ACPET Policy Bulletin

ASHOKA UNIVERSITY

CENTRE FOR A
People-centric
Energy Transition

Bridging the Climate-Energy Data Gap: A State-Level Electricity Demand Dataset for India's Energy Transition

Delhi NCR & Rajasthan

INTRODUCTION

In our previous policy bulletin, we analysed peak electricity demand in Delhi NCR for the period April-June in 2024. We also saw how the mean temperature and other climate variables correlated with the peak electricity demand in the region.

Building on the analysis presented in the previous policy bulletin, this edition examines peak electricity demand and its relationship with key climate variables in Delhi NCR over the period 2024–25. We further use climate variables to predict peak electricity demand using machine learning methods (Decision tree and XGBoost).

Further, we will also explore Rajasthan's peak electricity demand and climate variables for the year 2024-25.

AIM FOR THE POLICY BULLETIN

1. Understanding the relationship between electricity and climate predictors in the Delhi NCR region for the period 2024-25.
2. Predicting peak electricity demand using machine learning methods- XGBoost and Decision Tree.
3. Performing Energy-Meteorology analysis for the state of Rajasthan for summer monsoon and winter seasons.

METHODOLOGY USED BY ENERGY FUTURES LAB

Data Sources:

1. Hourly ERA5 reanalysis data for key climate variables (temperature, wind speed, humidity, radiation) for all Indian states.
2. Daily state-wise electricity demand data from POSOCO (April 2013–present).

Data Processing:

1. Climate variables aggregated to daily resolution using statistically relevant metrics (max, mean, diurnal range).
2. Created a harmonised, merged dataset linking climate variability with electricity demand across states.

Modelling Approach:

1. We have considered the period April 2024-April 2025 for energy-meteorology analysis for Delhi NCR and the state of Rajasthan.
2. Performed a Decision tree and XGBoost methods for predicting peak electricity demand using climate predictors for the Delhi NCR region.

