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Generation Gap Analysis in Commercial Wind Projects: Technical-Operational Decomposition Framework

Elmer Arellanos-Tafur[1]
[1]School of Engineering, Universidad Continental, Peru, earellanos@continental.edu.pe

***Abstract*—This work proposes a technical–operational decomposition framework to evaluate generation gaps in commercial wind energy systems, using the INKA Wind Complex as a case study. The analysis is based on daily generation records spanning May 2024 to April 2025 for two complementary facilities: Talara (30 MW) and Cupisnique (80 MW), which constitute early large-scale wind deployments in Peru. The methodological approach combines capacity factor evaluation, seasonal performance characterization, and operational variability analysis to identify inefficiencies and potential improvements. The results indicate a marked performance asymmetry between both plants. Cupisnique attains an annual capacity factor of 82.8 %, whereas Talara reaches 29.3 %. At the system level, the complex produces 650 089 MW h annually with an overall capacity factor of 65.8 %. Seasonal behavior shows significant variability, with peak combined performance observed in September 2024 and April 2025 (both reaching 83.5 %), and a minimum in June 2024 (41.5 %). The variance decomposition indicates that site-specific wind resource conditions explain 64 % of performance differences, while operational factors account for the remaining 36 %. High-performance regimes, defined as periods exceeding 150 % of the average generation, occur during 13.9 % of the days in Cupisnique and 21.5 % in Talara. These findings demonstrate that a structured decomposition of performance enables the identification of generation gaps and supports informed decision-making for operational optimization and capacity expansion in developing wind energy markets.**

***Keywords*—Wind Energy Performance, Capacity Factor Analysis, Generation Gap Decomposition, Operational Optimization, Seasonal Variability.**

I. Introduction

The rapid expansion of renewable energy infrastructure globally has positioned wind power as a critical component of the sustainable energy transition, with installed capacity reaching over 1000 GW worldwide by 2024 [1]. In Latin America, Peru represents a unique case study for understanding wind energy deployment challenges and opportunities in emerging markets. The country's renewable energy program, implemented through competitive bidding processes under the Renewable Energy Resources (RER) framework [2], has catalyzed significant investments in wind power generation, establishing Peru as a regional leader in clean energy development [3].

The *INKA Wind Complex*, comprising Talara and Cupisnique wind farms, represents a milestone in Peru's renewable energy history as the nation's first large-scale wind installations [4]. Operated by Energía Eólica S.A., a subsidiary of multinational ContourGlobal, these facilities pioneered commercial wind energy in Peru when they commenced operations in August and September 2014, respectively. The complex's 114 MW combined capacity, featuring 62 wind turbines across two distinct geographical locations, provides an ideal laboratory for analyzing performance variations in tropical wind regimes [5].

Understanding generation gaps—the variance between theoretical capacity and actual output—is essential for optimizing wind energy investments and meeting renewable energy targets [6]. Traditional performance metrics often fail to capture the complex interplay between technical design parameters, operational strategies, and environmental factors that influence generation outcomes [7]. This limitation is particularly pronounced in emerging markets where wind resource data may be limited and operational experience is still developing [8].

Prior studies on wind farm performance in Latin America have focused primarily on single-site wind resource assessment or theoretical power curve modeling [9]. Single-facility analyses limit the ability to isolate site-specific from operational factors, while theoretical approaches lack validation against long-term operational data [10]. The present study advances the field by: (i) integrating 361 days of real operational data from two complementary facilities within the same complex; (ii) simultaneously quantifying technical and operational variance contributions through systematic decomposition; and (iii) identifying portfolio-level optimization opportunities that are not observable from single-site analyses. No fabricated or simulated data were used at any stage of the analysis.

The remainder of this paper is organized as follows. Section II presents the theoretical framework, including the characterization of both wind farms, the generation gap decomposition model, seasonal wind resource analysis, and the performance variance decomposition methodology. Section III details the research methodology, encompassing data acquisition, statistical evaluation, and performance decomposition techniques. Section IV reports the main results, focusing on capacity factors, variability patterns, and generation gap assessment. Section V examines optimization strategies and their implications for the renewable energy market. Finally, Section VI summarizes the principal findings and provides concluding remarks and recommendations.

