24th International Conference on Renewable Energies and Power Quality (ICREPQ'26)
Santander (Spain), 10th to 12th June 2026
ISBN-13: 978-84-09-82044-3

Economic–Operational Assessment of the Spanish Power Market: A Monthly TOPSIS Approach with Endogenous Weights

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Abstract. The study examines how high levels of renewable penetration shape the economic and operational performance of the Spanish power system. It develops a monthly multicriteria index using the TOPSIS–CRITIC framework and evaluates two viewpoints. The demand perspective values tariff moderation and price stability, while the generator perspective focuses on value capture and revenue recovery. Both perspectives rely on the same data and weights; they diverge only in how each criterion is classified as a benefit or a cost. This structure sharpens the contrast between affordability for consumers and economic viability for producers. The 2025 results reveal high renewable participation alongside persistent intraday volatility and marked swings in economic margins. Winter exhibits positive average margins and a modest share of energy priced below LCOE. From March to May, margins turn negative and nearly all renewable energy trades below LCOE, reflecting abundant supply and depressed prices. Price-level variables add limited explanatory power, whereas volatility, penalized energy, and hourly alignment (ICPG) drive most of the variation in index values. System performance, therefore, does not follow a simple seasonal pattern; it reflects specific interactions between market signals and the evolving mix of renewable technologies.

Key words. Renewable Energy Markets, TOPSIS–CRITIC, Capture Price Dynamics, Solar-Wind Integration.

1. Introduction

The expansion of variable renewable generation has transformed the structure of European electricity markets over the past decade. In the Spanish case, high solar and wind penetration, growing intermittent capacity, and increasing reliance on hourly price signals have been reshaping operational dynamics and mechanisms of value formation. In this context, the conditions mentioned above tend to amplify revenue cannibalization, compress hourly spreads, and increase exposure to intraday volatility, thereby posing operational and financial challenges for market participants and system operators.

Recent research approaches these issues from multiple angles, including hourly price formation, value capture, system flexibility, and supply-curve displacement. Evidence reported in the aforementioned studies indicates that the interaction between renewable penetration and hourly price signals opens new analytical frontiers. To be more specific, the economic value of renewable technologies depends not only on levelized costs (LCOE) but also on the alignment between generation profiles and critical hourly spreads. This dependence points to the relevance of metrics such as market value, capture price, and residual demand, among others. As a result of these dynamics, the energy sector has increasingly demanded analytical frameworks that integrate operational, economic, and technological dimensions.

This article examines the Spanish electricity system using a multicriteria index constructed with the TOPSIS method and endogenous CRITIC-derived weights. The index incorporates metrics that are operationally meaningful and economically relevant in markets with high renewable participation, including capture price, price–generation correlation, technological shares, economic spreads, and intraday volatility. Taken together, these elements can be used to identify temporal performance patterns, distinguish favorable and unfavorable months from both demand and generator perspectives, and quantify the relative contribution of each criterion. The objective of this study is to provide a quantitative tool for interpreting recent market dynamics and to contribute to ongoing research and investigations on economic value, system flexibility, and the sustainability of investments in the context of the energy transition.

2. Literature Review

The expansion of variable renewable sources in European electricity markets is stimulating a research agenda focused on the interactions among prices, flexibility, and value capture. In this context, one relevant line of inquiry examines how wind and solar generation influence hourly price formation, induce cannibalization effects, and alter the distribution of operating margins, phenomena that relate directly to the dynamic described above. [1] investigate the European transition toward high renewable penetration and show that hourly price signals guide both investment allocation and system operation. [2] evaluate the impacts of wind and solar in Germany and conclude that renewable expansion compresses prices during high-output periods, generating cannibalization effects. In the Spanish case, [3] find that wind generation shifts the supply curve and lowers equilibrium prices, while [4]

confirm similar dynamics in several other European countries.
At the current stage of research, the literature also advances a microeconomic perspective on value capture by renewable technologies and introduces indicators that measure the difference between captured prices and the system's load-weighted average price. Evidence from [5] illustrates the North American experience and shows that solar capture prices decline as solar penetration rises, driven by supply saturation during high-irradiance hours. [2] apply the same framework to Europe and conclude that hourly generation patterns explain capture-price differentials across technologies and regions. More specifically, [6] develop an economic framework for wind and solar variability and find that increasing renewable penetration results in a consistent reduction in value capture relative to dispatchable technologies, due to the temporal mismatch between renewable generation and demand.
In the methodological domain, multicriteria approaches have, in turn, gained relevance in the power sector, particularly for performance evaluation, alternative prioritization, and the integration of heterogeneous indicators. [7] apply TOPSIS to multi-attribute energy planning and show that the method efficiently synthesizes economic and environmental dimensions. Likewise, [8] combines TOPSIS and CRITIC for solar site selection and show that endogenous weights improve the representation of conflicts across criteria. Finally, [9] conduct a systematic review and conclude that the TOPSIS–CRITIC combination has become an operationally meaningful tool in energy research because it weights variables based on statistical information rather than subjective preferences.