RESULTS

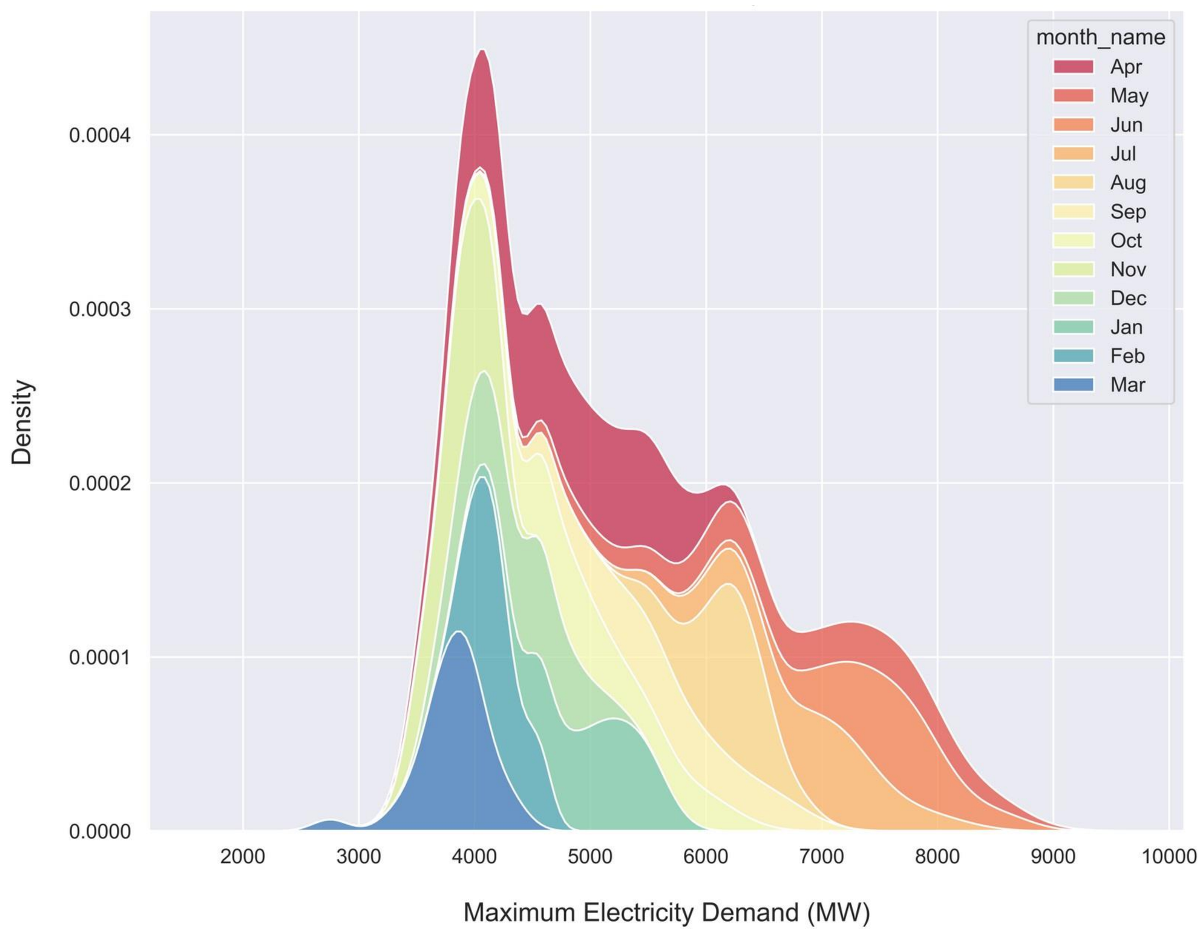


FIGURE 1| SEASONAL VARIATIONS IN PEAK ELECTRICITY DEMAND DELHI NCR| 2024-25

Figure 1 shows seasonal variations in peak electricity demand in the Delhi NCR region. Strong seasonal patterns are evident in the peak electricity demand data throughout the year.

- **Summer months (May–July):** These months display the highest density peaks at the upper end of the demand spectrum, often exceeding 7,000–8,000 MW. The tall and broad peaks indicate not only frequent occurrences of high electricity demand but also a wider variability, reflecting the intense and sustained use of air-conditioning and cooling systems during the hottest part of the year.
- **Winter months (December–February):** The density curves for these months are sharply concentrated around 3,500–5,000 MW, indicating lower and more stable electricity demand. The high density in this range suggests a consistent clustering of demand values, aligning with minimal cooling needs and relatively lower heating requirements in Delhi NCR.
- **Transitional months (March, October, November):** These months occupy the middle ground, with density peaks spread between 4,500–6,500 MW. The moderate height of the peaks suggests a more balanced demand profile, reflecting milder weather conditions and reduced reliance on energy-intensive cooling or heating systems.

