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Dynamic simulation and heuristic optimization of a photovoltaic system with solar tracking for reducing electricity consumption at a university institution in Cartagena, Colombia

Simulación dinámica y optimización heurística de un sistema fotovoltaico con seguimiento solar para la reducción del consumo eléctrico en una institución universitaria de Cartagena, Colombia

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Abstract: This work proposes a dynamic simulation and heuristic optimization methodology to evaluate the incorporation of photovoltaic systems with solar tracking at a university institution located in Cartagena de Indias, Colombia. The energy baseline was built from a real electricity bill, with a monthly consumption of 22,880 kilowatt-hours (kWh) and a total cost of 17,470,020 COP. Because only one institutional bill is available at this preliminary stage, an estimated annual consumption series was generated using monthly variation factors associated with academic dynamics. Daily solar radiation and ambient temperature were obtained from the NASA POWER database for the coordinates of Cartagena. Three configurations were simulated: a fixed photovoltaic system, a system with single-axis solar tracking, and a system with dual-axis solar tracking. The model incorporated thermal correction of the cell temperature, a dynamic performance ratio, tracking factors, economic savings, and CO2 emission reductions. In addition, a genetic algorithm was applied to estimate the installed capacity required under an energy coverage target. The results show that a 100-kilowatt-peak (kWp) system with dual-axis tracking could cover approximately 58.53 % of the estimated annual demand, whereas the heuristic optimization identified a capacity of 85.43 kWp to cover 50 % of the demand. These results suggest that photovoltaic systems with solar tracking can be a viable alternative for improving energy sustainability on tropical university campuses.

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Keywords: Solar photovoltaic energy; Solar tracking; Heuristic optimization; Genetic algorithm; University electricity consumption; Sustainable campus.

Resumen: El presente trabajo propone una metodología de simulación dinámica y optimización heurística para evaluar la incorporación de sistemas fotovoltaicos con seguimiento solar en una institución universitaria ubicada en Cartagena de Indias, Colombia. La línea base energética se construyó a partir de un recibo real de energía eléctrica, con un consumo mensual de 22.880 kilovatios-hora (kWh) y un costo total de 17.470.020 COP. Debido a que en esta etapa preliminar solo se dispone de un recibo institucional, se generó una serie anual estimada de consumo mediante factores mensuales de variación asociados a la dinámica académica. La radiación solar y la temperatura ambiente diaria fueron obtenidas de la base NASA POWER para las coordenadas de Cartagena. Se simularon tres configuraciones: sistema fotovoltaico fijo, sistema con seguidor solar de un eje y sistema con seguidor solar de dos ejes. El modelo incorporó corrección térmica de la temperatura de celda, performance ratio dinámico, factores de seguimiento, ahorro económico y reducción de emisiones de CO2. Adicionalmente, se aplicó un algoritmo genético para estimar la potencia instalada requerida bajo un objetivo de cobertura energética. Los resultados muestran que un sistema de 100 kilovatios-pico (kWp) con seguimiento de dos ejes podría cubrir aproximadamente el 58,53 % de la demanda anual estimada, mientras que la optimización heurística identificó una potencia de 85,43 kWp para cubrir el 50 % de la demanda. Estos resultados sugieren que los sistemas fotovoltaicos con seguimiento solar pueden constituir una alternativa viable para mejorar la sostenibilidad energética en campus universitarios tropicales.

Palabras clave: Energía solar fotovoltaica; Seguimiento solar; Optimización heurística; Algoritmo genético; Consumo eléctrico universitario; Campus sostenible.

1. Introduction

University campuses provide a setting in which the transition to renewable electricity can be linked to institutional operation, applied research, and technical education. Their electricity demand combines teaching spaces, laboratories, computing equipment, lighting, and air conditioning, while occupancy changes with the academic calendar. Photovoltaic (PV) generation can supply part of this demand and provide a platform for evaluating energy performance under actual operating conditions. In Colombia, the experience documented at Universidad Autónoma de Occidente in Cali illustrates the value of combining campus PV integration, monitoring, and energy simulation rather than assessing an installation solely by its nominal capacity [1].

Planning such an installation requires a connection between the available solar resource and the electricity services that the institution needs. Irradiance, ambient temperature, module orientation, shading, and conversion losses affect production, whereas the demand profile determines how much generation can be used locally. Installed capacity alone therefore does not establish the proportion of demand that a PV system can supply. Reviews of PV sizing methods identify energy requirements, physical space, economic criteria, and component characteristics as interdependent design inputs [2]. For a university, these considerations also imply that annual energy coverage and savings must be interpreted alongside demand variability and the quality of the available consumption records.

