



# Investigation of Renewable Energy Sources Effects on the Turkish Day-Ahead Market Price

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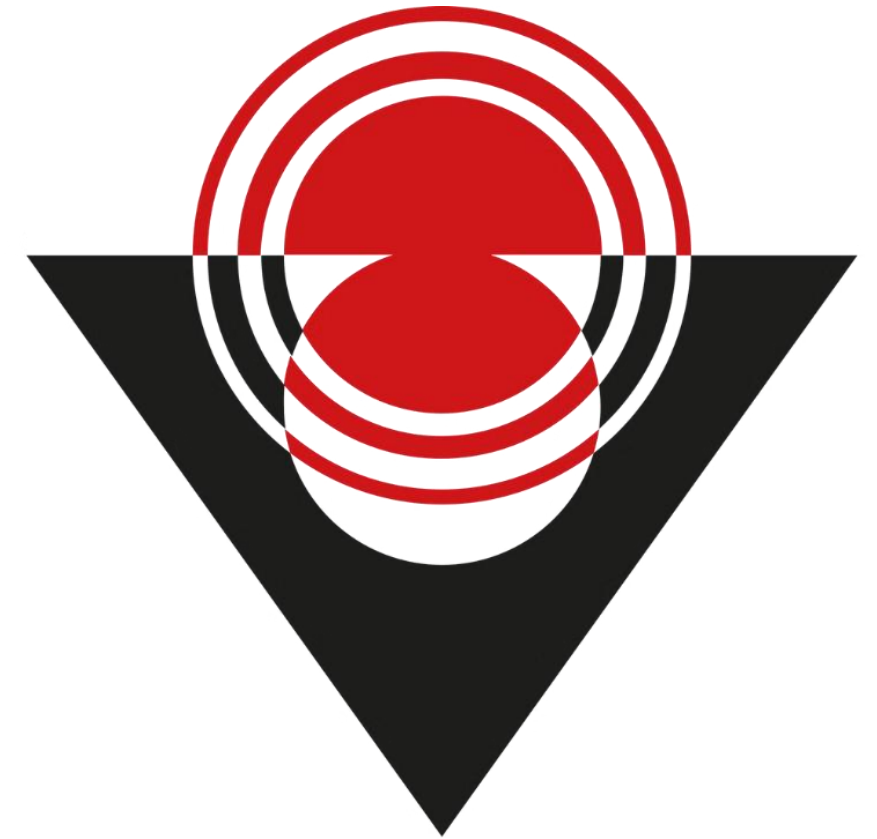
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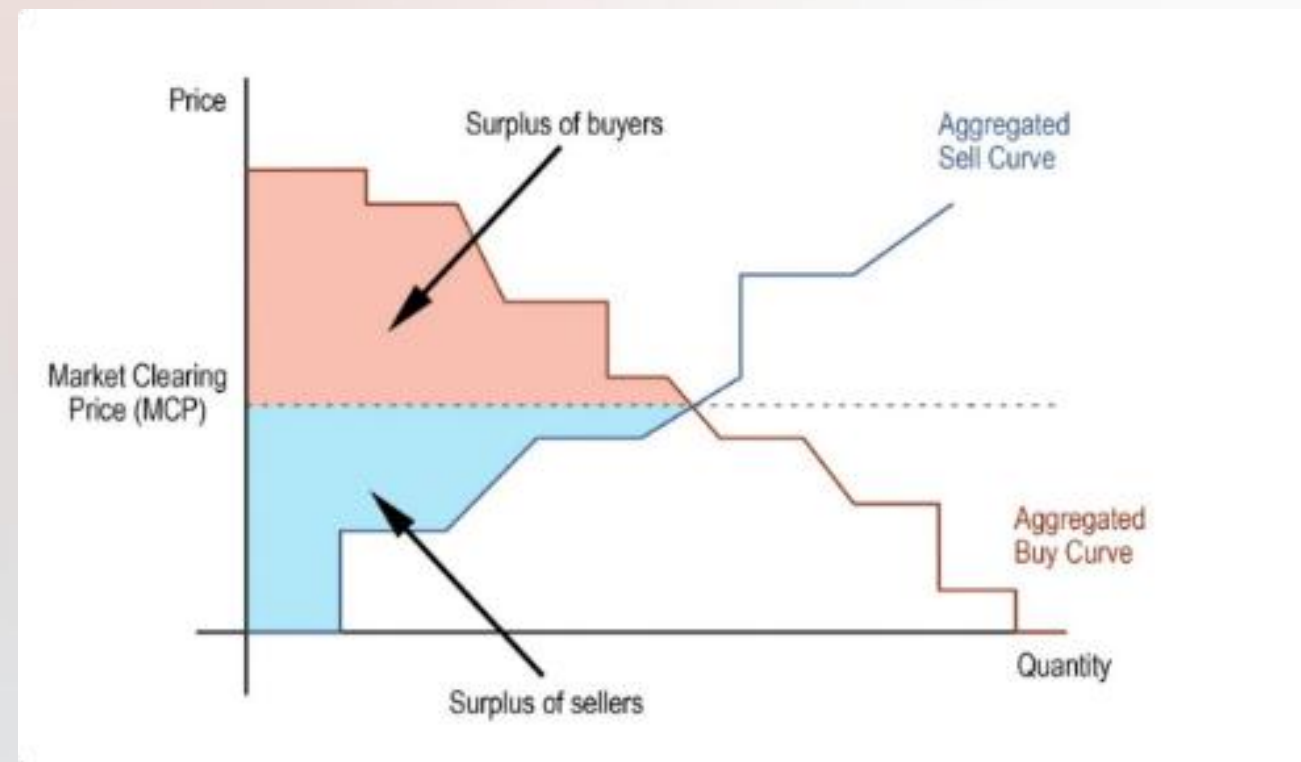
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# Agent-Based Simulation Model with Artificial Intelligence-Assisted Learning, Forecasting, and Optimization Algorithms for Electricity Markets and Market Analysis

