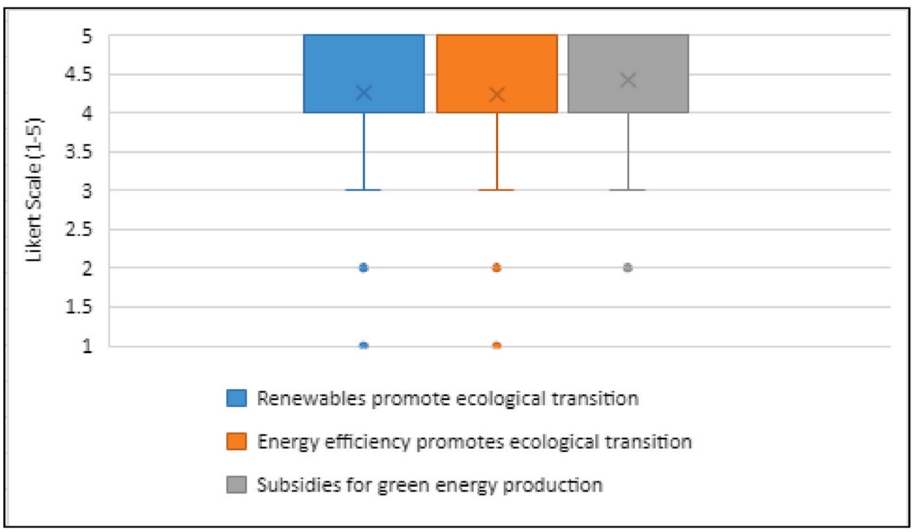

Fig. 13. Factors in support of the ecological transition.

Table 6
Factors in support of the ecological transition – Cluster analysis.

Variable	Renewables promote the ecological transition	Energy efficiency promotes the ecological transition	Subsidies should be provided for green energy production
Gender (Female)	4.2	4.1	4.5
Gender (Male)	4.3	4.2	4.4
Age (18–24)	4.1	4.1	4.4
Age (>24)	4.4	4.4	4.5

a trend toward agreement. Specifically, approximately 57 % believed that increased customer awareness would likely positively influence hotel choices (3.9) – (Fig. 14). There was also strong agreement that smart lighting would support the reduction of energy consumption and positively contribute to sustainability (4.2). In contrast, the item pertaining to sustainable purchasing received a middle rating (3.1), likely due to the higher costs associated with sustainable products rather than a tendency towards non-responsible purchasing choices.

No distinction by gender emerged for these items, and older respondents (i.e., >24 years old) demonstrated a greater inclination to make more green purchases, probably due to greater income and an awareness that sustainable demand can drive supply to become more sustainable (Table 7).

A Kruskal-Wallis H test indicated a significant difference in the dependent variable between age groups ($\chi^2 = 220.58$, $p < 0.001$). A post-hoc Dunn's test, using a Bonferroni corrected alpha of 0.017, showed that the mean rank among all variables statistically differed.

The remaining items in this section adopted a multiple-choice format. Regarding hotel booking priorities, respondents prioritised the distance from the destination (52.4 %) over economic considerations (30.8 %) and quality (16.8 %) (Fig. 15). When asked specifically about preferences for a hotel using green sources when all other factors were equal, only a third of the sample responded affirmatively, while 10 % provided a negative response, considering the use of green sources a non-decisive parameter at that stage. Respondents indicated that most hotel booking decisions were based on a mix of factors. A correlation analysis of the latter question with the responses depicted in Fig. 13 revealed that those who responded affirmatively presented higher

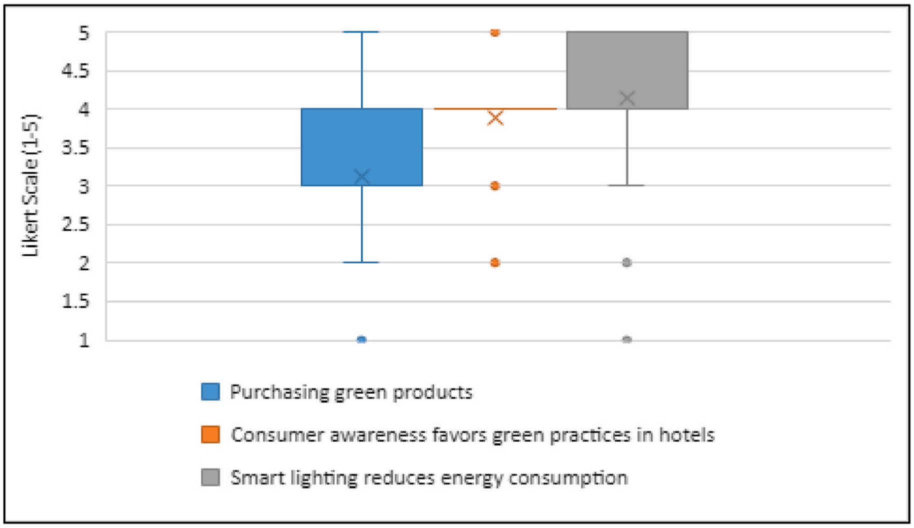

Fig. 14. Purchase of green products, consumer awareness and the role played by smart lighting.