Solar tracking introduces an additional design decision. Fixed modules retain their orientation, single-axis trackers modify one rotational degree of freedom, and dual-axis systems adjust both azimuth and elevation. Tracking can improve solar capture, but the resulting benefit depends on site conditions, the reference fixed configuration, and the operation of the mechanism [3;4]. The experimental work of Flores-Hernández et al. further shows that tracking decisions affect actuator energy consumption and mechanical operation as well as electricity generation [5]. A comparison for an institutional application must consequently distinguish the potential generation gain from the wider economic and maintenance assessment required before installation.

For the institution considered in Cartagena de Indias, the immediate planning question is how fixed, single-axis, and dual-axis PV scenarios would change estimated electricity coverage and the capacity needed to meet a specified coverage target. At this preliminary stage, one actual institutional electricity bill is available, rather than a complete annual consumption history. The present study therefore combines that observed baseline with explicitly estimated monthly variation and daily weather data from NASA POWER. POWER provides satellite- and model-based solar and meteorological time series that support resource assessment where local measurements are limited [6]. The resulting demand series is a planning assumption anchored to an actual bill, not a measured annual load profile.

Within this scope, the study integrates thermal correction, daily generation scenarios, estimates of electricity-cost savings and avoided emissions, and a genetic algorithm for capacity sizing. This approach addresses an early screening decision for the case-study institution; it does not establish a final investment optimum or validate tracker performance experimentally. More comprehensive campus-planning frameworks include rooftop suitability, investment and maintenance costs, and distribution-network constraints [7]. Those requirements provide a direction for subsequent design once additional institutional data become available.

The remainder of the article is organized as follows. Section 2 states the contribution and scope of the study. Section 3 reviews previous work on campus PV systems, solar tracking, and optimization. Section 4 describes the energy baseline, demand estimation, weather inputs, PV model, and heuristic sizing procedure. Section 5 presents the scenario comparisons and capacity-sizing results. Section 6 examines their implications and limitations, and Section 7 summarizes the findings and directions for further work.

2. Contributions

This study provides a preliminary framework for evaluating photovoltaic systems with solar tracking at a university institution in Cartagena de Indias. Its contributions are summarized as follows:

I. An institutional energy baseline anchored to an actual electricity bill, complemented by an estimated annual demand series that explicitly distinguishes observed consumption from assumed monthly variation associated with the academic calendar.

II. A daily photovoltaic simulation model integrating NASA POWER weather data, cell-temperature correction, a dynamic performance ratio, and solar-geometry calculations to compare fixed, single-axis, and dual-axis configurations under stated tracking assumptions.

III. A comparative assessment of installed-capacity scenarios in terms of estimated annual demand coverage, electricity-cost savings, and avoided carbon dioxide emissions, providing a common basis for preliminary institutional planning.

IV. A genetic-algorithm application to estimate the installed capacity required to meet a specified annual energy-coverage target in the dual-axis scenario, with its interpretation bounded by the available consumption data and the model assumptions.

3. Related Works

3.1. Photovoltaic integration and planning in university campuses

Previous campus studies address both operational assessment and the planning of future installations. Castrillón-Mendoza et al. evaluated PV integration at Universidad Autónoma de Occidente in Cali using monitoring and simulation, with performance indicators interpreted within the IEC 61724 framework [1]. Their study reported a performance-ratio range of 0.73–0.78 for the monitored subsystem during the four-month assessment. This Colombian experience supports the use of measured operating data to examine conversion losses and campus integration. Its performance values are specific to that installation and observation period, however, and cannot serve directly as validation of a different system in Cartagena.

Kucuksari et al. developed a framework combining geographical information systems, mathematical optimization, and electrical simulation for campus PV planning [7]. Rooftop suitability informed installa-

tion capacity, the optimization considered long-term net profit, and the simulation examined distribution-network voltage behavior. This work establishes that campus sizing is connected to location, costs, and network operation. The present study addresses an earlier decision stage: it compares generation configurations and coverage targets using limited consumption information, without claiming the spatial or electrical-network detail of that framework.

