# Economic Feasibility of PV Self-Consumption Scenarios in Peru: A Multi-Regional Analysis Using Experimental Performance Data

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**Abstract**

This study evaluates the economic feasibility of residential photovoltaic (PV) self-consumption systems in Peru using three years of experimental performance data and real-world market conditions. Performance metrics from PERC and HIT modules across five distinct climate zones are combined with current (2025) investment costs and electricity tariffs to compute key indicators: Levelized Cost of Electricity (LCOE), Net Present Value (NPV), and Discounted Payback Time (DPBT). The analysis also includes the emerging TOPCon technology via validated approximations. Results show that regional irradiance and local tariffs critically shape profitability, with Juliaca and Tacna offering the shortest payback periods and the highest returns. A sensitivity analysis examines self-consumption levels, system size, and incentive schemes (net metering, net billing, no compensation) on the economic performance of residential PV systems. The findings support data-driven recommendations for shaping Peru's distributed generation (DG) policy and expanding the residential solar market.

*Keywords: Photovoltaic systems, distributed generation, economic feasibility, outdoor performance, LCOE*

## 1. Introduction

Peru possesses vast renewable energy potential, particularly in solar and hydropower, yet its transition toward a low-carbon energy system remains incomplete due to persistent regulatory and institutional constraints. As of 2024, the country's technically exploitable solar potential exceeds 937 GW, positioning it among the most solar-rich nations in South America, especially in southern regions such as Arequipa, Moquegua, Tacna, Ica, and Puno (Ministerio de Energía y Minas, 2024). Despite this resource abundance, installed photovoltaic (PV) capacity remains limited: by the end of 2024, only 476.66 MW of PV capacity was operational, with an additional 1.77 GW under construction and 18.1 GW in the project pipeline (Peruvian Renewable Energy Association, 2025).

The *Plan Energético Nacional 2014–2025* set a national target of 60% electricity generation from renewable sources by 2025 (Ministerio de Energía y Minas, 2014). As of 2023, renewables accounted for approximately 55.4% of electricity generation, primarily due to hydropower (~53%). Non-conventional renewables—such as solar, wind, and biomass—contributed only 7–8%, with solar representing around 2.6% (International Energy Agency, 2023; LowCarbonPower.org, 2024). These figures highlight the persistent gap between Peru's technical solar potential and its actual deployment, particularly in the residential and small-scale sectors. Similar institutional challenges have been noted across the Global South, where policy fragmentation and limited financial tools continue to hinder distributed generation (DG) adoption (Barragán-Ocaña et al., 2025).

In Peru, policy and regulatory support for DG remains underdeveloped. While early frameworks such as the Electricity Concessions Law (D.L. 25844) and renewable energy auctions promoted utility-scale projects, small-scale PV systems were largely excluded. A draft law introduced in 2022 proposes key reforms such as net metering, simplified permitting, and surplus compensation that align with successful DG models implemented in Brazil, Chile, and Colombia (Chabla-Auqui et al., 2023). However, as of Q3 2025, the legislation remains pending (Enerdata, 2024), and no nationwide mechanism exists for compensating grid-injected electricity from residential systems. As a result, self-consumption installations in Peru operate without


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financial return for exported surplus, limiting their attractiveness to households. Comparative studies suggest that differentiated tariff schemes and well-designed net billing policies are key drivers of adoption in similar contexts (Silveira et al., 2024).

In the absence of a comprehensive regulatory framework, residential PV systems in Peru must assume zero compensation for exported energy. This severely undermines their financial viability—particularly in high-irradiance regions such as Tacna and Juliaca, where surplus generation could otherwise provide significant value (Espinoza et al., 2019; Humpire Mojonero et al., 2018). Addressing this regulatory deficit is essential if Peru is to unlock the potential of distributed solar and achieve its decarbonization goals (Cacciuttolo et al., 2024).

While several studies have assessed the technical and economic potential of residential PV in Peru and Latin America, critical gaps remain. Espinoza et al. (2019) conducted early regional evaluations based on tariff and cost data available at the time. Talavera et al. (2019) developed a robust methodological framework for techno-economic PV analysis, now widely applied. More recent reviews emphasize the influence of regulatory design, self-consumption rates, and retail tariffs on project feasibility (Chabla-Auqui et al., 2023). However, few studies incorporate long-term experimental performance data, evaluate spatial variability in irradiance and costs, or analyze newer high-efficiency technologies such as n-type Heterojunction with Intrinsic Thin layer (HIT) and Tunnel Oxide Passivated Contact (TOPCon) modules under current or future policy scenarios.

To address these gaps, this study evaluates the economic feasibility of residential PV self-consumption across five representative Peruvian cities: Lima, Arequipa, Tacna, Chachapoyas, and Juliaca. These sites were selected to reflect the country's geographic, climatic, and economic diversity. Lima represents the coastal capital with moderate irradiance and relatively low electricity prices. Arequipa and Tacna, in the arid south, receive high solar radiation. Juliaca, located in the Andean highlands, combines high irradiance with elevated tariffs, while Chachapoyas, situated in the humid tropical highlands, offers a contrast with frequent cloud cover and moderate yields. This spatial diversity allows for a robust assessment of how local conditions affect system profitability. The guiding question is under what regional conditions and policy frameworks residential PV self-consumption becomes economically feasible in Peru's diverse climates.