- The Impact of Renewable Energy Generation on the Day-Ahead Market Price in Türkiye: Ex-Post Analysis on the Merit Order Effect
- Impact of Market Factors on Day-Ahead Electricity Prices: Explainable Machine Learning Analysis of the Turkish Market
- A novel immune plasma-based automatic programming method for electricity price forecasting in the Turkish market



**TÜBİTAK**



## Motivation: The Importance of the MCP

The MCP plays a crucial role in daily electricity markets, influencing pricing and resource allocation. Understanding the effects of RES on the MCP is essential for optimizing market operations and promoting the integration of renewable energy.

### RES Potential in Türkiye

Türkiye possesses significant potential for renewable energy, making it a prime location for studying the impact of RES on electricity markets.

### Energy Exchange Istanbul (EXIST)

EXIST, the organized energy markets operator company in Türkiye, has experienced significant growth since its establishment in 2015, providing a valuable platform for analyzing market dynamics.

# Methodology

This study employs a multi-faceted approach to analyze the effects of RES on the Turkish day-ahead MCP. It utilizes a large dataset from the EXIST transparency platform and combines statistical analysis with machine learning techniques.

1

## Prais-Winsten Generalized Least Squares Estimation

The study applies the panel-corrected GLS (Prais-Winsten algorithm) estimation to linearly assess the price-reducing effect of RES.

2

## Machine Learning Algorithms

Several machine learning algorithms are employed to provide a comprehensive understanding of the RES' effects on the MCP.

3

## SHAP Value Analysis

SHAP value analysis is used to understand the contributions of different variables to the MCP, providing insights into the magnitude and direction of their effects.

4

## Automatic Programming (AP) Models

AP models are utilized to generate mathematical models that accurately explain the input-output relationships, aiding in predictions and further analysis.

# Methodology

This study employs a multi-faceted approach to analyze the effects of RES and other variables on the Turkish day-ahead MCP. We utilize a large dataset from the EXIST transparency platform and combine statistical analysis with machine learning techniques.

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## Panel-Corrected Generalized Least Squares Estimation

The study applies the panel-corrected GLS (Prais-Winsten algorithm) estimation to **linearly assess** the price-reducing effect of RES.

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## Machine Learning Algorithms

Several machine learning algorithms are employed to provide a **comprehensive understanding** of the RES' effects on the MCP.

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## SHAP Value Analysis

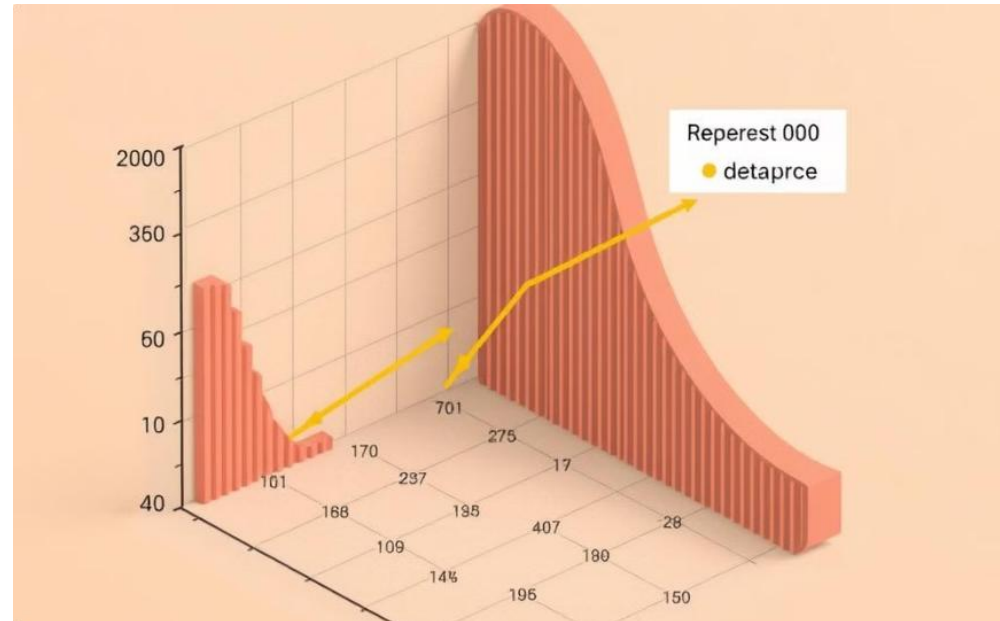
SHAP value analysis is used to understand the contributions of different variables to the MCP, providing insights into the **magnitude and direction** of their effects.

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## Automatic Programming (AP) Models

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# Prais-Winsten Generalized Least Squares



## Modeling the MCP

The Prais-Winsten GLS method is a modification of the Cochrane-Orcutt procedure used for estimating autoregressive models with serial correlation in the errors. This approach helps us understand the relationship between the Marginal Clearing Price (MCP) and key factors driving the Turkish day-ahead electricity market.



## Factors Influencing the MCP

Our model considers multiple factors such as load (demand), solar, wind, hydro, and natural gas. This comprehensive view provides a deeper understanding of how the MCP is influenced by the interplay of these various energy sources.

$$MPC_{it} = \alpha_1 Load_{it} + \alpha_2 Solar_{it} + \alpha_3 Wind_{it} + \alpha_4 Hydro_{it} + \alpha_5 Ngas_{it} + d_{year} + d_{month} + d_{day} + d_{hour} + \epsilon_{it}$$

This equation represents the model, incorporating dummy variables for year, month, day, and hour to capture any time-dependent patterns that might influence the MCP.