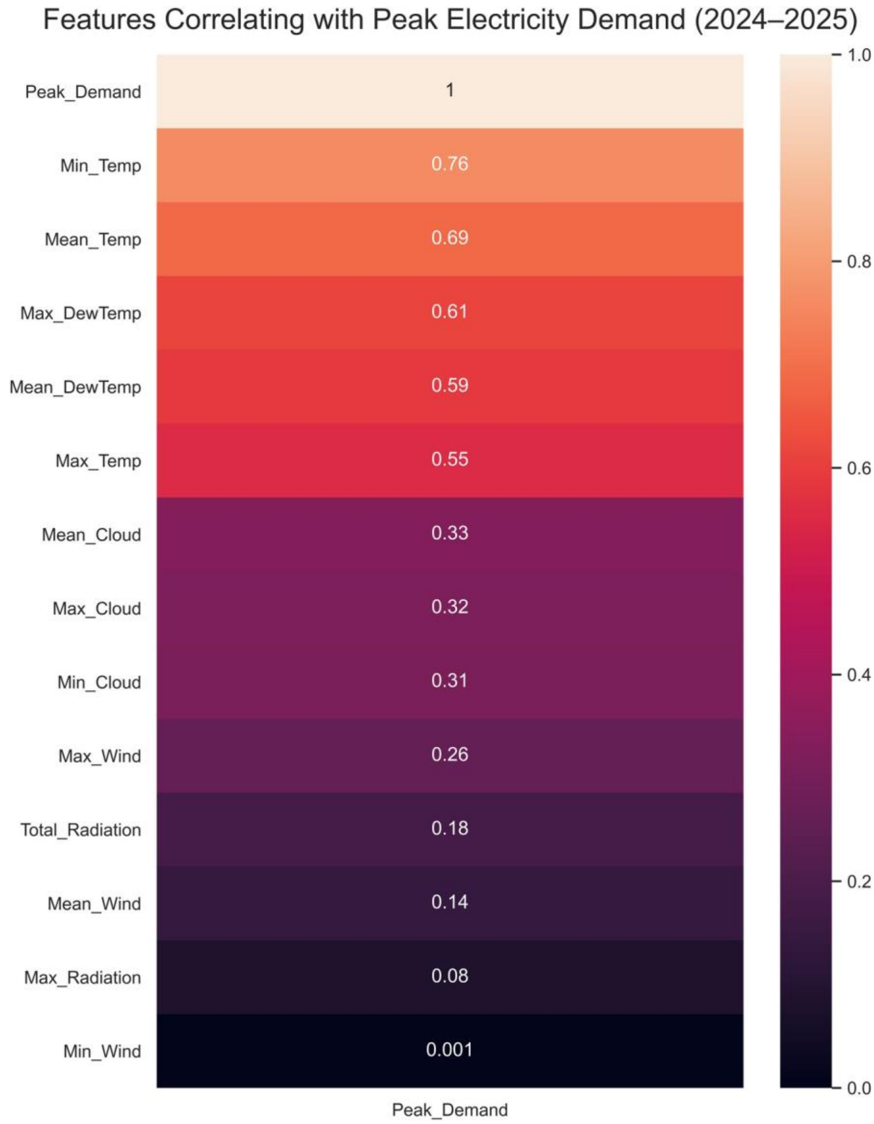
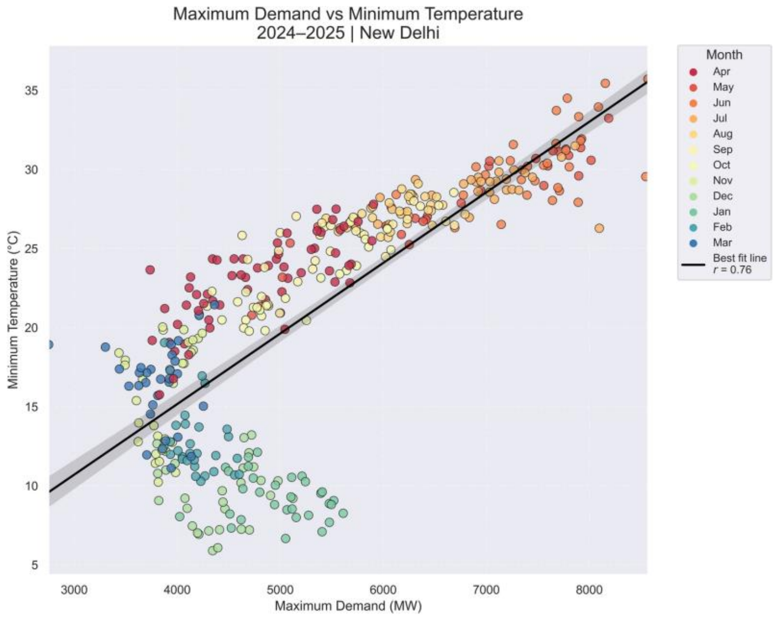