3.2. Solar tracking mechanisms and control strategies

Reviews of solar-tracking technologies describe fixed, single-axis, and dual-axis configurations and discuss their energy benefits alongside control and mechanical requirements [3;4;8]. These alternatives should be compared against a clearly defined fixed-system reference. In particular, a gain obtained for one climate, observation period, or mounting arrangement is not a universal tracking multiplier. In this article, the tracking factors are scenario assumptions for preliminary comparison; their use does not constitute a calibrated physical model of the trackers.

At the prototype level, Barrios Sánchez et al. described the design, material selection, and assembly of a two-degree-of-freedom mechanism for a 250 Wp PV panel [9]. That work focuses on the structure and actuators needed to orient the module. Barrios-Sánchez and Tlapanco-Ríos subsequently reported the implementation of a dual-axis system using solar-position equations and open-loop control [10]. These studies provide an electromechanical basis for discussing tracking, while the present work examines its assumed energy implications at an institutional demand scale. Prototype feasibility and campus-level demand coverage answer different engineering questions and require different validation data.

Flores-Hernández et al. compared a real-time decision-making strategy with conventional tracking in identical systems operating under the same weather conditions [5]. Their experimental findings indicate that movement and actuator consumption can be reduced while maintaining practically the same electricity generation. More recently, Delfianti et al. compared PID, fuzzy, hybrid fuzzy–PID, and model-predictive-control approaches in MATLAB/Simulink [11]. Their results emphasize the trade-offs among response speed, overshoot, and stability. Together, these studies show why a generation comparison alone cannot establish the preferred controller or the lifetime performance of a tracking installation.

Further evidence concerns the choice between continuous tracking and simpler adjustments. Nahim et al. combined simulation and prototype testing of a North–South single-axis tracker in Lebanon, reporting an energy-output improvement of approximately 36% over their fixed reference [12]. Monfared et al., by contrast, optimized the timing of two tilt settings for locations in Iran; their analysis also identified the increased row spacing associated with the proposed angles as a limitation where installation space is constrained [13]. These are distinct configurations and contexts, so their gains should not be transferred directly to Cartagena. They instead motivate an explicit comparison of capture benefit, control complexity, and installation conditions.

3.3. Simulation and optimization for photovoltaic sizing

Alsadi and Khatib organize PV sizing research around component modeling, optimization criteria, available software, and design constraints [2]. Their review discusses analytical, numerical, and heuristic approaches, including genetic algorithms, and distinguishes energy, reliability, and economic objectives. This distinction is relevant here: selecting capacity to meet an annual coverage target is a narrower problem than minimizing lifetime cost or ensuring supply reliability. A daily energy balance also does not establish the instantaneous match between generation and consumption, which would require finer time-resolution data.

Gómez-Lorente et al. applied genetic algorithms, CHC, and differential evolution to the design of PV plants with solar tracking [14]. Their objective was to minimize electrical Joule losses by choosing module and tracker arrangements and inverter-related design variables; differential evolution was promising for the problem examined. This work supports the use of evolutionary search in PV design while showing that algorithm performance must be assessed for the actual objective and decision variables. It does not imply

that a genetic algorithm is universally superior or that an energy-coverage solution is also an economic optimum.

3.4. Positioning of the present study

The reviewed literature connects campus integration with monitoring and planning, tracking mechanisms with control and maintenance requirements, and heuristic sizing with explicit objectives and constraints. For the Cartagena case, the specific task is to bring a bill-based institutional baseline, estimated demand variation, daily weather inputs, thermal correction, and alternative tracking assumptions into one preliminary evaluation. The contribution lies in this application and the comparison of coverage scenarios, rather than in a new tracking controller or a new optimization algorithm. The limited consumption history, assumed tracking gains, and absence of investment and site-layout constraints define the interpretation of the results and the measurements needed for subsequent validation.

4. Materials and methods

4.1. Overview of the methodological approach

The methodology followed in this work is composed of six stages. First, an energy baseline was defined from a real institutional electricity consumption bill. Second, an estimated annual series of monthly demand was constructed because only one bill is available in this preliminary stage. Third, daily solar radiation and ambient temperature data were downloaded from NASA POWER for Cartagena de Indias. Fourth, a photovoltaic model was formulated with correction for cell temperature. Fifth, three generation configurations were simulated: fixed panel, single-axis tracker, and two-axis tracker. Finally, a genetic algorithm was applied to find the installed power required under an energy coverage target.