# Merit Order

1

## Resource Ranking

Energy sources are ranked based on their production costs, with the lowest-cost sources used first.

2

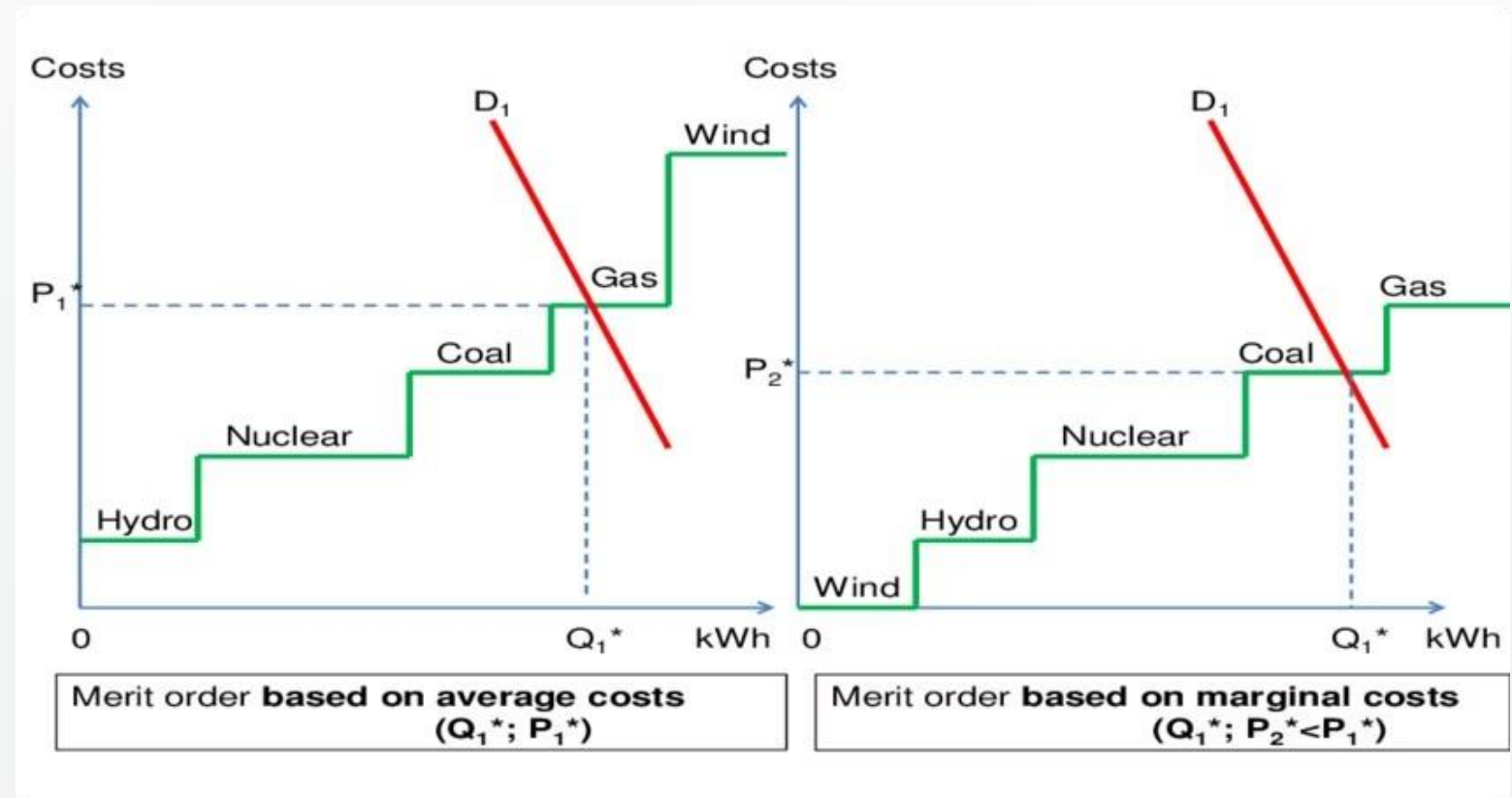
## Cost Minimization

This ranking ensures that the total production cost is minimized, leading to an economical and efficient process.

