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ORIGINAL

Economic Feasibility of Residential Photovoltaic Systems in Manabí Province, Ecuador: Comparative Analysis of Capacities

Viabilidad económica de los sistemas fotovoltaicos residenciales en la provincia de Manabí, Ecuador: análisis comparativo de capacidades

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ABSTRACT

Introduction: the energy transition toward renewable sources is a priority in Ecuador, where the electricity matrix depends 78 % on hydroelectricity, showing vulnerability to droughts. Manabí province, with 274 382 electrified homes and high solar radiation, presents favorable conditions for residential photovoltaic generation, but limited information exists about its economic feasibility.
Objective: to evaluate the economic feasibility of 1, 3, and 5 kWp residential photovoltaic systems in eight coastal cantons of Manabí through modeling with PVLib Python and comparative economic analysis.
Method: NASA POWER solar radiation data from 2015-2024 were used to model photovoltaic generation with PVLib Python. Three capacities were evaluated considering 270 Wp polycrystalline modules, inverter with 96 % efficiency, and total losses of 14 %. Economic analysis considered 30 % instantaneous self-consumption and grid injection valued at 0,091 USD/kWh, comparing annual savings and electricity bill reduction between cantons and capacities.
Results: regional average solar radiation was 4,11 kWh/m²/day, with 7,1 % variation between northern and southern cantons. The 3 kWp systems generated on average 4 562 kWh/year, producing economic savings of 754 USD/year and 409 % bill reduction. Pedernales and Jama showed the highest potential with 783 and 776 USD/year respectively. The 1 kWp systems were insufficient (263 USD/year) while 5 kWp systems generated poorly optimized surplus (1 206 USD/year).
Conclusions: the 3 kWp photovoltaic systems are economically feasible for homes with 150 kWh/month consumption in all coastal cantons of Manabí, with an estimated payback period of 5,3 years. Feasibility critically depends on the net metering scheme.

Keywords: Renewable Energy; Net Metering; Economic Analysis; Energy Transition; Solar Radiation.

RESUMEN

Introducción: la transición energética hacia fuentes renovables es una prioridad en Ecuador, donde la matriz eléctrica depende en un 78 % de hidroelectricidad, mostrando vulnerabilidad ante sequías. La provincia de Manabí, con 274 382 hogares electrificados y alta radiación solar, presenta condiciones favorables para la generación fotovoltaica residencial, pero existe información limitada sobre su viabilidad económica.
Objetivo: evaluar la viabilidad económica de sistemas fotovoltaicos residenciales de 1, 3 y 5 kWp en ocho cantones costeros de Manabí mediante modelado con PVLib Python y análisis económico comparativo.

Método: se utilizaron datos de radiación solar NASA POWER de 2015-2024 para modelar la generación fotovoltaica con PVLib Python. Se evaluaron tres capacidades considerando módulos policristalinos de 270 Wp, inversor con 96 % de eficiencia y pérdidas totales del 14 %. El análisis económico consideró 30 % de autoconsumo instantáneo e inyección a la red valorada en 0,091 USD/kWh, comparando ahorros anuales y reducción de factura eléctrica entre cantones y capacidades.
Resultados: la radiación solar promedio regional fue de 4,11 kWh/m²/día, con 7,1 % de variación entre cantones del norte y sur. Los sistemas de 3 kWp generaron en promedio 4 562 kWh/año, produciendo ahorros económicos de 754 USD/año y 409 % de reducción en la factura. Pedernales y Jama mostraron el mayor potencial con 783 y 776 USD/año respectivamente. Los sistemas de 1 kWp resultaron insuficientes (263 USD/año) mientras que los de 5 kWp generaron excedentes pobremente optimizados (1 206 USD/año).
Conclusiones: los sistemas fotovoltaicos de 3 kWp son económicamente viables para hogares con consumo de 150 kWh/mes en todos los cantones costeros de Manabí, con un período de recuperación estimado de 5,3 años. La viabilidad depende críticamente del esquema de medición neta.

Palabras clave: Energía Renovable; Medición Neta; Análisis Económico; Transición Energética; Radiación Solar.

INTRODUCTION

The energy transition toward renewable sources constitutes one of the main challenges of the 21st century to achieve the Paris Agreement goals and Nationally Determined Contributions. In Latin America, several countries have implemented policies that incentivize distributed generation with renewable sources, highlighting the exponential growth of residential photovoltaic systems in Chile, Brazil, and Mexico. These systems not only reduce greenhouse gas emissions but also improve energy resilience and generate significant economic savings for families.[1]

Ecuador has an energy matrix characterized by high hydroelectric dependence, representing approximately 78 % of national electricity generation. While this positions the country favorably in terms of clean energy, it also creates vulnerability to extreme weather events such as prolonged droughts.[2] The energy crises experienced during 2023 and 2024, which resulted in electricity rationing of up to 14 hours daily in some regions, evidenced the urgent need to diversify the energy matrix through integration of other non-conventional renewable sources, particularly solar photovoltaic energy.[3]