The analysis is based on three years of field and performance data from 1.5 kWp grid-connected systems using HIT and Passivated Emitter and Rear Cell (PERC) module technologies, comparing 2019 (year of acquisition) and current 2025 market conditions. Core financial indicators such as Levelized Cost of Electricity (LCOE), Net Present Value (NPV), and Discounted Payback Time (DPBT) are calculated for each site.

To account for recent technological developments in crystalline silicon photovoltaics, the 2025 analysis incorporates TOPCon modules — a high-efficiency n-type technology that has rapidly gained market share and is projected to surpass PERC in global installations (ITRPV, 2025). The ability of TOPCon cells to be produced on existing PERC manufacturing lines, combined with their superior passivation quality and cost reduction trajectory, has accelerated their deployment worldwide (IEA PVPS, 2025). In Peru, significant imports of TOPCon modules began in 2025, while PERC technology is progressively being phased out, reflecting broader international trends; local providers now offer PERC modules only from remaining stocks imported in previous years. In contrast, HIT modules remain largely unavailable in the Peruvian market and require special import arrangements, which substantially increase their cost.

The study also evaluates policy scenarios, including self-consumption-only, net metering, and net billing. The novelty and value of this research lie in its integration of long-term field performance data with regionally differentiated cost–benefit modeling and forward-looking policy scenarios. This multidisciplinary approach bridges engineering and economics to produce actionable evidence for policymaking. The results deliver quantitative benchmarks (LCOE, NPV, and DPBT) across diverse Peruvian contexts, illustrating where residential solar is already viable and how regulatory design could accelerate national decarbonization. In doing so, this study supports Peru's transition toward a decentralized, equitable, and data-driven distributed generation framework.

# 2. Methodology

## 2.1 Description and Performance of the PV Systems

This study employs multi-year operational data from grid-connected photovoltaic (PV) systems installed in five Peruvian locations representing distinct climatic conditions (Fig. 1): **Lima** (coastal desert), **Chachapoyas** (humid tropical forest), **Arequipa** (semi-arid highlands), **Tacna** (arid coastal plain), and **Juliaca** (high-altitude Andes). These sites cover a broad range of Köppen–Geiger climate classifications according to Beck et al. (2018), providing representative conditions for evaluating the performance and economic viability of residential PV self-consumption systems across Peru. The systems were acquired in 2019 and began operation in Lima and Arequipa in 2020, and in Chachapoyas, Tacna, and Juliaca in 2021.

Each site consisted of two 1.5 kWp grid-connected PV systems, each using monocrystalline silicon module technologies, one based on PERC and another on HIT. Across all sites, modules were mounted on fixed-tilt structures facing north with a 15° inclination, to ensure a fair technology comparison. Each array consists of five modules in series and is connected to an SMA Sunny Boy inverter rated at 1.5 kW nominal AC power.

Environmental and electrical parameters were monitored simultaneously at 1-minute intervals, and the performance metrics were calculated in accordance with IEC 61724-1 standards (IEC, 2021). Plane-of-array irradiance was measured using calibrated EKO MS-80S secondary-standard pyranometers, while AC output power was recorded via the inverter's data logging system. The raw data were processed using standardized quality-control procedures (Berastain *et al.*, 2022) to remove gaps, correct inconsistencies, and harmonize data formats across all locations.

All PV modules were cleaned periodically every 2–4 weeks, depending on local precipitation and dust deposition. For instance, in Lima's arid coastal desert climate, modules are cleaned biweekly due to negligible rainfall, while in Chachapoyas, characterized by frequent precipitation, cleaning is performed monthly.