3

## Sequential Deployment

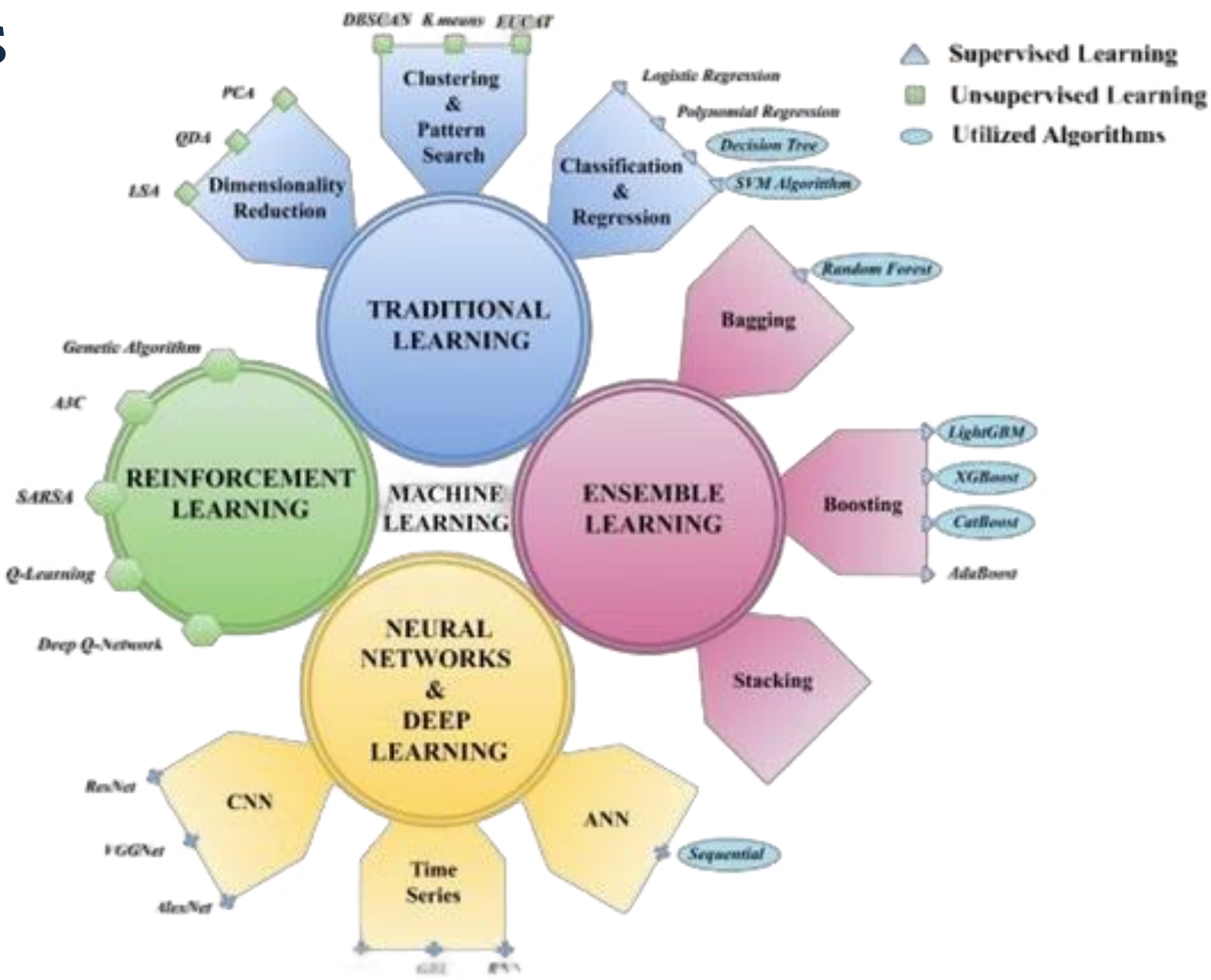
Higher-cost resources are only deployed when necessary, minimizing overall costs.



# Machine Learning Models

- Random Forest
- Decision Tree
- Support Vector Machine
- CatBoost
- XGBoost
- LightGBM
- Sequential Artificial Neural Networks

The study also utilized the KerasTuner to optimize hyper-parameters for each model, further enhancing their predictive capabilities.



# SHAP Value Analysis

1

## Unveiling Feature Influence

SHAP values act like a magnifying glass, revealing how individual features contribute to a model's prediction.

2

## Visualizing Feature Impact

The color of each point indicates the feature value, with red representing high values and blue representing low values. This visual representation helps understand how feature values influence the predicted Market Clearing Price (MCP).