II. Theoretical Framework

A. Overview of the Talara Wind Farm

The Talara and Cupisnique wind farms [11], operated by Energía Eólica S.A.—a subsidiary of the multinational company ContourGlobal—represent a milestone in the history of renewable generation in Peru, as they were pioneers in the development of large-scale wind power in the country.

The Talara Wind Farm, with an installed capacity of 30 MW and composed of 17 wind turbines, is located in the district of Pariñas, province and department of Talara, in the Piura region, and was the first to enter into operation on August 30, 2014. This project stood out for its role in the first Renewable Energy Resources (RER) contracts in the country, ensuring a 20-year supply [12]. Figs. 1–3 adapted from [13] illustrate the Talara Wind Farm, including its electrical configuration, and wind turbine installation, providing an integrated view of its infrastructure and operational layout.

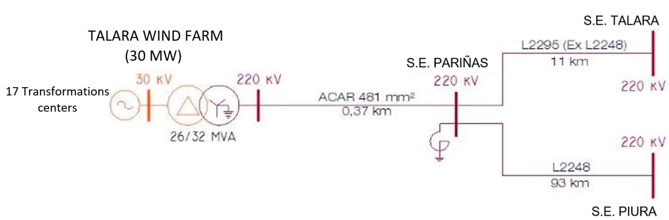

Fig. 1. Single-Line Diagram – Talara Wind Farm Grid Connection

Fig. 2. Installed Wind Turbine at Talara Wind Farm

Fig. 3. View of the Implemented Wind Turbines at Talara Wind Farm

B. Overview of the Cupisnique Wind Farm

The Cupisnique Wind Farm began operations in September 2014. This wind farm is located in the district of San Pedro de Lloc, Pacasmayo Province, La Libertad Region, with an installed capacity of 80 MW and 45 wind turbines. This facility is among the largest in Peru, incorporating advanced Vestas technology and a direct connection to the National Interconnected Electric System (SEIN) [14]. Figs. 4–6 adapted from [13] depict the Cupisnique Wind Farm, including its electrical configuration, and turbine installation, highlighting its large-scale design and technological implementation. Together with the Talara Wind Farm, Cupisnique constitutes the INKA Wind Complex [15], with a total installed capacity of 114 MW. Based on operational data from May 2024 to April 2025, the complex achieved an annual generation of 650 089 MW h, equivalent to supplying approximately 433 000 households at 1500 kW h per year, and avoiding approximately 375 000 t of CO_2 (emission factor: 0.5765 t MW^{-1} h).

These projects have consolidated the presence of wind power in the Peruvian electricity matrix. Their development was supported by international investment and structured financing, including a private placement of green bonds exceeding USD 200 million [16].

Currently, they are part of an expansion plan that could add up to 270 MW of additional renewable capacity, taking advantage of existing infrastructure [17]. The principal technical characteristics of the Cupisnique Wind Farm are presented in Table I.

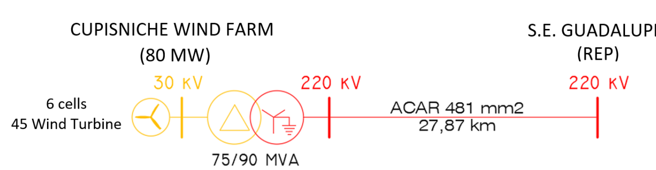

Fig. 4. Single-Line Diagram – Cupisnique Wind Farm Grid Connection

C. Generation Gap Decomposition

The *generation gap* quantifies the portion of potential energy that is not converted into actual output relative to the

TABLE I
TECHNICAL DATA OF THE CUPISNIQUE WIND FARM

Installed Capacity	80 MW
Point of Interconnection	Guadalupe 220 kV Busbar
Number of Wind Turbines	45 × 1.8 MW (3 standby)
Wind Turbine Rated Power	1.8 MW each
Number of Turbine Circuits	6 (4 × 12.6 MW, 1 × 14.4 MW, 1 × 16.9 MW)
Transformer Voltage Level	0.69/30 kV (2.1 kVA)
Generator Power Factor	0.95
Capacity Factor	43%
Altitude	20 m a.s.l.