3. Methodology

The construction of the monthly performance indicator for the Spanish power system was based on hourly series of spot market prices (€/MWh), system load (MW), and generation by technology (MWh), obtained from the system operator. After collection, the series underwent preprocessing procedures, including temporal consistency checks, unit harmonization, and integration of the different datasets, followed by aggregation to monthly frequency. Let $m$denote the month, h the hours belonging to month m, and $t$the set of generation technologies. We define $P_h$as the hourly price, $L_h$as the hourly load, and $G_{t,h}$as the hourly generation of technology t.
Methodological approaches based on hourly electricity market data and monthly aggregation have been adopted in recent power system studies addressing market performance under high renewable penetration [10].
Based on these series, indicators were constructed to synthesize value capture, temporal alignment between generation and prices, and energy participation across technologies. The monthly energy produced by technology $t$is defined as $E_{t,m} = \sum_{h\in m} G_{t,h}$, while total system energy is obtained as $E_m^{tot} = \sum_{h\in m} L_h$. Renewable participation is thus expressed as $\text{share\_renewable}_m = E_m^{ren}/E_m^{tot}$, where E_m^{ren}denotes monthly renewable generation.
For each technology $t$and month m, the capture price $CP_{t,m}$represents the effective average revenue received in the spot market, weighted by the hourly generation profile:

$$CP_{t,m} = \frac{\sum_{h\in m} P_h \cdot G_{t,h}}{\sum_{h\in m} G_{t,h}}. \quad (1)$$

This indicator reflects the technology's ability to generate during hours with higher remuneration. Capture-based valuation metrics are commonly used in electricity market literature to assess the ability of generators to internalize hourly price signals [10].
The temporal alignment between generation and prices is measured by the Price–Generation Correlation Index (ICPG), computed as the Pearson correlation between the hourly generation profile and hourly prices:

$$ICPG_{t,m} = Corr(G_{t,h}, P_h), \quad (2)$$

Correlation-based alignment metrics have been applied in electricity markets to quantify the interaction between generation profiles and system price formation [11].
which takes positive (negative) values when technology tends to generate in high-price (low-price) hours.
Relative performance is assessed by comparing each technology's capture price to the system's load-weighted spot price, defined as:

$$P_m^{sys} = \frac{\sum_{h\in m} P_h \cdot G_h^{tot}}{\sum_{h\in m} G_h^{tot}}, \quad (3)$$
$$G_h^{tot} = \sum_t G_{t,h}.$$

The capture ratio is then given by:

$$CR_{t,m} = \frac{CP_{t,m}}{P_m^{sys}}, \quad (4)$$

where $CR_{t,m} > 1$indicates capture above the system average and $CR_{t,m} < 1$indicates a discount. A tolerance band $\tau$is applied around unity to avoid excessive sensitivity near the threshold. Combining $CR_{t,m}$and $ICPG_{t,m}$, technologies are classified monthly into rewarded, neutral, or penalized categories, allowing the energy mix to be decomposed according to prevailing price signals.
This classification enables the derivation of monthly systemic indicators summarizing the composition of the generation portfolio. Denoting by $E_m^{prem}$and $E_m^{pen}$the monthly energies associated with rewarded and penalized technologies, we define:

$$\text{share rewarded}_m = \frac{E_m^{prem}}{E_m^{tot}} \quad (5)$$
$$\text{share penalized}_m = \frac{E_m^{pen}}{E_m^{tot}}.$$

In addition, economic attributes were derived from spot price formation. The load-weighted price, an indicator of tariff affordability, is expressed as:

$$p_m^L = \frac{\sum_{h\in m} P_h \cdot L_h}{\sum_{h\in m} L_h}, \quad (6)$$

while the monthly average spot price is:

$$\bar{P}_m = \frac{1}{H_m} \sum_{h\in m} P_h, \quad (7)$$

and the intraday volatility of hourly prices is given by:

$$\sigma_{P,m} = \sqrt{\frac{1}{H_m - 1} \sum_{h \in m} (P_h - \bar{P}_m)^2}. \quad (8)$$

Finally, the aggregate alignment between system-wide generation and price signals is captured by the weighted ICPG:

$$\text{icpg\_weighted}_m = \frac{\sum_t ICP\, G_{t,m} \cdot E_{t,m}}{\sum_t E_{t,m}}, \quad (9)$$

Hourly price levels and volatility metrics are well-established indicators in power market analysis, particularly in systems with high renewable penetration where price dynamics reflect variability and flexibility constraints [10]. So that technologies with greater energy participation exert proportionally higher influence.