4.2. Case Study & Energy Baseline

The case study corresponds to a university institution located in Cartagena de Indias, Colombia. As a starting point, a real electricity bill of the institution was used, corresponding to a monthly consumption of 22,880 kilowatt-hours (kWh), unit of energy, and a total cost of 17,470,020 COP. Table 1 summarizes the main data.

Table 1. Base data of the electricity bill used as a baseline.

Concept	Value
Base monthly consumption	22,880 kWh/month
Total monthly cost	17.470.020 COP
Cost associated with energy	16.898.840 COP
Total cost per kWh	763.55 COP/kWh
Energy cost per kWh	738.59 COP/kWh
Daily average reported on receipt	1,199.12 kWh/day

The total average cost per unit of energy was calculated by:

$$C_{\mathrm{kWh}} = \frac{C_{\mathrm{total}}}{E_{\mathrm{mes}}} \tag{1}$$

where Ctotal is the total monthly cost and Emes is the monthly consumption. Substituting the values of the bill:

$$C_{\mathrm{kWh}} = \frac{17{,}470{,}020}{22{,}880} = 763.55\ \mathrm{COP/kWh} \tag{2}$$

4.3. Construction of estimated annual demand

Because only one institutional bill is available, the annual demand was constructed as an estimated series, not as twelve actual bills. To this end, monthly variation factors associated with academic dynamics were defined. These factors represent months of greater or lesser institutional activity and were normalized to maintain as a monthly average the consumption observed in the actual bill.

The estimated monthly demand was calculated as:

$$D_m = D_{\text{base}}\, f_m \tag{3}$$

where Dm is the estimated demand for month m, Dbase is the base monthly consumption and fm is the normalized monthly factor. Table 2 presents the estimated monthly series of electricity consumption and its associated cost.

Table 2. Estimated monthly series of electricity consumption.

Month	Estimated consumption (kWh)	Estimated Cost (COP)
January	19.080	14.568.000
February	22.104	16.878.000
March	23.268	17.766.000
April	24.199	18.477.000
May	25.129	19.187.000
June	22.337	17.055.000
July	18.149	13.858.000
August	23.733	18.121.000
September	25.595	19.543.000
October	26.060	19.898.000
November	24.431	18.654.000
December	20.476	15.634.000

The estimated annual demand was:

$$D_{\text{annual}} = 274{,}560 \text{ kWh/year} \tag{4}$$

with an average daily demand of:

$$\overline{D} = 752.22 \text{ kWh/day} \tag{5}$$

Figure 1 presents the estimated daily demand from the actual baseline.

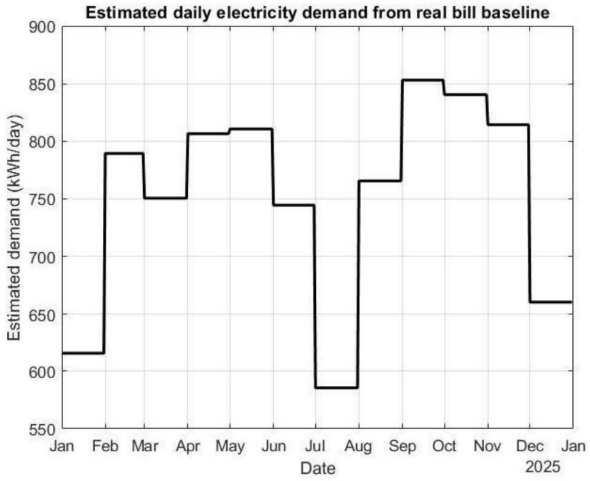


Figure 1. Estimated daily demand from actual bill and monthly variation factors.

4.4. Weather data

Daily data on horizontal global solar radiation and ambient temperature were obtained from NASA POWER [15] for the approximate coordinates of Cartagena de Indias:

$$\varphi = 10.400^{\circ}, \qquad \lambda = -75.514^{\circ} \tag{6}$$

The variables used were daily solar radiation, mean temperature, maximum temperature and minimum temperature. Daily solar radiation is shown in Figure 2. This variable determines the energy available for photovoltaic conversion.

