24TH INTERNATIONAL CONFERENCE ON RENEWABLE ENERGIES AND POWER QUALITY (ICREPQ'26)

IMPACT OF ELECTRICITY MARKET VOLATILITY ON THE MANAGEMENT OF HYBRID RENEWABLE SYSTEMS WITH STORAGE

Lizbeth Tipán-Salazar, Natalia Naval, Jose M. Yusta

Department of Electrical Engineering, University of Zaragoza, Spain

ABSTRACT

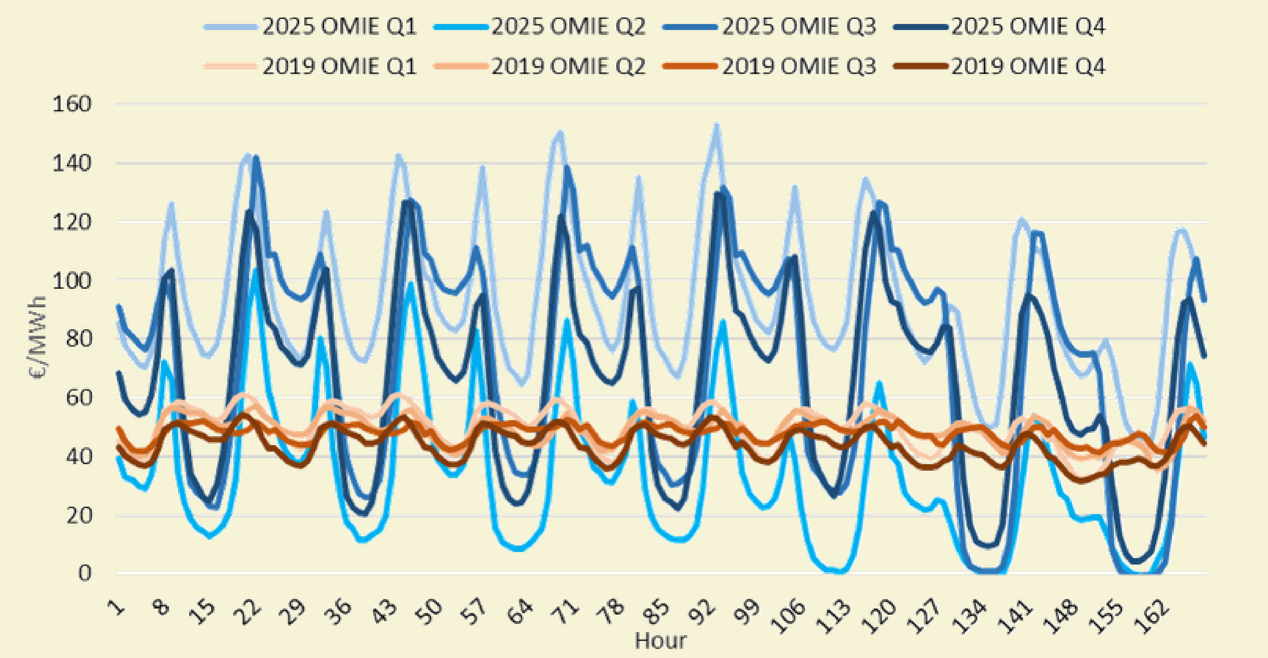
This study evaluates a hybrid PV–Wind system with Pumped Hydro Energy Storage (PHES) under two electricity market scenarios in Spain: 2019 (low volatility) and 2025 (high volatility). Results show that higher daily price spreads (the difference between maximum and minimum daily prices) in 2025 significantly increase PHES utilization, reducing grid imports by up to 85% in summer and enabling profitable energy arbitrage. PHES improves renewable self-consumption and system flexibility under volatile market conditions.

INTRODUCTION

The Spanish electricity market has undergone a profound transformation, doubling its wind and solar capacity between 2019 and 2025. While this has reduced average prices, it has introduced significant intraday fluctuations and negative prices.

- **Current context**: The lack of flexibility in managing renewable energy surpluses has led to extreme price variability.
- **Role of storage**: Systems like PHES are critical for storing surplus energy during low-price valleys and generating during peak-price hours.
- **Objective**: To evaluate how daily price spreads influence the operational and economic performance of a hybrid PV-Wind-PHES system.