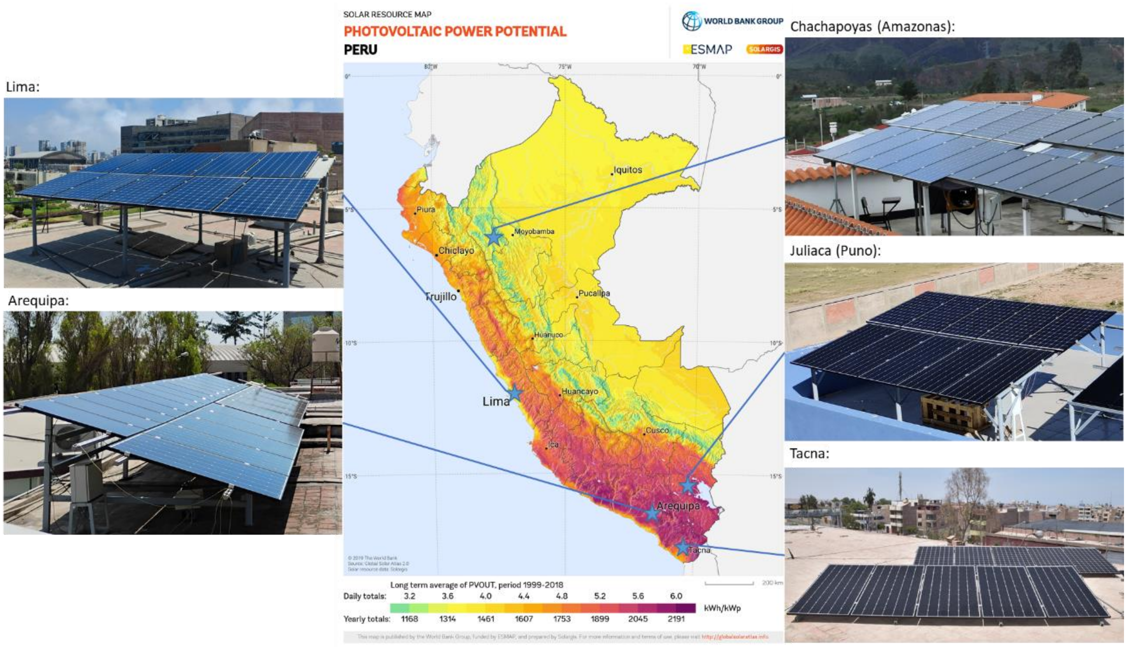


**Figure 1: Map of PV energy potential for Peru (from Solar resource map © 2025 Solargis), indicating the locations of the monitored grid-connected PV systems with PERC and HIT technology.**

From the processed data, daily and annual reference yields ($Y_r$), final yields ($Y_f$), and performance ratios (PR) were previously determined for the first three years of operation as part of a separate detailed performance analysis (Angulo *et al.*, 2025). In the present study, those three years of experimentally derived $Y_r$, $Y_f$, and PR values are used as input parameters to calculate the economic performance indicators of PV self-consumption scenarios in different Peruvian climatic regions.

Table 1 summarizes the experimentally obtained annual $Y_r$, $Y_f$, and PR obtained during the three-year analysis period. The lowest $Y_r$ (1522 kWh/kW/year) was observed in Lima, while Juliaca reached the highest (2314 kWh/kW/year). Consequently, the highest $Y_f$ are recorded in Juliaca and Tacna, where HIT reaches 1989 kWh/kWp/year, while Lima shows the lowest values, around 1263 kWh/kWp/year. Overall, the HIT systems outperform the PERC ones in all climates, maintaining stable PR values between 0.83 and 0.87. PERC performs well in humid and temperate regions (PR 0.80–0.83) but drops to 0.67–0.70 in arid zones, likely due to early degradation.

**Table 1: Summary of yields and performance ratio (PR) averaged over the three-year analysis period.**

| Location | $Y_r$ (kWh/kW/year) | $Y_f$ (kWh/kW$_p$/year) | | PR | |
|---|---|---|---|---|---|
| | | PERC | HIT | PERC | HIT |
| Lima | 1522 | 1219 | 1263 | 0.80 | 0.83 |
| Chachapoyas | 1515 | 1256 | 1318 | 0.83 | 0.87 |
| Arequipa | 2099 | 1471 | 1763 | 0.70 | 0.84 |
| Tacna | 2154 | 1442 | 1810 | 0.67 | 0.84 |
| Juliaca | 2314 | 1898 | 1989 | 0.82 | 0.86 |

## 2.2 Cost Assumptions and Technology Update for 2025

The economic parameters used in this study are summarized in Table 2, which reports the actual capital (CAPEX) and operational (OPEX) expenditures incurred for the installation of 1.5 kWp residential PERC and HIT systems under 2019 market conditions. These figures represent the actual investment costs paid by our laboratory, including VAT, equipment, labor, and logistics. Installation costs vary moderately among sites due to regional differences in transport and labor, with Arequipa, Lima, and Tacna showing the lowest values (≈ 2400–2550 USD/kWp for PERC) and Chachapoyas and Juliaca the highest. HIT systems are about 7–10% more expensive than PERC. OPEX figures were adapted from Espinoza et al. (2019), which reports representative annual maintenance costs for residential PV self-consumption in Peru.

**Table 2: CAPEX and OPEX values for 1.5 kWp PERC and HIT systems in 2019 across the five study regions.**

| Location | CAPEX (USD/kWp) | | OPEX (USD/kW/year) |
|---|---|---|---|
| | PERC | HIT | |
| Lima | 2502 | 2697 | 22.4 |
| Chachapoyas | 2675 | 2883 | 19.4 |
| Arequipa | 2375 | 2581 | 19.4 |
| Tacna | 2544 | 2751 | 19.4 |
| Juliaca | 2898 | 3108 | 19.4 |

The cost data for 2025 (Table 3) were compiled from a combination of experimental records, market quotations, and official inflation statistics. Quotations were obtained from several PV system integrators operating in Peru; TOPCon and PERC prices were derived as the simple average of local offers, while HIT costs were taken from international market quotations, also inclusive of VAT. Transport and logistics costs were taken from a single local installer’s quote. When only one vendor provided a detailed size breakdown, size-scaling coefficients were derived from that schedule and applied consistently to harmonize all suppliers’ price points.

