LANDSCAPE INTEGRATED PV: A CASE STUDY

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ABSTRACT: This paper presents a comprehensive proposal for a photovoltaic (PV) system aimed at supplying electricity to an ecotourism project at Quinta do Carmo, Estremoz, Portugal. The analysis begins by estimating and analysing electricity consumption for three distinct categories: water pumping, buildings and accommodations, and electric vehicle charging. Based on these estimations, a PV system is sized, and energy production along with self-consumption rates are simulated and calculated. Moreover, a technical-economic analysis of the proposed system and its decarbonization potential is provided. For water pumping, consumption estimates are based on monthly water consumption, area calculations, and elevation differences. The proposed PV system comprises three installations with varying capacities and orientations, strategically placed across different sections of the land. By simulating the consumption and production profiles, the study achieves an 70% self-consumption rate, demonstrating the viability of the PV solution to meet the ecotourism project's energy demands. The proposal also considers innovative solutions like single-axis solar trackers and agrivoltaic integration, showcasing a holistic approach towards sustainability and efficient land use.

Keywords: Photovoltaic System, Ecotourism, Integrated PV, Self-consumption, Sustainability

1 INTRODUCTION

The European Union (EU) is committed to reducing greenhouse gas emission by 55% by 2030 when compared to the 1990 levels and aims to become the first climate neutral continent by 2050. Achieving climate neutrality by 2050 requires an authentic revolution in the energy sector that will only be carried out with local or proximity production. As climate change is becoming more pronounced each year, several solutions must be researched and developed so the goals can be achieved. This will require an effort from all energy sectors, including the tourism sector.

In this paper a study is presented to offer the best solution for the design of a grid-tied PV system for the eco-resort located in Quinta do Carmo, Estremoz, Portugal. This eco-resort is still in the procurement and construction phases and aims to become as sustainable and energetically autonomous as possible.

The design of this PV system comes with some challenges, one of them being the different loads present at the resort, which can be divided into 3 groups: buildings and accommodations; water pumping systems and electric vehicles charging. Beside this challenge, the resort owners want to enhance and keep the natural values of its land by protecting as much as possible the landscape, natural habitats, and biodiversity. This means that all electrical infrastructures must blend with the landscape and remain hidden from guests during their experience. Other challenge is the area of the resort's land, which totals an area of 873.06 ha with several buildings spread, which will require the electrical distribution to be done in medium voltage (MV), thus implying the incorporation of transformers in the electrical distribution infrastructure.

This PV system was designed and optimized to satisfy as much as possible the resort's demand. As no usage data is available in this design phase, demand was estimated using: an average daily guest occupancy estimation for the resort; the average arrival of EVs (both full electric and hybrid); the water requirements of the different agricultural areas and natural areas; and, the electrical consumption of the pumps located in the different water wells, pits, and dams, according to their relative heights.

2 CONSUMPTION CHARACTERIZATION

The electricity consumption for the proposed photovoltaic (PV) system is characterized across three main consumers. First, water pumping consumption is estimated for accommodations, vineyards, gardens, and other areas based on the monthly water usage and elevation differences. Second, electricity consumption for various accommodations and buildings is estimated using forecasted guest numbers. Third, electric vehicle charging consumption is estimated considering the number of EVs, hybrids, and its weekly consumption. Consumption profiles are provided for each category, reflecting seasonal variations linked to irrigation needs and occupancy rates. This data is vital for understanding consumption patterns, aiding in system design and optimization.

Both water pumping and EV charging were treated as exclusively daytime activities, as they can be easily scheduled. Electricity consumption at the accommodations and buildings follows the average daily consumption profile [1] based on the representative profiles given by E-REDES (main electricity distribution grid operator in mainland Portugal) [2].