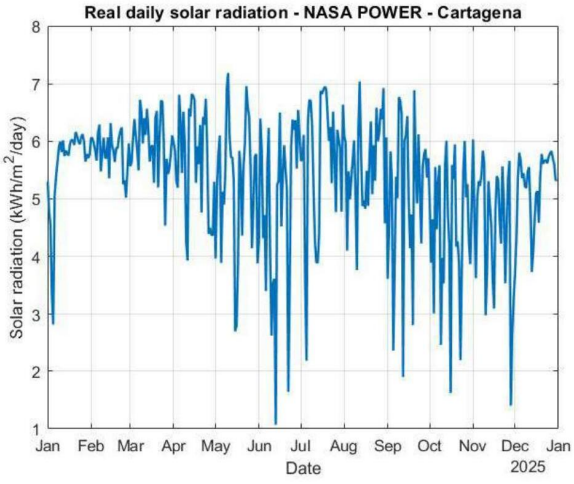


Figure 2. Daily solar radiation obtained from NASA POWER for Cartagena de Indias.

Figure 3 shows the average, maximum, and minimum daily temperature. Temperature is important because PV performance decreases when the operating temperature of the cell increases.

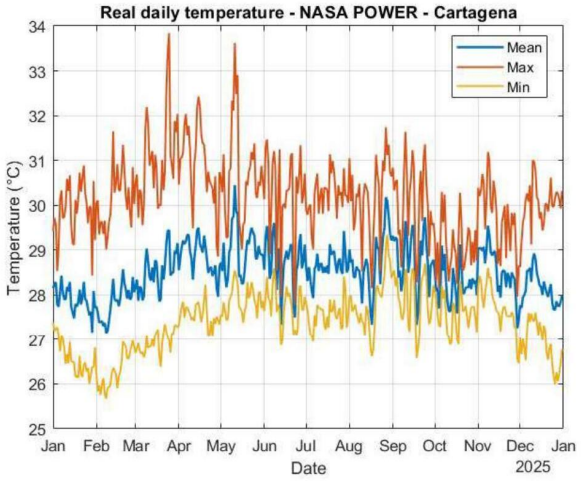


Figure 3. Average, maximum and minimum daily temperature obtained from NASA POWER for Cartagena de Indias.

4.5. Photovoltaic model

The daily generation of the photovoltaic system was calculated by:

$$E_{\mathrm{PV}}(t) = P_{\mathrm{inst}}\, H(t)\, PR(t)\, F_{\mathrm{track}} \tag{7}$$

where EPV(t) is the energy generated on day t, Pinst is the installed power, expressed in kilowatt-peak (kWp), which corresponds to the nominal peak power of the photovoltaic system, H(t) is the daily solar radiation in kWh/m2/day, PR(t) is the dynamic performance ratio and Ftrack is the factor associated with the type of solar tracking.

Three configurations were simulated:

$$F_{\mathrm{fixed}} = 1.00 \tag{8}$$

$$F_{1\mathrm{axis}} = 1.15 \tag{9}$$

$$F_{2\mathrm{axes}} = 1.25 \tag{10}$$

These factors represent a preliminary approximation of the energy improvement associated with solar tracking. At a later stage, these values should be calibrated with experimental measurements or system operational data.

4.6. Correction by cell temperature

The cell temperature was estimated based on the NOCT model:

$$T_c(t) = T_a(t) + \frac{NOCT - 20}{800}\, G(t) \tag{11}$$

where Tc(t) is the cell temperature, Ta(t) is the ambient temperature, and G(t) is the equivalent mean irradiance during solar hours.

The equivalent mean irradiance was approximated as:

$$G(t) = \frac{H(t)}{HSE}\, 1000 \tag{12}$$

where HSE represents the equivalent solar hours.

The thermal correction factor was defined as:

$$f_T(t) = 1 + \gamma\,(T_c(t) - 25) \tag{13}$$

where γ is the thermal power coefficient. Therefore, the dynamic performance ratio was calculated as:

$$PR(t) = PR_{\text{base}}\, f_T(t) \tag{14}$$

The technical parameters used are summarized in Table 3.

Table 3. Technical parameters of the photovoltaic model.

Parameter	Value
Performance ratio base, PRbase	0,78
NOCT	45 řC
Thermal coefficient, γ	-0.004 řC^{-1}
Equivalent Solar Hours	5 h
Average dynamic performance ratio	0,665
Emission Factor Used	0.164 kgCO2/kWh

4.7. Solar Geometry

Solar geometry was included to characterize the apparent path of the sun and to justify the comparison between fixed systems and systems with tracking. Solar declination was estimated as:

$$\delta = 23.45^\circ\, \sin\left[\frac{360^\circ(284 + n)}{365}\right] \tag{15}$$

where n is the day of the year. The solar elevation αs was calculated as:

$$\sin(\alpha_s) = \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\cos(\omega) \tag{16}$$

where φ is the latitude of the site and ω is the time angle:

$$\omega = 15^\circ(h - 12) \tag{17}$$

Figure 4 shows the solar elevation angle for four representative days of the year. The results reflect a high solar elevation for much of the year, a favorable condition for photovoltaic generation in Cartagena.

