SYSTEM PERFORMANCE EVALUATION OF THREE PV TECHNOLOGIES ACROSS FIVE CLIMATIC ZONES IN PERU

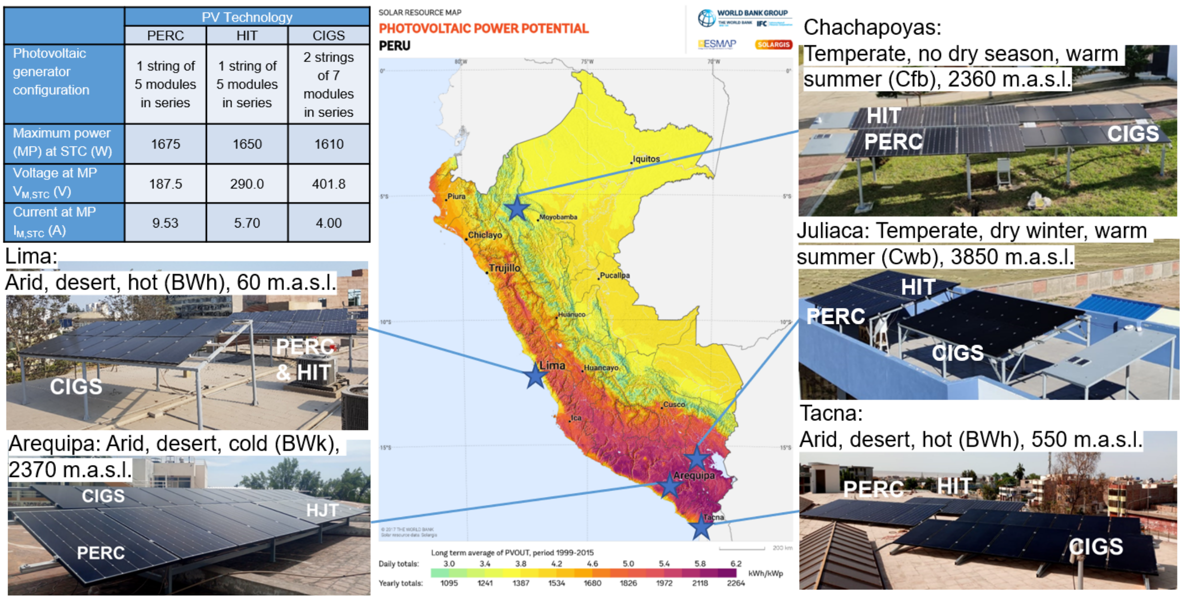
Summary

This work presents a comparative performance analysis of three photovoltaic technologies—PERC, HIT, and CIGS—based on multi-year outdoor monitoring in five contrasting climatic zones in Peru. Key performance metrics including reference yield, capture losses, system losses, and performance ratio (PR) were analyzed according to IEC 61724-1 standards. HIT consistently achieved the highest PR (>0.8) across all sites and showed minimal degradation. CIGS demonstrated strong performance in arid conditions (e.g., Tacna) but degraded rapidly in more humid or variable climates. PERC performed reliably in moderate climates but exhibited yield losses in harsher conditions. The findings underscore the importance of climate-adapted technology selection to maximize system performance and durability.

Keywords: PV performance, outdoor monitoring, yield analysis, PERC, HIT, CIGS

1. Introduction

Selecting appropriate photovoltaic (PV) technologies for specific climatic conditions is essential for maximizing energy yield and ensuring system longevity. Peru's diverse geography offers an excellent testbed for PV performance assessment across different climates. Prior studies have highlighted the country's vast solar potential and its suitability for deploying various photovoltaic technologies (Romero-Fiances *et al.*, 2019). This study evaluates three commercially available PV technologies—Passivated Emitter Rear Cell (PERC), Heterojunction with Intrinsic Thin layer (HIT), and Copper Indium Gallium Selenide (CIGS)—installed at five sites representing high-altitude Andes, coastal desert, tropical montane forest, and arid highlands. Each system was monitored continuously for at least three years following IEC 61724-1 standards.



	PV Technology		
	PERC	HIT	CIGS
Photovoltaic generator configuration	1 string of 5 modules in series	1 string of 5 modules in series	2 strings of 7 modules in series
Maximum power (MP) at STC (W)	1675	1650	1610
Voltage at MP $V_{M,STC}$ (V)	187.5	290.0	401.8
Current at MP $I_{M,STC}$ (A)	9.53	5.70	4.00

Fig. 1. Locations of PV systems in Peru with Köppen-Geiger climate classifications and system configurations.