WEEKLY AVERAGE PRICE CURVES FOR THE ELECTRICITY MARKET BY QUARTER IN 2019 AND 2025



MARKET SCENARIOS: 2019 VS. 2025

The "Daily Spread" is identified as the key metric for arbitrage potential

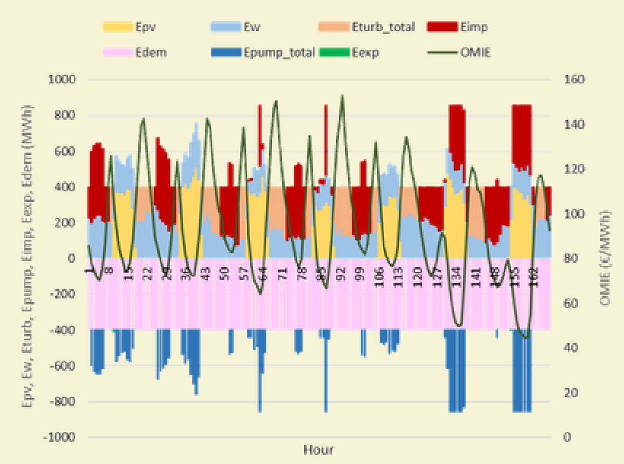
- 2019 (Baseline): Stable prices (~50 €/MWh) with a low average spread of 16.90 €/MWh.
- 2025 (Volatility): High-volatility environment with an average spread of 101.77 €/MWh.
- Price Peaks: Summer 2025 recorded price peaks exceeding 140 €/MWh and valleys reaching 0 €/MWh.

METHODOLOGY & CASE OF STUDY

The study uses an optimization model (MINLP) in GAMS to optimize energy operation and minimize weekly net costs.

- Hybrid plant: 860 MW PV and 465 MW Wind.
- PHES: 5,750 MWh energy capacity with a reversible variable-speed unit.
- Temporal resolution: Hourly analysis across four average weeks (Q1-Q4) to capture seasonal variations in generation and prices.
- Data inputs: It uses generation profiles from plants in Zaragoza, Spain, and real price curves from the Iberian Energy Market Operator (OMIE).
- Comparative scenario analysis: The article applies this model to two specific environments: 2019 and 2025 scenarios.

Optimal hourly operation during an average week in the winter quarter



RESULTS

		Epv	Ew	Eimp	Eexp	Epump	Eturb	Cost	Revenue	Total cost
2019	Q1	20,148	27,734	21,571	218	10,712	8,677	1,900,306	11,473	1,889,323
	Q2	47,043	30,048	9,477	17,734	8,599	6,966	1,434,409	855,573	579,366
	Q3	59,807	24,030	10,795	26,309	5,914	4,790	1,482,399	1,208,646	274,172
	Q4	30,975	22,045	16,308	17	11,111	9,000	1,473,617	785	2,050,234
2025	Q1	20,148	27,734	22,027	10	14,207	11,508	3,103,178	874	3,102,913
	Q2	47,043	29,771	2,911	7,531	26,287	21,292	1,123,909	481,000	643,388
	Q3	59,807	23,891	1,629	12,364	30,339	24,575	1,117,185	1,220,695	- 103,030
	Q4	30,975	22,045	18,439	12	22,351	18,104	2,092,550	879	3,216,894

The integration of PHES allowed the system to adapt its dispatch strategy to meet a constant 400 MW demand.

Q1 (winter): High grid dependency (22,027 MWh) and electricity price (145.63 €/MWh) increased pumping activity by 33%. Net cost rose by 64%.

Q2 (spring): A sixfold increase in price spread (15.63 → 95.13 €/MWh) reduced imports from 9,477 to 2,911 MWh through intensive storage use.

Q3 (summer): Best system performance. Storage utilization quadrupled, reducing imports by 85% (1.6 MWh) and shifting the system from −274,172 € to +103,030€ profit.

Q4 (autumn): Pumped energy doubled compared to 2019 to manage price peaks, although higher import costs increased net cost by 57%.

ANALYSIS

The comparison between both scenarios demonstrates that electricity price spread is the main factor driving storage operation.
Seasonal conditions also strongly influenced system behavior, with summer showing the best economic performance due to high solar generation and large price spreads.

Under low-volatility conditions (2019):
- Storage activity remained limited.
- The system relied more on direct grid imports.

Under high-volatility conditions (2025):
- PHES was intensively used for arbitrage.
- Energy was pumped during low-price periods and generated during peak-price hours.
- Renewable self-consumption increased significantly.

CONCLUSIONS

- Electricity market volatility is a key catalyst for PHES utilization.
- High daily spreads significantly increase storage activity and renewable energy optimization.
- In 2025, PHES operation increased fourfold compared to 2019.
- The hybrid PV–Wind–PHES system reduced grid imports by up to 85% during summer conditions.
- Despite seasonal economic imbalances, PHES remains essential for reducing import costs and improving system flexibility in renewable-based electricity systems..

REFERENCES

- IEA, Electricity Market Design: Building on strengths, addressing gaps, (2025) 116.
- S.M. Sirin, A.M. Elshurafa, N. Cakmak, The impact of variable renewables on price dynamics within wholesale electricity markets, Util. Policy 95 (2025) 101928.
- J. Alonso-Perez, A. Arcos-Vargas, Storage deployment and its impact on wholesale electricity prices, Energy Reports 15 (2026) 108991.
- L.M. Abadie, N. Goicoechea, Optimal management of a mega pumped hydro storage system under stochastic hourly electricity prices in the Iberian Peninsula, Energy 252 (2022) 123974.
- Precio del mercado diario | OMIE, (n.d.). https://www.omie.es/es/market-results/daily/daily-market/day-ahead-price