In addition to price-based indicators, the analysis incorporates a cost dimension to assess the system's economic performance.

The LCOE values assigned to each generation of technology are explicitly reported in Table X. These values are based on standardized cost estimates from [12] and [13] and are converted into euros using a consistent exchange rate to ensure comparability across technologies. By fixing LCOE values over time, the analysis avoids introducing additional variability from cost-side fluctuations and ensures that observed changes in economic margins arise from market price dynamics and renewable penetration patterns.

These seven monthly criteria, renewable share, rewarded share, penalized share, load-weighted price, average spot price, intraday volatility, and weighted ICPG, constitute the multicriteria decision matrix $X_{\text{mes}} \in \mathbb{R}^{M\times 7}$, where each month $m$is represented by a vector $(x_{m1}, \dots, x_{m7})$describing its economic–operational configuration.

The selection of criteria follows a structured process based on three complementary dimensions, namely economic relevance, operational interpretability, and data consistency at the hourly level. It is important to emphasize that the selected variables aim to reflect key mechanisms identified in the literature on electricity markets with high renewable penetration, particularly with respect to value capture (capture price and ICPG), tariff affordability (load-weighted price), and system variability (intraday volatility), as highlighted by [2] and [5]. Nevertheless, the criteria are defined to capture the composition of the generation mix (renewable share, rewarded share, and penalised share) and the interaction between generation profiles and price signals, which are central to understanding cannibalisation effects and the degree of market alignment. It is also important to note that all the aforementioned indicators can be constructed consistently from the same hourly dataset, without the need to introduce external assumptions or heterogeneous data sources, thereby preserving internal coherence and comparability across months.

The evaluation proceeds with endogenous weight determination via CRITIC and synthetic index computation via TOPSIS. The methodology integrates multi-criteria decision making using TOPSIS for performance ordering and CRITIC for objective weight determination, a combined framework increasingly adopted in energy-related decision problems.

Criteria were normalized according to their orientation (benefit or cost), applying vector normalization for benefit criteria:

$$z_{mk} = \frac{x_{mk}}{\sqrt{\sum_m x_{mk}^2}}, \quad (10)$$

and inverse transformation followed by normalization for cost criteria. The CRITIC method estimates criterion weights $w_k$by combining variability and informational redundancy through:

$$C_k = \sigma_k \sum_{\ell \neq k} (1 - |\rho_{k\ell}|), \quad (11)$$

where $\sigma_k$is the standard deviation of criterion $k$and $\rho_{k\ell}$is the Pearson correlation between criteria $k$and ℓ. Final weights are obtained as:

$$w_k = \frac{C_k}{\sum_{r=1}^{K} C_r}. \quad (12)$$

The CRITIC method provides objective weights by incorporating both variability and inter-criterion conflict, originally formulated for multi-criteria decision evaluation by [8].

TOPSIS is then applied to compute Criterion weights were determined endogenously using. Let $v_{mk} = w_k \cdot z_{mk}$denote the weighted matrix; the ideal and anti-ideal solutions are defined as $v_k^+ = \max_m v_{mk}$and $v_k^- = \min_m v_{mk}$, respectively (. The Euclidean distances to each solution are:

$$D_m^+ = \sqrt{\sum_k (v_{mk} - v_k^+)^2} \quad (13)$$

$$D_m^- = \sqrt{\sum_k (v_{mk} - v_k^-)^2}.$$

The final index is given by:

$$C_m = \frac{D_m^-}{D_m^+ + D_m^-}, 0 \le C_m \le 1, \quad (14)$$

allowing months to be compared, ranked, and interpreted in terms of systemic performance.

TOPSIS has been widely applied in energy planning and power system decision problems to synthesize heterogeneous indicators by ranking alternatives based on their distances to ideal and anti-ideal solutions [4].

3.1 Application of TOPSIS–CRITIC under Different Objective Functions

The use of TOPSIS under two objective functions, a System Performance Index and a Generator Sustainability Index, reveals structural trade-offs in electricity markets with high renewable penetration. A single month may score well from the system perspective by supporting lower and more stable consumer prices, while scoring poorly from the generator perspective by limiting economic returns and slowing cost recovery. This dual perspective removes interpretative ambiguity and increases the explanatory power of the multicriteria analysis.