Table 7
Purchase of green products, consumer awareness and the role played by smart lighting – Cluster analysis.

Variable	Purchase of green products	Consumer awareness favouring green practices in hotels	Smart lighting to reduce energy consumption
Gender (female)	3.2	3.9	4.2
Gender (male)	3.1	3.9	4.2
Age (18–24)	3.0	3.8	4.1
Age (>24)	3.3	4.0	4.2

values than those answering negatively (4.4 vs. 3.8, 4.4 vs. 3.9 and 4.5 vs. 4.2 with respect to renewable energy, energy efficiency and subsidies).

Some items aimed at determining whether other factors (e.g., price, marketing strategies) could influence this result. Price may have emerged as a critical factor, if it had been decisive with respect to distance. Marketing strategy seemed to impact hotel visibility, but it depended exclusively on the hotel's ability to implement an engaging marketing campaign, irrespective of its sustainable choices. In all cases, the survey results underlined a few hotel characteristics hindering the effective equality between increased WTP and actual payment (Fig. 15). Of these, distance was the most significant factor. The potential obstacle to translating willingness into action was therefore a consumer preference for convenience. This should be addressed through sustainable education to convey that a consideration of factors that are more attuned to ecosystem balance could generate greater and more widespread benefits.

Thus, respondents seemed to place less emphasis on sustainability considerations when choosing a hotel, as reflected in the answers to the question: 'Have you ever noticed whether sustainable products (e.g., organic soaps) were present in the hotels where you stayed?' Negative responses slightly outnumbered positive ones (51 vs. 49 %) (Fig. 16). Of note, respondents who answered negatively were highly convergent (approximately 86 %) with those expressing a negative preference for hotels using green sources (Fig. 15). In contrast, those who responded positively aligned closely (78 %) with those affirming a preference for hotels using green sources, highlighting a consistency in respondent perspectives. Another question gauged the extent to which respondents observed inadequate recycling collection at hotel front desks, with only 14.7 % responding affirmatively. A correlation emerged between this group and those noting the use of sustainable products in hotels (71 %). Notably, this group did not consist of respondents who responded negatively to the prompt of whether they would prefer a hotel using green sources. Most respondents expressed a willingness to engage in their own recycling collection (approximately 46 %).

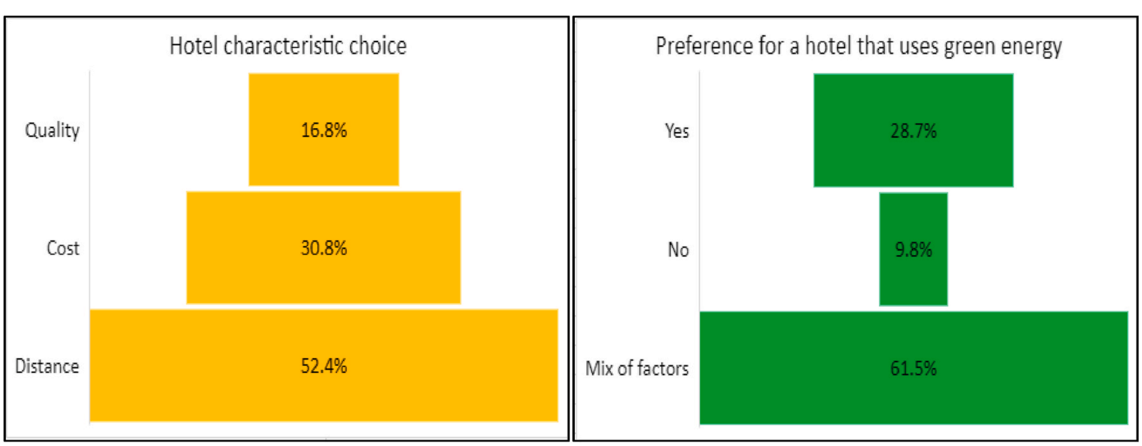

Fig. 15. Hotel choice factors and preference for a hotel using green energy.