3

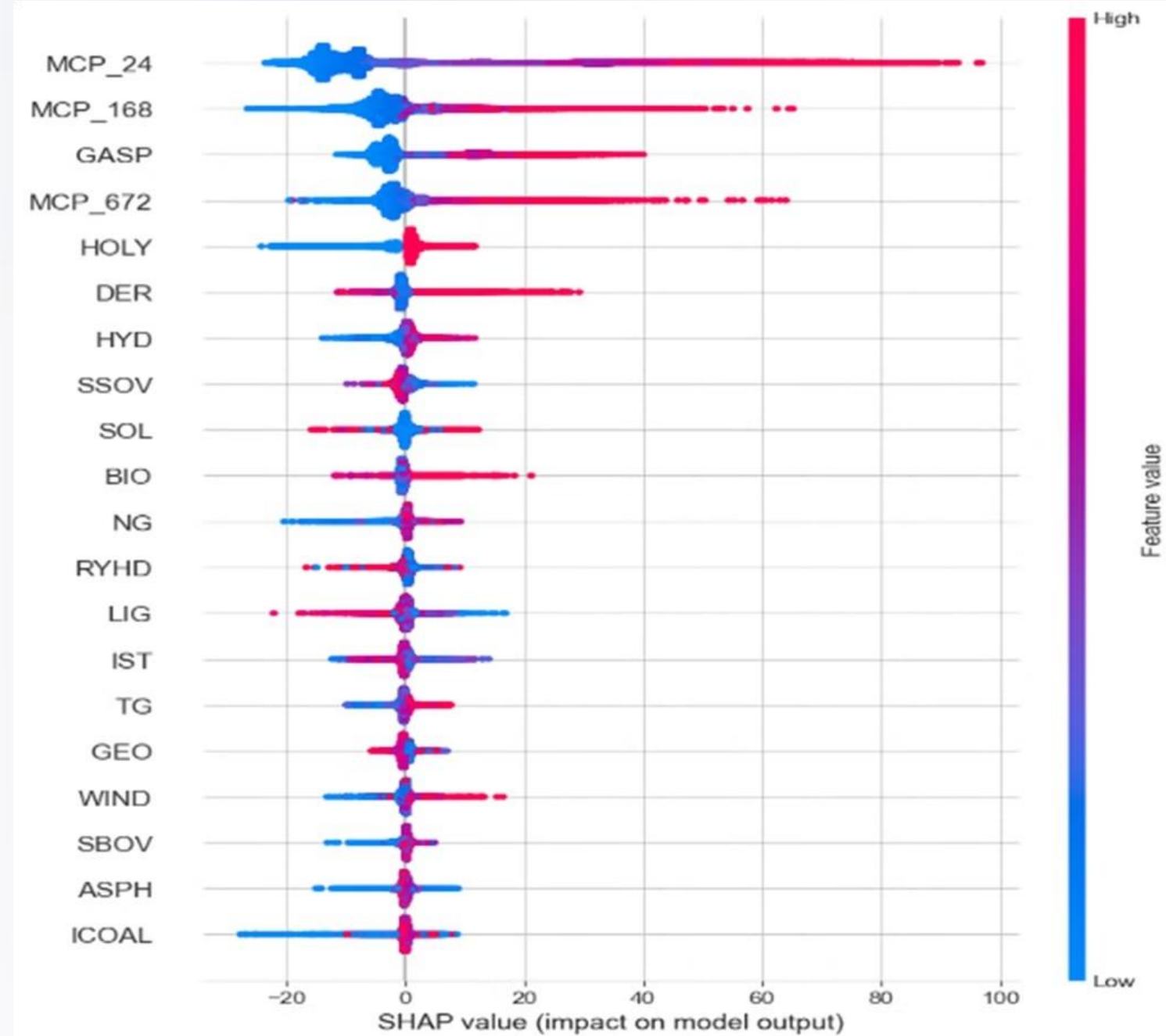
## Magnitude and Direction

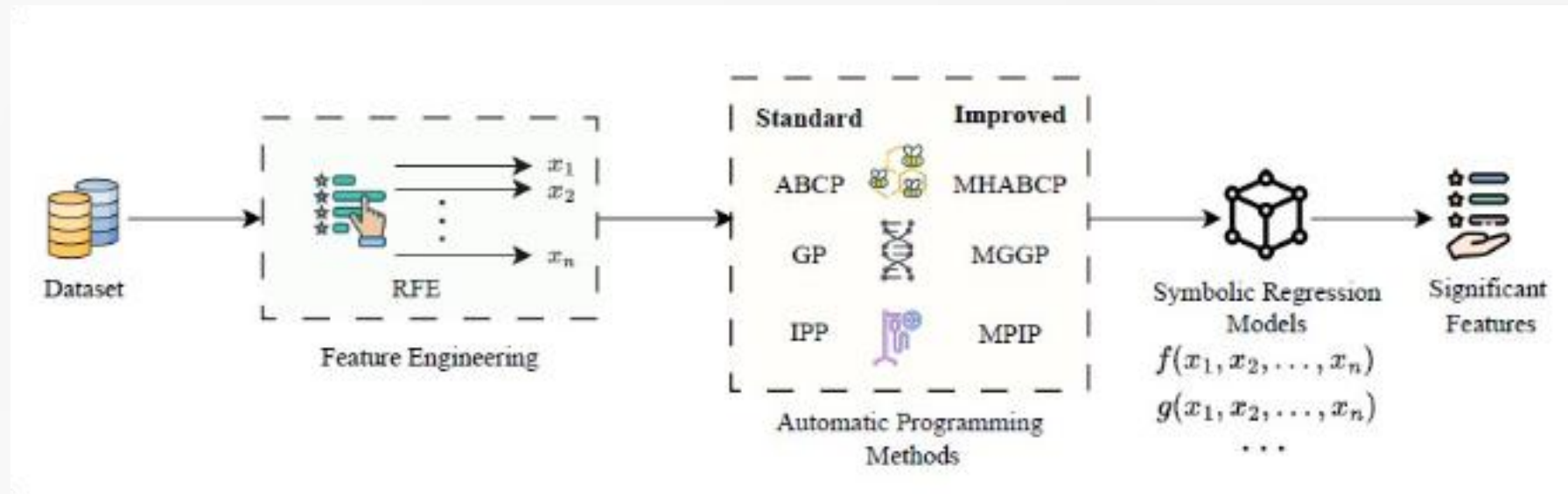
The distribution of points along the x-axis showcases the magnitude and direction of each feature's impact on the predicted MCP.

4

## Importance

The y-axis ranks the features based on their importance in influencing the MCP forecast.





# Automatic Programming (AP) Models

AP methods describe the relation between input and output variables by generating non-linear mathematical equations, which are very useful for further predictions and analysis.

## Model Advantages

- Improved accuracy in predicting MCP
- Enhanced understanding of complex relationships
- Support for informed decision-making

## Models

- ABCP: Artificial Bee Colony Programming
- GP: Genetic Programming
- IPP: Immune Plasma Programming
- MHABCP: Multi Hive Artificial Bee Colony Programming
- MGGP: Multi Gene Genetic Programming
- **MPIP: Multi Plasma Immune Programming**

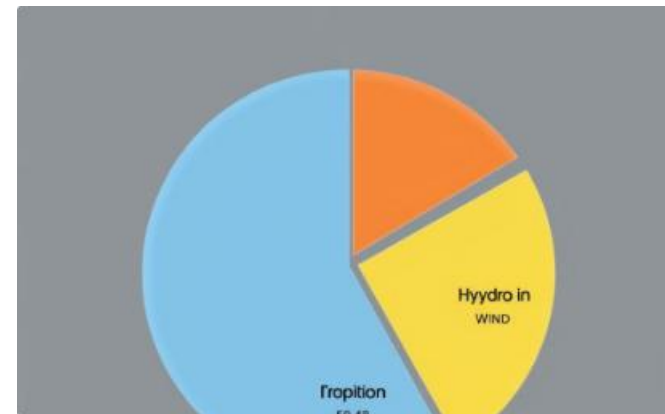
# Key Findings - GLS

Merit Order Effect of the Renewable Energy Sources to MCP.