For 2025, the OPEX figures from Espinoza et al. (2019) were inflation-adjusted using official consumer price index (CPI) data published by the Instituto Nacional de Estadística e Informática (INEI, 2025) and the Banco Central de Reserva del Perú (BCRP, 2025). Specifically, 2018 OPEX values were inflated by the 2019/2018 CPI ratio for the baseline year, and the cumulative CPI change between 2019 and 2025 was applied to obtain updated 2025 figures.

**Table 3. Capital (CAPEX) and operational (OPEX) expenditures for residential PV systems by location, technology, and system size (2025 values).**

| Location | PV Module Technology | CAPEX (USD/kWp) by Nominal Power (kWp) | | | | | OPEX (USD/kWp/year) |
|---|---|---|---|---|---|---|---|
| | | 1 - 3 | 10 | 50 | 100 | 200 | |
| Lima | PERC | 1276 | 1112 | 706 | 608 | 529 | 26.1 |
| | HIT | 1489 | 1086 | 832 | 698 | 606 | 26.1 |
| | TOPCon | 1077 | 839 | 551 | 494 | 423 | 26.1 |
| Chachapoyas | PERC | 1541 | 1192 | 738 | 632 | 545 | 22.5 |
| | HIT | 1754 | 1166 | 864 | 721 | 622 | 22.5 |
| | TOPCon | 1342 | 919 | 583 | 518 | 439 | 22.5 |
| Arequipa | PERC | 1506 | 1182 | 733 | 628 | 543 | 22.5 |
| | HIT | 1718 | 1156 | 859 | 717 | 620 | 22.5 |
| | TOPCon | 1306 | 909 | 578 | 514 | 437 | 22.5 |
| Tacna | PERC | 1276 | 1112 | 706 | 608 | 529 | 22.5 |
| | HIT | 1489 | 1086 | 832 | 698 | 606 | 22.5 |
| | TOPCon | 1077 | 839 | 551 | 494 | 423 | 22.5 |
| Juliaca | PERC | 1541 | 1192 | 738 | 632 | 545 | 22.5 |
| | HIT | 1754 | 1166 | 864 | 721 | 622 | 22.5 |
| | TOPCon | 1342 | 919 | 583 | 518 | 439 | 22.5 |

The resulting CAPEX and OPEX datasets provide the economic input parameters for the subsequent modeling of photovoltaic self-consumption scenarios, feeding directly into the LCOE and DPBT calculations presented in Section 2.3.

In the absence of local field data for TOPCon, the economic evaluation of the TOPCon systems employed the measured performance ratios from the HIT installations presented in Table 1 as a proxy. This approach is justified by the shared n-type architecture, advanced passivation schemes, and similar temperature coefficients of both technologies, which result in comparable thermal behavior and energy yield performance under field conditions (Kivambe et al., 2025; Wang et al., 2022).

## 2.3 Economic Calculation Framework

The economic evaluation of residential photovoltaic systems was performed through standard financial indicators, including LCOE, NPV, Internal Rate of Return (IRR), and DPBT. The methodology builds on the analytical frameworks established by Talavera et al. (2019) and Espinoza et al. (2019), and is adapted to the conditions of the Peruvian market. All scenarios assume full equity financing, no subsidies, and complete self-consumption of generated energy, reflecting the current absence of remuneration mechanisms for residential grid injection in Peru.

The LCOE represents the discounted cost of electricity generation over the system lifetime, providing a direct benchmark against retail electricity tariffs:

$$LCOE = \frac{\sum_{t=0}^{N} \frac{I_t + M_t}{(1+d)^t}}{\sum_{t=1}^{N} \frac{E_t(1-r_d)^{t-1}}{(1+d)^t}} \quad \text{(eq. 1)}$$

where $I_t$ is the initial investment (CAPEX from Tables 2 and 3), $M_t$ is the annual operation and maintenance cost (OPEX) increasing with the escalation rate $r_{om}$, $r_d$ is the annual energy degradation rate, $E_t$ is the energy produced in year $t$, $d$ is the discount rate, and $N$ is the system lifetime. This formulation follows Talavera's present-worth approach, where both costs and energy generation are discounted to year 0.

To quantify investment profitability, the Net Present Value (NPV) was computed as

$$NPV = \sum_{t=1}^{N} \frac{(B_t - M_t)}{(1+d)^t} - I_0 \quad \text{(eq. 2)}$$

where $B_t$ denotes the annual monetary benefits derived from avoided electricity purchases, $M_t$ the annual operation and maintenance costs, and $I_0$ the initial investment. A positive NPV indicates that the discounted benefits exceed the total costs, confirming economic feasibility under the given assumptions.

The IRR and DPBT were derived directly from the NPV profile. The IRR corresponds to the discount rate that sets the NPV to zero, while the DPBT indicates the year when the cumulative discounted cash flow equals the initial investment, reflecting the period required for capital recovery.

All monetary values were expressed in U.S. dollars and updated to 2025 using official inflation indices from INEI (2025) and BCRP (2025). Key financial parameters applied in the calculations are summarized in Table 4. Additional assumptions (no taxation, depreciation, or debt service) follow Espinoza et al. (2019).