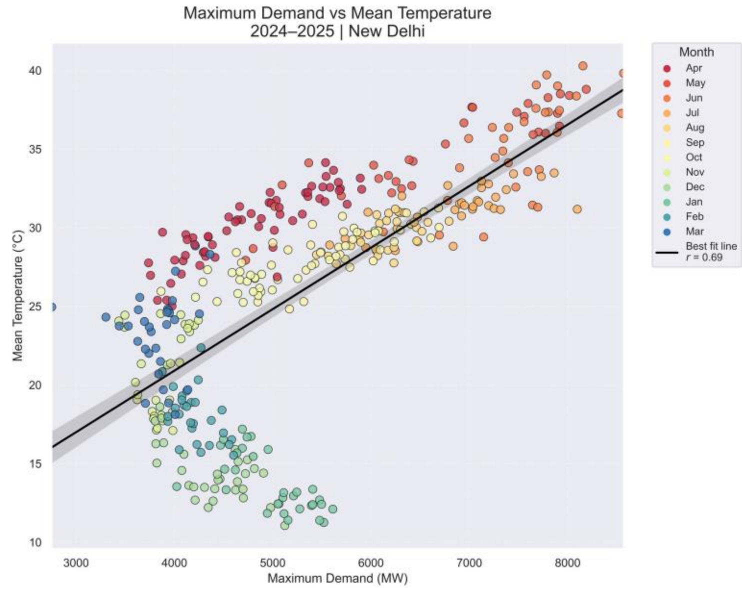
FIGURE 2| CORRELATION HEATMAP - FEATURES CORRELATING WITH PEAK DEMAND

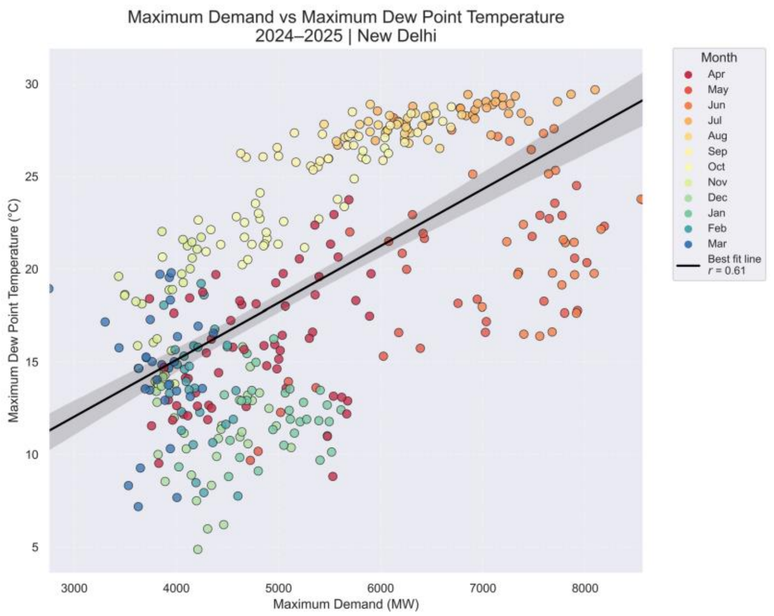
The 5 strongly correlated climate variables with peak electricity demand for the Delhi NCR region are: minimum temperature (0.76), mean temperature (α=0.69), maximum dewpoint temperature (α=0.61), mean dewpoint temperature (α=0.59), and maximum temperature (α=0.55).

