Introduction of Electricity Storage and Photovoltaics for an Adequate Self-Sufficiency in Large Building Complexes

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Abstract: Energy usage in large-scale premises exhibits a distinctive pattern, encompassing both thermal energy and electricity. As a result of the recent energy crisis, the operational expenditures associated with these demands have markedly risen. In line with EU Energy Policies, one of the future goals is the transition towards energy-wise self-sufficient buildings powered by renewable energy sources (RES). Nowadays, a combination of contemporary energy management systems, electricity storage and RES are proposed to achieve nearly zero emission-producing energy consumption in buildings. This paper examines the energy consumption patterns of a hotel situated on the Mediterranean, in order to investigate the potential of RES-induced independence and forecast future expansion prospects. An algorithm has been introduced to both optimize and enhance the self-sufficiency of the hotel under consideration. The proposed algorithm successfully enhances the hotel's energy self-sufficiency, achieving a remarkable 99% rate through the dimensions of PV power and corresponding battery capacity for all years under examination, yielding the corresponding financial and environmental conclusions.

Key-Words: - Energy transition, prosumers, self-sufficiency, RES, sustainable hospitality, GHG emissions.

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1 Introduction

Sustainability in premises of large scale has emerged as a significant concern for numerous nations in recent decades, [1], [2], [3]. The infrastructure sector ranks among the largest energy consumers, accounting for approximately 30% to 40% of total energy consumption, [4]. Furthermore, over a third of all greenhouse gas (GHG) emissions, [5], a pivotal factor in global warming and climate change, [6], [7], are produced by building complexes, contributing to atmospheric imbalance, [8]. Hence, attaining sustainability in buildings is a concept supported by multidimensional pillars, such as environmental, economic, social, ecological, technical, and technological ones, [5].

To manage the increased operational expenditures associated with energy demands during an energy crisis, individuals and businesses often need to take steps to reduce their energy consumption, invest in energy-efficient technologies, explore renewable energy options, and adapt their operations to the changing energy landscape, [9], [10], [11]. This may also involve government and industry collaboration to address the crisis and finding solutions to stabilize energy costs.

The energy policies of the European Union aim at decarbonising the economy, towards energy transition, [12] and thus outline a future goal of achieving self-sufficiency in energy through renewable sources and the construction of buildings that are close to achieving net-zero energy consumption, [13], [14], [15].

This concept necessitates that a building's local installation of renewable energy sources (RES) should provide sufficient thermal and electrical energy to meet its needs. In accordance with EU goals, Greece has conceptualized certain policies and measures aspiring to achieve similar goals. Such measures include RES system installation through the scheme of net metering and virtual net metering, promotion of renewable energy systems for heating and cooling and improving the energy efficiency of existing machinery and installations, [16], [17].

A combination of RES technologies and state of the art storage systems, which are developed with the use of green technologies, permits the extension of a system's efficiency. A storage system contributes to the stabilization of RES production and strives to remove the stochastic aspect of the process, to ensure the system's self-sufficiency, [18], [19].

According to the latest inventory of building stock conducted the by Hellenic Statistical Authority in 2011, hotel buildings constitute 1.7% of Greece's building stock. Thus, the present study adopts a Mediterranean hotel's energy consumption as the object of research, since the specific geolocation combined with the financial approachability of PV technologies, embedded with a storage system, leads to the successful introduction of the specific coupling to an energy system integrated to the local network. The energy demand until 2030 is forecasted, in an effort to determine whether a long-term investment is feasible for potential interested investors.

In order to determine the optimal characteristics of the coupling to be installed, an algorithm is implemented that determines the PV power and storage capacity required to ensure a satisfactory percentage of self-sufficiency, allowing the potential investor to maintain a competitive business model in the hospitality industry. The algorithm calculates the required annual system expansion after the initial installation, maintaining the same rate of self-sufficiency for the entirety of the investment's time horizon.