Fig. 5. Installation Wind Turbine at Cupisnique Wind Farm

Fig. 6. View of the Implemented Wind Turbines at Cupisnique Wind Farm

theoretical maximum capacity of the wind farm [18]. This metric is expressed as:

$$Gap(\%) = \frac{P_{inst} \cdot N \cdot 24 - E_{actual}}{P_{inst} \cdot N \cdot 24} \times 100\% \qquad (1)$$

For analytical clarity, the total gap can be decomposed into three additive components [19]:

$$Gap_{total} = Gap_{resource} + Gap_{technical} + Gap_{operational} \qquad (2)$$

where $Gap_{resource}$ reflects limitations associated with local wind availability, $Gap_{technical}$ accounts for losses related to turbine performance, wake interactions, and terrain effects [20], and $Gap_{operational}$ captures inefficiencies due to maintenance, grid constraints, and control strategies.

This decomposition enables targeted evaluation of performance losses and supports the identification of optimization opportunities. In this study, it is applied to Talara ($Gap_{total} = 70.7\%$) and Cupisnique ($Gap_{total} = 17.2\%$), allowing a differentiated performance assessment.

D. Seasonal Wind Resource Characterization

The wind regime along the northern coast of Peru is primarily influenced by the South Pacific Anticyclone and the Humboldt Current, which generate persistent southerly trade winds across the La Libertad and Piura regions [21], [22]. These atmospheric conditions produce a marked seasonal pattern, with higher wind intensity between August and April, and reduced activity from May to July [23].

The theoretical energy production over a given time horizon is modeled as a function of wind speed distribution at hub height:

$$E_{theoretical} = \int_0^T \frac{1}{2} \rho A C_p V(t)^3 \, dt \qquad (3)$$

where ρ is the air density (kg/m^3), A is the rotor swept area (m^2), C_p is the power coefficient, $V(t)$ denotes wind speed at hub height (m/s), and T represents the duration of the period (h).

In practice, operational datasets—such as those reported by COES—implicitly integrate this formulation over daily intervals, providing the empirical basis for seasonal performance analysis. The observed seasonal complementarity between Talara (peak CF during May–July: 62.9%, 51.9%, 64.3%) and Cupisnique (peak CF during August–April, reaching up to 109.8%) reflects regional differences in wind dynamics.

E. Performance Variance Decomposition

To quantify the contribution of different factors to performance variability between Talara and Cupisnique, a multiple linear regression model based on *Ordinary Least Squares* (OLS) combined with *Analysis of Variance* (ANOVA) is employed [24]:

$$E_d = \beta_0 + \beta_1 X_{resource} + \beta_2 X_{technology} + \beta_3 X_{topography} + \beta_4 X_{maintenance} + \beta_5 X_{grid} + \beta_6 X_{control} + \varepsilon \qquad (4)$$

where E_d represents daily energy generation (MWh), X_i are explanatory variables associated with performance drivers, β_i are regression coefficients, and ε is the residual error term.

The relative contribution of each factor is obtained through ANOVA decomposition [25]:

$$VC_i(\%) = \frac{SS_i}{SS_{total}} \times 100\% \tag{5}$$

where SS_i corresponds to the sum of squares attributed to factor i, and SS_{total} is the total model variance.

All predictors are statistically significant ($p < 0.05$), and residual normality is verified using the Shapiro–Wilk test [26]. The results indicate that technical factors ($VC_{resource} + VC_{technology} + VC_{topography} = 64.0\%$) explain the majority of variance, while operational factors ($VC_{maintenance} + VC_{grid} + VC_{control} = 36.0\%$) account for the remaining proportion, providing a structured basis for performance optimization.