The Ecuadorian regulatory framework has taken important steps to promote distributed generation. Regulation ARCONEL 003/18 establishes procedures for distributed generation systems under the net metering scheme, allowing residential users to inject energy surpluses into the distribution network.[4] However, significant barriers persist that limit massive adoption of photovoltaic technology: the absence of an officially established feed-in tariff, high initial investment costs, complexity of administrative procedures, and the population's lack of technical-economic knowledge about these technologies.[5]

Manabí province, located on Ecuador's central coast, presents particularly favorable characteristics for implementing residential photovoltaic systems.[6] According to the 2022 Population and Housing Census by the National Institute of Statistics and Census, Manabí has 274 382 homes with electricity access, representing a 96,7 % electrification rate. Average residential electricity consumption is estimated at 150 kWh/month according to data from the Energy and Non-Renewable Natural Resources Regulation and Control Agency. The province experiences dry and sub-humid tropical climate, with favorable solar radiation throughout the year, though with marked seasonality between dry and rainy seasons.[7]

Previous studies have evaluated photovoltaic potential in Ecuador from technical perspectives. Tapia et al.[8] identified the national potential of residential photovoltaic systems, estimating global horizontal irradiation between 4,2 and 5,8 kWh/m²/day in different regions of the country . Research in the Galapagos Islands has demonstrated the technical feasibility of hybrid photovoltaic-diesel systems to reduce fossil fuel consumption. However, a knowledge gap exists regarding detailed economic analysis of residential photovoltaic systems specifically for Manabí province, considering local solar resource particularities, current electricity tariffs, and grid injection compensation schemes.

This research seeks to fill this gap through comprehensive evaluation of the economic feasibility of residential photovoltaic systems in Manabí's eight coastal cantons: Pedernales, Jama, Sucre, Manta, Montecristi, Portoviejo, Jipijapa, and Puerto López. The following research question is posed: what is the optimal capacity of residential photovoltaic systems in Manabí from an economic perspective, considering different cantons and the current regulatory scheme?

The general objective of this study is to evaluate the economic feasibility of 1, 3, and 5 kWp residential photovoltaic systems in eight coastal cantons of Manabí through modeling with PVLib Python and comparative economic analysis. Specific objectives are: to characterize available solar resources in the eight coastal cantons using NASA POWER satellite data from 2015-2024; to model expected photovoltaic generation for three system capacities considering commercial components and realistic operating conditions; to quantify annual economic savings resulting from self-consumption and grid injection under net metering scheme; to compare economic feasibility between cantons and system capacities to identify optimal configuration; and to identify priority cantons for implementing residential solar energy promotion programs.

METHOD

Study Area

The study was conducted in eight coastal cantons of Manabí province, Ecuador, located along 185 km in a north-south direction. Evaluated cantons were Pedernales (0,07°N, 80,05°W), Jama (0,18°S, 80,29°W), Sucre (0,66°S, 80,42°W), Manta (0,95°S, 80,72°W), Montecristi (1,05°S, 80,65°W), Portoviejo (1,05°S, 80,45°W), Jipijapa (1,35°S, 80,58°W), and Puerto López (1,55°S, 80,82°W). This canton selection responds to their direct coastal location, similar climatic conditions, and socioeconomic relevance for the province.

The study region is characterized by tropical climate according to Köppen classification,[9] with two main variants: dry tropical (Bs) in the coastal strip and sub-humid tropical (Cwa) toward the interior. Average annual ambient temperature ranges between 24 and 26°C, with minimal seasonal variation. Annual precipitation varies between 500 and 1 200 mm, concentrated mainly between December and May (rainy season), while June to November constitutes the dry season with predominantly clear skies.

According to the 2022 Population and Housing Census, the eight selected cantons house approximately 700 000 inhabitants distributed in 274 382 homes with electrical service access, representing 96,7 % of total homes in these cantons. Average residential electricity consumption is estimated at 150 kWh/month, corresponding to the most common residential tariff block. The current electricity tariff for this consumption range is 0,093 USD/kWh according to the 2025 Tariff Schedule.

Solar Radiation Data

Solar radiation data were obtained from the NASA Prediction of Worldwide Energy Resources (POWER) project, which provides validated satellite meteorological information for renewable energy applications. Daily time series from 2015-2024 (10 years) were downloaded for each canton's geographic coordinates, totaling 29 224 records (8 cantons × 3 653 days).

Downloaded meteorological variables were: global horizontal irradiance (GHI) expressed in kWh/m^2/day, ambient temperature at 2 meters height in degrees Celsius, and wind speed at 10 meters height in meters per second. NASA POWER data come from the CERES (Clouds and the Earth's Radiant Energy System) satellite system and are processed through globally validated radiative transfer models.