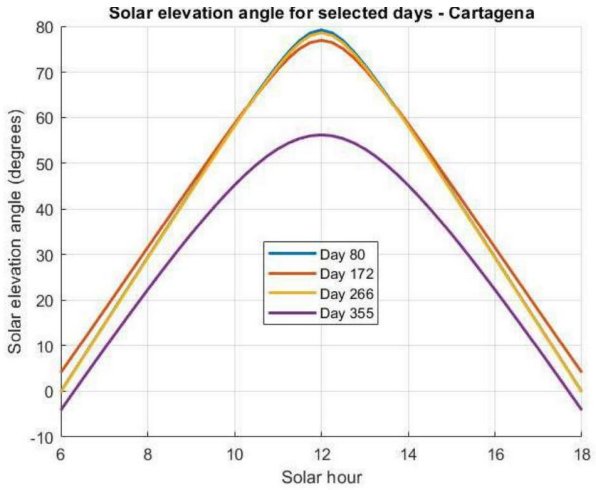


Figure 4. Solar elevation angle for representative days in Cartagena de Indias.

Figure 5 shows the angle of solar azimuth, as a function of solar time, for the same selected days. This information allows the daily angular variation and the relevance of solar tracking systems to be visualized.

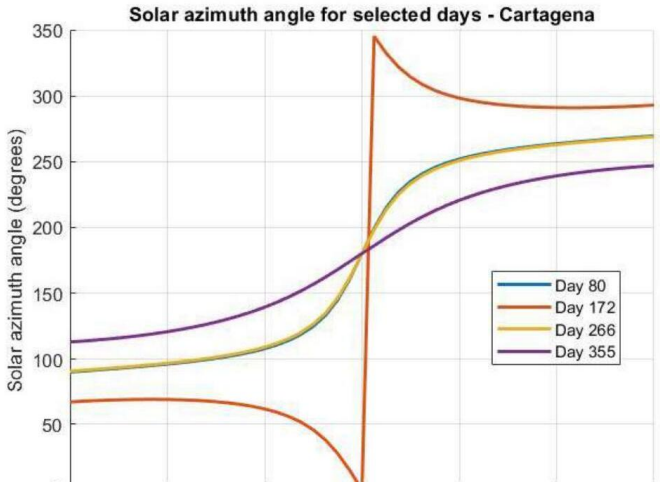


Figure 5. Solar azimuth angle as a function of solar time for representative days in Cartagena de Indias.

4.8. Heuristic optimization

Optimization was formulated as a problem of searching for the installed power required to achieve a desired energy coverage. The objective function was defined as:

$$J(P) = \left[\frac{\sum_{t=1}^{365} E_{\mathrm{PV}}(t) - \rho \sum_{t=1}^{365} D(t)}{\rho \sum_{t=1}^{365} D(t)}\right]^2 + \lambda P_{\mathrm{exc}} \quad (18)$$

where ρ is the target coverage, D(t) is the estimated daily demand, EPV(t) is the daily PV generation and Pexc represents a penalty for daily surpluses. In this work, a genetic algorithm was applied for the scenario with two-axis tracking and a target coverage of 50%.

5. Results

5.1. Comparison of PV scenarios

Table 4 presents the simulation results for installed powers of 50, 100, 150 and 200 kWp. Energy coverage, estimated annual economic savings and avoided CO2 emissions are reported.

Table 4. Annual results by photovoltaic scenario.

P (kWp)	Configuration	Coverage (%)	Savings (COP)	Avoided CO_2 (kg)
50	Fixed	23,41	49.079.000	10.542
50	Single-axis	26,92	56.441.000	12.123
50	Dual-axis	29,26	61.349.000	13.177
100	Fixed	46,82	98.159.000	21.083
100	Single-axis	53,85	112.880.000	24.246
100	Dual-axis	58,53	122.700.000	26.354
150	Fixed	70,23	147.240.000	31.625
150	Single-axis	80,77	169.320.000	36.368
150	Dual-axis	87,79	184.050.000	39.531
200	Fixed	93,65	196.320.000	42.166
200	Single-axis	107,69	209.640.000	45.028
200	Dual-axis	117,06	209.640.000	45.028

For an installed power of 100 kWp, the fixed system achieves an approximate annual coverage of 46.82%, while the system with a single-axis tracker reaches 53.85% and the system with a two-axis tracker reaches 58.53%. This shows a clear improvement in solar tracking compared to the fixed configuration. Figure 6 compares the estimated daily demand with the PV generation for an installed capacity of 100 kWp.