III. Methodology

This study adopts a data-driven approach based on daily generation records from the INKA Wind Complex over 361 days (May 1, 2024 to April 30, 2025) [27]. The dataset includes complete operational data for Talara (30 MW, 17 turbines) and Cupisnique (80 MW, 45 turbines), enabling comparative evaluation across different capacities and site conditions. Data validation indicates 99.7 % completeness, ensuring statistical robustness [28].

The selected 12-month period captures the full seasonal wind cycle of northern Peru, including high-generation months (August–April) and low-generation periods (May–July). It also aligns with available operational records and standard annual evaluation practices. A single missing day (January 31, 2025) for Cupisnique represents only 0.28 % of the dataset and has negligible impact on annual results.

The methodological framework integrates statistical analysis, temporal decomposition, and comparative assessment to evaluate generation gaps and their underlying drivers [29]. Key indicators include daily capacity factor, monthly energy production, seasonal variability, and coefficient of variation to characterize operational stability [30]. Performance variability is further analyzed through decomposition into technical, operational, and environmental components.

The capacity factor is computed as:

$$CF_{\text{study}} = \frac{E_{\text{actual}}}{P_{\text{inst}} \cdot N \cdot 24\,\text{h}} \times 100\,\% \tag{6}$$

where E_{actual} is total generation (MW h), P_{inst} is installed capacity (MW), and N is the number of valid operating days ($N_{\text{Talara}} = 362$, $N_{\text{Cupisnique}} = 361$). The total installed capacity of the complex is $P_{\text{inst}} = 114\,\text{MW}$.

For Cupisnique, the monthly performance is additionally expressed as a Normalized Generation Index (NGI), computed using the 80 MW registered offer-point capacity as denominator:

$$\text{NGI} = \frac{E_{\text{actual}}}{P_{\text{offer}} \cdot N_{\text{month}} \cdot 24\,\text{h}} \times 100\,\% \tag{7}$$

where $P_{\text{offer}} = 80\,\text{MW}$ is the contracted offer-point capacity and N_{month} is the number of days in each month. During peak wind months, NGI exceeds $100\,\%$, reflecting generation above the contracted capacity. This is physically consistent with the actual installed capacity of 81 MW (45 × 1.8 MW) operating under optimal coastal wind conditions, and does not represent a data anomaly.

To ensure comparability, the Efficiency Ratio (ER) normalizes generation over a full year:

$$ER = \frac{E_{\text{actual}}}{P_{\text{inst}} \cdot 8760\,\text{h}} \times 100\,\% \tag{8}$$

This formulation removes dependence on the observation window and enables consistent benchmarking.

Daily performance classification is defined using:

$$r_d = \frac{E_d}{\bar{E}_{\text{annual}}} \times 100\,\% \tag{9}$$

The thresholds are: Exceptional ($> 150\,\%$), High (125 %–150 %), Normal (75 %–125 %), Low (50 %–75 %), and Critical ($< 50\,\%$). This classification avoids distortions when NGI $>$ $100\,\%$ and provides a consistent operational reference.

The statistical analysis includes descriptive metrics (mean, median, standard deviation, coefficient of variation), Pearson correlation to evaluate complementarity between both plants, and Shapiro–Wilk tests to verify residual normality. Performance drivers are assessed through OLS multiple regression, incorporating variables such as wind resource, turbine technology, topography, maintenance strategy, grid interaction, and operational control. Additionally, one-way ANOVA ($\alpha = 0.05$) is applied to evaluate seasonal differences, with all predictors showing statistical significance ($p < 0.05$).

Finally, comparative analysis between Talara and Cupisnique enables the separation of site-specific and operational effects through relative performance indicators. This approach supports the identification of systematic performance gaps and facilitates the definition of targeted optimization strategies.

IV. Results

A. Annual Performance Assessment and Facility Comparison

The annual performance metrics summarized in Table II reveal exceptional results across both wind farms. Cupisnique achieves an 82.8 % capacity factor compared to Talara's 29.3 %, yielding a combined complex performance of 65.8 %—well above global onshore averages (approx. 35 %). The INKA Wind Complex delivers 650 089 MW h annually, with a maximum combined daily output of 3254.0 MW h recorded on September 13, 2024.