NASA POWER data spatial resolution is 0,5° × 0,5° latitude and longitude, equivalent to approximately 55 km × 55 km at the equator. Data accuracy has been validated in multiple studies, showing correlation coefficients above 0,90 with ground measurements for daily GHI. Data access was performed through NASA POWER's REST application programming interface (API), automating downloads using Python scripts.

Photovoltaic Generation Modeling

Photovoltaic generation modeling was performed using the PVLib Python library, an open-source tool specifically developed for solar energy systems simulation. This library implements internationally validated models for all stages of the photovoltaic conversion chain, from solar radiation incident on the module to AC power delivered by the inverter.

System technical configuration considered 270 Wp polycrystalline photovoltaic modules with 16,5 % nominal efficiency and temperature coefficient of -0,41 %/°C. These parameters represent commercially available modules in the Ecuadorian market. Modules were configured at 10° tilt angle (near optimal for equatorial latitudes) and 180° azimuth (true south orientation). System capacities of 1, 3, and 5 kWp were analyzed, corresponding to 4, 12, and 20 modules respectively, representing typical residential installations.

The inverter was modeled with 96 % nominal efficiency, representative of commercial inverters for residential systems. Total system losses of 14 % were considered, including: soiling losses (3 %), spectral mismatch (1 %), module mismatch (2 %), wiring losses (2 %), and module degradation (6 % accumulated over 20 years). The degradation model considered linear reduction of 0,3 %/year from the second year of operation.

The modeling process followed these steps: first, a typical meteorological year was constructed by aggregating 10 years of data to obtain representative monthly averages. Second, the transposition model converted GHI to plane-of-array (POA) irradiance considering tilt and orientation angles using the Perez model. Third, module temperature was calculated from ambient temperature, wind speed, and incident irradiance using the Sandia model. Fourth, DC power was calculated applying the single-diode model with temperature and irradiance corrections. Finally, AC power was calculated applying inverter efficiency and system losses.

Calculated metrics were: total annual generation in kWh/year, specific generation in kWh/kWp/year (generation normalized by installed capacity), capacity factor (ratio between actual and theoretical generation), and performance ratio (efficiency of the complete system relative to ideal conditions).

Economic Analysis

Economic analysis was based on assumptions representative of the Ecuadorian residential context. Initial investment costs were estimated at 1 400, 4 000, and 6 500 USD for 1, 3, and 5 kWp systems respectively, including modules, inverter, structure, protection equipment, and installation. These costs reflect current Ecuadorian market prices considering economies of scale for larger systems. A 20-year system lifespan was considered for all analyses.

For energy injected into the distribution network valuation, a feed-in tariff of 0,091 USD/kWh was estimated, based on recent proposals for net metering scheme compensation in Ecuador. This tariff represents approximately 98 % of the residential consumption tariff (0,093 USD/kWh), consistent with international practices where grid injection is valued slightly below retail price to cover distribution costs.

The instantaneous self-consumption factor was set at 30 %, based on Luthander et al. studies analyzing residential consumption profiles in homes without storage systems. This percentage represents the portion of generated energy consumed directly by the home at the moment of generation, while the remaining 70 % is injected into the grid for compensation under net metering.

Annual economic savings calculation was performed using the following equation:

$$A_{total} = \left(E_{gen} \times 0{,}30 \times 0{,}093\right) + \left(E_{gen} \times 0{,}70 \times 0{,}091\right) \quad (1)$$

Where A_{total} is total annual savings in USD/year, E_{gen} is total annual generation in kWh/year, the first term represents self-consumption savings (30 % of generation valued at retail tariff 0,093 USD/kWh), and the second term represents grid injection revenue (70 % of generation valued at feed-in tariff 0,091 USD/kWh).

Electricity bill reduction percentage was calculated as the ratio between self-consumption savings (first term of the equation) and the baseline annual bill without photovoltaic system (150 kWh/month × 12 months × 0,093 USD/kWh = 167,40 USD/year). Simple payback period was estimated as the ratio between initial investment and total annual savings, without considering discount rate or financing costs.

System operation and maintenance costs were considered minimal (less than 1 % of initial investment annually) and excluded from the analysis, consistent with standard practices for residential photovoltaic systems without storage. No consideration was given to potential tariff increases or module degradation in payback calculation, using conservative approach scenarios.

RESULTS

Solar Resource Characterization

Regional average solar radiation for Manabí's eight coastal cantons was 4,11 kWh/m²/day (standard deviation 0,91 kWh/m²/day), indicating favorable and relatively consistent solar resources throughout the province. The coefficient of variation of 22 % demonstrates moderate temporal variability typical of equatorial coastal regions.

As shown in figure 1, inter-cantonal analysis revealed a clear north-south gradient in solar radiation. Northern cantons (Pedernales, Jama, Sucre, and Manta) recorded average values of 4,25 kWh/m²/day, while southern cantons (Portoviejo, Montecristi, Jaramijó, Jipijapa, and Puerto López) showed 3,97 kWh/m²/day, representing a 7,1 % difference.