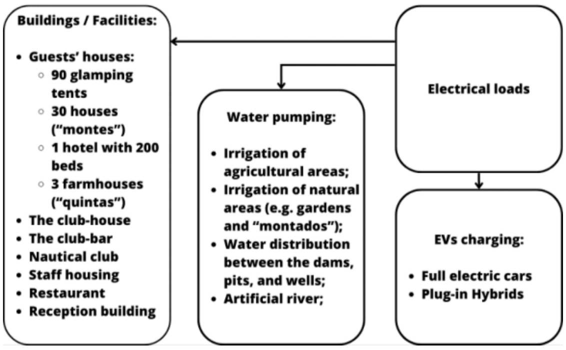

Fig. 1: Representation of the 3 types of Electrical loads.

2.1 Water Pumping

The water pumping consumption entails water supply for various accommodation types, the winery, and irrigation of gardens, agricultural, and forested areas.

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The estimates are based on:

- Monthly water consumption for each sector;
- Water supply pipeline network;
- Pipeline network for inundated soils;
- Maximum elevations (C_{max}) of pipelines near supply areas.

Table I: Annual water consumption volume.

Sector	Water Volume [m^3/year]
Vineyard 1,10 ha	25,000.00
Vineyard 2,50 ha	125,000.00
Vineyard 3,60 ha	150,000.00
Cork Forest 1995	120,000.00
Olive Trees	12,500.00
“Oliveiras do Carmo” Garden + Main House + Winery	127,300.00
Glamping + Garden + Natural Pools	156,870.00
Serra da Ossa Hotel	15,792.00
Serra da Ossa Hotel Garden + Valley	60,000.00
“Montes” + Gardens	138,198.00
“Quintas”	3,400.00
Total	**934,060.00**

All measurements of areas, distances, and elevations were determined using Google Earth Pro [3].

For the vineyard, considering the varied elevation across its three distinct areas, water consumption was determined using a specific consumption of 2,500 m^3/ha.

The water source was assumed to be the Mesquita Dam at an elevation of 302 m (C_o), four meters below the full reservoir level of 306 m (FSL - Full Storage Level), an estimate for drier periods. ΔH is the height difference between the consumption point elevation and the 302 m elevation of the Mesquita Dam:

$$\Delta H = C_{max} - C_o = C_{max} - 302 \text{ [m]}$$

As the pipelines are still under design, head losses (P) had to be estimated, assuming 0.20 mH$_2$O for every 100 m of linear pipe distance (D). This value will later be adjusted after the final hydraulic system design. The sum of ΔH and losses gives the manometric height, H_m:

$$H_m = \Delta H + P = \Delta H + 0.2 \times D/100 \text{ [m]}$$

To estimate the energy required for water pumping, the following equation [4] was employed:

$$E_i = (\rho g V_i H_m) / (\eta 3.6\times10^6) \text{ [kWh/month]}$$

Where ρ is the water density (998.34 kg/m^3 [5]), g the gravitational acceleration (9.81 m/s^2), V_i the monthly water volume in m^3/month, and η the pump efficiency (assumed as 0.90).

According to the calculations, the consumption for water pumping exhibits pronounced seasonality, with higher electricity consumption during Spring-Summer months, peaking in August. This pattern reflects typical irrigation and occupancy needs in the tourism sector (**Fig. 2**).

2.2 Accommodations and Buildings

In this eco-resort there are several buildings and accommodations that will demand electricity. A summary of this facilities can be found on **Table II**, where the number of units and beds can be observed.

Table II: Summary of the facilities in the eco-resort.

RESORT	Units	Pax/Beds
		tot
Accommodations	**203**	**714**
Glamping	90	216
Montes	30	272
Hotel	80	200
Quintas	3	26
Buildings	**8**	**60**
Nautical Club	1	0
ETAR	1	0
Equestrian Center	2	0
Staff Housing	1	60
Club-House	1	0
Club-Bar	1	0
Reception Building	1	0
Total	**203**	**774**

The electricity consumption associated to the various types of accommodations, as well as other buildings was estimated based on a forecast of the number of guests per month (**Table III**).

Table III: Forecast of the number of guests per month.