The specified algorithm estimates the annual needed system expansion required for 99% of self-sufficiency, with a total expenditure of 16,950,000 € and a payback period of 15.5 years. The results of the study are quite discouraging for any interested party, an obstacle that could be surpassed through governmental support in the form of subsidies that would reduce the initial investment needed for such an investment.

Nonetheless, apart from the financial investigation of the proposed installation, the environmental impact is estimated. Despite the decline in global interest due to the lockdowns induced by COVID-19 and the disruptions in the supply chains due to the Ukrainian war, the frequent heat waves and heavy rainfalls noted in the southern and middle European countries resurface the public's concern, [20].

As both energy production and consumption are considered crucial factors for the reduction of greenhouse gas emissions, to succeed in the sustainability of energy usage and supply, the CO_2 footprint calculation is one of the effective ways to evaluate GHG emissions. The concept of a CO_2 footprint originated from the ecological footprint concept proposed by William in 1992, which refers to the number of greenhouse gases (GHG) emitted through production and consumption activities, [21].

According to the literature (C2es.org & Statista.com), in 2019 electricity and heat were responsible for 32% of world greenhouse gas emissions. Therefore, this study will attempt to calculate CO_2 mitigation, thus, outlining a different important outcome of the proposed algorithm.

2 Materials and Methods

2.1 Data Analysis

In this study, a representative 5-star hotel on the Crete Island was analysed and its energy needs were investigated. The specific hotel occupies a surface area equal to 384,451.4 m^2, with a total capacity of 411 rooms.

The period of electricity consumption that has been used in this study is two years: 2021 and 2022. Figure 1 presents the total annual electricity demand and the corresponding power peaks for 2021 and 2022, respectively.

In 2021, the total demand for electricity reached 382MWh with a peak power at 1.53MW. In 2022, the total demand increased up to 576MWh with approximately the same peak power at 1.55MW.

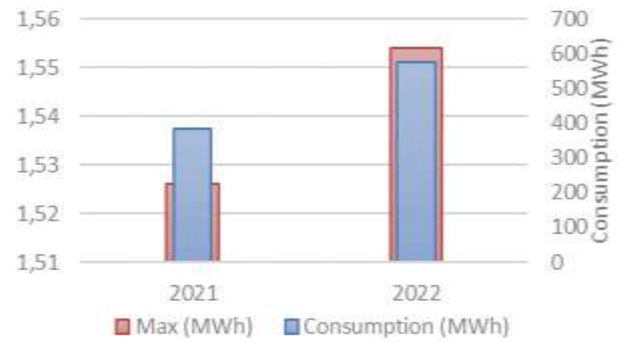

Fig. 1: Annual consumption and hourly recorded max

Taking into account the annual consumption, as well as the total numbers of rooms, the annual average consumption per room is calculated at 1,208 kWh/room for 2021 and 1,706kWh/room for 2022.

Furthermore, as expected, the highest monthly energy consumption values for the specific two-year period range between April and October. The following Figure 2 and Figure 3 show the monthly consumption as well as the maximum hourly recorded consumption for each month, respectively.