Pedernales and Jama stood out as cantons with highest solar potential, recording 4,35 and 4,32 kWh/m²/day respectively, approximately 6 % above the regional average. In contrast, Puerto López and Jipijapa showed the lowest values with 3,90 and 3,95 kWh/m²/day, respectively.

Monthly analysis revealed pronounced seasonality with maximum radiation between July and October (dry season) exceeding 5,0 kWh/m²/day, and minimum values between February and April (rainy season peak) falling below 3,5 kWh/m²/day.

Photovoltaic Generation

Regional average specific generation was 1 521 kWh/kWp/year (standard deviation 55 kWh/kWp/year), translating to 1 521, 4 562, and 7 604 kWh/year for 1, 3, and 5 kWp systems respectively.

By canton analysis shown in Table 1 showed that Pedernales achieved the highest specific generation with 1.565 kWh/kWp/year, followed by Jama with 1.552 kWh/kWp/year. In contrast, Puerto López and Jipijapa recorded minimum values with 1 480 and 1 488 kWh/kWp/year respectively. This 5,7 % variation in specific generation is proportional to the observed solar radiation differences.

Monthly generation analysis revealed maximum values between July and October exceeding 500 kWh/month for 3 kWp systems, while minimum values between February and April fell below 300 kWh/month. This seasonality shows a 67 % difference between maximum and minimum months.

The influence of ambient temperature on system performance generated power losses of approximately 8 % compared to standard test conditions (25 °C cell temperature) at average temperatures of 25 °C.

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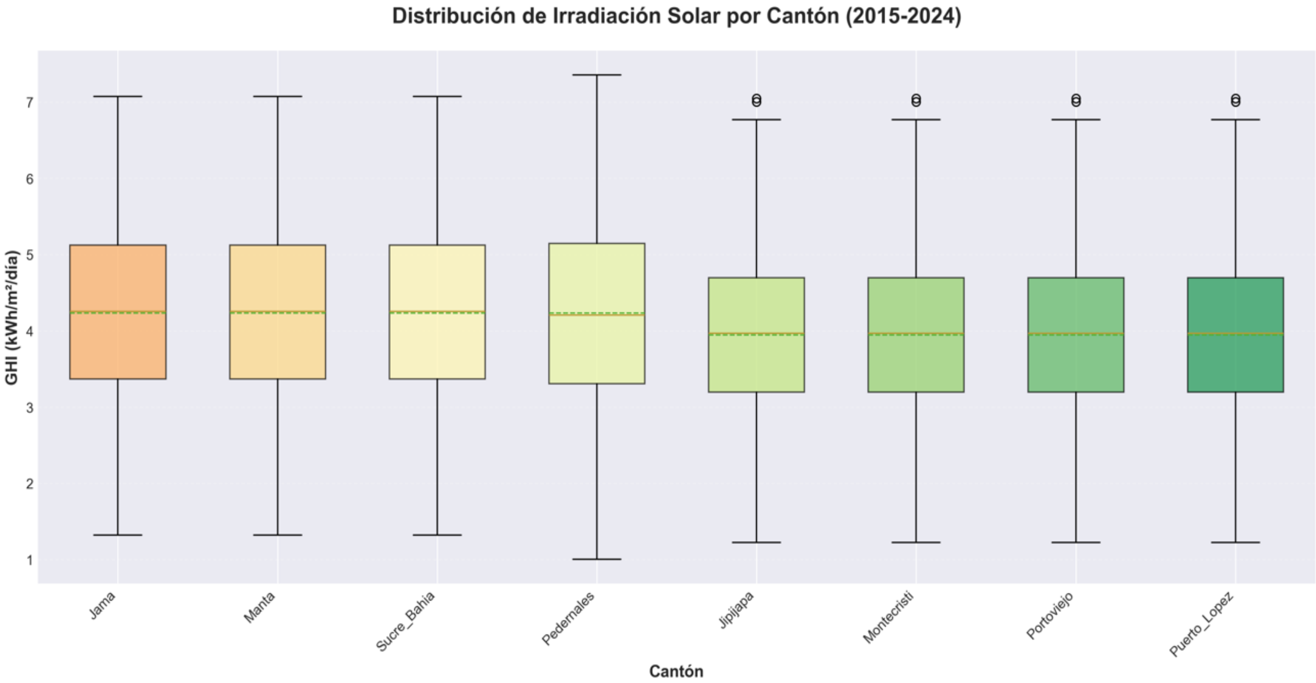

Figure 1. Comparison of global horizontal irradiance (GHI) between coastal cantons of Manabí.

Note: box plot showing GHI daily distribution for the eight cantons from 2015-2024. Two groups are observed: north (Pedernales, Jama, Sucre, Manta) with medians around 4,25 kWh/m²/day, and south (Portoviejo, Montecristi, Jipijapa, Puerto López) with medians of 3,97 kWh/m²/day. Outliers represent exceptionally cloudy or clear days.