Using the monthly criteria defined earlier, the TOPSIS and CRITIC procedure runs under two objective perspectives without changing the dataset, the normalization method, or the endogenous weight calculation via CRITIC. The two indices differ only in the benefit or cost orientation assigned to each criterion according to the economic agent under evaluation.

The following table summarizes the benefit/cost orientation of criteria under each objective:

Table I. Classification of criteria according to demand (consumer) and supply (generator) perspectives.

Criterion	Demand (Consumers)	Supply (Generators)
Renewable share	Benefit	Benefit
Rewarded share	Benefit	Benefit
Penalized share	Cost	Cost
Load-weighted price (p_m^L)	Cost	Benefit
Average price (P_m)	Cost	Benefit
Volatility ($\sigma_{P,m}$)	Cost	Cost
Weighted ICPG	Benefit	Benefit

The classification differs across perspectives because demand and supply agents face distinct economic incentives. Lower prices and reduced volatility benefit consumers, while higher prices improve revenue and cost recovery conditions for generators. Price-related variables are treated as costs from the demand perspective and as benefits from the supply perspective, while volatility is classified as a cost for both due to its association with uncertainty and risk exposure.

The two orientations reflect distinct objectives: system demand pursues affordability and stability, while generators prioritise revenue recovery and economic viability.

The System Performance Index adopts a demand perspective and favours low and stable prices. It treats price level and volatility as cost criteria and renewable penetration, rewarded energy, penalised energy reversal, and weighted ICPG as benefit criteria.

The Generator Sustainability Index emphasises value capture. Capture price, weighted ICPG, and rewarded and penalised energy shares drive its behaviour, so very low prices reduce its scores due to weaker revenue recovery and higher cannibalisation risk.

The comparison of both indices highlights periods that benefit consumers while harming generators, and the reverse, which allows the identification of compromise regions between affordability and investment sustainability. Importantly, the index does not assess global market welfare, but rather relative performance conditioned by the objective function and the perspective under analysis. High values, therefore, reflect proximity to the ideal configuration for that perspective, not universally favourable outcomes.

4. Results

The empirical analysis uses hourly demand, price, and generation data from the Spanish power system obtained from the ESIOS platform of the system operator REE. The dataset covers the period from January 2023 to December 2025. It includes timestamps, national demand, spot prices, and disaggregated generation by technology, such as wind, nuclear, combined cycle, hydropower, photovoltaic and solar thermal, renewable thermal, cogeneration, waste-to-energy, and interconnections. The preprocessing stage verifies gaps, removes duplicates, harmonizes technology identifiers, and aligns demand, price, and generation series.

After preprocessing, the analysis aggregates the hourly data to a monthly frequency and builds technology-level and system-level indicators for energy generation, revenue exposure, and price statistics. This monthly panel supports multicriteria evaluation using TOPSIS and CRITIC and enables comparisons of technologies over time.

To assess the robustness of the weighting scheme, the study applies uniform and entropy-based weights and compares them with CRITIC, while keeping the TOPSIS structure unchanged. The analysis also uses monthly capture price CP, price generation correlation ICPG, and capture ratio to classify technologies as rewarded, neutral, or penalized relative to the load-weighted system price, with a tolerance band to avoid marginal misclassification. A heatmap displays the resulting technology month matrix.

From an economic viewpoint, the CP measures the value captured by each technology, the ICPG measures temporal alignment between generation and hourly prices, and the capture ratio integrates both dimensions. High CP and positive ICPG indicate concentration of output in high price hours, while low CP and negative ICPG reveal exposure to price depression and misalignment. The classification highlights rewarded flexible technologies during scarcity and penalized variable renewables during cannibalization episodes.

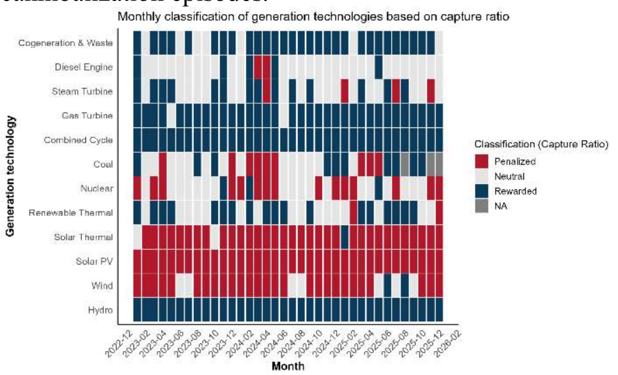

Fig. 1. Monthly classification of generation technologies according to the capture ratio

The results (Fig. 1) reveal a clear distinction between dispatchable and variable renewable technologies. Dispatchable sources such as combined cycle, hydropower, gas turbines, steam turbines, and cogeneration are predominantly classified as rewarded, reflecting their operational flexibility and ability to capture prices above the system's load-weighted average. In contrast, variable renewables such as wind, solar photovoltaic, and solar thermal appear mostly penalized, as their production frequently coincides with low-price hours, leading to capture ratios below 1 and negative ICPG values. Nuclear generation tends to be penalized or neutral, consistent with its inflexible and constant output profile, while specific fossil technologies such as coal and diesel exhibit more heterogeneous behavior, alternating between rewarded and penalized months depending on market and dispatch conditions.