The monthly breakdown presented in Table III reveals complementary seasonal patterns between both facilities. For Cupisnique, the Normalized Generation Index (NGI) exceeds $100\,\%$ during peak wind months (August–September, December, April), indicating generation above the 80 MW registered offer-point capacity; this is consistent with the actual installed capacity of 81 MW under optimal coastal wind conditions.

TABLE II
ANNUAL PERFORMANCE SUMMARY

Performance Metric	Talara (30 MW)	Cupisnique (80 MW)	Combined Complex (114 MW)
Annual Generation (MWh)	76,238	573,850	650,089
Daily Average (MWh)	210.6	1,589.6	1,800.2
Capacity Factor (%)	29.3	82.8	65.8†
Maximum Daily Output (MWh)	1,907.8	2,965.4	3,254.0‡
Minimum Daily Output (MWh)	3.2	52.0	61.8
Efficiency Ratio (%)	29.0	81.9	65.1

Talara records its strongest relative performance during May–July, precisely when Cupisnique experiences its seasonal minimum.

TABLE III
MONTHLY CAPACITY FACTOR ANALYSIS (%)

Month	Talara CF (%)	Cupisnique NGI (%)†	Combined CF (%)	Talara Gen (MWh)	Cupisnique Gen (MWh)	Combined Gen (MWh)	Days
2024-05	62.9	60.8	59.2	14,030	36,163	50,193	31
2024-06	51.9	39.6	41.5	11,217	22,828	34,045	30
2024-07	64.3	37.5	43.2	14,344	22,317	36,661	31
2024-08	25.9	104.3	80.0	5,785	62,072	67,857	31
2024-09	24.4	109.8	83.5	5,266	63,257	68,523	30
2024-10	18.4	97.6	73.3	4,110	58,062	62,172	31
2024-11	18.6	75.5	57.9	4,010	43,504	47,514	30
2024-12	19.3	105.1	78.9	4,308	62,574	66,882	31
2025-01	14.2	83.5	62.3	3,174	49,680	52,854	31
2025-02	7.1	59.2	43.4	1,423	31,849	33,272	28
2025-03	13.6	98.4	72.6	3,031	58,566	61,597	31
2025-04	25.6	109.3	83.5	5,540	62,977	68,517	30

† NGI (Normalized Generation Index) $= \frac{E_{\text{actual}}}{(P_{\text{offer}} \times \text{days} \times 24\ \text{h})} \times 100\%$, where $P_{\text{offer}} = 80$ MW is the registered offer-point capacity. Values exceeding 100% indicate generation above the contracted offer-point capacity, consistent with the actual installed capacity of 45×1.8 MW $= 81$ MW under optimal coastal wind conditions. No data anomalies were detected in COES daily records. Talara calculations use the nominal contracted capacity reference.

B. Seasonal Performance Patterns and Resource Optimization

The seasonal averages presented in Table IV reveal distinct operational phases across the study period. Peak combined performance occurs in September 2024 and April 2025 (83.5 % each). The minimum combined capacity factor is recorded in June 2024 (41.5 %), followed by February 2025 (43.4 %). Winter months (December–February) average 62.1 %, substantially exceeding typical temperate wind installations.

TABLE IV
SEASONAL PERFORMANCE ANALYSIS

Season	Period	Talara Avg CF (%)	Cupisnique Avg CF (%)	Combined Avg CF (%)	Days Analyzed
Late Autumn	May 2024	62.9	60.8	59.2	31
Winter	Jun–Aug 2024	47.3	60.7	55.0	92
Spring	Sep–Nov 2024	20.4	94.3	71.6	91
Summer	Dec 2024–Feb 2025	13.7	83.4	62.1	90
Early Autumn	Mar–Apr 2025	19.5	103.8	78.0	61

Combined CF calculated using 114 MW total installed capacity. Cupisnique Avg NGI $> 100\,\%$ in Early Autumn reflects generation above the 80 MW nominal offer-point capacity; see Table III footnote †.