2. Experimental setup and methods

The grid-connected, 1.5 kW PV systems, each using identical configurations per technology, were deployed with fixed-tilt, north-facing arrays. Irradiance, temperature, and electrical parameters were logged at oneminute intervals. Fig. 1 illustrates the installation sites and their Köppen-Geiger climate classifications. The key module parameters and configurations are summarized in Tab. 1.

Tab. 1: Main characteristics of the PV system with electric parameters at STC according to module datasheet

PV module Technology	PERC	HIT	CIGS
Current at the maximum power point (A)	8.96	5.7	2
Voltage at the maximum power point (V)	37.4	58	57.2
Power at maximum power point (W)	335	330	115
Power temperature coefficient (%/°C)	-0.37	-0.28	-0.23
Module efficiency	19.9	19.7	>14.3
Configuration (series, parallel)	(5,1)	(5,1)	(7,2)

3. Results and discussion

Fig. 2 presents the monthly reference yield (Y_r) trends for HIT, PERC, and CIGS in Lima over a 54-month period. The data highlight the seasonal nature of energy production, with clear peaks during summer months (December–April) and troughs in winter (June–August). HIT maintained the most consistent performance throughout the period, with relatively stable interannual variation (Gopi *et al.*, 2021). PERC followed a similar seasonal pattern, albeit with slightly lower yield. CIGS exhibited a marked decline in monthly yield after the first year, indicating long-term degradation effects potentially caused by humidity, dust accumulation, or maintenance-related shading events.

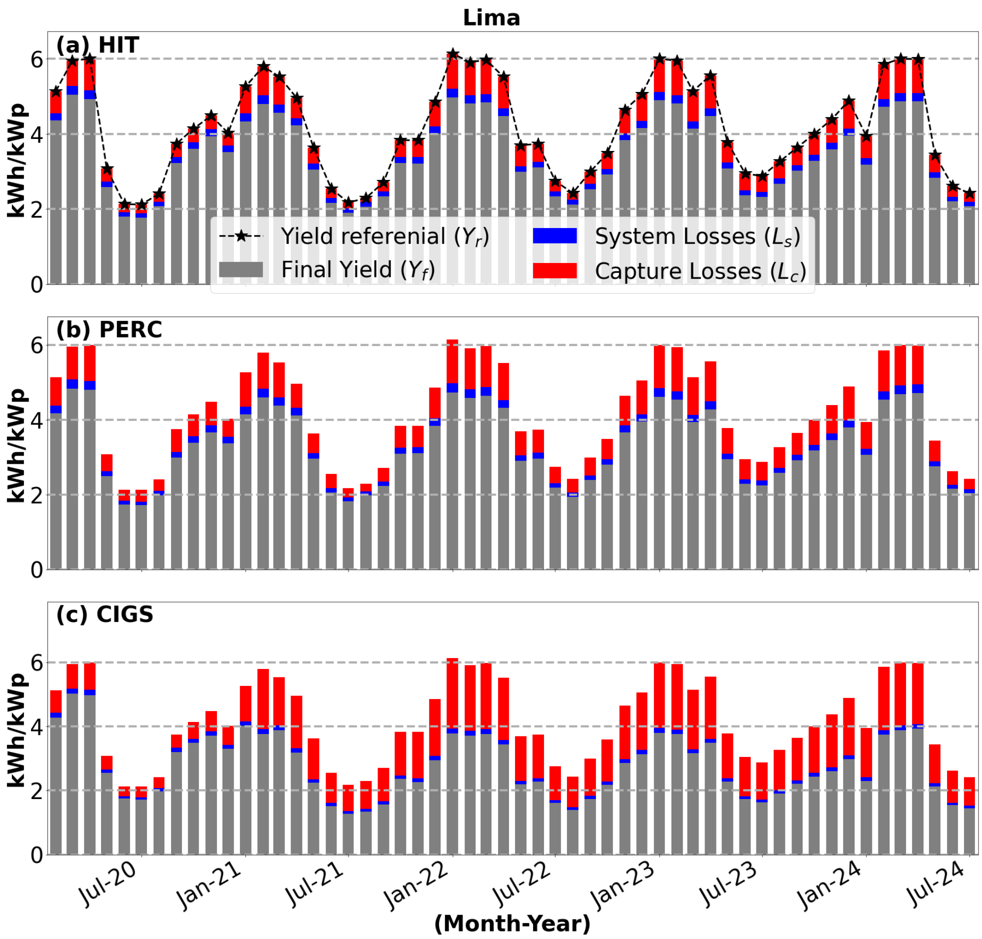


Fig. 2. ***Y_r, L_s, L_C values for (a) HIT, (b) PERC and (c) CIGS in Lima from February 2020 to July 2024.***