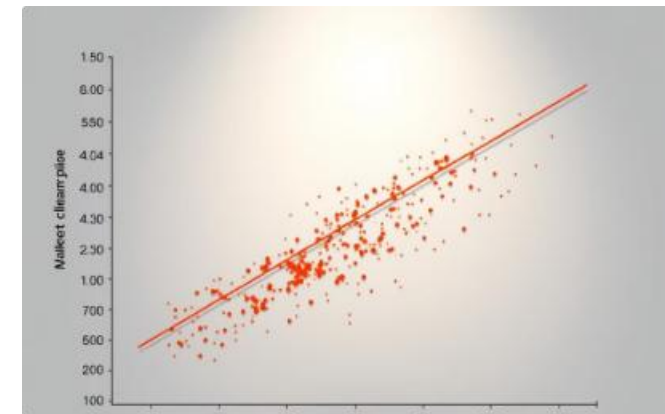
	Model 1	Model 2
<i>MOE of Wind</i>	-16.595	
<i>MOE of Solar</i>	-2.009	
<i>MOE of Hydro</i>	-35.362	
<i>MOE of RES</i>		-63.479
<i>Total MOE of RES</i>	-53.97	-63.48



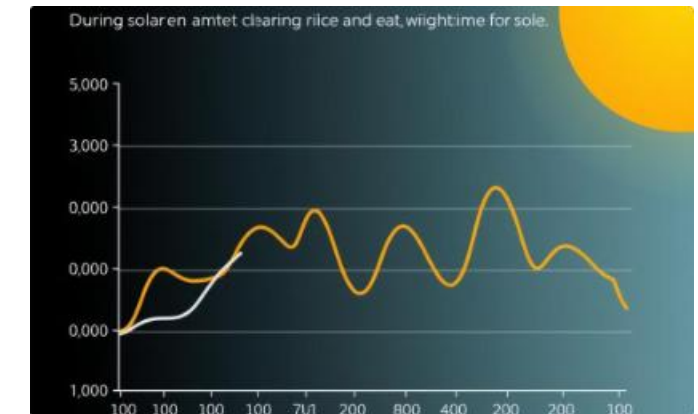
An increase in renewable energy use decreases the market clearing price.



The share of hydro is the highest so its MOE is the highest.