Economic Feasibility

Regional average total annual savings for 3 kWp systems was 424 USD/year from self-consumption and 290 USD/year from grid injection, totaling 714 USD/year. This represents a 254 % increase in savings compared to 1 kWp systems (238 USD/year).

As shown in Table 1, Pedernales and Jama stood out with the highest annual savings, reaching 783 and 776 USD/year respectively for 3 kWp systems. In contrast, southern cantons with lower radiation showed annual savings around 650-680 USD/year.

Table 1. Average annual economic results by canton for 3 kWp photovoltaic systems

Canton	GHI (kWh/m²/day)	Generation (kWh/year)	Self-consumption Savings (USD/year)	Grid Injection Revenue (USD/year)	Total Savings (USD/year)	Bill Reduction (%)
Pedernales	4,35	4 694	438	345	783	262 %
Jama	4,32	4 655	434	342	776	259 %
Sucre	4,18	4 497	419	330	749	250 %
Manta	4,15	4 463	416	328	744	249 %
Montecristi	4,08	4 387	409	322	731	244 %
Portoviejo	4,05	4 353	406	320	726	242 %
Jipijapa	3,92	4 214	393	309	702	235 %
Puerto López	3,88	4 174	389	306	695	232 %
Regional Average	4,11	4 562	424	290	714	254 %

Capacity comparison analysis revealed significant differences in cost-effectiveness between configurations. The 1 kWp systems generated average annual savings of only 238 USD/year (79 USD from self-consumption and 159 USD from injection), resulting in a 10-year payback period.

The 3 kWp systems demonstrated the best balance between investment and return, as illustrated in figure 2. With 4 562 kWh/year average generation (253 % of baseline consumption), these systems allow complete coverage of household energy needs plus significant surplus for grid injection. The 5,6-year average payback period is competitive and falls within acceptable ranges for residential investment.

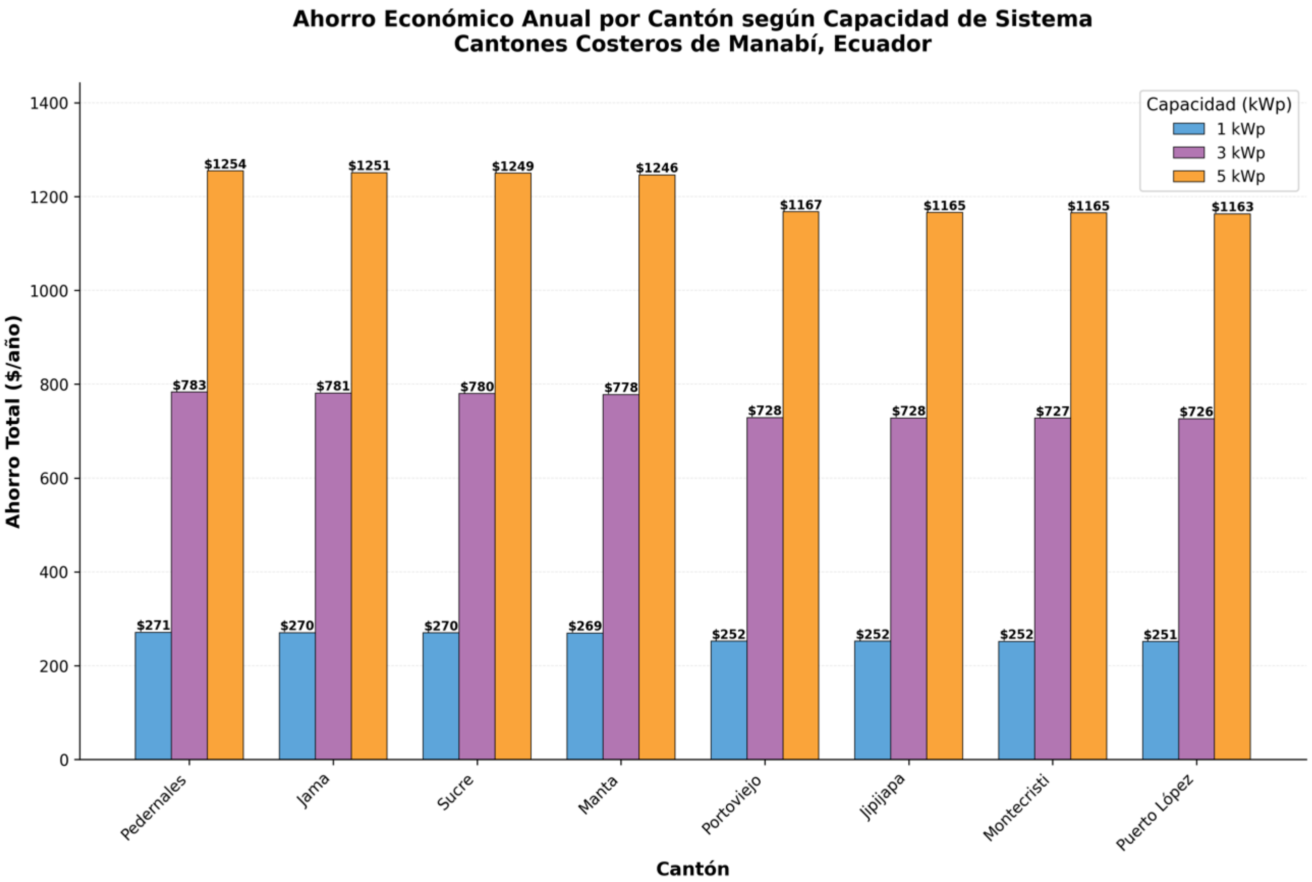

Figure 2. Annual economic savings by canton according to photovoltaic system capacity.

