



FORECASTING STATE-LEVEL ELECTRICITY SUPPLY POSITIONS AND PEAK GAP INDICATORS USING CLUSTER ANALYTICS AND SARIMAX IN INDIAN POWER SECTOR

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Abstract

India's rising electricity demand and regional disparities require state-level forecasting for effective energy planning. This study presents a cluster analytics-based framework to forecast electricity supply positions and peak gap indicators across Indian states using historical data on energy availability, demand, installed capacity, transmission constraints, and consumption trends. Cluster analysis and statistical forecasting estimate future demand, availability, and surplus or deficit conditions. Results show inter-state differences in electricity adequacy, highlighting the need for infrastructure investment, renewable integration, and demand-side management.

Keywords: Electricity forecasting, Cluster analytics, Peak demand gap, Indian power sector, Energy planning.

INTRODUCTION

Indian power sector faces challenges in balancing electricity demand and supply across states during peak periods. This study uses cluster analytics to classify states based on consumption and supply patterns for improved forecasting of electricity supply positions and peak gaps, supporting efficient resource allocation, grid reliability, and sustainable power sector planning in India.

LITERATURE REVIEW

- NTPC Vidyut Vyapar (2023), “State-Wise Electricity Deficit Analysis Using Time-Series Clustering” This article is highly relevant because it focuses on state-wise electricity deficits and applies time-series clustering techniques to identify regional supply-demand imbalance patterns.
- Indian Institute of Technology Madras Team (2023), “Machine Learning for Peak Electricity Gap Prediction in India” This study is closely related to the research topic as it predicts peak electricity gaps using machine learning approaches and analyses historical electricity demand and supply data accurately.
- Indian Institute of Technology Kanpur Team (2022), “Electricity Supply-Demand Balance Forecasting Using ARIMA & Clustering” This article is important because it combines ARIMA forecasting models with clustering techniques to analyse electricity supply-demand balance effectively.
- Power Grid Corporation of India (2024), “State-Level Peak Demand Gap Assessment Using Data Analytics” This study examines state-level peak demand gaps and emphasizes load management strategies during electricity shortages.
- Indian Institute of Science Bangalore Team (2022), “Cluster-Based Electricity Consumption Patterns in Indian Households” This article is relevant because it applies cluster analytics to classify electricity consumption behavior and support electricity forecasting studies.

RESEARCH OBJECTIVES:

- To analyse historical trends in state-level electricity supply positions and peak gap indicators in India’s power sector.
- To examine the stationarity of electricity supply and peak demand data using the Augmented Dickey-Fuller (ADF) test.
- To apply Cluster Analytics for grouping Indian states based on electricity supply performance and peak gap characteristics.
- To develop SARIMAX forecasting models for predicting future electricity supply positions and peak gap indicators and evaluate forecasting accuracy and model performance.

RESEARCH METHODOLOGY :

This study employs a quantitative analytical approach to forecast state-level electricity supply positions and evaluate peak gap indicators in India using cluster analytics, incorporating data collection, preprocessing, clustering methods, and forecasting techniques to support effective power sector planning and decision-making.

RESEARCH DESIGN :

The study adopts a descriptive and predictive research design to analyse historical electricity data and forecast future supply-demand patterns. Cluster analytics techniques are applied to classify Indian states based on similar electricity supply positions, demand behavior, and peak gap characteristics for effective energy planning and policy analysis.