**Table 4. Key economic and financial parameters adopted for the LCOE and NPV calculations under 2019 and 2025 conditions.**

| Parameter | Symbol | Unit | 2019 | 2025 |
|---|---|---|---|---|
| Annual Opex Escalation Rate | $r_{om}$ | % $yr^{-1}$ | 2.0 | 2.0 |
| Tariff Escalation Rate | $r_p$ | % $yr^{-1}$ | 3.5 | 4.0 |
| Discount Rate | $d$ | % | 4.6 | 5.0 |
| VAT | | % | 18 | 18 |
| PEN/USD Exchange Rate | | PEN $USD^{-1}$ | 3.3 | 3.6 |
| System Lifetime | $N$ | years | 25 | 25 |
| Annual Energy Degradation | $r_d$ | % $yr^{-1}$ | 0.5 | 0.5 |

# 3. Economic Results

## 3.1 Evolution of PV Economics: 2019 vs. 2025

To assess the evolution of PV system competitiveness in Peru, the LCOE of PERC and HIT technologies in 2019 was compared with updated 2025 conditions, which additionally include the emerging TOPCon technology. This analysis captures the combined effects of declining capital expenditures, improved module efficiencies, and evolving electricity tariffs on the feasibility of residential self-consumption. The corresponding results for each region and year are presented in Figure 1.

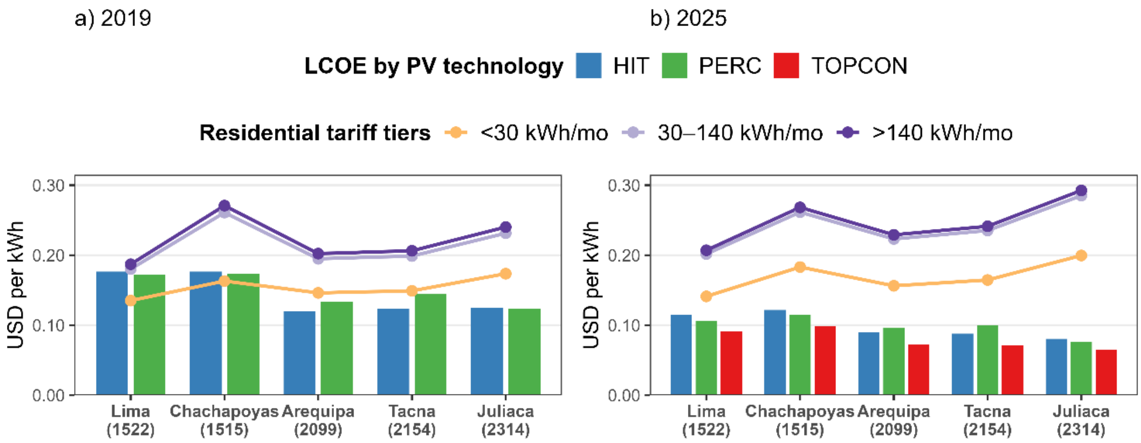


**Figure 1: Comparison of electricity tariffs (for different monthly consumptions) and PV LCOE for 2019 (a) and 2025 (b) across five Peruvian regions. Calculations are representative of small residential PV systems with a nominal power ≤ 3 kWp. The number in the parenthesis indicates the reference yield in kWh/kW/year taken from Table 1.**

The tariffs for low-consumption (<30 kWh/mo) are typically assigned to low-income households. In contrast, the middle (30-140 kWh/mo) and higher (>140 kWh/mo) consumption tariffs are representative of the middle- and high-income households, taken from OSINERGMIN (2025). In 2019, residential electricity tariffs ranged from 0.135 to 0.271 USD/kWh, depending on consumption tier and location. The lowest tariffs were observed in Lima (0.135–0.187 USD/kWh), while Chachapoyas exhibited the highest (0.163–0.271 USD/kWh). Over the same period, the LCOE for PERC and HIT systems ranged from 0.12 USD/kWh for Arequipa to up to 0.18 USD/kWh for Lima. For low-consumption households, socket-parity (i.e., LCOE ≤ tariff) was achieved only in high-irradiance regions such as Arequipa, Tacna, and Juliaca. For mid- and high-consumption households, socket parity was already evident in all locations.

By 2025, residential tariffs increased moderately to 0.141–0.293 USD/kWh, with Juliaca and Chachapoyas again showing the highest rates. During the same period, continued cost reductions, combined with the introduction of TOPCon modules, lowered PV generation costs to 0.07–0.11 USD/kWh across all regions. TOPCon achieved the lowest LCOE, approximately 10–15% below HIT and 20% below PERC, reflecting both technological advancement and lower production costs. As a result, rooftop PV became universally competitive with grid electricity in all consumption tiers. In the southern Andes, particularly Tacna and Juliaca, generation costs now fall well below even the lowest tariff category (< 0.17 USD/kWh), confirming full socket-parity.