Table II. - Monthly system indicators in 2025 – Part A: total energy, renewable energy, and renewable share.

Data	Total Energy (MWh)	Renewable Energy (MWh)	Renewable Share
jan/25	23,64	14,34	0,606
Feb/25	21,14	12,69	0,6
mar/25	23,04	15,07	0,654
Apr/25	19,38	13,42	0,692
May/25	20,01	13,23	0,661
jun/25	22,23	13,16	0,592
jul/25	24,34	14,61	0,6
Aug/25	22,92	13,08	0,571
Sep/25	21,16	12,29	0,581
Oct/25	21,36	11,83	0,554
nov/25	21,71	13,41	0,618
Dec/25	22,88	12,65	0,553

Table III. - Monthly system indicators in 2025 – Part B: pricing metrics, volatility, weighted ICPG and rewarded/penalized shares

Data	Load-Weighted Price (€/MWh)	Average Spot Price (€/MWh)	Spot Price Volatility (€/MWh)	Weighted ICPG (Correlation)	Rewarded Share	Penalized Share
jan/25	100,43	96,69	48,53	0,134	0,339	0,638
Feb/25	111,23	108,31	42,93	0,198	0,335	0,573
mar/25	56,2	53,09	44,12	0,288	0,343	0,436
Apr/25	28,59	26,83	33,78	0,132	0,384	0,449
May/25	17,98	16,93	25,3	0,176	0,538	0,273
jun/25	73,96	73,2	51,27	0,169	0,524	0,283
jul/25	71,06	69,94	43,31	0,035	0,311	0,497
Aug/25	68,77	68,44	42,44	0,117	0,49	0,276
Sep/25	61,59	61,04	42,9	0,044	0,318	0,257
Oct/25	77,28	75,77	43,87	0,134	0,381	0,405
nov/25	60,92	58,65	37,08	0,112	0,327	0,649
Dec/25	80,24	77,91	27,5	0,186	0,345	0,567

Table IV. - Monthly system indicators in 2025 – Part C: margins and negative-margin share

Data	Weighted Average Margin (CP_{LCOE})	Share of Energy with Negative Margin
jan/25	35,1	0,236
Feb/25	41,49	0,019
mar/25	-8,41	0,547
Apr/25	-34,66	0,99
May/25	-46,81	0,99
jun/25	5,11	0,489
jul/25	2,71	0,252
Aug/25	-1,86	0,706
Sep/25	-8,33	0,751
Oct/25	8,17	0,213
nov/25	-3,32	0,606
Dec/25	11,61	0,24

Tables 2 to 4 report the monthly indicators for the Spanish power system in 2025, grouped into the physical, economic market, and economic cost dimensions.

Table 2 summarizes the physical dimension. Monthly electricity output ranged from 19 to 25 TWh, and renewable generation supplied roughly 60% of total consumption throughout the year, exceeding 65% in March and April. These figures highlight an advanced decarbonization stage with high loads and high renewable penetration, although seasonal weather variation continued to drive intermittency across the year.

Table 3 adds economic market indicators. Notably, load-weighted and average spot prices exceeded 100 euros per megawatt-hour in January and February, then declined sharply from March onward. The system reached its lowest price levels in April and May. Yet, price volatility remained high, peaking in June and July, underscoring that lower price levels did not guarantee smoother intraday profiles. The weighted ICPG fluctuated across months, with higher values in March, and the distribution between rewarded and penalized shares indicates that a substantial portion of the generation captured prices below the load-weighted system average, a pattern consistent with the production profile of variable renewables.

Table 4 introduces the cost dimension by comparing market remuneration with LCOE. Weighted margins remained strongly positive in January and February, with low negative margin shares, which favored cost recovery. From March onward, the system shifted into negative margins: March recorded a negative margin of around eight euros per megawatt hour, with more than half of total energy below LCOE, and April and May exhibited the most adverse outcomes, with negative margins of 35 and 47 euros per megawatt hour and all output below cost. This configuration aligns with high renewable output, depressed prices, and altered marginal conditions. During the summer months, the system displayed partial recovery, with June and July posting positive margins despite elevated negative-margin shares, while August returned to negative territory. The last quarter alternated between favorable and unfavorable months, with negative margins in September and November and positive margins in October and December.

