Extended Abstract

Multi-Objective Explainable AI Framework for Romanian Electricity Market Dynamics: A Comprehensive Analysis of Price, Volatility, and Directional Predictions

Background and Motivation

The Romanian electricity market, like many European energy markets, exhibits significant complexity and volatility driven by diverse generation sources, demand fluctuations, and the increasing integration of renewable energy. While machine learning models have demonstrated superior performance in electricity price forecasting compared to traditional statistical methods, their "black-box" nature presents significant challenges for market participants and regulators who require transparent and interpretable insights for critical decision-making. This opacity is particularly problematic in the energy sector, where decisions carry substantial economic and societal implications.

Research Objectives and Innovation

This research addresses the critical gap in multi-objective explainable artificial intelligence (XAI) for electricity market analysis by introducing a novel framework that simultaneously analyzes three interconnected market objectives: price forecasting, volatility prediction, and price direction classification. Unlike conventional single-objective approaches that may provide incomplete or misleading insights, our framework recognizes that different aspects of electricity market behavior are governed by distinct yet interrelated driving factors.

Methodology

The framework employs separate Random Forest models for each objective, leveraging SHAP (SHapley Additive exPlanations) values to provide unified feature importance analysis across all three dimensions. This approach enables the identification of both consensus features—variables that are critical across all objectives—and specialized features that are crucial for specific market behaviors. The methodology was applied to the Romanian electricity market using a comprehensive dataset of fifteen market variables.

Key Findings

The empirical analysis reveals fundamental insights into Romanian electricity market dynamics. The remarkably low correlation of 0.192 between price and volatility feature importance rankings empirically validates the multi-objective approach, demonstrating that different market aspects are indeed governed by largely independent factor sets. The price prediction model achieved substantial performance with an R^2 score of 0.7679 and RMSE of 21.39, while the volatility model attained an R^2 of 0.7052. Directional prediction, though more challenging, achieved 60.35% accuracy, significantly exceeding random baseline expectations.

Critical Market Insights

The analysis identifies only two consensus features from fifteen analyzed variables, representing merely 13.3% of the feature set and highlighting the highly specialized nature of market dynamics. Hydroelectric run-of-river generation emerges as the paramount multi-objective feature (importance score: 4.5967), underscoring Romania's unique position as a hydro-dependent market where hydrological conditions drive systemic uncertainty across all prediction objectives. Natural gas generation constitutes the secondary consensus feature,

revealing its fundamental influence on price levels, volatility patterns, and directional movements.

Specialized features provide equally compelling insights, with nuclear generation, reservoir hydroelectric operations, and forward demand forecasts demonstrating exclusive importance for directional prediction. These findings suggest that baseload nuclear characteristics and dispatchable hydro operations create predictable directional signals while showing minimal impact on absolute price levels or volatility measures.

Policy and Practical Implications

The scarcity of consensus features necessitates a fundamental reconsideration of regulatory approaches, suggesting that effective policy interventions must abandon traditional unified strategies in favor of objective-specific approaches. Price stabilization initiatives should prioritize demand-side management, while volatility reduction strategies must focus on weather-dependent generation management systems. The framework reveals Romania's critical vulnerability to hydrological variability, indicating that climate change adaptation strategies must become integral components of energy security planning.

Methodological Contributions

This research establishes a novel, scalable framework for multi-objective XAI analysis that can be extended to other electricity markets and complex economic systems. The comprehensive identification of consensus and specialized features provides a systematic template for market analysis that acknowledges the multifaceted nature of economic phenomena rather than reducing them to oversimplified single-objective models.

Significance and Future Directions

The framework represents a significant methodological advancement that provides both theoretical insights and practical tools for navigating contemporary energy systems' increasing complexity. It offers actionable intelligence for multiple stakeholder groups: policymakers can design targeted regulatory interventions, market participants can enhance risk management strategies, and grid operators can improve system reliability. Future research extensions could include temporal SHAP analysis to reveal feature importance evolution across market conditions and integration of detailed meteorological data to enhance predictive performance and policy relevance.

Conclusion

This research demonstrates that the complexity inherent in modern electricity markets demands analytical approaches that match this sophistication rather than seeking oversimplified solutions. By embracing market complexity through multi-objective XAI analysis, the framework enables more informed decision-making that acknowledges the multifaceted nature of electricity market dynamics and supports the development of more effective, targeted policy interventions for Europe's evolving energy landscape.