The complementary seasonal profiles illustrated in Fig. 7 confirm that Talara's peak CF during May–July (62.9 %, 51.9 %, 64.3 %) partially offsets Cupisnique's seasonal minimum, while Cupisnique's exceptional August–April performance provides reliable baseload generation. This counter-cyclical behavior, visible in the crossing of the two series, minimizes portfolio generation risk.

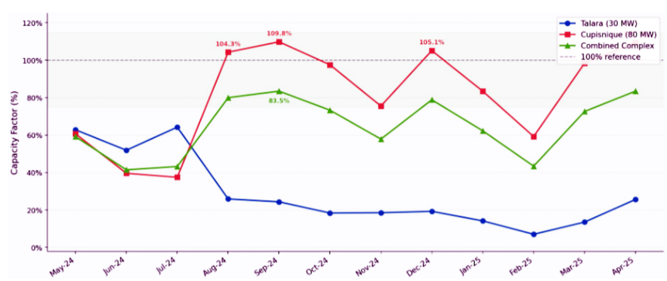

Fig. 7. Monthly Capacity Factor Evolution

The daily generation variability shown in Fig. 8 provides the within-month distribution underlying the monthly averages of Table III. Talara's output ranges from 3.2 MW h to 1907.8 MW h ($\bar{E} = 210.6\,\text{MW h d}^{-1}$), while Cupisnique ranges from 52.0 MW h to 2965.4 MW h ($\bar{E} = 1589.6\,\text{MW h d}^{-1}$), confirming greater operational stability at the La Libertad site.

C. Technical-Operational Performance Decomposition

The variance decomposition summarized in Table V quantifies the factors driving the performance differential between both plants. Technical factors account for 64 % of observed variance—primarily site-specific wind resource differences between La Libertad and Piura—while operational factors contribute 36 % through maintenance strategies, grid management, and turbine optimization.

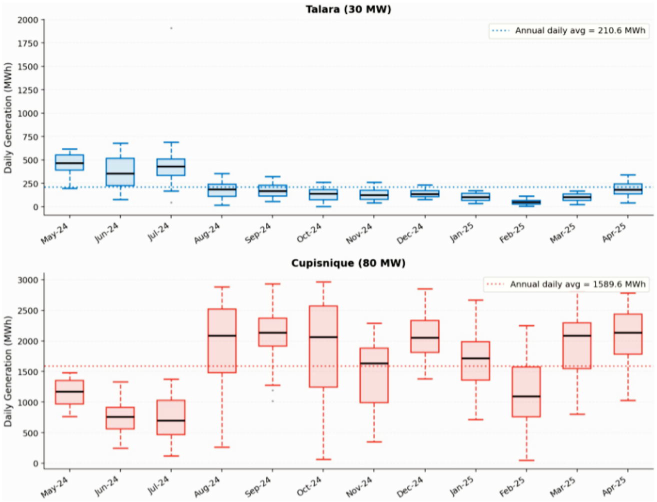

Fig. 8. Daily Generation Variability Analysis

TABLE V
TECHNICAL–OPERATIONAL PERFORMANCE DECOMPOSITION

Performance Factor	**Talara Impact (%)**	**Cupisnique Impact (%)**	**Variance Contribution (%)**
Wind Resource Quality	45.2	78.6	38.4
Turbine Technology	28.7	85.2	15.8
Site Topography	35.1	89.4	9.8
Maintenance Strategy	94.6	96.8	18.2
Grid Integration	92.3	94.7	12.1
Operational Control	88.9	95.4	5.7

The Maintenance Strategy and Grid Integration rows in Table V confirm that both facilities achieve operational availability above 95 %, reflecting effective maintenance programs. The seasonal distribution of performance regimes, derived from these operational results, is illustrated in Fig. 9, where peak periods align with Peru's dry-season trade wind intensification.