In addition to the LCOE comparison, Figure 2 illustrates the evolution of other key economic indicators such as DPBT, IRR, and NPV between 2019 and 2025. These results demonstrate a clear improvement in investment performance across all regions. From 2019 to 2025, DPBT decreases from approximately 9–12 years to below 6 years in the most favorable sites, while IRR rises from 12–18% to values exceeding 25–35%, driven by lower module prices and enhanced performance ratios. NPV more than doubles, confirming the increasing profitability of residential PV under 2025 conditions. Among the technologies, TOPCon (included only for 2025) yields the highest returns, outperforming HIT and PERC by 10–20%. Regionally, Juliaca, Tacna, and Arequipa show the strongest financial performance, whereas Lima remains the least favorable location despite substantial improvement.

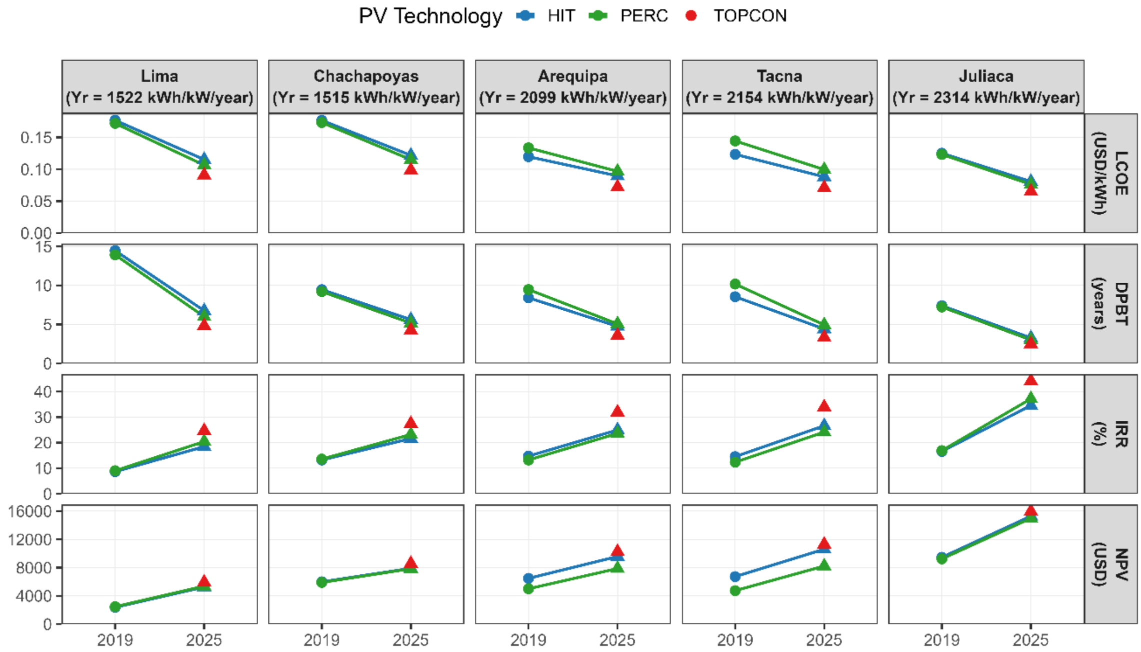


**Figure 2: Evolution of PV economic indicators (LCOE, DPBT, IRR, and NPV) by technology and location for 2019–2025. Calculations are representative of small residential PV systems with a nominal power ≤ 3 kWp. Each panel shows 2019-2025 change per technology; scales are free by metric.**

These results indicate a significant transition in Peru's residential PV economics between 2019 and 2025. While earlier installations struggled to reach cost competitiveness outside high-irradiance areas, the updated scenario demonstrates that all five evaluated locations now achieve positive NPV and reach or exceed grid parity. Notably, favorable outcomes are no longer contingent on government subsidies or high retail tariffs, indicating that PV adoption is becoming intrinsically viable under realistic market conditions.

## 3.2 Sensitivity Analysis

Building on the 2025 baseline, a sensitivity analysis was performed for TOPCon systems to evaluate how system size, investment cost, self-consumption ratio, and regulatory framework influence economic feasibility across the five study regions. System size directly affects CAPEX and, therefore, both LCOE and DPBT. The self-consumption index (SCI) represents the share of PV generation consumed on-site, with surplus electricity either curtailed or grid-injected, depending on the applicable incentive mechanism such as net metering, net billing, or no compensation.

All computations were based on consistent baseline assumptions representative of typical residential installations in 2025. The analysis considered a TOPCon system with the same PR values as a HIT system (from Table 1) and with household electricity consumption between 30 and 140 kWh per month, reflecting an average Peruvian household. Systems were assumed to be entirely self-financed, with no subsidies or tax incentives, and to operate under stable financial conditions with constant discount and inflation rates.

Regional variations primarily reflect differences in annual solar reference yield ($Y_r$) and in investment costs (CAPEX), both of which jointly determine the observed differences in LCOE and payback time across cities. Figure 3 illustrates the effect of installed power on LCOE by technology and city. As system size increases, LCOE decreases sharply, reflecting economies of scale and reduced specific CAPEX. Beyond approximately 50–100 kWp, the decline levels off, indicating limited marginal cost benefits from further scaling. The influence of location is consistent with irradiance: Tacna and Juliaca achieve the lowest LCOE values (below 0.04 USD/kWh), while Lima remains higher due to its lower solar yield.