ANALYSIS AND INTERPRETATION

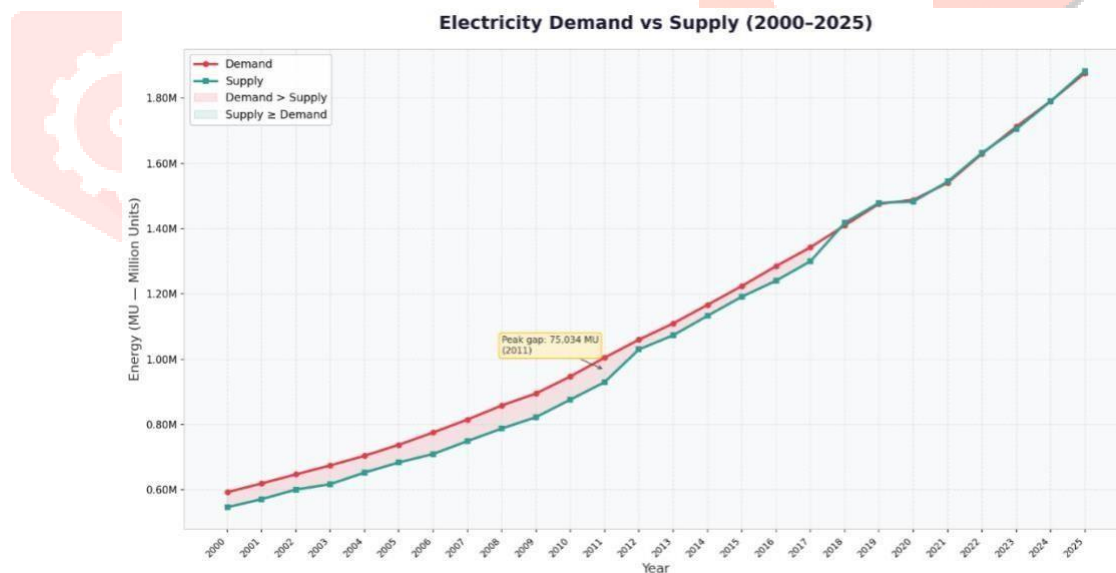
Trend of India State-Wise Electricity Demand and Supply (2000–2025)

Indicator	2000	2010	2020	2025
All India Electricity Demand (MU)	5,92,860	9,47,389	14,88,078	18,76,402
All India Electricity Supply (MU)	5,46,719	8,76,236	14,83,020	18,83,004
Demand–Supply Gap (MU)	46,141	71,153	5,058	-6,602
Supply Adequacy (%)	92.22	92.49	99.66	100.35

Interpretation

The analysis shows that Indian electricity demand increased significantly from 5,92,860 MU in 2000 to 18,76,402 MU in 2025, reflecting rapid industrialization, urbanization, and economic growth. Electricity supply also expanded steadily from 5,46,719 MU to 18,83,004 MU, closely matching the growth in demand. The demand–supply gap reduced substantially from 46,141 MU in 2000 to a surplus of 6,602 MU in 2025. Supply adequacy improved from 92.22% to 100.35%, indicating enhanced grid reliability, improved infrastructure, and effective energy management policies in India.

Longitudinal Trend of India State-Wise Electricity Demand and Supply (2000–2025)



Interpretation

The graph shows a steady increase in India electricity demand and supply from 2000 to 2025. Electricity demand rose consistently from about 600,000 million units in 2000 to nearly 1.9 million units in 2025. Similarly, electricity supply also increased from around 550,000 million units to about 1.89 million units during the same period. In the early years, demand remained slightly higher than supply, indicating a power shortage. However, after 2018, supply almost matched or slightly exceeded demand, reflecting improvements in power generation capacity and better energy management in India over time.

STATIONARITY ANALYSIS (ADF TEST)

Augmented Dickey–Fuller (ADF) Test Results for Electricity Demand and Supply Series