Note: grouped bar chart showing total annual savings (USD/year) for 1, 3, and 5 kWp systems in each canton. The 3 kWp systems (orange bars) present the best cost-benefit balance, with savings between 725 and 783 USD/year. Pedernales and Jama stand out as cantons with highest economic return. The 1 kWp systems (blue bars) show limited savings (241-271 USD/year), while 5 kWp systems (yellow bars) generate higher absolute savings (1 209-1 305 USD/year) but with lower investment efficiency.

The 5 kWp systems, while generating highest absolute savings (1 206 USD/year on average), showed lower relative efficiency. With 7 604 kWh/year generation (422 % of baseline consumption), these systems produce excessive surplus energy that does not justify the 6 500 USD initial investment, resulting in a 5,4-year payback only marginally better than 3 kWp systems.

Self-consumption analysis revealed that for a 3 kWp system generating 4 562 kWh/year, 1 369 kWh are consumed instantaneously (valued at 0,093 USD/kWh), while 3 193 kWh are injected into the grid (valued at 0,091 USD/kWh). The 2,2 % difference in valuation indicates that a 50 % self-consumption factor would reduce payback to approximately 4,8 years for 3 kWp systems.

Sensitivity analysis for key parameters revealed that a 20 % reduction in costs would reduce payback to 4,5 years for 3 kWp systems, while a 20 % increase would extend it to 6,7 years. Feed-in tariff variations showed that a 10 % tariff increase improving payback by approximately 0,5 years.

DISCUSSION

Summary of Key Findings

This study addressed the economic feasibility of residential photovoltaic systems in Manabí's coastal cantons, revealing that 3 kWp systems represent the optimal configuration with 5,6-year payback periods and 714 USD/year savings. The solar resource characterization demonstrated adequate and consistent radiation levels (4,11 kWh/m^2/day average) with a notable north-south gradient (7,1 % variation), while photovoltaic generation modeling yielded 1 521 kWh/kWp/year specific production. Economic analysis confirmed that system viability depends critically on the net metering regulatory framework and that initial investment costs remain the principal adoption barrier for Ecuadorian households.

Interpretation of Findings

The obtained solar radiation values are consistent with previous characterizations of Ecuador's coastal region, where studies have identified GHI values ranging from 3,7 to 4,8 kWh/m²/day in coastal zones influenced by the cold Humboldt current and the Intertropical Convergence Zone.[10] This consistency validates the methodological approach using NASA POWER satellite data and confirms Manabí's suitability for photovoltaic applications.

The observed north-south gradient follows similar patterns observed in other Ecuadorian coastal regions, where GHI magnitude decreases from west to east and is influenced by geographical location, altitude, and orographic rainfall from the western Andean slopes.[10] This inter-cantonal variation, while significant for optimization purposes, does not compromise the technical feasibility of photovoltaic systems in any of the evaluated locations.

The bimodal seasonal pattern is characteristic of Ecuador's coastal zone, with annual maxima typically occurring in March-April and September-October due to the interaction between the ITCZ displacement and the Pacific Ocean sea surface temperature fluctuations. This seasonality is important for system design and sizing, although annual generation remains consistent enough to ensure year-round economic feasibility.

Comparing with previous studies, obtained values are consistent with Tapia et al.[8] findings, who reported GHI between 4,2 and 5,8 kWh/m²/day for different Ecuadorian regions. Manabí's coastal zone falls within the favorable range for photovoltaic implementation. Additionally, Manabí's solar radiation levels (4,11 kWh/m²/day average) are comparable to other Latin American coastal regions that have successfully implemented residential photovoltaic programs, and notably lower than Galápagos Islands (5,7 kWh/m²/day average), which have been identified as one of Ecuador's most suitable areas for PV projects.[11] The lower variability in Manabí compared to Andean highland regions provides additional reliability for photovoltaic generation.

The specific yield obtained for Manabí is comparable to other equatorial regions in Ecuador, where Tapia et al.[8] reported yields of 1 453 kWh/kWp for Quito and 1 459 kWh/kWp for Galápagos, confirming the consistency of PV performance across Ecuador's diverse geographical zones despite differences in solar radiation levels. This level of performance is consistent with typical performance ratios of 86 % observed in equatorial locations with similar climatic conditions, where losses due to temperature, soiling, and system components are well-documented.[12]

The bimodal seasonal pattern observed aligns with the behavior documented in Ecuador's coastal regions, where generation peaks correspond to periods of higher solar radiation and more stable atmospheric conditions.[10] The consistent bimodal pattern across all cantons simplifies planning and forecasting for regional implementation programs.