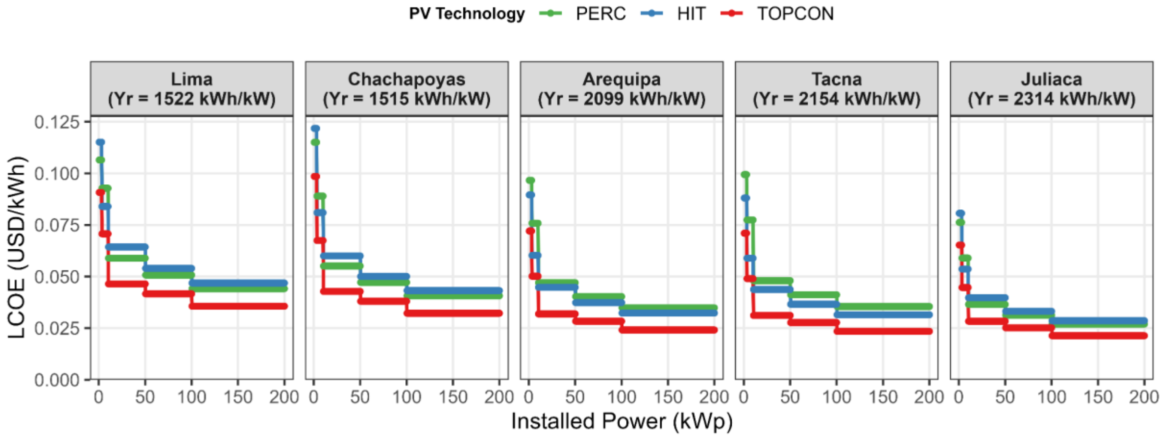


**Figure 3: Effect of Installed Power on LCOE by Technology and City.**

Figure 4 presents a similar trend for DPBT, which declines sharply with increasing system size. Expanding from small to medium-scale systems (up to ~50 kWp) reduces the payback period from about 6–7 years to 2–3 years. Arequipa, Tacna, and Juliaca exhibit the most favorable conditions, while Lima and Chachapoyas show longer paybacks due to lower irradiation.

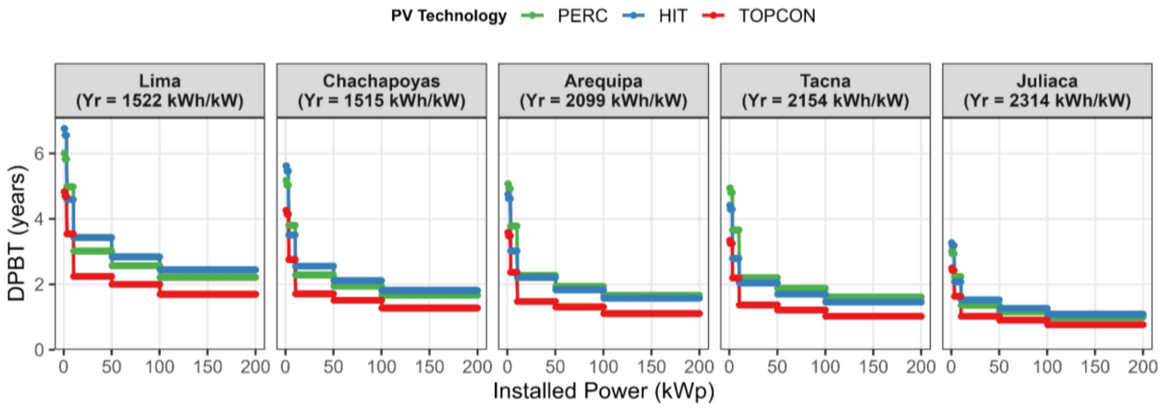


**Figure 4: Effect of Installed Power on DPBT by Technology and City.**

The analysis of self-consumption and regulatory schemes, illustrated in Figure 5, explores how these factors affect DPBT for a representative 3 kWp TOPCon residential system across the five study regions. The results show that DPBT is highly sensitive to both SCI and the local solar resource, as well as to the regulatory framework governing surplus electricity. As the self-consumption ratio increases, a larger share of PV generation directly offsets electricity purchases, increasing annual savings and shortening the time required to recover the initial investment.

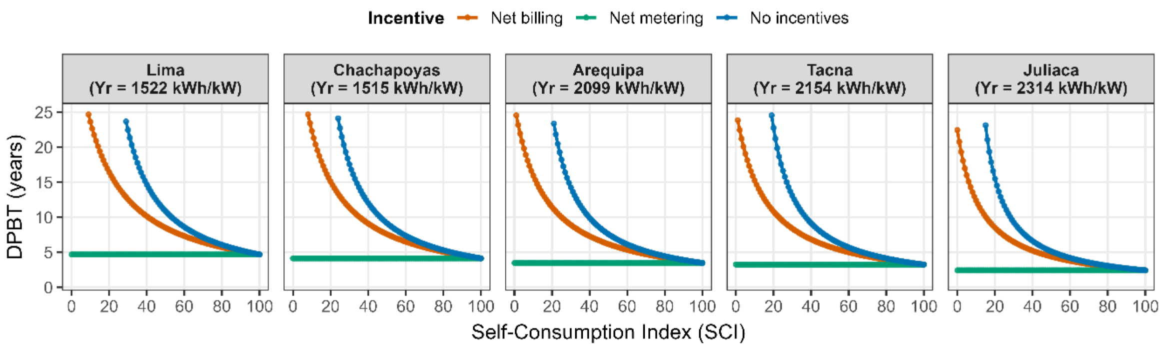


**Figure 5: DPBT vs SCI by incentives × technology (TopCon).**

Under net metering, payback periods are the shortest in all regions, typically ranging between 3.5 and 5 years.