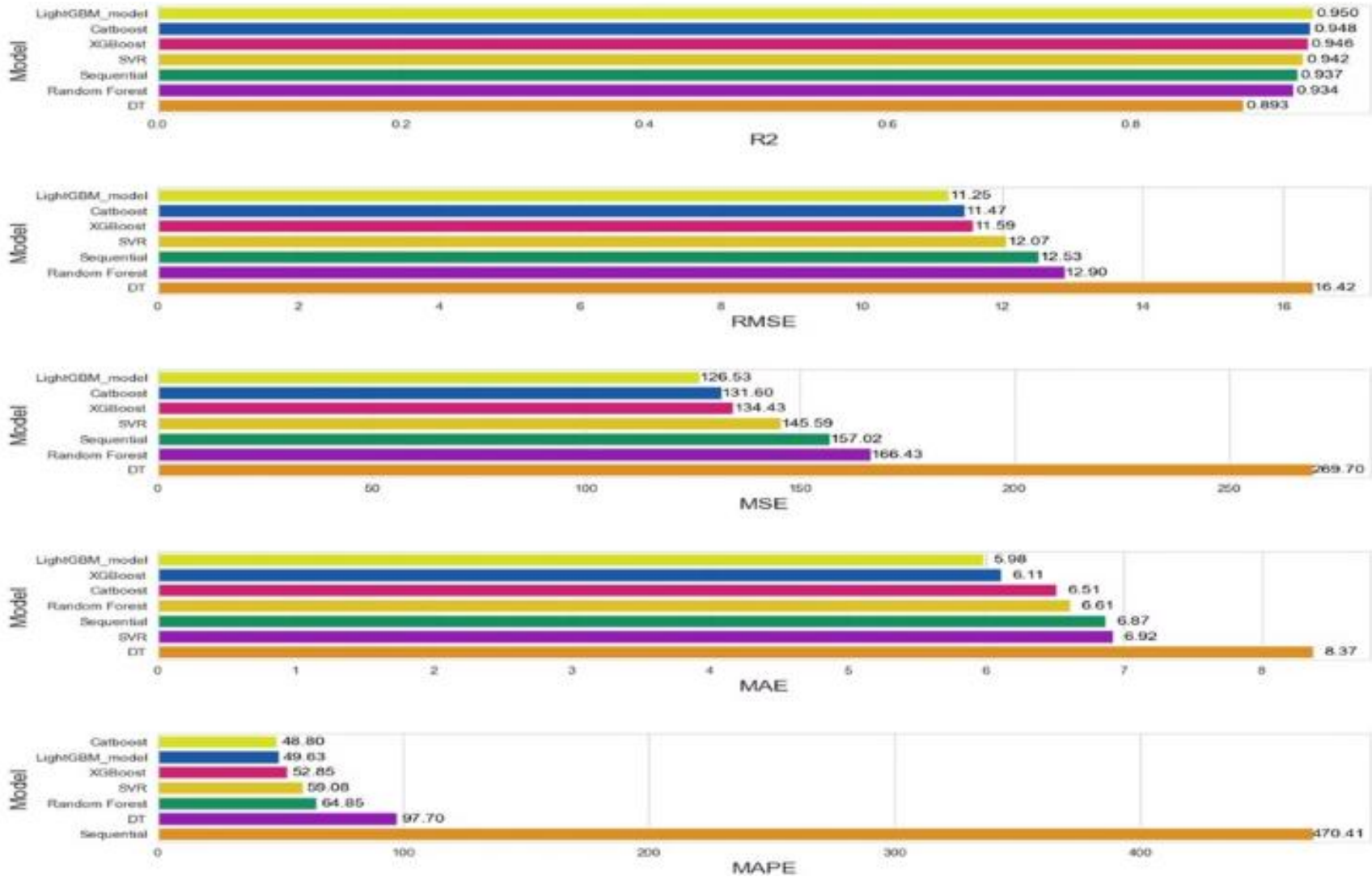


The marginal effect of solar energy is the highest.



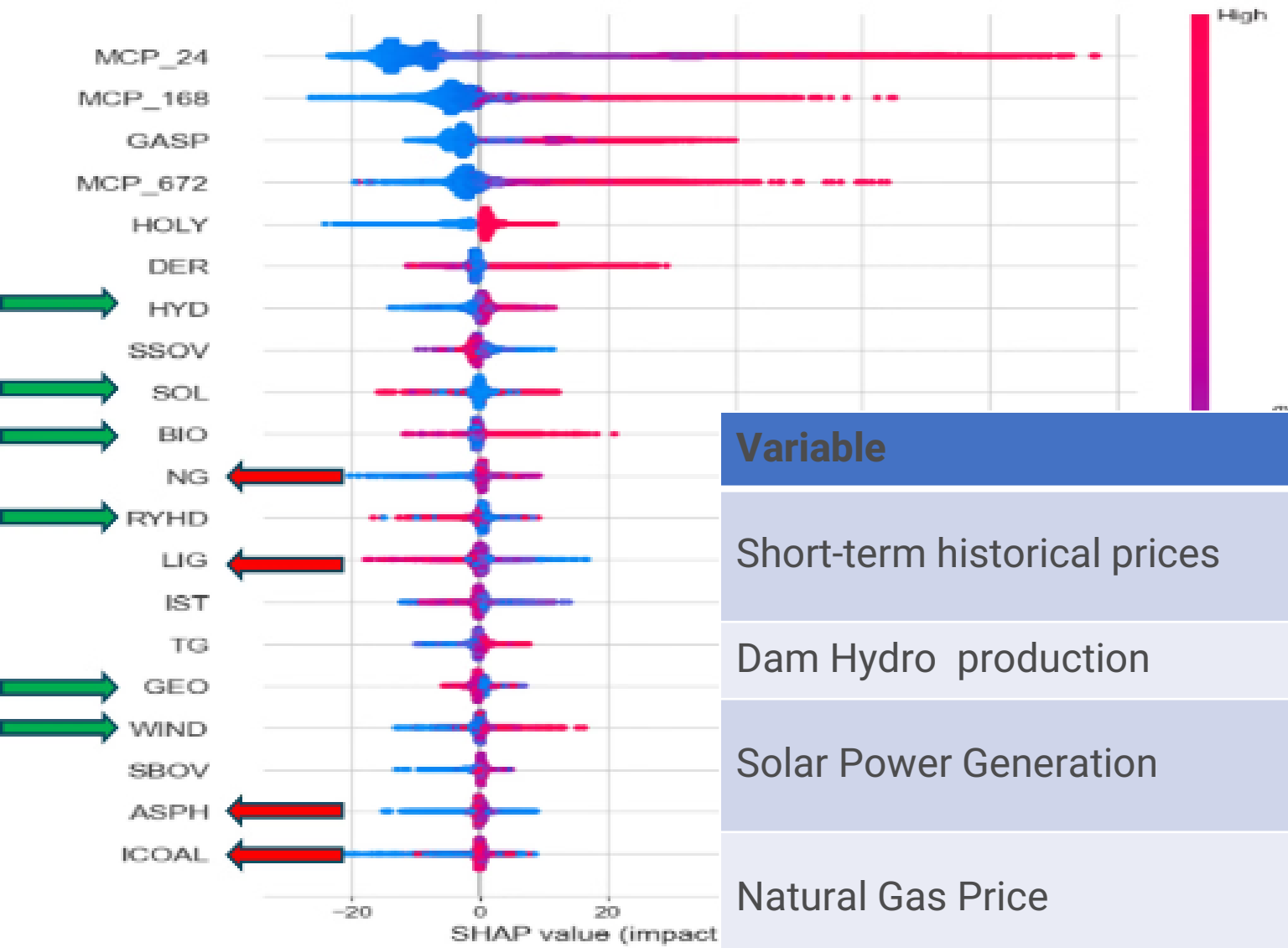
The hourly impact of solar energy is significant.