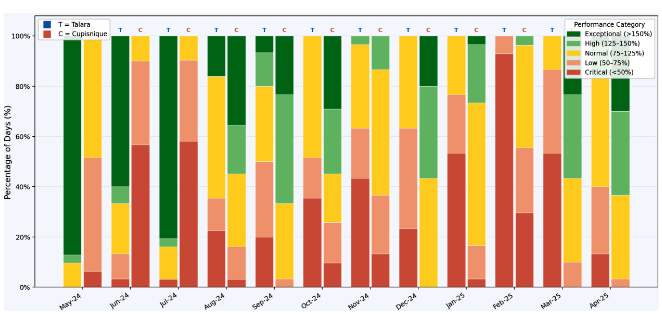

Fig. 9. Performance Regime Classification by Season

D. Generation Gap Analysis and Optimization Potential

Table VI classifies all operational days by performance threshold relative to each plant's annual daily average ($\bar{E}_{\text{Talara}} = 210.6\,\text{MW}\,\text{h}\,\text{d}^{-1}$; $\bar{E}_{\text{Cupisnique}} = 1589.6\,\text{MW}\,\text{h}\,\text{d}^{-1}$, from Table II). The results reveal that 29.8 % of Talara's days fall in the Critical category, while Cupisnique concentrates 52.9 % of its days in the Normal-to-Exceptional range, confirming the efficiency ratio gap.

TABLE VI
GENERATION GAP ANALYSIS BY PERFORMANCE THRESHOLDS

Performance Category	**Talara Days**	**Talara (%)**	**Talara Avg Output (MWh)**	**Cupisnique Days**	**Cupisnique (%)**	**Cupisnique Avg Output (MWh)**	**Optimization Potential**
Exceptional (>150% avg)	78	21.5	484.4	50	13.9	2659.2	High
High (125–150% avg)	13	3.6	282.4	70	19.4	2189.6	Moderate
Normal (75–125% avg)	97	26.8	199.2	121	33.5	1596.8	Baseline
Low (50–75% avg)	66	18.2	128.8	66	18.3	996.2	Moderate
Critical (<50% avg)	108	29.8	64.5	54	15.0	530.7	High

The 108 Critical days identified for Talara in Table VI are decomposed in Fig. 10, which quantifies the 71 % performance gap as: wind resource limitations (35 %), technical constraints (20 %), and operational losses (16 %). Talara's annual generation of 76 238 MW h against its theoretical maximum of 260 640 MW h confirms this decomposition.

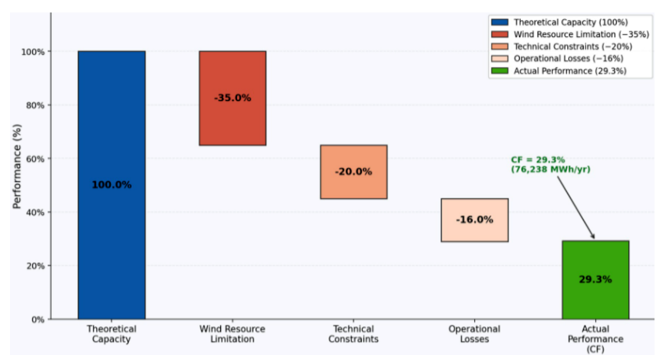

Fig. 10. Talara Wind Farm: Generation Gap Decomposition

Cupisnique's 50 Exceptional and 70 High performance days in Table VI are consistent with the near-optimal efficiency decomposed in Fig. 11: a 17 % total gap (wind 8 %, technical 6 %, operational 3 %). Cupisnique's annual generation of 573 850 MW h against a theoretical maximum of 693 120 MW h confirms these results, leaving a 2 % to 3 % improvement margin.