Table V. Technology-specific LCOE assumptions used in the economic margin analysis.

Technology	LCOE (USD/MWh)	LCOE (EUR/MWh)
Onshore wind	33	30.69
Solar PV	44	40.92
Hydropower	57	53.01
Combined cycle gas	90	83.70
Coal	100	93.00
Nuclear	115	106.95
Solar thermal	117	108.81
Diesel	175	162.75
Gas turbine	220	204.60

Note: LCOE values are based on Lazard (2023) and IRENA (2023), expressed in USD/MWh and converted to EUR/MWh. Values are assumed constant and used to compute economic margins (CP − LCOE).

Table V introduces the cost dimension by comparing market remuneration with technology-specific LCOE values. The table identifies periods in which market conditions do not ensure cost recovery, defined as when the capture price (CP) falls below the corresponding LCOE ($CP < LCOE$), resulting in negative economic margins for part of the generation, particularly under high renewable penetration.

Table VI. - CRITIC Weights and Criterion Orientations under Demand and Generator Perspectives

Criterion	CRITIC Weight	Demand Orientation	Generator Orientation
Renewable Share	0.0864	benefit	benefit
Rewarded Share	0.1519	benefit	benefit
Penalized Share	0.1767	cost	cost
Weighted ICPG	0.1234	benefit	benefit
Load-Weighted Price (€/MWh)	0.0658	cost	benefit
Average Spot Price (€/MWh)	0.0658	cost	benefit
Spot Price Volatility (€/MWh)	0.1690	cost	cost
Weighted Average Margin (CP – LCOE)	0.0665	cost	benefit
Negative Margin Share	0.0945	benefit	cost

The monthly TOPSIS–CRITIC index for the Spanish power system provides an integrated representation of system performance by jointly accounting for renewable penetration, spot prices, price volatility, and generation–price alignment. The temporal distribution of the index shows that both high- and low-performance months are dispersed across seasons and years, indicating that aggregate system performance is not driven solely by seasonality. Instead, extreme outcomes arise from specific configurations of price dynamics, renewable availability, and hourly market conditions, which vary with meteorological patterns and short-term market equilibria.

Descriptive statistics show a moderate average index value (≈0.46 on a 0–1 scale) and non-negligible dispersion, with lower and upper bounds near 0.20 and 0.85, respectively. Half of the observations lie within a relatively narrow intermediate range, suggesting a stable performance core interspersed with episodes of distinctly favorable or adverse conditions. These results illustrate the usefulness of the TOPSIS–CRITIC framework in identifying relatively “efficient” or “critical” operational months by integrating market signals with the physical and operational attributes of the generation fleet.

The trade-off chart compares demand and generator perspectives using monthly TOPSIS–CRITIC indices, calculated separately for each objective while keeping criteria, normalization, and CRITIC weights constant. Each point represents a month, with the horizontal axis showing demand performance and the vertical axis showing generator performance. Dashed lines mark the empirical medians, dividing the chart into four quadrants that identify months favourable to both agents, unfavourable to both, or reflecting asymmetric outcomes (Fig. 2).

The distribution shows that months in the upper-right quadrant have favourable conditions for both consumers and generators, while those in the lower-left reflect poor performance for both. The mixed quadrants illustrate trade-offs: some months favor generators over demand (e.g., 2025-05 and 2024-02), while others show the reverse (e.g., 2023-02 and 2023-06). These asymmetric regimes suggest that transitions between supportive and adverse conditions can occur nonlinearly, driven by price levels, intraday volatility, renewable penetration, and hourly generation–price alignment. These factors ultimately shift incentives for market participants (Fig. 2).