Month	Jan	Feb	Mar	Apr
# Guests	4,508	6,011	9,016	10,519
Month	May	Jun	July	Aug
# Guests	13,524	15,027	18,033	21,038
Month	Sep	Oct	Nov	Dec
# Guests	21,038	9,016	12,022	10,519

Using the data in **Table III** and assuming an average consumption per guest of **23 kWh** [6] [7]**,** the annual consumption curve in **Fig. 2** was obtained.

The estimated consumption for buildings also exhibits seasonal variation, with the higher electricity consumption component occurring during the summer months, peaking in August and September. This pattern reflects the typical needs of hotel establishments as well as the guest occupancy profile in tourism enterprises.

2.3 Electric Vehicles

Electricity consumption associated with electric vehicles charging was estimated based on the forecast of the number of guests per month (**Table III**) and the following assumptions:

- Nights per guest: 7
- Guests per car: 2.5
- Percentage of EVs in 2026:
  - EVs: 30%
  - Hybrids: 33%
- EV consumption for 7 days:
  - EVs: 165 kWh
  - Hybrids: 33 kWh

Based on the above assumptions, the annual consumption curve for electric vehicle charging was obtained, as shown in **Fig. 2**.

As depicted in **Fig. 2**, the estimated consumption for electric vehicle charging also displays seasonal variation, with the primary electricity consumption component occurring during the summer months, peaking in August and September. This pattern is directly related to the estimated number of guests.

2.4 Annual consumption curves and daily profile

In the following figures, the annual consumption curves for each type and its combined total, as well the daily consumption profile for each type can be observed.

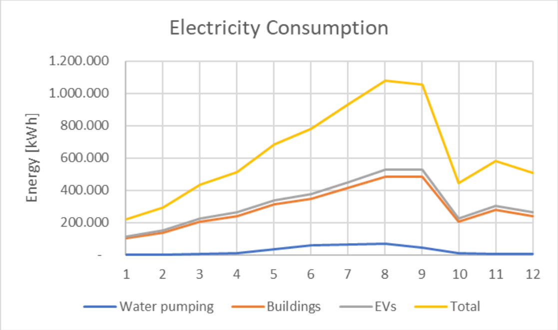

Fig. 2: Annual consumption curves estimated for the 3 types and its combined total.

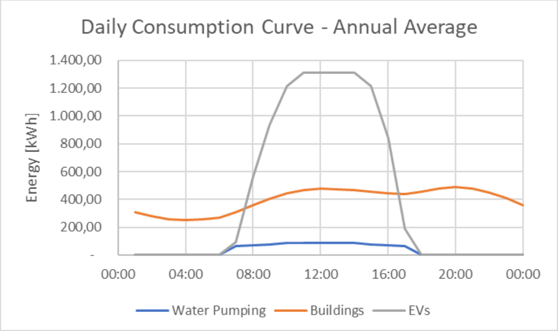

Fig. 3: Daily consumption profile for the 3 types.

As can be seen in **Fig. 3**, 100% of the consumption for water pumping and EVs charging is done during the day, while for the buildings the self-consumption rate reached is 56%.

3 PROPOSED PHOTOVOLTAIC SYSTEM

The sizing of the PV system was optimized for the load profile, maximizing self-consumption of photovoltaic electricity and decarbonization potential, while minimizing surpluses during the autumn and winter months to optimize the technical and economic indicators of this investment. To achieve this, three photovoltaic systems (A, B, and C) are proposed, occupying three distinct plots of the land (I4, I5, I6).

A photovoltaic system (A) is proposed, installed on single-axis horizontal trackers aligned from North to South with 750 kWp of installed photovoltaic power, located on plot I4. Another photovoltaic system (B) is proposed, also installed on single-axis horizontal trackers aligned from North to South with 1,200 kWp of installed photovoltaic power, located on plot I5. Finally, another photovoltaic system is proposed, installed on double East-West CarPort structures with a 15° inclination and 1,800 kWp of installed photovoltaic power, located on plot I6. These structures will serve as shading for the parking area.

The summaries of characteristics for the 3 photovoltaic systems can be observed in **Table IV**.