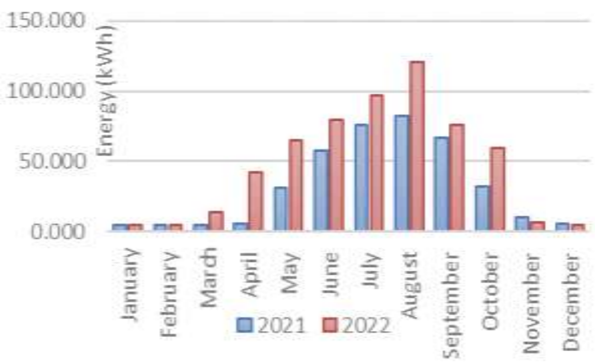

Fig. 2: Monthly consumption of 2021 and 2022

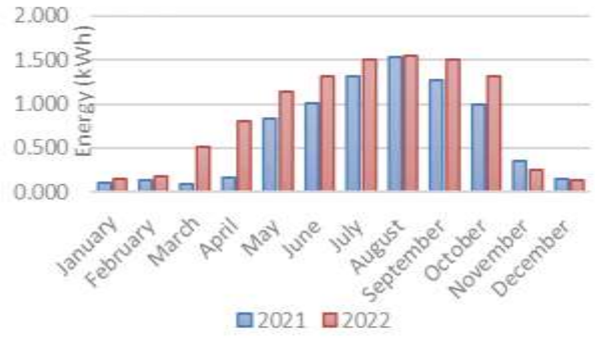

Fig. 3: Demand peaks of 2021 and 2022

By observing the monthly analysis, it is evident that in August the highest consumption of the whole year was recorded, a typical case for a hotel located in the island of Crete, where the peak of traffic attributed to tourism is notified in the specific month. In comparison to 2021, the consumption for each month of the year 2022 has increased, indicating an annual rise in hospitality levels. In Figure 4 and Figure 5, the electricity demand, for both the days of this specific month and the most demanding week of the month, are depicted.

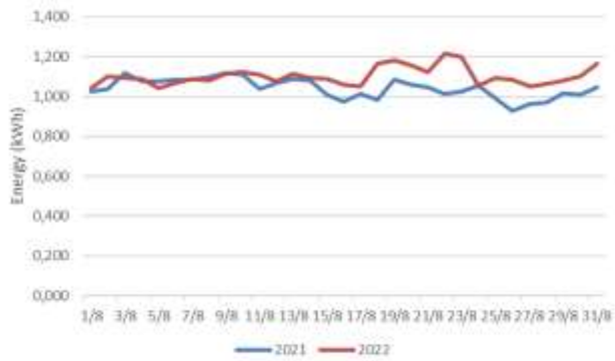

Fig. 4: Calculation of energy imported from the grid

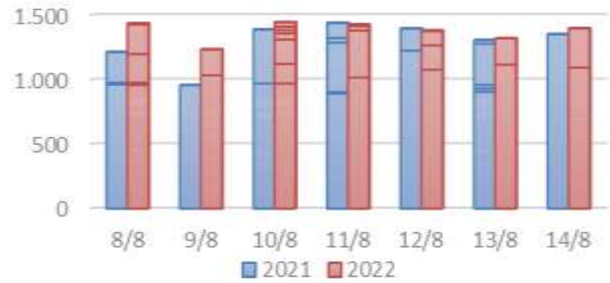

Fig. 5: Most demanding week of August

Moreover, a notable observation from Figure 4 and Figure 5 is the increase in electricity consumption between the two years, with variation in the differences for each week.

2.2 Methodology

The annual pattern of demand is present in both years, indicating a rise during summer and a decrease in winter, fluctuations that, as previously mentioned, remain the same every year. The seasonality spotted in the time series of the demand for the two years, along with the increase in the values of 2022, permit an elementary forecasting method for the years 2023-2030. For every forecasted year, the total annual demand is selected to be equal to that of the year 2022 multiplied by a factor of value greater than one, leading to a saturation level, equal to the total visitation capacity of the hotel, as presented in Figure 6. The assumption being made is that there will be a rise in the hotel's popularity in the coming years. Each year's hourly values are multiplied by their respective factor, allowing the implementation of the algorithm to be described.

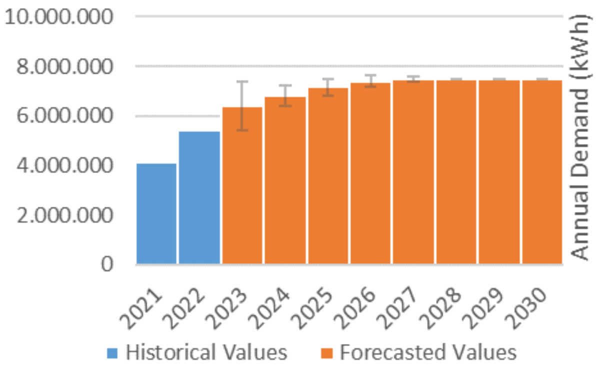

Fig. 6: Estimation of imported electricity from grid

The algorithm's successful implementation requires the acquisition of two datasets, the hourly values of the hotel's annual demand for 2021 and 2022 and the hourly energy output data from a solar panel situated in Crete. Using these datasets, the algorithm computes the status of the energy storage system for each hour, as well as the distribution of energy derived from photovoltaic production and the grid's contribution to meeting the energy demand. Subsequently, overall metrics related to the system's efficiency can be calculated and utilized to establish a correlation between these metrics and the decision variables within the model.

