Forecasting Germany's Energy Consumption (2015–2025): A Time Series Modeling Project

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Executive Summary

As Germany advances its ambitious energy transition agenda ("Energiewende"), driven by the expansion of renewables and phasing out of fossil fuels, forecasting electricity demand with precision becomes a cornerstone of operational and policy planning. This project presents a comprehensive time series analysis of Germany's daily energy consumption from 2015 to 2024, with a forward forecast for the year 2025.

Using SARIMA (Seasonal AutoRegressive Integrated Moving Average) modeling, I built a robust forecasting pipeline that includes exploratory data analysis, decomposition, diagnostics, hyperparameter tuning, and performance evaluation.

Objectives

The goal of this project was to:

- Build a reliable, interpretable model to forecast Germany's daily energy load for 2025.
- Evaluate model performance using real 2024 data as a test set.
- Analyze the seasonal and structural behavior of the time series.
- Translate modeling outputs into actionable business and policy insights.

Methodology

The project followed a structured data science workflow within Python (using DataCamp's DataLab environment):

1. Data Preparation

- Raw hourly energy load data was aggregated to daily granularity.
- Missing values were interpolated; datetime formatting and indexing ensured time-aware transformations.

2. Exploratory Analysis and Seasonal Decomposition

- Seasonal decomposition revealed both weekly cycles and long-term structural changes post-2020.
- The Augmented Dickey-Fuller (ADF) test confirmed the series was stationary at daily frequency.

3. Baseline and Initial Modeling

- A SARIMA(1,0,0)(1,0,0,7) model captured basic autoregressive and seasonal patterns.
- Initial forecast errors: RMSE $\approx$ 57,127 MW, MAPE = 24.26%.

4. Model Tuning and Grid Search

- Grid search over SARIMA hyperparameters optimized for RMSE using combinations of (p, d, q) and (P, D, Q, s).
- The best model: SARIMA(1,0,0)(0,1,1,7), which reduced RMSE to 20,698 MW and MAPE to 8.34%.

5. Residual Diagnostics

- Residuals were approximately normally distributed and centered around zero.
- Ljung-Box test confirmed white noise (no autocorrelation).
- ACF plots validated model fit; no significant seasonal error remained.

Results and Evaluation

- **Best Model:** SARIMA(1,0,0)(0,1,1,7)
- **RMSE (2024 test):** 20,698 MW
- **MAPE:** 8.34%
- **Forecast Horizon:** Daily predictions for 2025
- **Validation:** Forecasts aligned well with seasonal demand trends; residuals passed normality and autocorrelation checks.

Business and Operational Insights

- The model correctly captured winter demand surges and summer dips, reflecting heating and cooling loads.
- With a MAPE of 8.34%, forecasts can be used for short-term grid balancing, reserve margin planning, and operational scheduling.
- Policy planners can use the projections to benchmark against energy efficiency goals and renewable integration efforts.

Limitations and Future Enhancements

- The model is univariate — it does not incorporate exogenous variables such as temperature, holidays, or renewable energy supply.
- SARIMA assumes linearity and constant seasonality, which may not hold under extreme energy shocks (e.g., geopolitical disruptions, climate events).
- Future work includes extending to SARIMAX or machine learning models (e.g., XGBoost, LSTM) with multivariate inputs.

Conclusion

This project demonstrates the application of classical time series methods to a real-world energy forecasting challenge. The SARIMA model, properly tuned and validated, produced highly accurate short-term forecasts and actionable insights. The approach offers a solid foundation for operational decision-making in energy markets and could be extended for smart grid, load shifting, or renewable integration scenarios.