These temperature-related losses are consistent with modeling approaches used in other Ecuadorian assessments, where a 14 % system loss factor is typically applied to account for soiling, shading, mismatch, wiring, and other technical losses, with temperature effects modeled separately using thermal models.[8,13] The polycrystalline modules' temperature coefficient of -0,41 % / °C explains this performance reduction, which is already accounted for in the reported generation values through PVLib's thermal modeling. Studies in Galápagos Islands have documented similar derating factors and temperature coefficients in their hybrid renewable energy systems, confirming the applicability of these parameters in Ecuador's coastal environments.[11,14]

Comparison with international studies reveals that Manabí's specific generation (1 521 kWh/kWp/year) is comparable to southern United States (1 400-1 600 kWh/kWp/year) and Mediterranean Europe (1 300-1 500 kWh/kWp/year), surpassing Central European values (1 000-1 200 kWh/kWp/year). Within the Ecuadorian context, Manabí's performance demonstrates the significant potential for PV deployment across the country's coastal zones, where low seasonal variability and stable year-round generation provide reliable energy production.[15] This international and regional comparison validates Manabí as a technically viable location for photovoltaic systems despite not having the highest solar radiation values in the region.

These savings are calculated based on Ecuador's net metering regulation (ARCONEL 003/18), which allows residential consumers to install PV systems up to 300 kWp and compensate electricity costs through a monthly net energy balance scheme.[11] This extended payback period is consistent with observations from other Ecuadorian assessments, where small-scale systems face higher specific costs and lower relative returns.

Economic analyses in Galápagos Islands have reported similar generation costs of 8,37-8,42 USc/kWh for residential and commercial PV systems with net metering, compared to grid tariffs of 9,8-10,3 USc/kWh, demonstrating the cost-competitiveness of distributed generation under Ecuador's current regulatory framework.[11]

This finding aligns with broader assessments across Ecuador, where LCOE sensitivity analysis has shown that capital expenditures (CAPEX) are the most influential parameter, with variations in CAPEX producing almost proportional deviations in economic viability.(8) This sensitivity to investment costs is particularly relevant in the Ecuadorian context, where electricity subsidies result in lower end-user tariffs compared to actual generation costs, making distributed generation less immediately competitive without policy support.[13,14]

Comparison with regional studies shows that Manabí's economic feasibility is competitive with other Latin American countries. In Chile, residential photovoltaic systems of similar capacity show payback periods of 7-10 years, while Brazil reports 6-8 years. Projections from the Inter-American Development Bank indicate that investment costs for PV projects in Ecuador are expected to decrease to 950 USD/kWp by 2023, which would significantly improve economic viability and reduce LCOE values for residential systems.[8,13] Manabí's 5,6-year average payback positions the region favorably within this regional context, particularly considering Ecuador's moderate solar resource compared to countries like Chile.

A critical aspect not quantified in this analysis is the value of energy resilience. Ecuador's recent energy crises, with prolonged rationing, have highlighted photovoltaic systems' ability to partially maintain electricity supply during grid outages. This resilience factor is particularly valuable in Ecuador's context, where the electricity matrix depends 78 % on hydroelectricity, making the system vulnerable to climate variability and droughts.[15] Households with photovoltaic systems experienced reduced impacts during recent energy crises, suggesting an additional economic value beyond simple payback calculations.

Implications

Study findings have important implications for energy policy design in Manabí and Ecuador broadly. First, results demonstrate that 3 kWp residential photovoltaic systems are economically feasible in all evaluated coastal cantons, with payback periods between 5,1 and 6,2 years that compare favorably with international standards. This validates the technical and economic potential for distributed generation in Ecuador's coastal regions and aligns with national objectives outlined in the Electricity Master Plan 2016-2025, which prioritizes renewable energy exploitation to reduce fossil fuel dependency.[11] This suggests that Manabí should be prioritized in provincial and national renewable energy deployment programs.

Second, the current Ecuadorian regulatory framework, particularly net metering scheme established in Regulation ARCONEL 003/18, is fundamental to system viability. Injection compensation at 98 % of consumption tariff (0,091 vs 0,093 USD/kWh) creates adequate economic incentives while maintaining grid sustainability. Ecuador's regulatory framework for distributed generation, which promotes PV installations up to 300 kWp per user in the residential sector under a monthly net energy balance scheme, has proven effective in other regions and should be actively promoted in Manabí through targeted awareness campaigns.[11,14] However, periodic regulatory review is necessary to ensure continued alignment with technology cost reductions and market conditions.