Table IV: Summary of Photovoltaic Installations.

System	**Structure Type**	**Orientation**	**Tilt (°)**	**Plot**
A	Trackers	N-S	0	I4
B	Trackers	N-S	0	I5
C	Fixed	E-W	15	I6
System	**Available area (m²)**	**Power to install (kWp)**	**Price (€/Wp)**	**Estimated Installation Cost**
A	18,585	750	1.00 €	750,000 €
B	26,475	1,200	1.00 €	1,200,000 €
C	27,755	1,800	1.10 €	1,980,000 €

The installed systems should have the following general configuration:

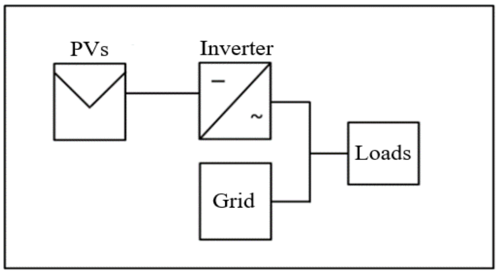

Fig. 4: Electrically hybridized systems: hybridization between PV generators and other energy sources is done in the electrical part of the system.

This configuration involves hybridization between the PV generator and the public utility electricity grid in the electrical part of the system. This system is considered a self-consumption system and is subject to the applicable regulations/legislation in Portugal, under Decree-Law No. 15/2022, dated January 14.

3.1 PV Trackers

A significant observation regarding Quinta do Carmo's electricity consumption (**Fig. 2**) is the notable asymmetry between summer and winter consumption. To address this disparity, the installation of photovoltaic modules on movable support structures capable of tracking the movement of the Sun, rotating around a North-South aligned horizontal axis, has been proposed. This approach of solar trackers proves to be the most effective in terms of maximising the difference in energy production between different seasonal periods.

It is essential to note that the horizontal arrangement of photovoltaic modules plays a pivotal role in the visual context of the landscape. This layout contributes to minimised visual impact, discreetly integrating into the environment.

In summary, the installation of photovoltaic trackers with a single horizontal axis tracking from North to South is a strategic solution for the seasonal asymmetry in electricity consumption at Quinta do Carmo. This approach not only optimises energy production but also offers notable advantages in terms of productivity and visual integration.

This type of tracker can be combined with an agrivoltaic approach. Vegetation control can be addressed through innovative methods such as sheep grazing or mechanical cutting, aimed at keeping the land under the solar trackers productive. Additionally, some areas can be designated for soil recovery measures and promoting native vegetation, contributing to improving the health of the local ecosystem.

A prominent highlight in the agrivoltaic approach is the incorporation of horticulture, which focuses on organic farming. To effectively integrate this “farm”, the adaptation of a portion of the photovoltaic system is required, raising the axis from approximately 1.75 meters to about 2 meters. This intelligent integration not only demonstrates a holistic approach to space utilization but also exemplifies the potential to combine clean energy production with the production of healthy food.

Furthermore, as part of educational and awareness efforts, a visitor's circuit can be developed in this space. This circuit will allow visitors to closely explore the various sustainability and decarbonization measures implemented at Quinta do Carmo. Through this interactive experience, visitors can gain a deeper understanding of innovative practices and ongoing environmental commitment.

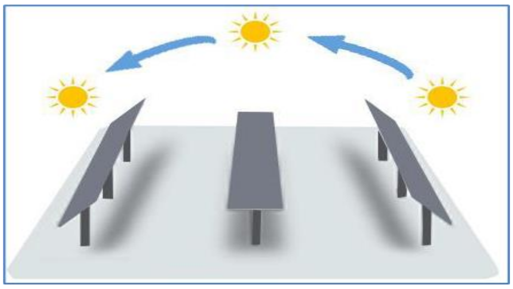

Fig. 5: Diagram of single-axis horizontal trackers aligned from North to South.