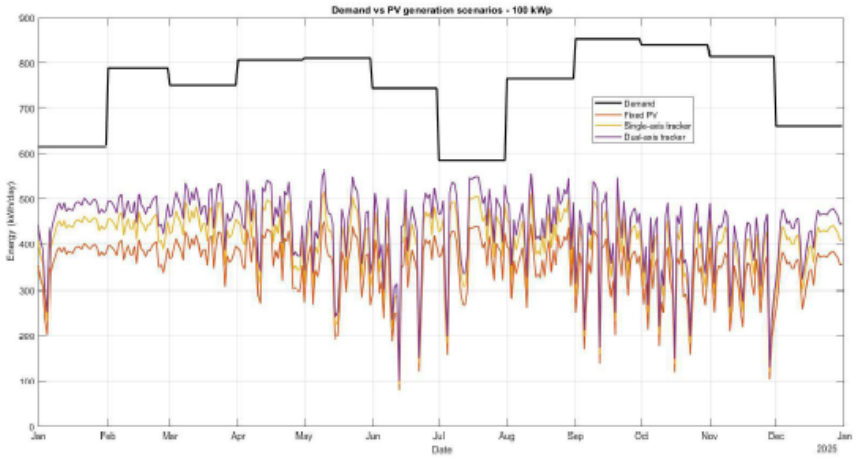


Figure 6. Comparison between estimated daily demand and photovoltaic generation for an installed capacity of 100 kWp.

Figure 7 shows the annual accumulated energy. It can be seen that the cumulative generation of the two-axis tracking system is higher than that of the single-axis system and that of the fixed system.

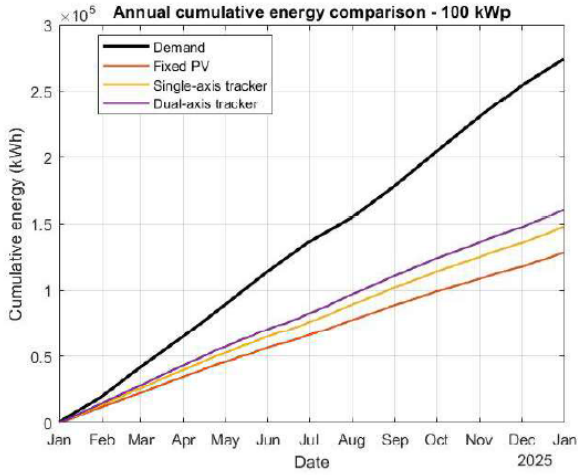


Figure 7. Comparison of annual cumulative energy for an installed power of 100 kWp.

5.2. Power Required by Target Coverage

Table 5 presents the installed power required to cover 30%, 50%, 70% and 100% of the estimated annual demand.

Table 5. Power required per target coverage.

Target coverage (%)	Fixed panel (kWp)	Single-axis (kWp)	Dual-axis (kWp)
30	64,07	55,72	51,26
50	106,79	92,86	85,43
70	149,50	130,00	119,60
100	213,57	185,72	170,86

To cover 50% of the estimated annual demand, the fixed system would require 106.79 kWp, while the two-axle system would require 85.43 kWp. This implies a reduction of 21.36 kWp compared to the fixed system.

Figure 8 shows the relationship between target coverage and required installed power. The two-axis system requires less installed power to achieve the same level of coverage.

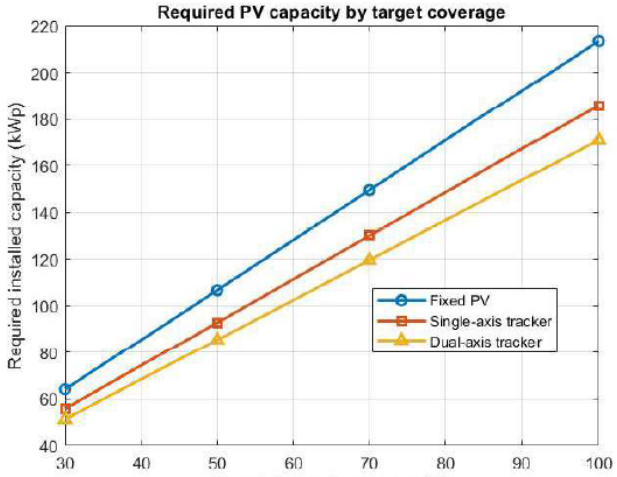


Figure 8. Photovoltaic power required for different levels of demand coverage.