The hourly demand values are represented as Load[t], where 't' represents the number of hours after installation, and the normalized PV (Photovoltaic) output as PV[t]. So, for a specific hour 't,' the PV output PV_out[t] is equal to:

$$PV_{out}[t]=PV_{power}*PV[t] \quad (1)$$

here, PV[t] represents the normalized PV output for that specific hour, and "PV Capacity" denotes the capacity or potential of the solar panel installation. The product of these values gives the actual PV output for that hour.

Before the theoretical installation, it is assumed that the storage system starts at full capacity upon integration into the energy system (Storage[0] = Capacity). Additionally, both output and storage efficiencies are set at 90%, with the maximum output determined as 'max(Load[t])' for each hour from t=1 to t=8760.

Using the collected data, essential hourly values that characterize the system's behaviour are computed.

First, the output of the storage system integrated into the system for each hour, denoted as "Battery_out[t]," is computed following the procedure outlined in Figure 7.

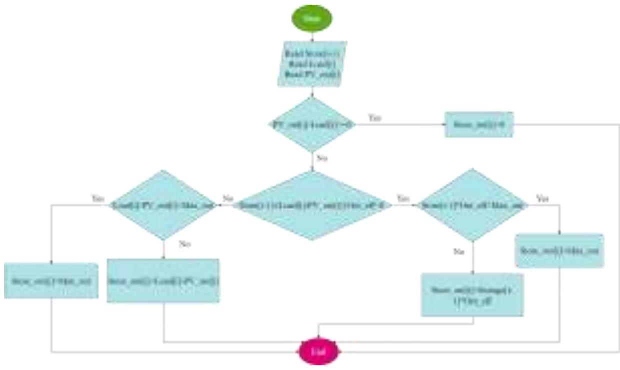

Fig. 7: Calculation of battery storage discharge after each hour

Thereafter, the total amount of energy stored in the battery at the conclusion of each hour 't' is determined, as depicted in Figure 8.

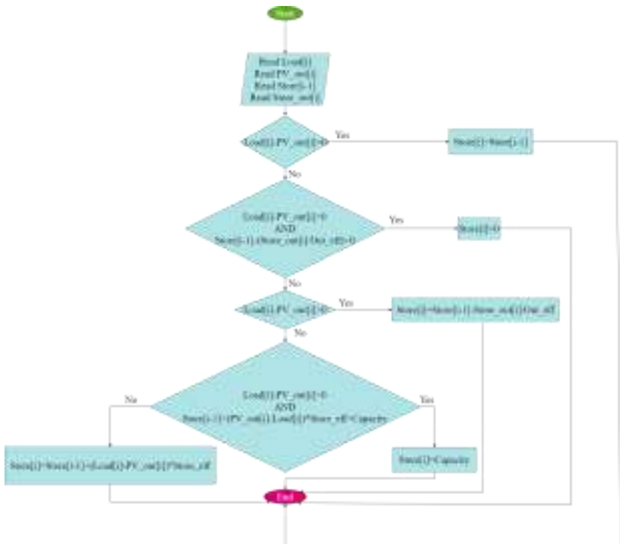

Fig. 8: Calculation of battery storage level each hour

In situations where neither the PV production nor the battery storage is adequate to meet the energy demand, the system resorts to importing power from the grid. The calculation of the amount to be imported is detailed in Figure 9.