3.2 Parking Lot

The effective design and sizing of a shading system for a parking lot involve several important considerations. One approach is to implement a rational space management, opting for a parking layout at a 45° angle. This configuration not only maximises shading capacity but also reduces the width of necessary access lanes. Furthermore, the use of double East-West CarPort structures offers significant benefits, minimising the need for additional posts and ground fixation points.

The integration of electric vehicle charging stations is another crucial consideration in this project. Ideally, these stations would be bidirectional, providing a future-proof approach capable of meeting emerging needs. Strategically positioned next to the central pillars, these charging stations would be accessible from both sides, providing convenience to users.

Additionally, sustainable water management is also contemplated in the design. A practical solution is rainwater collection along the central axis of the system. This simplified approach contributes to operational efficiency and the seamless integration of the shading system with the surrounding environment.

A fundamental consideration in the parking lot design is the compliance with relevant regulations. According to Decree-Law No. 123/97, for parking facilities with a capacity between 25 and 100 spaces, a minimum of 3 spaces must be reserved for people with reduced mobility. In this context, a parking facility with 450 spaces was designed, with 27 spaces for people with reduced mobility, distributed in groups of 3 for every 50 spaces.

Moreover, compliance with safety standards is of utmost importance. Decree-Law No. 66/95 establishes specific regulations for fire safety in covered parking facilities. These guidelines ensure that adequate measures are implemented to ensure the safety of users in case of emergencies.

In summary, the design of the shading system for the parking facility involves careful choices, from spatial layout to the integration of technologies such as bidirectional charging stations. Additionally, the consideration of sustainable elements, such as rainwater management, demonstrates a commitment to environmental efficiency and innovation. It is crucial to also consider compliance with established regulations. Adherence to accessibility, fire safety, and urban planning requirements contributes to creating a functional, safe, and well-integrated environment.

Fig. 6: Example of double East-West CarPort structure.

4 PHOTOVOLTAIC GENERATION

For the purpose of analysing the performance of these systems' energy production, simulations of energy production were conducted, and annual production curves (**Fig. 7**) were generated using the same methodology employed for the load curves of each type of consumption.

The simulations were carried out using PVGIS [8] and SISIFO [9] softwares, both photovoltaic systems simulation tools.

Regarding the environmental parameters of the location, the typical meteorological year (TMY 2005-2020) was used for solar radiation and air temperature data. These data are obtained from the PVGIS - Photovoltaic Geographical Information System database (European Commission).

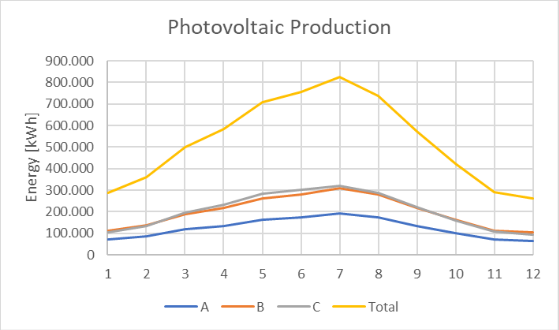

Fig. 7: Annual production curves of the 3 systems and its combined total.

As we can see from the graph, the chosen installation types allow for a significant asymmetry in energy production between the summer and winter months, confirming their suitability for the consumption patterns at Quinta do Carmo's ecotourism facility.

In **Fig. 8** the daily generation profile for the 3 systems can be observed.

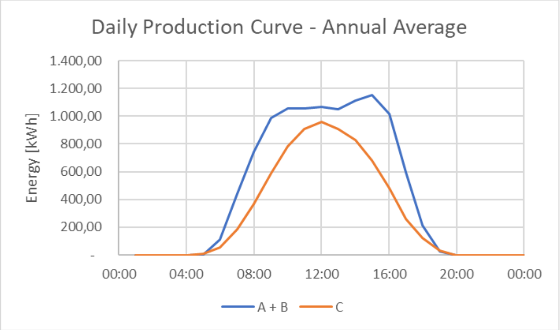

Fig. 8: Daily production profile for the 3 PV systems.