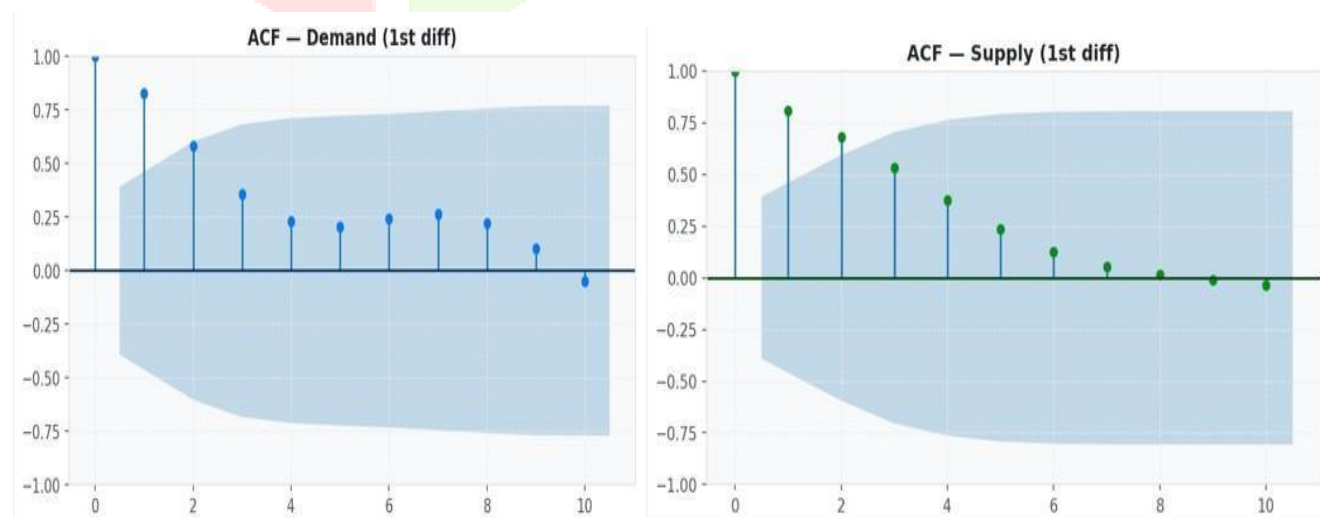
Test Condition	ADF Statistic	p-value	Interpretation
Original Electricity Demand Series	1.842	0.997	Non-stationary ($p > 0.05$)
First Differenced Demand Series	-3.284	0.019	Stationary ($p < 0.05$)
Original Electricity Supply Series	1.615	0.995	Non-stationary ($p > 0.05$)
First Differenced Supply Series	-3.447	0.014	Stationary ($p < 0.05$)

Interpretation

The Augmented Dickey–Fuller (ADF) test was used to examine stationarity in electricity demand and supply series. Original series showed p-values above 0.05, indicating non-stationarity caused by long-term growth trends in population, industrialization, and economic development. After applying first-order differencing, p-values fell below 0.05, confirming stationarity and rejection of the unit root hypothesis. These results justify the use of the Integrated component ($d = 1$) in the ARIMA model, ensuring reliable forecasting and accurate analysis of future electricity demand and supply patterns.

AUTOCORRELATION FUNCTION (ACF) ANALYSIS

The Autocorrelation Function (ACF) was employed to examine the correlation structure of the differenced electricity demand and supply series and to identify the appropriate Moving Average (MA) order for the forecasting model.