Even at moderate self-consumption levels of around 60%, users can achieve paybacks below five years because all exported electricity is credited at the full retail rate. High-irradiance locations such as Juliaca and Tacna perform exceptionally well, with DPBT values near 3 years, while Lima and Chachapoyas, with lower solar yields, exhibit slightly longer paybacks of around 5 years.

In the net billing case, payback periods increase to between 5 and 7 years, reflecting the lower compensation rate for exported energy valued at wholesale generation prices ("precios en barra") defined by OSINERGMIN (2025). The difference between retail and wholesale prices, typically 0.04 to 0.07 USD/kWh, reduces the financial return from surplus electricity. Regions with strong solar resources still maintain competitive returns under this mechanism; for example, DPBT in Juliaca remains close to 4 years, while Lima and Chachapoyas can exceed 6 years unless self-consumption ratios surpass 70–80%.

When no compensation is available, the DPBT increases sharply, particularly for low self-consumption ratios, as any surplus generation is injected into the grid without financial return. In this situation, only users with daytime loads that align closely with PV generation can achieve reasonable payback times.

These findings underscore the critical role that both technical design (e.g., system size and load matching) and regulatory frameworks play in determining the financial viability of residential PV. While Peru's current lack of export compensation may not preclude profitability in high-yield regions, incentive mechanisms such as net metering and net billing can substantially improve investment attractiveness, particularly in cities with lower energy yield.

## 4. Discussion and Conclusion

This study shows a clear and measurable improvement in the economic performance of residential PV self-consumption systems in Peru over the period 2019-2025. In 2019, only a few high-irradiance regions – most notably Arequipa, Tacna, and Juliaca – offered conditions where solar power could compete with grid electricity. At that time, LCOE ranged from 0.12 to 0.18 USD/kWh, and DPBT typically exceeded 9 years. By 2025, the situation has changed considerably. The steady decline in equipment prices, the moderate rise in retail tariffs, and the introduction of new high-efficiency technologies such as TOPCon have collectively improved project economics across the country. Current LCOE values now range from 0.07 to 0.11 USD/kWh, which is lower than residential tariffs, which range from 0.14 to 0.29 USD/kWh. As a result, payback periods have shortened to about three to six years, and IRR commonly surpass 25%. Positive Net Present Values are observed across all locations studied, indicating that rooftop PV has achieved full grid parity. Regional differences remain relevant. Juliaca and Tacna continue to stand out as the most attractive sites, benefiting from both strong solar resources and relatively high electricity prices. In contrast, Lima and Chachapoyas, which receive less solar radiation, show longer payback times but still yield positive financial outcomes.

These findings underscore the pressing need for a coherent and predictable regulatory framework to enable the effective expansion of distributed generation in Peru. The current absence of explicit provisions for managing surplus electricity discourages households from investing in systems capable of producing beyond their immediate consumption needs. This regulatory uncertainty particularly constrains users with high daytime generation or those considering larger installations. Establishing transparent, stable mechanisms, such as net billing or simplified net metering, would enhance investor confidence and improve the financial performance of residential PV projects, especially in regions with moderate solar potential. In parallel, streamlining grid interconnection procedures and reducing administrative barriers would help lower transaction costs and facilitate broader adoption across the residential sector.

Access to financing remains a decisive factor for scaling up residential PV. While the present analysis assumes full equity financing, many households cannot afford the upfront capital cost of a 3 kWp system (≈ 3,000–4,000 USD). Expanding access to credit through on-bill financing, microloans, or third-party ownership models could enhance affordability, especially for low-income and rural users. Complementary public initiatives, such as information campaigns, technical assistance, and standardized installation programs, would further bridge the gap between economic potential and real deployment, following successful models in Brazil and Chile.

Future work should enhance the current economic framework by integrating time-resolved household demand profiles, allowing a more accurate representation of how load patterns align with PV generation. The inclusion of battery storage would enable a realistic assessment of hybrid self-consumption systems under diverse tariff and incentive scenarios. Moreover, incorporating alternative financing schemes and environmental indicators such as avoided carbon dioxide emissions and contributions to grid resilience would provide a more comprehensive evaluation of the broader socio-economic benefits of residential PV in Peru's energy transition.

Overall, the results confirm a structural shift in the competitiveness of residential solar in Peru. Photovoltaic self-consumption has evolved from a marginal technology to a financially attractive and technically mature solution. With supportive regulation and accessible financing, it can meaningfully contribute to national decarbonization goals while enhancing energy access and affordability. The challenge now lies not in proving its value, but in creating the enabling conditions for its widespread realization.

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