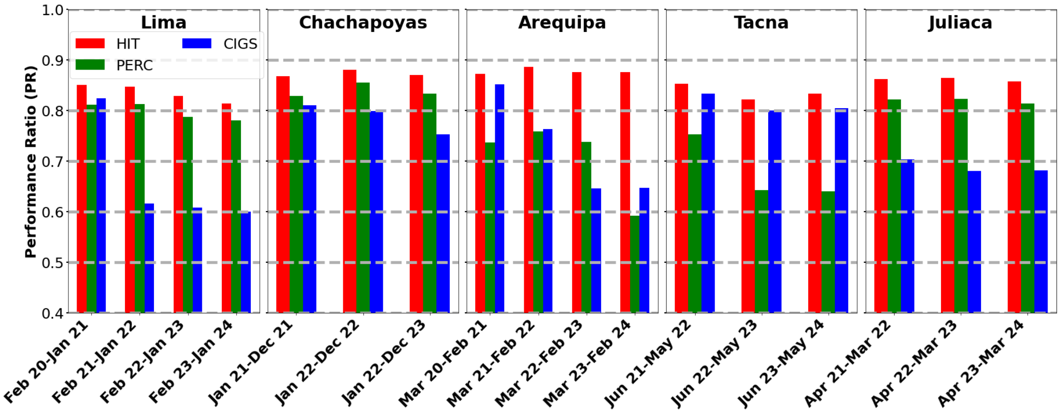


Fig. 3. Anual performance ratio for Lima, Chachapoyas, Arequipa, Tacna and Juliaca.

Fig. 3 displays the annual PR for each technology at all five locations. HIT again stands out for its long-term stability, maintaining annual PRs above 0.80 at every site. PERC showed stable PR in Chachapoyas and Juliaca but experienced a downward trend in Arequipa and Tacna, consistent with environmental stress and thermal degradation. CIGS initially performed well across sites but declined notably in Lima and Arequipa over time. These trends corroborate electroluminescence imaging results showing irreversible shunt defects in degraded CIGS modules. Tab. 2 summarizes the average Y_r and PR for each technology and location across the monitoring periods. Y_r ranged from 4.15 to 6.34 kWh/kWp/day, with the highest values recorded in Juliaca and Tacna. Across all sites, HIT consistently achieved the highest PR (Bansal et al,. 2021), ranging from 0.83 in Lima to 0.87 in Chachapoyas. PERC maintained relatively strong performance in Lima, Chachapoyas, and Juliaca (PR $\geq$ 0.80), but showed reduced efficiency in Arequipa and Tacna (PR = 0.70 and 0.67, respectively). CIGS performance was highly site-dependent, performing well in Tacna (PR = 0.81), but declining in humid or variable climates, most notably in Lima (PR = 0.66).

Tab. 2: Main characteristics of the PV system with electric parameters at STC according to module datasheet

Location	Period	Months	Y_r (kWh/kW/day)	PR		
				PERC	HIT	CIGS
Lima	Feb 20- Jul 24	54	4.17	0.80	0.83	0.66
Chachapoyas	Jan 21- Jul 24	40	4.15	0.83	0.87	0.77
Arequipa	Mar 20- Jul 24	53	5.75	0.70	0.84	0.72
Tacna	Jun 21- Jul 24	38	5.9	0.67	0.84	0.81
Juliaca	Apr 21- Jul 24	40	6.34	0.82	0.86	0.69

4. Conclusions

The data highlight the importance of matching PV technology to local environmental conditions. HIT modules exhibited high and stable performance regardless of location, while PERC showed climate sensitivity and CIGS remained viable primarily in arid regions like Tacna. These findings can guide future PV deployments in diverse geographies by aligning technology choice with site-specific climatic constraints.

5. References

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