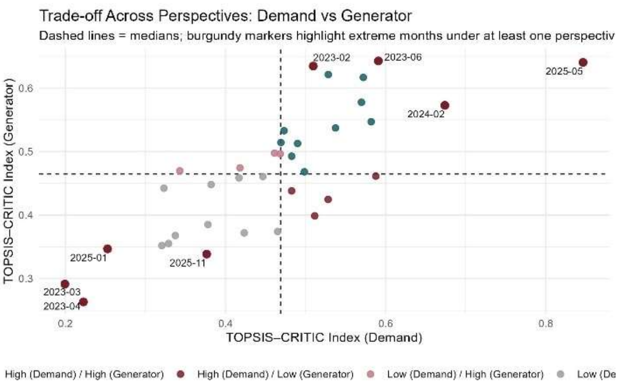

Fig. 2. Comparative Monthly Performance Under Dual System Perspectives

Figure 2 shows that monthly performance does not follow seasonal regularities and that consumer-oriented and generator-oriented outcomes frequently diverge. To contextualise this dynamic, it is useful to interpret three months explicitly mentioned during the evaluation process: January 2024, April 2024, and May 2025. In April and May 2025, the System Performance Index (demand perspective) reaches high values because exceptionally low spot prices improve tariff affordability and price stability, even as they generate adverse revenue conditions for producers. This is confirmed by (i) negative margins relative to LCOE and (ii) the predominance of penalised renewable energy in the corresponding tables. From the generator sustainability perspective, however, those same months perform poorly because low prices imply limited cost recovery and a higher risk of cannibalisation. In contrast, January 2024 presents intermediate price levels, low penalised shares, and positive average margins, a configuration that favours generators without imposing significant tariff burdens on consumers. This combination yields intermediate–high results under both perspectives. It should be emphasised that the TOPSIS–CRITIC ranking does not identify “good months” in an absolute sense, but rather relative performance configurations conditioned by the selected viewpoint (demand versus generator). Importantly, high index values do not mean that the month is universally favourable, but that it aligns with the objective function under analysis (tariff affordability for demand or economic sustainability for generators).

The robustness assessment demonstrates that the selection of weighting scheme has only a marginal impact on monthly TOPSIS–CRITIC rankings. A comparison of indices calculated using CRITIC and Entropy-based weights reveals strong alignment across the entire sample, despite the distinct underlying principles of each method. In practice, months with high scores under the CRITIC approach also tend to score highly under the Entropy method, and this correspondence is similarly observed for low-scoring months.

Statistical indicators further support this conclusion. Rank correlations, measured by Spearman and Kendall coefficients, exceed 0.68 in all relevant comparisons, indicating substantial agreement in the ordering of months. Additionally, tercile-transition analysis demonstrates low migration rates when substituting CRITIC weights with Entropy weights, suggesting that months classified as favorable or critical generally remain within the same categories regardless of the weighting scheme. Collectively, these findings indicate that the temporal patterns identified by the index, which are influenced by price levels, price volatility, renewable penetration, hourly alignment between generation and market signals, and economic margins, remain consistent across different weighting choices. Consequently, the index enables reliable inference without reliance on a specific weighting scheme.

The monthly TOPSIS–CRITIC index monitors the aggregated performance of the Spanish power system over time (Fig. 3). This index integrates renewable penetration, price levels, price volatility, price–generation alignment, and additional operational dimensions into a single multicriteria measure, with weights determined by the CRITIC method. Empirical terciles (p33 and p67) are used to classify observations into low, intermediate, and high-performance categories, thereby avoiding the imposition of arbitrary thresholds.

The time-series analysis indicates that high-performance months are distributed throughout the sample period, rather than being concentrated in a particular year or season. This distribution suggests that favorable outcomes result from specific interactions between market signals and generation structure, rather than from consistent seasonal dynamics (Fig. 3). May 2025 exhibits the highest index value within the sample. Low-performance months also occur sporadically, reflecting less efficient configurations of the same criteria. Intermediate months represent a transitional group in which no single dimension is predominant. Overall, the time series underscores the dynamic nature of system performance and the importance of concurrent market and operational factors.

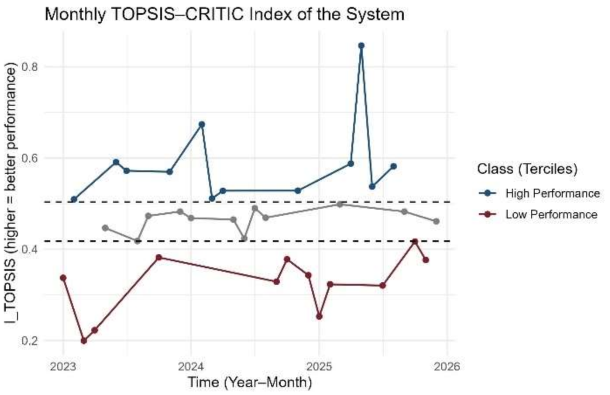

Fig. 3. Evolution of the Monthly TOPSIS–CRITIC Performance Index

To complement the interpretation of the TOPSIS–CRITIC monthly index, we computed the signed contribution of each criterion over time, where the benefit/cost orientation of each variable determines the sign. Figure 4 displays a heatmap of the signed monthly contributions under the demand and generator perspectives, allowing us to assess the intensity, direction, and temporal persistence of each criterion.