5.3. Result of heuristic optimization

The genetic algorithm was applied to estimate the optimal power required in the scenario with two-axis solar tracking, considering a target coverage of 50%. The result was:

$$P_{\text{opt}} = 85.43 \text{ kWp} \tag{19}$$

With this power, the model achieved a coverage of 50%, an estimated annual saving of 104,820,105.97 COP and a reduction in emissions of 22,513.92 kgCO2/year. Table 6 summarizes the results of the optimization.

Table 6. Result of the optimization by genetic algorithm.

Indicator	Value
Target coverage	50 %
Optimal power	85.43 kWp
Achieved coverage	50,00 %
Estimated Annual Savings	COP 104,820,105.97
CO2 avoided annually	22,513.92 kgCO2
Objective function	0,0000

6. Discussion

The results obtained show that the installation of photovoltaic systems can significantly reduce the energy purchased from the electricity grid. In particular, for an installed power of 100 kWp, the fixed system would cover about 46.82% of the estimated annual demand, while the system with two-axis tracking would reach an approximate coverage of 58.53%.

The difference between the fixed system and the two-axis tracked system is relevant from an energy point of view. However, the selection of technology should not be based solely on annual generation. Solar trackers incorporate mechanical elements, actuators, sensors, and control systems, which can increase the initial cost, maintenance needs, and likelihood of failures. Therefore, the final evaluation should include economic analysis, return on investment, maintenance costs, mechanical reliability, and structural constraints of the installation site.

From an environmental point of view, the results show significant emission reductions. For 100 kWp, the fixed system would avoid approximately 21,083 kgCO2/year, while the system with two-axis tracking would avoid 26,354 kgCO2/year. These results are preliminary and depend on the emission factor used.

An important limitation of the study is that the annual demand was estimated from a single actual bill. Therefore, the monthly consumption series should not be interpreted as real historical billing, but as an estimated baseline for preliminary simulation. In a final version of the study, it is recommended to use at least twelve real bills, validate the available installation area, define the exact type of panel, consider investment costs, include storage if applicable, and compare the results with real generation measurements.

7. Conclusions

This work presented a dynamic simulation and heuristic optimization methodology to evaluate the incorporation of photovoltaic systems with solar tracking in a university institution in Cartagena de Indias. Based on a real electricity consumption bill, daily weather data from NASA POWER and a photovoltaic model with thermal correction, fixed panel, single-axis tracker and two-axis tracker scenarios were evaluated.

The results indicate that solar tracking improves energy coverage compared to a fixed system. For an installed power of 100 kWp, the fixed system covered 46.82% of the estimated annual demand, the system with a single-axis tracker covered 53.85% and the system with a two-axis tracker reached 58.53%. Optimiza-

tion by genetic algorithm identified a power of 85.43 kWp to cover 50% of the estimated annual demand in the two-axis tracking scenario.

The proposed model can be used as a preliminary tool to support energy transition decisions on university campuses.

Future work will focus on strengthening the demand baseline with at least twelve months of actual electricity bills and higher-resolution load measurements, and on validating the simulated generation against local irradiance data and a solar-tracking prototype. Further development should incorporate available installation area, actuator energy consumption, investment and maintenance costs, and economic-return analysis. Sensitivity analysis of demand, weather conditions, and tracking gains would help quantify uncertainty and assess the robustness of the capacity-sizing results before implementation.

Author Contributions: **Ángel David Ariz:** Software, Data curation, Visualization, Writing – original draft. **Jorge Manuel Barrios Sánchez:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Karin Sofía Zúñiga López:** Investigation, Formal analysis, Writing – original draft, Writing – review & editing. **Carlos Arnulfo Garzón Mercado:** Methodology, Validation, Resources, Writing – review & editing. **Dario Jiménez Velandia:** Conceptualization, Formal analysis, Validation, Writing – review & editing.

Please refer to the CRediT taxonomy for the definitions of the terms. Authorship should be limited to those who have made substantial contributions to the reported work.

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