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Renewable Energy Optimization Using Data-Driven Models: A Comparative Study of Solar and Wind Power Systems

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Abstract

The rapid transition toward renewable energy systems requires efficient optimization strategies to improve power generation reliability and grid stability. This study examines the application of data-driven models for optimizing solar and wind energy output. Using multi-year operational datasets, machine learning techniques were applied to predict energy generation and optimize system performance. The findings indicate that data-driven models significantly enhance prediction accuracy and operational efficiency for both solar and wind energy systems. The study highlights the growing importance of artificial intelligence in sustainable energy research and infrastructure planning.

Keywords: Renewable energy, solar power, wind energy, machine learning, energy optimization

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1. Introduction

Renewable energy sources such as solar and wind power play a critical role in addressing global energy demands and mitigating climate change. However, their intermittent nature presents challenges related to prediction accuracy, grid integration, and energy storage planning. Traditional statistical forecasting methods often fail to capture the nonlinear dynamics of renewable energy systems. Recent advances in data-driven modeling offer new opportunities to improve forecasting precision and optimize system performance. This study evaluates the effectiveness of machine learning models in optimizing solar and wind power generation.

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2. Methodology

2.1 Study Design

A comparative analytical study was conducted using operational data collected from renewable energy installations between **2019 and 2024**.

2.2 Data Sources

- Solar photovoltaic (PV) plants (irradiance, temperature, output power)
- Wind farms (wind speed, air density, turbine output)
- Grid demand and weather datasets

2.3 Models Applied

- Multiple Linear Regression (baseline)
- Support Vector Regression (SVR)
- Random Forest Regression

2.4 Performance Metrics

- Root Mean Square Error (RMSE)
- Mean Absolute Percentage Error (MAPE)
- Energy prediction accuracy (%)

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3. Results

Table 1. Solar Power Prediction Performance

Model	RMSE (kW)	MAPE (%)	Prediction Accuracy (%)
Linear Regression	0.92	18.6	71.4
SVR	0.58	10.2	85.1
Random Forest	0.49	8.7	88.9

Table 2. Wind Power Prediction Performance

Model	RMSE (kW)	MAPE (%)	Prediction Accuracy (%)
Linear Regression	1.14	21.3	68.2
SVR	0.71	12.4	83.7
Random Forest	0.63	10.9	86.5

4. Discussion

The results demonstrate that machine learning models substantially outperform traditional regression methods in predicting renewable energy output. Random Forest models achieved the highest accuracy for both solar and wind systems, highlighting their capability to manage nonlinear relationships and variable interactions.

Improved prediction accuracy enables better grid integration, reduced energy curtailment, and more effective storage utilization. These findings support the adoption of data-driven optimization frameworks in renewable energy planning and operations. Nevertheless, model interpretability and data availability remain challenges that require further research.

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5. Conclusion

Data-driven modeling techniques significantly enhance the optimization of renewable energy systems. Machine learning approaches, particularly ensemble models, offer robust solutions for improving solar and wind power forecasting accuracy. Integrating these models into energy management systems can strengthen renewable energy reliability and support sustainable energy transitions.

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