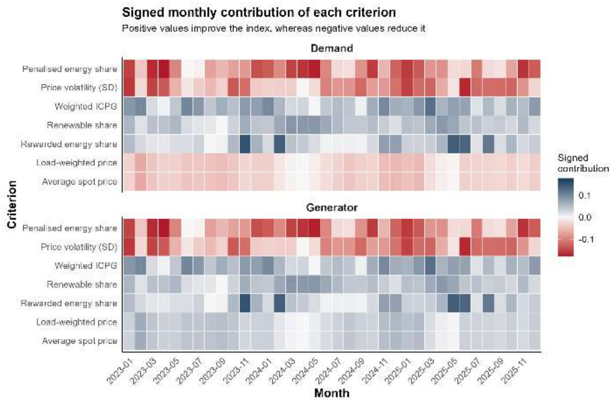

Fig. 4. Signed monthly contribution of each criterion to the TOPSIS–CRITIC index (Demand vs. Generator perspective)

The heatmap shows clear asymmetry among the criteria. The share of penalised energy produces negative contributions in both perspectives and consistently drags down system performance. Price volatility also negatively affects demand, especially when tariff stability carries more weight. In contrast, the weighted ICPG oscillates between positive and negative values and sharply distinguishes favourable from unfavourable months: a reasonable price–generation alignment lifts the index. At the same time, misalignment or oversupply pulls it down.

Renewable penetration and rewarded energy usually add moderate positive contributions, particularly when prices and alignment favour renewable output. Price-level variables make small, irregular contributions. They benefit generators during high-priced months and disadvantage consumers, thereby exposing the classic trade-off between revenue sustainability and tariff moderation.

Figure 5 summarises the static decomposition of average contributions. Volatility and ICPG dominate both indices; penalisation-related criteria follow next, and renewable penetration sits in the middle. Price levels contribute the least. This hierarchy suggests that volatility, alignment, and penalisation carry most of the informational content captured by the CRITIC weighting.

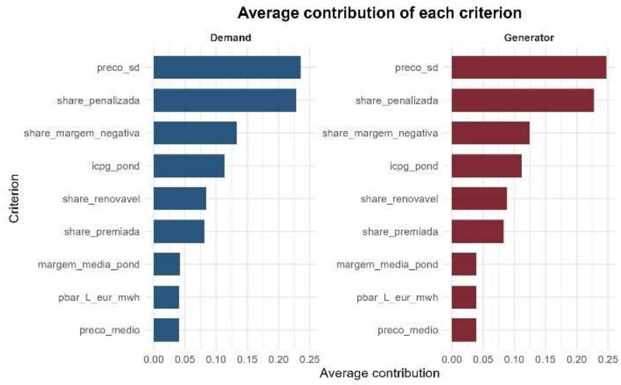

Fig. 5. Average contribution of each criterion to the TOPSIS–CRITIC index (Demand vs. Generator perspective)

5. Conclusion

We applied a monthly TOPSIS–CRITIC framework to evaluate the economic and operational performance of the Spanish power system under high renewable penetration. Results indicate that system performance is driven by the interaction between market signals and generation structure. Seasonal patterns alone do not account for performance. Both high- and low-performance months are observed throughout the sample period. This suggests that the alignment between hourly price dynamics and renewable generation plays a central role in shaping outcomes.

Price-level variables do not constitute the primary drivers of the index's variation. Load-weighted and average spot prices exhibit limited discriminatory power across months. In contrast, intraday price volatility, penalised energy shares, and negative-margin shares emerge as the dominant factors. These explain differences in system performance. These results indicate that price variability and the distribution of economic margins provide greater explanatory power for extreme outcomes than average price levels alone.

High levels of renewable penetration alone do not guarantee improved system performance. Months with high renewable shares may still show moderate or low index values when price volatility increases. Performance can also suffer when generation profiles fail to align with high-price periods. This finding indicates that renewable penetration interacts with system flexibility constraints, cost conditions, and hourly market dynamics.

Some months improve consumer outcomes by lowering prices and making them more stable, but worsen revenue conditions for generators. Other periods show the opposite trend. These asymmetries highlight the importance of analyzing affordability and economic sustainability as distinct and often conflicting dimensions of system performance.

Robustness checks indicate that the CRITIC weighting scheme does not drive the empirical results. Alternative weighting approaches, such as uniform and entropy-based schemes, produce highly consistent rankings and classifications. These findings confirm that the main empirical patterns, driven by volatility, alignment, penalisation, and renewable penetration, remain stable across different weighting structures.

Acknowledgement

The authors acknowledge the support from the Coordenação de Aperfeiçoamento de Pessoal de Nível

Superior (CAPES), the Programa de Apoio à Pós-Graduação (PROAP/CAPES), and the Universidade do Estado do Rio de Janeiro (UERJ). This research benefited from institutional resources and graduate program support made available through these initiatives.

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