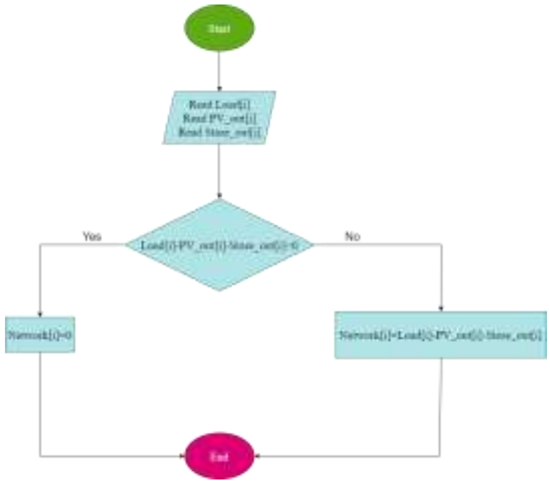

Fig. 9: Calculation of energy imported from the grid

Given the constraints of both storage capacity and round-trip efficiency, the surplus energy generated by the photovoltaic system, after accounting for losses, cannot, always, be entirely stored. As a result, the system must consider and calculate rejections, as demonstrated in Figure 10.

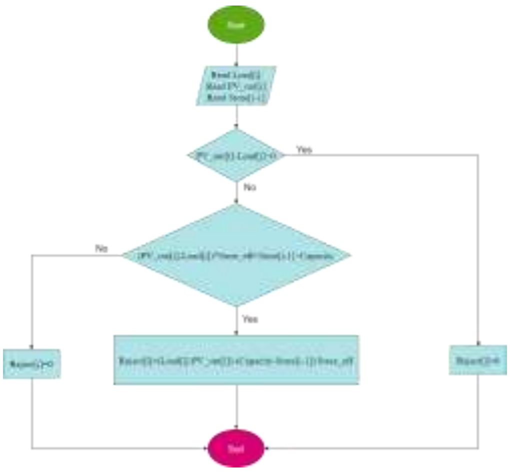

Fig. 10: Calculation of rejections of each hour

Furthermore, the losses incurred by the storage system following each charge or discharge operation are determined according to the procedures outlined in Figure 11.

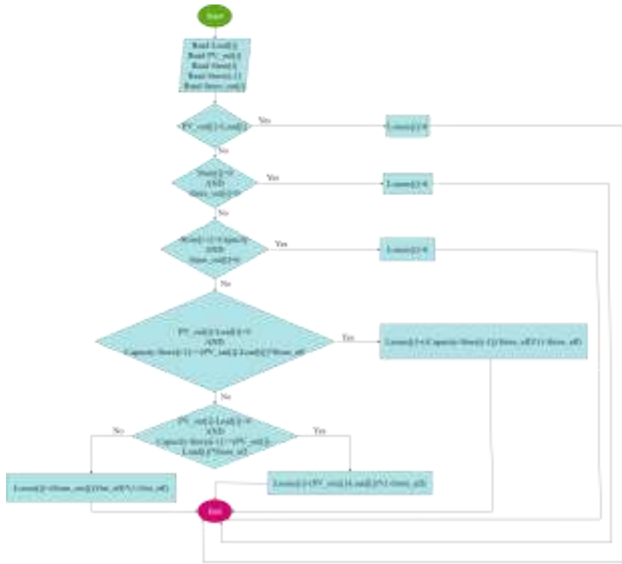

Fig. 11: Calculation of system losses in each hour

Through the hourly attribute calculations outlined earlier, the system derives the annual percentages for rejections, network contributions, and its self-sufficiency.