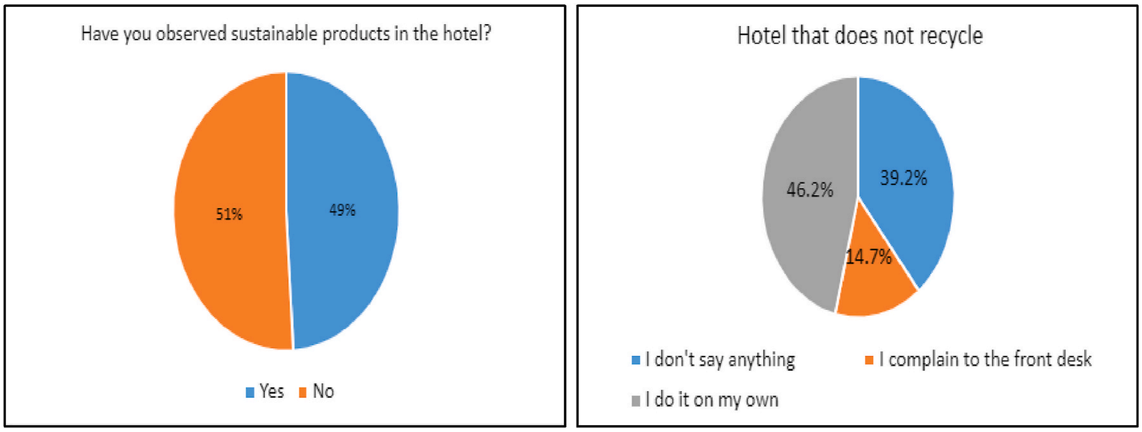

Fig. 16. Sustainable hotel products and waste collection.

3.6.3. *WTP – the economic side of the social analysis*

The final section of the questionnaire pertained to economic aspects, specifically investigating the existence of a green premium associated with choosing a hotel using green sources, compared to one using less sustainable energy sources. Most respondents opted not to state their preference with regard to this aspect (45 %). However, among those who responded, a higher number responded in the affirmative, rather than the negative (33 vs. 22 %) (Table 8).

A cluster analysis was performed with respect to gender and age. Here, an initial difference by gender emerged, with both genders favouring the neutral response, but males demonstrating a more pronounced negative response relative to females (who instead demonstrated a more pronounced neutral response). The age-based analysis confirmed a lower propensity among younger respondents (aged 18–24 years) to prefer hotels using green sources, demonstrating a 17 % point difference (25 vs. 42 %) from older respondents, who were otherwise equally split between the affirmative and neutral responses. Respondent answers to this question were verified by a further question investigating their preferences for green hotels. From this, it emerged that those responding positively reported a higher WTP for green hotels (i.e., a green premium), while those responding negatively did not, as they were instead interested in a mix of other factors.

Finally, the questionnaire sought to quantify WTP for a generic hotel. Responses indicated an average value of 59.7 €/day. Further questions inquired into how much more respondents would be willing to pay if the hotel used renewable energy (Fig. 17). The average value of this premium was 13.2 €/day, representing a significant 18 % of the total value. This question was repeated to assess WTP for hotels without smart lighting, resulting in an average value of 56.3 €/day. Of note, this value aligned with the value identified previously. To assess the green premium for smart lighting, respondents were asked to indicate any increase in their WTP, resulting in an average value of 8.3 €/day, corresponding to 13 % of the total value. An ANOVA revealed significant differences in the mean WTP and green premium values between all four groups ($F(3, 1140) = 829.06$, $p < 0.001$).

At this stage, a cluster analysis was conducted to uncover nuances among the respondents (Table 9). Notably, females demonstrated a higher green premium for both sustainable aspects relative to males. Although the survey data could not provide a clear rationale for this result, they suggested a general willingness among females to recognise a higher WTP for hotels. Regarding age, the findings aligned with the previous observations, indicating that respondents older than 24 years expressed a WTP of 15.5 and 9.8 €/day for green sources and energy efficiency, respectively – values that were significantly higher than those registered for younger respondents. Finally, those expressing a positive preference for hotels using green sources recognised a higher green premium than those responding negatively, with a significant delta of 12.9 and 7.1 €/day for green sources and smart lighting, respectively.

Table 8
Are you willing to pay more to stay at a hotel using green sources?

	Yes	I don't know	No
Entire sample	33 %	45 %	22 %
Gender (female)	32 %	53 %	15 %
Gender (male)	34 %	41 %	25 %
Age (18–24)	25 %	48 %	27 %
Age (>24)	42 %	42 %	16 %
Yes (green hotel)	63 %	22 %	15 %
No (green hotel)	0 %	50 %	50 %

3.7. *Discussion*

The main implication of this work is to provide a clear indication of pragmatic sustainability, applied to the context of hotels involving the lives of many citizens. The replicability of the model, with the limitations highlighted above, allows the evaluation of not only the three dimensions of sustainability but also the impact of two different technologies.