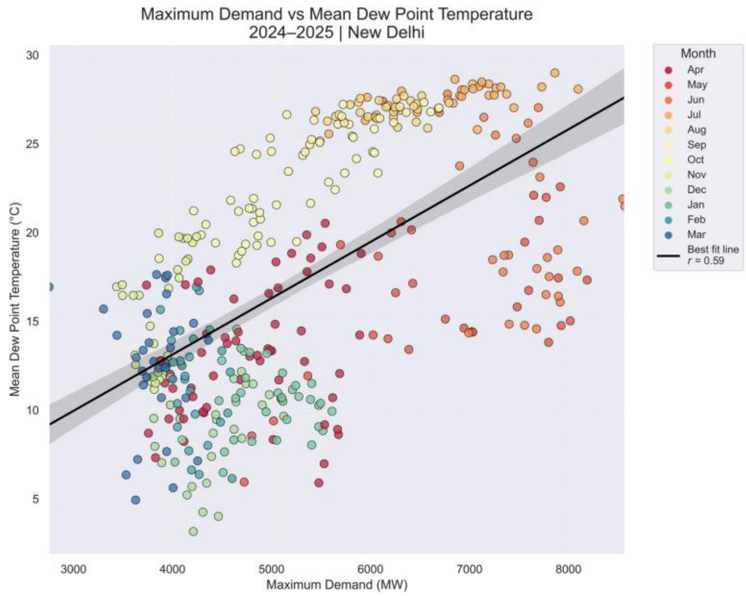
RESULTS

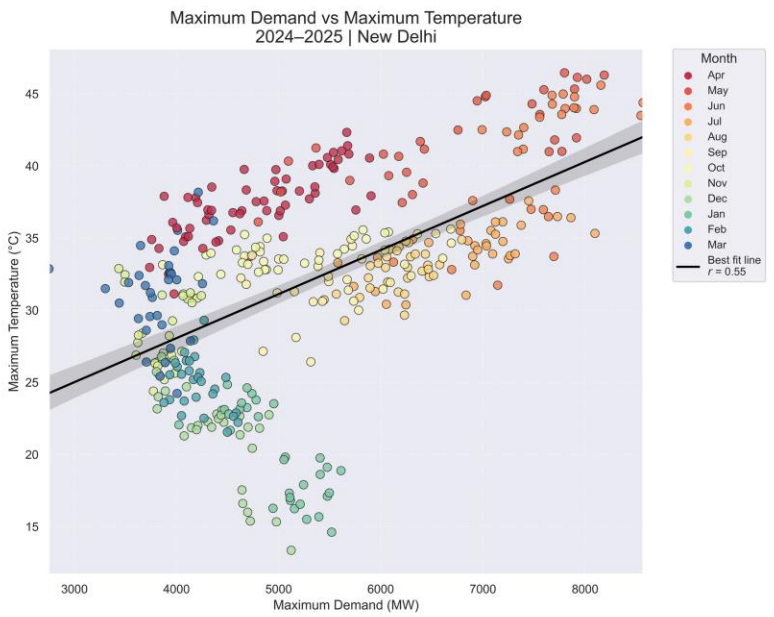
FIGURE 3| PEAK ELECTRICITY DEMAND AND STRONGLY CORRELATED CLIMATE VARIABLES











The aim is to predict peak electricity demand (target) using climate variables (features). For the Delhi NCR region, we have considered the above-mentioned 5 climate variables as features.