4.1 Production vs. Consumption

After obtaining the consumption profile (**Fig. 2** and **Fig. 3**) and the production profile (**Fig. 7** and **Fig. 8**) for Quinta do Carmo's ecotourism, we overlaid these data sets and generated the following graphs:

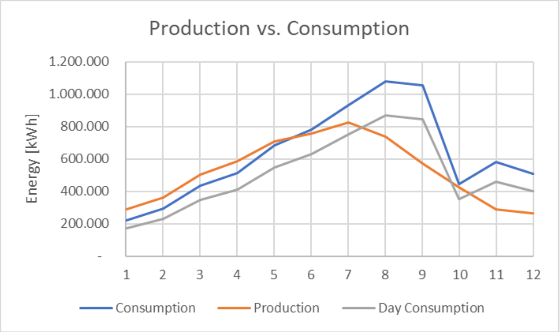

Fig. 9: Comparison of consumption vs. PV production.

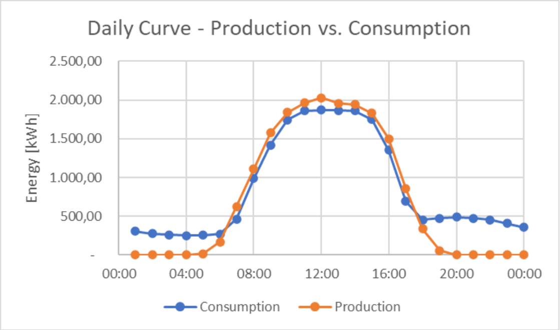

Fig. 10: Daily profiles for consumption vs. PV production.

Upon analysing the graphs, it's evident that the two profiles almost perfectly match. Using these profiles, the data in **Table V** was calculated.

Table V: PV electricity produced, consumed, excess and the self-consumption rate.

PV Electricity – Annual Values (kWh)	
Produced	6,304,515
Consumed	5,295,407
Excess	1,009,108
Self-consumption rate	**70%**

As shown in **Table V**, the proposed photovoltaic system achieves a self-consumption rate of 70% with an initial investment of €3,930,000. This self-consumption rate can be further improved with the installation of an energy storage system capable of storing excess electricity produced by the photovoltaic system.

5 TECHNICAL AND ECONOMIC ANALYSIS

5.1 Methodology

There is no standard or universal method for obtaining the irrefutable value of a company or business, as the elements to be evaluated include, among many others of a material and objective nature, management capacity, the quality of human resources, and market characteristics and expectations. On the contrary, there are accepted formulas to establish parameters of reasonableness to determine the value of a business.

The following general considerations were considered regarding the methodology used for the analysis:

- In this analysis, a conservative approach is assumed in the financial parameters used. This ensures that the results presented represent a conservative scenario.
- Financing costs are not considered in this economic analysis, given their variability related to the source of investment capital selected by Quinta do Carmo (equity, debt, credit, subsidized credit, etc.).
- The electricity price considered is a weighted average defined by the Renewable Energy Chair, using a conservative value.
- A projection period of 25 years was considered, the usual power warranty period for photovoltaic modules.
- The analysis does not include costs for the dismantling of equipment at the end of its life.
- Estimated costs for each photovoltaic system were considered based on the best available knowledge from the Renewable Energy Chair, with a relative margin of safety. However, due to the current European context, the evolution of the international market for raw materials and logistics of goods is particularly unstable, so the costs considered may vary at the time of investment execution.
- The economic analysis does not account for costs related to the medium-voltage to low-voltage distribution network, distribution network transformer substations, parking lot pavement and landscaping, EV chargers, or pumping stations.

4.3 Results

The results of the technical and economic analyses can be observed in **Table VI** and **Fig. 11**.

Table VI: Results of the technical and economic analyses.