The percentage of the network's contribution is calculated as the annual energy imported over the annual energy requirement:

$$Network_{perc}=\frac{\sum_{t=1}^{8760} Network[t]}{\sum_{t=1}^{8760} Load[t]} \quad (2)$$

The annual rejection percentage is determined by dividing the annual amount of rejected energy by the total PV production that was neither discarded due to the storage system's inefficiency nor adequately stored by the end of the year:

$$Rej_{perc}=\frac{\sum_{t=1}^{8760} Rej[t]}{\sum_{t=1}^{8760} PV_{out}[t]-\sum_{t=1}^{8760} Losses[t]-(Store[8760]-Cap)} \quad (3)$$

The percentage of annual energy successfully harnessed is calculated by subtracting the combined amount lost, rejected, and stored at the end of the year from the annual PV production and full charge of the storage system. This result is then divided by the annual energy requirement:

$$SS_{perc}=\frac{\sum_{t=1}^{8760} PV_{out}[t]+Cap-\sum_{t=1}^{8760} Rej[t]-\sum_{t=1}^{8760} Losses[t]-Store[8760]}{\sum_{t=1}^{8760} Load[t]} \quad (4)$$

Through the calculation of the values derived from equations (2), (3), and (4), it is possible to ascertain the relationship between annual self-sufficiency, installed PV power, and storage capacity. Additionally, the correlation between capital expenditure and these variables can be determined.

2.3 Calculation of CO_2 Emission

The dual needs of economic growth and emission reduction constitute a grand challenge for all countries, [22], leading, thus, nations, researchers and scholars on measurements of CO_2 footprints and their evaluation.

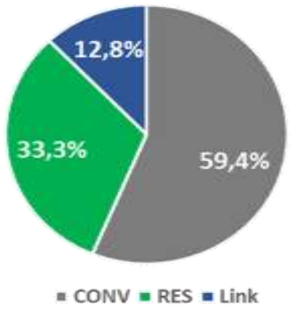

Fig. 12: Crete's Island Energy Balance of 2021

Within this study for the calculation of CO_2 emissions, the energy balance of Crete, presented in Figure 12, will be taken under consideration, as energy balance data depict the balance between the supply, transformation (i.e., conversion), and consumption of specific energy types and sectors, [22]. Analysing the yearly electricity consumption values for the years 2022 till 2030 (Table 1), it becomes apparent that the acquired energy from the PVs instalment is significant.

Table 1. Record of Electricity consumption per year

Year	Electricity Need (kWh)	From grid (kWh)
2022	5,396,550.45	53,051.85
2023	6,399,938.81	63,346.78
2024	6,799,934.98	67,320.39
2025	7,149,931.63	70,823.42
2026	7,399,929.24	73,020.20
2027	7,499,928.29	75,029.68
2028	7,499,928.29	75,029.68
2029	7,499,928.29	75,029.68
2030	7,499,928.29	75,029.68

For the transformation of the above data to CO_2 emissions, the EF from the CoM Default Emission Factors for the Member States of the European Union for the year 2013 was used and its value was 0.757 $tnCO_2/MWh$, as published in their respective report of 2017, **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**. Figure 13 presents the final annual percentage of the calculation of the CO_2 emissions due to electricity with and without the installation of PVs.

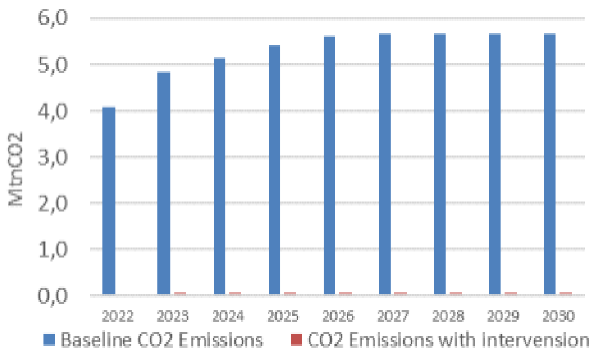

Fig. 13: Calculation of CO2 emissions

The previous Figure 13 highlights the significant mitigation of CO_2 emissions, which are reduced to negligible, as a result of extensive use of PV and batteries, which lead to a significant level of self-sufficiency up to 99% of the annual energy mix of the hotel's electricity needs.