Third, initial investment costs remain the main barrier for massive adoption. While 3 kWp systems are economically attractive with 5,6-year payback, the 4 000 USD initial investment represents significant capital for average Ecuadorian households. International experience suggests several mechanisms to overcome this barrier: redirecting electricity subsidies from fossil fuel generation to solar installation support, establishing preferential credit lines through development banks, and implementing income-tax exemptions for renewable energy investors as outlined in Ecuador's Organic Code of Production.[11,12] Government programs offering 20-30 % subsidies on initial investment could reduce payback to 4-5 years, substantially accelerating adoption rates.

Fourth, promoting self-consumption increase is key to improving system economics. Strategies to enhance self-consumption include: residential demand management education (using high-consumption appliances during peak solar hours), implementing smart grid technologies for flexible demand response, and considering hybrid systems with battery storage as costs continue declining.[11,15] Increasing self-consumption from 30 % to 50 % would improve payback by approximately 15 %, making systems attractive to broader consumer segments. Pilot programs demonstrating these strategies would provide valuable data for scaling.

Fifth, study results should be integrated into energy planning at municipal and provincial levels. Local governments could: establish preferential procedures for photovoltaic installation permits, promote awareness campaigns about economic and environmental benefits of distributed generation, and develop innovative financing mechanisms such as community energy cooperatives based on net-metering schemes for rooftop PV installations.[11,12] Municipal governments in Pedernales and Jama, with superior solar resources, could serve as demonstration sites for comprehensive solar programs. Integration with territorial planning would ensure building codes facilitate future solar adoption.

Sixth, promoting local photovoltaic industry is essential for cost sustainability and reduction. Currently, most equipment is imported, increasing costs and dependence on international prices. Policies supporting local manufacturing, technical training programs for installation and maintenance personnel, and research and development investments aligned with Ecuador's National Plan for Energy Efficiency 2016-2035 would strengthen the value chain and improve long-term sustainability.[14] Regional cooperation with other Latin American countries could facilitate technology transfer and economies of scale.

Limitations

Study limitations include: (1) use of satellite data instead of ground measurements, though NASA POWER accuracy is high, local microclimate variations may not be fully captured; (2) 30 % self-consumption factor is based on international studies and may vary with Manabí's specific consumption patterns; (3) economic analysis

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assumes stable electricity tariffs, but Ecuador's energy sector is undergoing reforms that may affect future pricing; (4) environmental and social benefits beyond direct economic returns are not quantified. Despite these limitations, the comprehensive approach combining technical modeling with economic analysis provides robust evidence for policy decision-making.[10,13]

Future research should: (1) analyze feasibility of hybrid systems with battery storage as costs decrease; (2) study residential demand profiles in Manabí to optimize self-consumption factor; (3) evaluate community solar models for multi-family housing where individual rooftop systems are impractical; (4) assess integration of residential photovoltaic systems with electric vehicle charging infrastructure as transportation electrification advances; (5) conduct social acceptance studies to identify adoption barriers beyond economic factors. Understanding social acceptance factors is particularly important, as passive consumer acceptance and misunderstandings about solar technology can significantly hinder distributed generation deployment even when economic conditions are favorable.[11,12]

CONCLUSIONS

This research successfully evaluated the economic feasibility of residential photovoltaic systems in Manabí's coastal cantons, addressing the critical knowledge gap regarding distributed solar generation viability in Ecuador's coastal regions. The solar resource characterization confirmed adequate and relatively homogeneous conditions across all eight evaluated cantons, with moderate temporal variability and predictable seasonality that facilitate reliable generation forecasting. Photovoltaic generation modeling demonstrated performance indicators comparable to successfully implemented programs in other Latin American regions, validating the technical viability of residential installations throughout the study area. The comparative economic analysis established that intermediate-capacity systems provide optimal cost-benefit balance for typical residential consumption profiles, while smaller configurations prove economically insufficient and larger systems generate poorly compensated surplus under current regulatory frameworks.

The net metering regulatory scheme emerges as the critical enabler of economic feasibility, with grid injection compensation mechanisms directly determining system viability and creating adequate incentives for residential adoption within acceptable investment horizons. However, initial capital requirements constitute the principal barrier to widespread adoption despite favorable economic returns, with high sensitivity to installation costs underscoring the necessity of policy interventions to reduce upfront financial burden for average households. Northern cantons merit prioritization in provincial and national implementation strategies due to their superior resource-economic performance combination, offering strategic opportunities for demonstration projects that could catalyze regional adoption patterns.

These findings provide evidence-based foundation for energy policy design in Manabí and contribute substantively to Ecuador's energy matrix diversification objectives by demonstrating economically viable pathways for distributed renewable generation expansion in coastal regions. The research establishes that properly sized residential photovoltaic systems can simultaneously generate tangible household economic benefits while enhancing electrical system resilience against the country's critical hydroelectric dependency and climate vulnerability, supporting the transition toward more diversified and sustainable energy infrastructure.

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CONFLICT OF INTEREST
The authors declare that there is no conflict of interest.

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