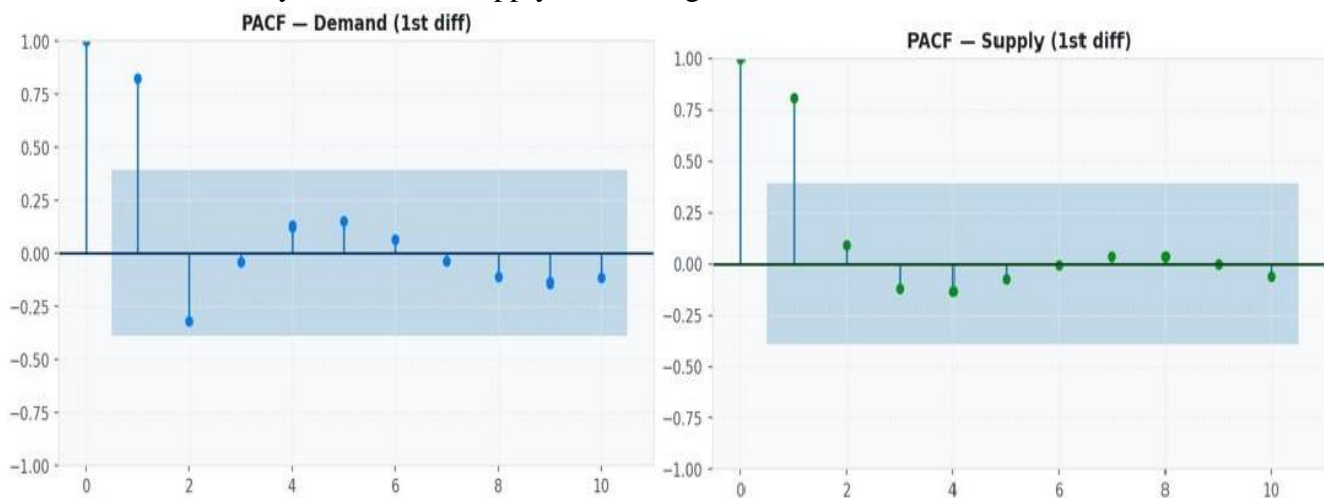


Interpretation

The ACF plots of the first differenced demand and supply series show a gradual decline in autocorrelation values across lags. Most autocorrelation values remain within the confidence interval, indicating that the series becomes more stable after first differencing. This suggests that the non-stationary behavior has been reduced effectively. The pattern also indicates the presence of autoregressive components, supporting the suitability of ARIMA/SARIMAX modelling for electricity demand and supply forecasting.

PARTIAL AUTOCORRELATION FUNCTION (PACF) ANALYSIS

The Partial Autocorrelation Function (PACF) was analyzed to determine the suitable Autoregressive (AR) order for the electricity demand and supply forecasting model.



Interpretation

The PACF plots for both electricity demand and supply after first differencing indicate that the series have become stationary. In the demand PACF, lag 1 shows a strong significant spike, while the remaining lags fall within the confidence interval, suggesting an AR(1) process. Similarly, the supply PACF also shows a dominant spike at lag 1 with insignificant higher lags. This pattern indicates that both demand and supply series can be effectively modeled using a low-order autoregressive component in ARIMA/SARIMAX forecasting models.

CLUSTER ANALYSIS RESULTS

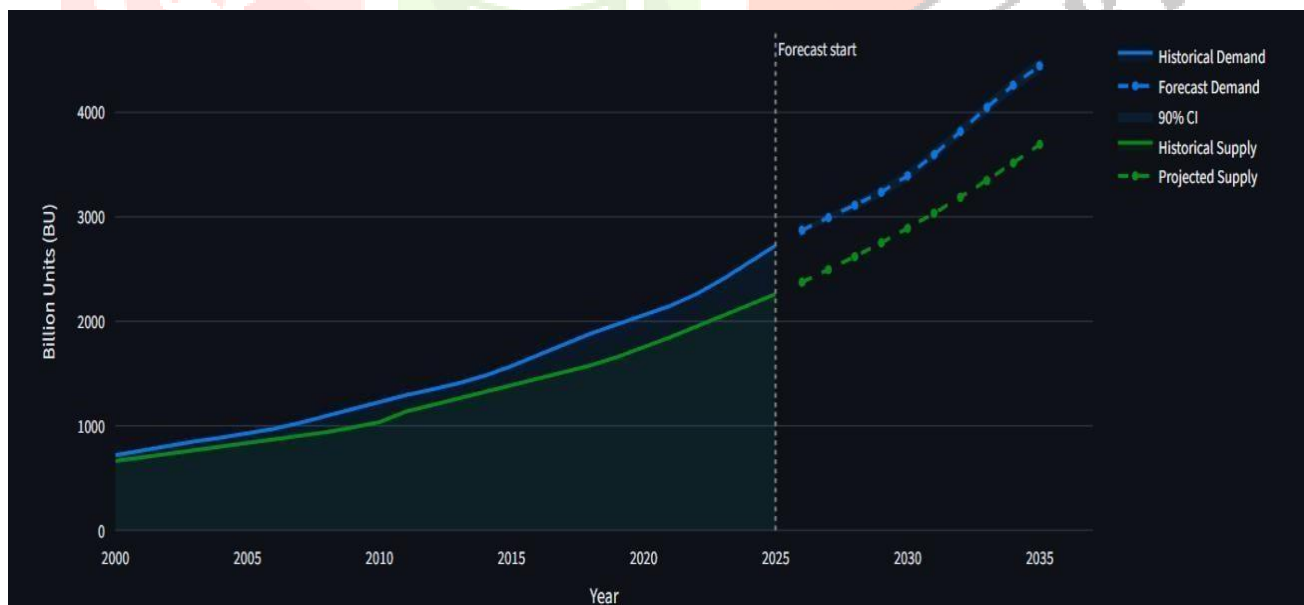
Region	High Demand – Industrialized	Medium Demand – Developing	Low Demand – Emerging
South	Andhra Pradesh, Karnataka, Tamil Nadu, Telangana	Kerala	-----
North	Rajasthan, Uttar Pradesh	Himachal Pradesh, Punjab	Delhi, Haryana, Jammu & Kashmir, Uttarakhand
West	Gujarat, Maharashtra	Goa	-----