This work in accordance with previous studies [29] has focused on the energy component which is found to be very significant in the hotel sector [30,31]. The idea of proposing multiple economic indicators is geared toward countering business approaches that may have an unsustainable and short-term oriented outlook [32], and it should be understood that the success of pragmatic sustainability is one that is based on sustainable community models [17]. In this regard, what had been proposed in the literature is confirmed [34].

Some analyses have placed the importance of assessing the different dimensions of sustainability also linked to the technical component [40,40,41] and highlighted how sustainable tourism is based on hotels [43]. This work with a pragmatic approach aimed to show the benefits that can be achieved with a combination of technologies and confirmed how social analyses are essential. However, although some analyses show positive results from this perspective [44,45], several aspects emerge in our research that deserve more attention and also the implementation of precise policies to mitigate phenomena of lack of knowledge or lack of interest on the topic. Sustainability is a challenge that is won by identifying the balance point between environmental protection, social welfare and economic opportunities, but also by problem-solving oriented actions that thus allow sustainability to be combined with competitive models and competitiveness. The choice of the two technologies considered in this paper assumed in accordance with previous work [52,53] are part of the set of a wide range of opportunities for hotels to be more sustainable. Such analyses need to be framed in a model in which green innovations provide financial benefits [57], frame

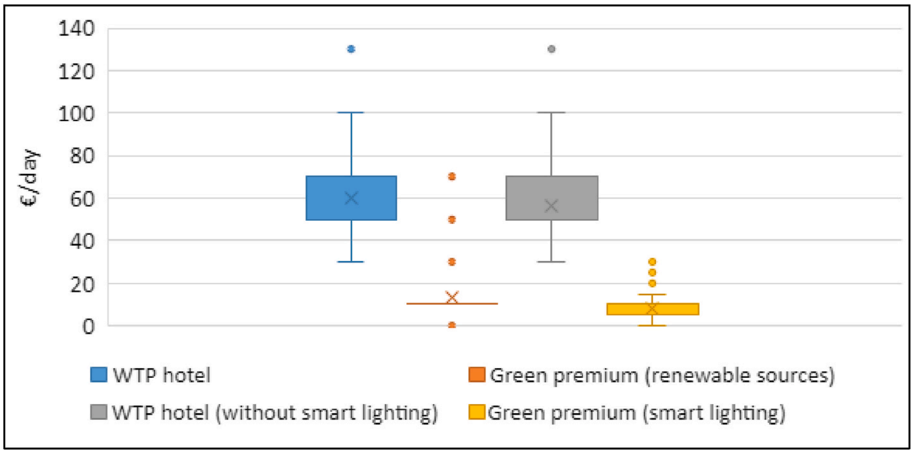

Fig. 17. WTP for a hotel – Impact of green energy and energy efficiency.

Table 9
WTP for a hotel (€/day) – Cluster analysis.

	Green premium (renewable sources)	Green premium (smart lighting)
Entire sample	13.2	8.3
Gender (female)	16.2	10.4
Gender (male)	10.4	6.7
Age (18–24)	11.4	7.2
Age (>24)	15.5	9.8
Yes (green hotel)	18.8	10.7
No (green hotel)	5.7	3.6

the development of sustainable communities [56] such that different green and circular projects are shared. However, the real challenge lies in human resources [48] capable of achieving change in this area.

4. Conclusions, policy implications and way forward

The present study aimed at evaluating the impact of adopting a PV system and installing LED bulbs in a hotel to encourage a sustainable transformation. The assessment considered all three dimensions of sustainability, thereby representing a novel contribution to the literature. Specifically, the research investigated the profitability of these investments, quantified the environmental reduction associated with PV systems compared to fossil fuels and proposed an online survey of an Italian sample to assess consumer attitudes toward sustainability in hotels. The results confirmed the cost-effectiveness of PV systems, with NPV in the range of 967–3624 €/kW, depending on the energy market scenario. Notably, the prosumer realised greater economic gains as electricity prices increased. This highlights the first limitation of the work, confirming that sustainability should involve all stakeholders, through a pragmatic approach. Thus, all hotels should be able to access support for the green transition, as the work quantified the economic losses that result from the non-implementation of a project. This indicator (i.e., do nothing cost) should be communicated more to stakeholders.