# Key Findings - ML



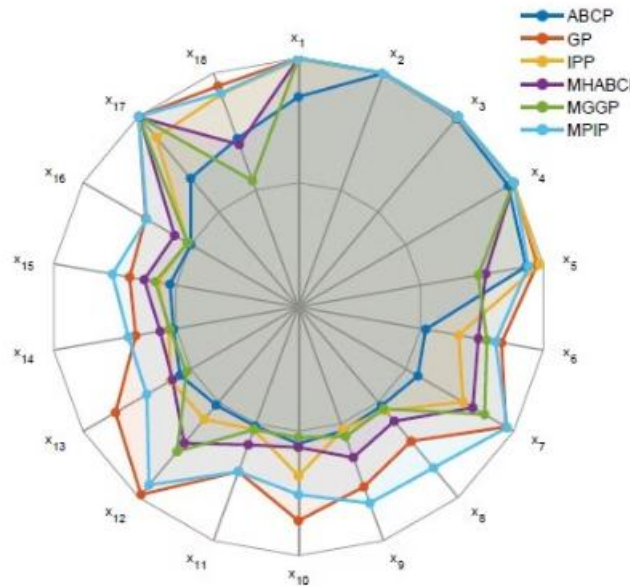
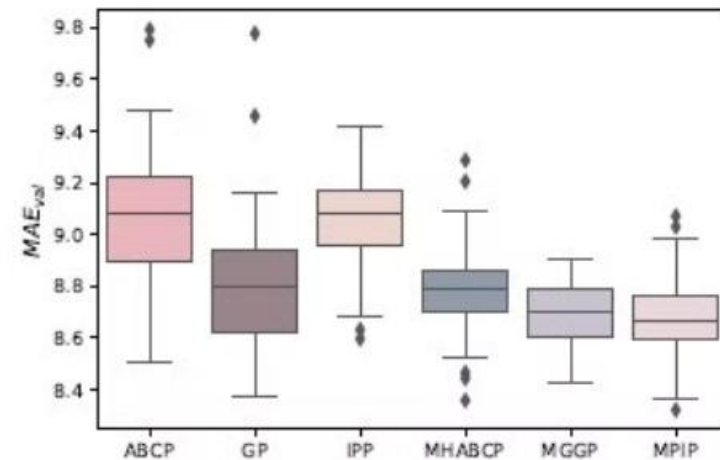
- The LightGBM model excelled in making the most accurate predictions.
- The CatBoost and XGBoost models outperforms the rest.
- DT model fell short in predicting accurately

# Key Findings - SHAP Analysis



Variable	SHAP Value (Magnitude)	Effect
Short-term historical prices	Highest	Positive (higher previous price, higher day-ahead price)
Dam Hydro production	Moderate	Positive
Solar Power Generation	Moderate	Negative (higher solar generation, lower price)
Natural Gas Price	High	Positive (higher gas price, higher price)
Lignite coal generation	Moderate	Negative
Import coal	Unilateral, Moderate	Negative Unilateral: Low generation decreases MCP

# Key Findings - AP Models



$$\frac{0.5018x_2 + 0.1224x_3 - 0.001101x_9 - 0.05642x_{17} - 0.3794e^{x_9/x_{10}}}{1.0(2.755e + 15x_2 + 2.755e + 15x_3)} - \frac{4.398e + 12x_7 + 8.796e + 12x_9 - 4.398e + 12x_{16} + 4.398e + 12x_1x_{12}x_{13}}{0.0005505x_1x_{17} + 0.002202x_5x_{17} + 1.461\sqrt{x_2 + x_{18} + \frac{x_4}{x_5}}} - \frac{0.3794x_2}{x_5} + \frac{1.004x_3}{x_5} + 0.5018\sqrt{x_2 + x_{17}} + 0.0005505(x_4 - 7.777)^2 + 2.067\sqrt{x_{17}}$$

$$+ \frac{7.734e + 15x_1(x_3 + x_4 + x_5)}{3.518e + 13x_7 + 7.037e + 13x_{18} + 3.518e + 13|x_3 - 1.0x_{16}|} - \frac{2.426e + 15x_1x_{14}(x_2 - 1.0x_{12})}{9.007e + 15x_7 + 1.801e + 16x_{12} - 9.007e + 15x_{14}} - \frac{0.03238x_2^2x_8x_{12}}{x_5(x_3 + x_7)(x_3 + x_4 + x_{12})} - 24.21$$

## MPIP Formulation

- The effect of the previous day, week, and month are generally the same direction (mostly price-increasing).
- Previous week and month have a regulator effect on previous day price effect.

## MAE Results

- ABCP and IPP have higher median error values compared to the other methods
- GP and MHABCP perform better.
- MGGP and MPIP exhibit a smaller error distribution.
- **MPIP has the best fit.**

## AP Feature Analysis

- MCP is affected mostly by the previous day, week, and month prices.
- Then, natural gas.



# Conclusion

## **Agent-Based Simulation Model with Artificial Intelligence-Assisted Learning, Forecasting, and Optimization Algorithms for Electricity Markets and Market Analysis**

Our studies provide valuable insights into the impact of RES on the Turkish day-ahead MCP. The findings highlight the importance of considering the interplay of electricity demand, energy technologies, and financial factors in shaping electricity market dynamics.

The use of advanced ML algorithms, SHAP value analysis and AP models, offers a comprehensive understanding of the complex relationships involved. These insights can be leveraged to optimize market operations, promote the integration of renewable energy, and ensure a sustainable and efficient electricity system in Türkiye.

# Future Research Directions

This ambitious project aims to model and understand electricity markets. By creating a cutting-edge, agent-based simulation (ABS) model, we'll unlock new insights and possibilities.

## Electricity Market as a Game

We'll model the market as an interactive game, where AI-powered players make strategic decisions and respond to one another in real-time.

## Advanced Analytics

By combining cutting-edge machine learning, optimization, and simulation methods, we'll develop a comprehensive model to examine the impacts of renewable energy and market structures.

1

2

3

## Intelligent Agents

Firms and other market actors will be represented by AI agents, whose learning, forecasting, and decision-making capabilities will be powered by machine learning and optimization techniques.

When complete, this project will deliver 7 unique contributions to the field, including a novel ABS model, innovative algorithms for learning and forecasting, and groundbreaking insights into the future of electricity markets.