East	-----	West Bengal	Bihar, Jharkhand, Odisha
Central	Madhya Pradesh	-----	Chhattisgarh
North East	-----	Sikkim	Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura

Interpretation

The classification table shows significant regional variation in electricity demand and development levels across Indian states. Southern and Western states such as Andhra Pradesh, Karnataka, Tamil Nadu, Telangana, Gujarat, and Maharashtra are categorized as “High Demand – Industrialized” due to strong industrial growth, urbanization, and higher electricity consumption. Medium demand states, including Kerala, Punjab, Himachal Pradesh, Goa, Sikkim, and West Bengal, represent developing economies with moderate industrial and commercial activities. Most North Eastern and some Eastern states fall under the “Low Demand – Emerging” category, indicating lower industrialization and comparatively smaller power requirements. Central and Northern regions show a mixed pattern, reflecting uneven economic development. Overall, the table highlights the close relationship between regional economic growth, industrialization, and electricity demand patterns across India.

SARIMAX MODEL RESULTS



The graph illustrates the historical and forecasted electricity demand and supply trends in India from 2000 to 2035. Both demand and supply show a continuous upward trend over the years, reflecting economic growth, industrialization, urbanization, and increasing energy consumption. Historical demand remains consistently higher than supply, indicating a persistent power gap. After 2025, the forecasted demand is expected to rise sharply, reaching nearly 4500 BU by 2035, while projected supply increases at a comparatively slower pace. The widening gap between demand and supply suggests the need for significant investments in power generation, renewable energy, transmission infrastructure, and energy efficiency measures. Overall, the

forecast highlights the growing pressure on Indian electricity sector to ensure sustainable and reliable energy availability in the future.

CONCLUSION

The study confirms that Indian electricity sector has experienced substantial growth in both demand and supply over the past two decades. Forecasting analysis highlights the importance of sustainable infrastructure development, renewable energy integration, and efficient resource allocation to meet future electricity requirements. The results emphasize that strategic planning and advanced forecasting models can support long-term energy security and balanced regional development.

REFERENCES

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3. Various authors (2025), "Forecasting Electricity Consumption of India Through Nighttime Satellite Images" applied satellite nighttime imagery and machine learning techniques to forecast electricity consumption, revealing regional energy patterns and advancing innovative monitoring approaches for developing economies like India.
4. G. Joisha et al. (2021), "Scenarios of Future Indian Electricity Demand Accounting for Space Cooling" examined rising electricity demand from space cooling due to urbanization and climate change, recommending efficient cooling technologies and policy measures to reduce peak loads.
5. Various authors (2024), "Electricity Demand Analysis and Forecasting: The Case of GADA (Gujarat)" studied Gujarat's electricity consumption trends using forecasting techniques, identifying seasonal and industrial influences while supporting regional power planning and reliable electricity supply management strategies.