Electricity Consumption		
Water Pumping	308,570	kWh
Accomodations and Buildings	3,456,233	kWh
Electric Vehicles Charging	3,756,790	kWh
Total Electricity Consumed	7,521,593	kWh
Photovoltaic Production		
System A	1,485,975	kWh
System B	2,377,560	kWh
System C	2,440,980	kWh
Total PV Electricity Produced	6,304,515	kWh
Consumed PV Electricity	5,295,407	kWh
Excess PV Electricity	1,009,108	kWh
Annual Efficiency Loss	0.45%	
Considered Electricity Price		
Average Electricity Price	0.1200	€/kWh
Financial Assumptions		
Inflation Rate	2.50%	
Discount Rate	5.00%	
Electricity Price Increase Rate	2.00%	

Economic Indicators		
Net Present Value (NPV)	5.921.082,92 €	
Total Life Cycle Cost (TLCC)	5.305.960,13 €	
Payback Period	6.25	years
Internal Rate of Return (IRR)	10.82 %	
Levelized Cost of Electricity (LCOE)	0.0425	€/kWh
CO2 Emissions		
CO_2 Emissions Factor (EDP 2023)	262.88	g/kWh
Avoided CO_2 Emissions per Year	1,657.33	t

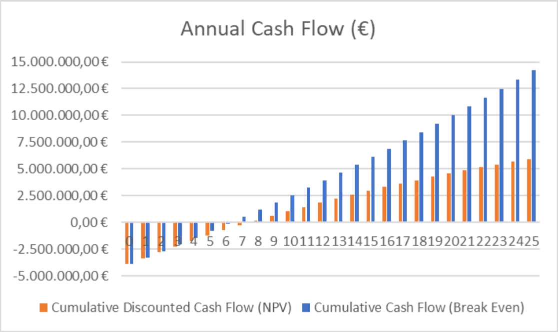

Fig. 11: Annual Cumulative Cash Flow Graph.

5 CONCLUSIONS

In conclusion, this paper has presented a comprehensive analysis of a sustainable energy project aimed at transforming the Quinta do Carmo into an eco-friendly ecotourism destination. By integrating renewable energy sources, the project seeks to minimize its environmental footprint while providing a unique and sustainable experience for visitors.

The analysis began by assessing the different energy consumption profiles on the eco-resort, including buildings, water pumping, and electric vehicles charging. This thorough evaluation allowed us to design and size a photovoltaic system strategically, optimizing energy self-sufficiency during peak demand months while minimizing surpluses in the autumn and winter.

The choice of single-axis solar trackers for the photovoltaic installations proved to be an effective solution, maximizing energy production and ensuring a more even power output throughout the day. Additionally, these solar trackers can be integrated with innovative agrivoltaic practices, promoting sustainable land use and even supporting local organic farming.

The design of the parking lot structures also followed sustainable principles, incorporating shading elements, EVs charging stations, and rainwater collection systems. These elements not only enhance the visitor experience but also contribute to the overall sustainability of the project.

Analysing the technical and economic aspects, the paper presents a conservative approach, ensuring that the results represent a cautious scenario. The analysis includes considerations such as electricity production, consumption, financial parameters, and environmental impacts. Notably, the project achieves an 70% energy self-sufficiency rate, with an initial investment of €3,930,000. This self-sufficiency rate could be further improved with the addition of an energy storage system capable of storing the excess PV electricity.

The economic analysis indicates a positive outlook for the project, with a NPV of €5,921,082.92, a Payback Period of 6.25 years, and a competitive LCOE of 0.0425 €/kWh. Additionally, the project is estimated to save 1,657.33 tons of CO_2 emissions annually.

In financial terms, the project demonstrates its feasibility and potential for long-term sustainability. Furthermore, the Quinta do Carmo's transformation into an eco-friendly destination serves as a model for sustainable development, blending environmental responsibility with a unique and enjoyable visitor experience.

In summary, the Quinta do Carmo sustainable energy project showcases the possibilities of integrating renewable energy solutions within the ecotourism sector. Beyond its economic viability, it exemplifies a commitment to environmental stewardship, sustainability, and innovation, setting a compelling example for similar ventures in the future. This holistic approach to sustainable tourism not only benefits the environment but also contributes to a more resilient and eco-conscious world.

6 ACKNOWLEDGMENTS

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