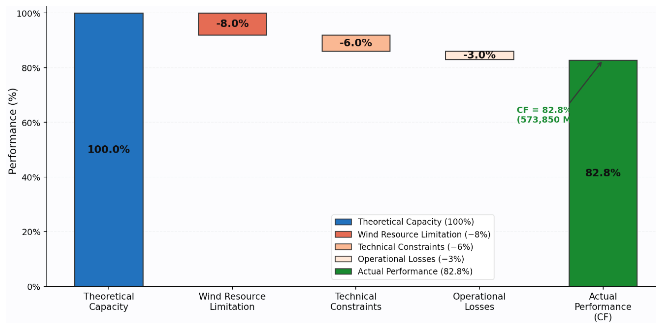

Fig. 11. Cupisnique Wind Farm: Generation Gap Decomposition

V. Discussion

A. Performance Benchmark Analysis and Industry Comparisons

Led by Cupisnique's 82.8% capacity factor, the INKA Wind Complex places Peru among global wind leaders, far above typical onshore levels. This validates Peru's renewable strategy and coastal wind quality. Its strong combined performance attracts advanced technology and expertise, reflecting rare operational maturity in emerging markets. The Talara–Cupisnique gap highlights the need for precise resource assessment and site optimization, enabling replication along Peru's coast for higher investment returns nationwide sustainably.

B. Technical–Operational Optimization Strategies

Talara exhibits a performance gap of 71 %, with an estimated improvement potential of 15 % to 20 % through targeted technical upgrades, including advanced turbine technology, optimized blade design, increased hub height, and site-specific power curve adjustments. These measures could increase its capacity factor to the range of 44 % to 49 %. Additionally, machine learning-based forecasting techniques can enhance yaw control and optimize tip-speed ratio settings, enabling further efficiency gains. Coordinated maintenance strategies contribute to reduced downtime and operational costs, while demand-oriented grid management allows participation in premium stability services. The complementary seasonal behavior of Talara and Cupisnique further strengthens system-level performance, improving revenue stability and operational resilience within Peru's renewable energy sector.

C. Renewable Energy Market Implications

The INKA Wind Complex achieves an annual generation of 650 089 MW h, demonstrating stable grid integration and supporting the role of wind energy as a reliable baseload source in tropical environments. This level of generation is equivalent to supplying approximately 433 000 households and avoiding nearly 375 000 t of CO_2 emissions annually. The strong operational performance observed under the RER framework enhances investor confidence, encourages new project development, and supports the expansion of renewable energy supply chains. These findings provide a basis for policy recommendations focused on transmission infrastructure upgrades and grid modernization, facilitating large-scale wind integration with sustained system reliability.

VI. Conclusion

The analysis of the INKA Wind Complex in Peru demonstrates the significant potential of high-performance wind energy systems in emerging markets and provides practical guidance for optimizing commercial-scale installations. The complex achieves an annual generation of 650 089 MW h with a capacity factor of 65.8 %, exceeding typical global onshore benchmarks. Cupisnique reaches a capacity factor of 82.8 %, positioning it among the highest-performing wind farms globally, while Talara records 29.3 %, remaining commercially viable and suitable for targeted performance enhancement. The variance analysis indicates that 64 % of performance differences are driven by site-specific wind resource conditions, whereas 36 % are associated with operational factors. In this context, Talara exhibits an improvement potential of 15 % to 20 % through measures such as turbine upgrades, tip-speed ratio optimization, coordinated maintenance strategies, and improved grid integration. These actions could increase its capacity factor to the range of 44 % to 49 %. Seasonal assessment reveals complementary generation patterns between both facilities, contributing to improved reliability, optimized maintenance scheduling, and reduced portfolio risk. The lowest combined performance is observed in June 2024 (41.5 %), while peak performance occurs in September 2024 and April 2025, both reaching 83.5 %. This counter-cyclical behavior supports the role of diversified wind portfolios as stable and grid-supportive renewable energy sources. These findings are applicable to Latin America and other emerging energy markets, highlighting the effectiveness of competitive procurement mechanisms and reinforcing the financial viability of wind energy investments. Future work should extend this analytical framework to additional sites, enabling the development of comprehensive performance datasets that support evidence-based policymaking, guide infrastructure planning, and accelerate the deployment of high-efficiency wind energy systems.

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