In a high-price energy context, DPBT was approximately 1 year; however, in a low-price context, it could extend up to 9 years. The IRR, ranging between 20 and 91 %, was also very attractive, and the 50 % subsidised tax deduction enhanced affordability (relative to the 36 % tax deduction). Nevertheless, the variables with the most significant influence on the economic results were the purchase price of energy and the percentage of self-consumption. The alternative scenarios confirmed these assumptions, with profitability always verified in the high MS and achieved 79–84 % of the time in the low MS.

From an environmental perspective, the PV plant saved 61 tCO_2eq/year, though efficiency loss over its lifetime reduced this value to 51.5 tCO2eq/year. LED bulb replacements further yielded significant economic benefits, with NPV varying between 105 and 216 €/lamp, IRR ranging between 67 and 123 % and DPBT falling between roughly 1 and 2 years. Analyses of alternative scenarios confirmed these results and highlighted the strategic role played by the energy purchase price. From an environmental perspective, additional benefits emerged, as less electricity was consumed; however, further analyses are required, considering the entire product life cycle.

Finally, a social analysis was conducted to verify sustainability requirements. Respondent attitudes indicated a preference for renewable and energy-efficiency installations as strategic choices to further the ecological transition, while also recognising the significant relevance of subsidies. While respondents seemed aware that their virtuous behaviour would push hotels down a more sustainable path, they placed less priority on hotels' sustainability choices, and instead prioritised hotel location (i.e., the distance between the hotel and their preferred destination) in their booking decisions. Thus, hotels must strengthen their sustainable consumption while maintaining their accessibility to attractive destinations. Alongside this, sustainable education and knowledge models may increase consumer awareness of the benefits of choosing hotels using sustainable principles.

Despite respondents' limited inclination for choosing such hotels, their WTP demonstrated green premiums of 13.2 €/day for hotels using green sources and 8.3 €/day for hotels using smart lighting. In light of the profitability determined for these projects in the previous analyses, hotels may capitalise on this green premium, while improving their sustainable footprint. However, a discrepancy may remain between respondents' stated WTP and the actual amount they will pay. Thus, a field experiment presenting consumers with an actual choice would be valuable. No significant differences emerged between genders at the cluster level, though females reported a higher green premium. With respect to age, younger respondents (aged 18–24 years) demonstrated less sustainable preferences throughout the questionnaire.

Some limitations of the present work must be acknowledged: (i) from an economic perspective, further exploration of the impact of storage is warranted, but also the proposition of alternative policies (i.e. capital deduction); (ii) from an environmental point of view, an assessment of the life cycle of LED bulbs should be included but also the development of new analysis related to the comparison between fossil and green sources; and (iii) from a social perspective, testing respondent responses in light of financial incentives and conducting field experiments could refine the accuracy of the present quantifications of WTP. Therefore, a hotel capitalising on economic opportunities could simultaneously install PV systems and LED bulbs, translating these initiatives into environmental benefits.

The policy implications of this work suggest the necessity of promoting sustainable education with targeted actions to increase citizens' sense of responsibility. Businesses in the hotel sector are called upon to contribute to this transition. Therefore, measures to support them are needed, alongside green economy and circular economy practices. Sustainable certifications for hotels, emphasising environmental concerns, could be encouraged by the acceptance of increased WTP, linked to green public/private transportation initiatives, considering the priority given to hotel location. Similarly, complementary services could be proposed to enrich leisure and entertainment needs: clearly the choices would be different depending on clients who travel for work or not and depending on disposable income. Circular practices and product recovery (of, e.g., PV systems and LED bulbs) should also be supported to extract valuable materials and reduce the elimination of hazardous ones – especially with regards to LED bulbs. To this end, a proper recycling policy and minimisation of landfill disposal should be encouraged. Potentially, a bonus could incentivise the purchase of new efficient bulbs and the return of old ones. The development of sustainable communities should involve minimal bureaucratic impediments but paying attention to measures to control the use of public money.

Transformation toward a pragmatic sustainability model hinges on individuals' recognition of the benefits of sustainable choices beyond the personal economic sphere. Thus, further investigation into the policy mix (i.e., subsidies for sustainable choices, taxes for non-sustainable choices) that could foster hotel transformation (distinguishing, e.g., between accommodations that operate in mountain versus coastal locations or those based in large or medium-sized cities) is warranted.

The combination of renewable energy sources and energy efficiency initiatives stands out as a winning choice for policy makers. Thus, policy makers should support transformation in this direction within the hospitality sector. Tourism, representing a key driver of national economies, requires support to develop the necessary clean and affordable energy models.

CRediT authorship contribution statement

Christian Enrico Barbara: Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Idiano D Adamo:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Data curation, Conceptualization. **Massimo Gastaldi:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Abdul Sattar Nizami:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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