3 Results

An immediate result of equations (2), (3) and (4) is the calculation of the energy system's self-sufficiency for a wide range of PV power and storage capacity. The set which yields at least 99% of annual self-sufficiency and ensures at the same time a minimum CAPEX is sought after for each year. As the energy demand increases annually, so does the required PV and storage capacity that provide the same percentage of self-sufficiency, meaning a requirement for an additional investment that negatively impacts the annual operational expenditure. For total installation costs of PV power and storage capacity equal to 1,000€/kW and 250€/kWh respectively, the total investment after each year is calculated and presented in Table 2.

Table 2. Methodology results per year till 2030

Year	PV (kW)	Battery (kWh)	CAPEX (€)
2022	7,200	19,800	12,150,000
2023	9,000	22,100	14,525,000
2024	9,200	24,600	15,350,000
2025	9,800	25,400	16,150,000
2026	10,400	25,600	16,800,000
2027	10,400	26,200	16,950,000
2028	10,400	26,200	16,950,000
2029	10,400	26,200	16,950,000
2030	10,400	26,200	16,950,000

In each year, the system's expansion requires less increase of PV power and storage capacity for 99% of annual self-sufficiency, due to the declining pace of visitation growth, as previously forecasted. Once the hospitality capacity is reached, additional installation is not required, assuming total occupancy for the following years.

In the table below, two scenarios are calculated, one assuming the annual system expansion scheme and a scheme of total dependency on the network. In the first scenario, the annual cost is equal to the annual cost of system expansion plus the cost of energy imported from the grid. In the second scenario, the annual cost is the total cost of load satisfaction through total dependency on the grid. For the indicative energy cost of 0.15€/kWh originating from the grid, the total costs are presented in Table 3.

Table 3. CAPEX and OPEXs of the examined scenarios

Year	PV+Bat cost (€)	Base-line cost (€)
2023	2,384,502.02	959,990.82
2024	835,098.06	1,019,990.25
2025	810,623.51	1,072,489.75
2026	660,953.03	1,109,989.39
2027	161,254.45	1,124,989.24
2028	11,254.45	1,124,989.24
2029	11,254.45	1,124,989.24
2030	11,254.45	1,124,989.24
Total:	**4,886,194.43**	**8,662,417.17**
Profit:		**3,776,222.74**

Comparing the eight-year profit to the initial CAPEX, the ratio is calculated as:

$$\frac{Eight - year\ Profit}{Initial\ Investment} = \frac{3{,}776{,}222.74€}{12{,}150{,}000€} = 0.31$$

Concluding that in eight years, the return of investment is about a third of the initial expenditure, a discouraging conclusion for a potential investor.

Assuming that for the following years the hotel maintains the occupancy levels at maximum capacity, and the grid price remains at 0.15€/kWh, the initial payback period of the investment will be in 7.5 years after 2030.

4 Conclusion

The conclusions drawn from the data calculated and presented in Table 2 and Table 3, could possibly ward off any entrepreneur willing to maintain competitiveness in the hospitality industry from investing in such RES technologies and their implementation to their energy system as described in the specific methodology. For the hotel serving as an object of study, a payback period of 15.5 years and a total cost of 16,950,000 € were calculated as attributes of the specific investment, significant values for the estimated cost imported energy equal to 0.15€/kWh. Incentives in the form of government subsidies could lighten the financial burden of the investor's CAPEX, in an effort to direct the sector towards the achievement of EU climate goals, ensuring its sustainability and economic growth at the same time.

However, when viewed from the energy's environmental variable, the significant mitigation in carbon dioxide emissions which causes severe environmental damage and influences a nation's sustainable development, adds further value to the exploitation of environmentally friendly technologies. Especially in the tourism industry, where green consumers are increasing.

Despite the discouraging results, the methodology developed for the purposes of the study could be altered to fit different, more suitable market designs, materialized with contemporary storage technologies, such as hydrogen storage, that aspire to achieve the same goals of the current model. The methodology could, also, serve as a benchmark for alternative models of demand response analysis to optimize energy systems of varied energy profile attributes. All these prospects will occupy the team's time and resources in the near future.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed to the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

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Conflict of Interest

The authors have no conflicts of interest to declare.