FIGURE 4| ACTUAL VS. PREDICTED VALUES OF PEAK ELECTRICITY DEMAND DECISION TREE AND XGBOOST

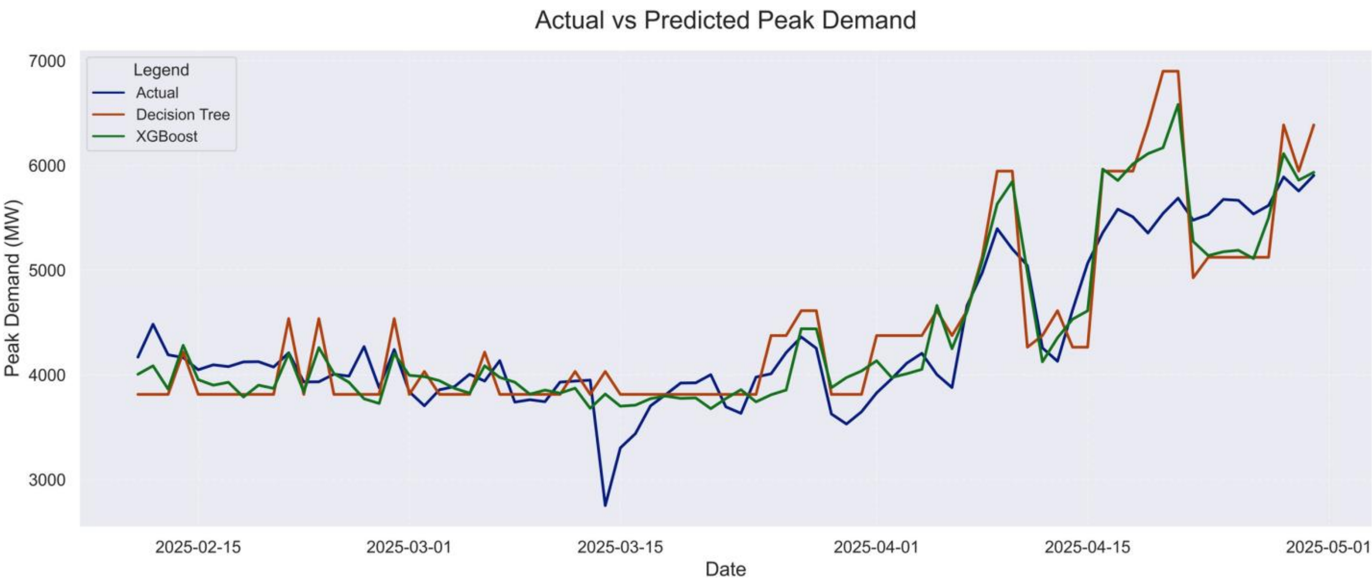
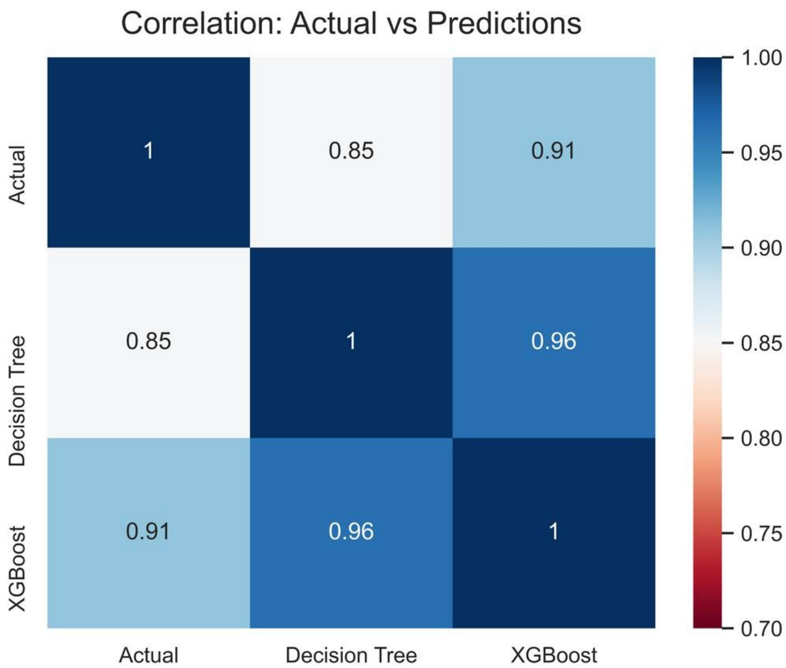


Figure 4 compares the actual peak electricity demand values with the predicted peak electricity demand values. The prediction values produced using two machine learning methods—Decision Tree and XGBoost — were compared.

FIGURE 5| CORRELATION BETWEEN ACTUAL AND PREDICTION VALUES COMPARING DECISION TREE AND XGBOOST METHODS



Decision tree method

The correlation between the predicted values and actual values of peak electricity demand is 0.85

XGBoost method

The correlation between the predicted values and actual values of peak electricity demand is 0.91

DISCUSSION AND POLICY INSIGHTS

Discussion

- Both ML methods- XGBoost and Decision Tree identified minimum daily temperatures as the strongest predictor of peak electricity demand. This means that if the temperatures at night and early morning periods are higher than normal, it impacts the electricity consumption (Figure 2).
- Mean and maximum temperatures also have a strong influence on the electricity consumption. Hence, for energy forecasting, temperature aggregates are essential features to be considered as input variables (Figure 2).
- Further, the dew point temperature, which acts as a proxy for humidity, also influences the electricity consumption. These variables are consistent with the humid heatwaves and sunny days, which increase the cooling demand (Figure 2).
- In terms of peak electricity demand management zones, daytime as well as nighttime climate conditions drive the electricity consumption. For instance, higher minimum temperatures, which are usually seen around the heatwave season in the Delhi NCR region, increase cooling load and thus imply higher electricity demand.
- The mean absolute percentage error (MAPE) is high for the Decision Tree method, about 79%. The same for the XGBoost method is about 58%, making it a more reliable method for electricity demand forecasting (Figure 5).

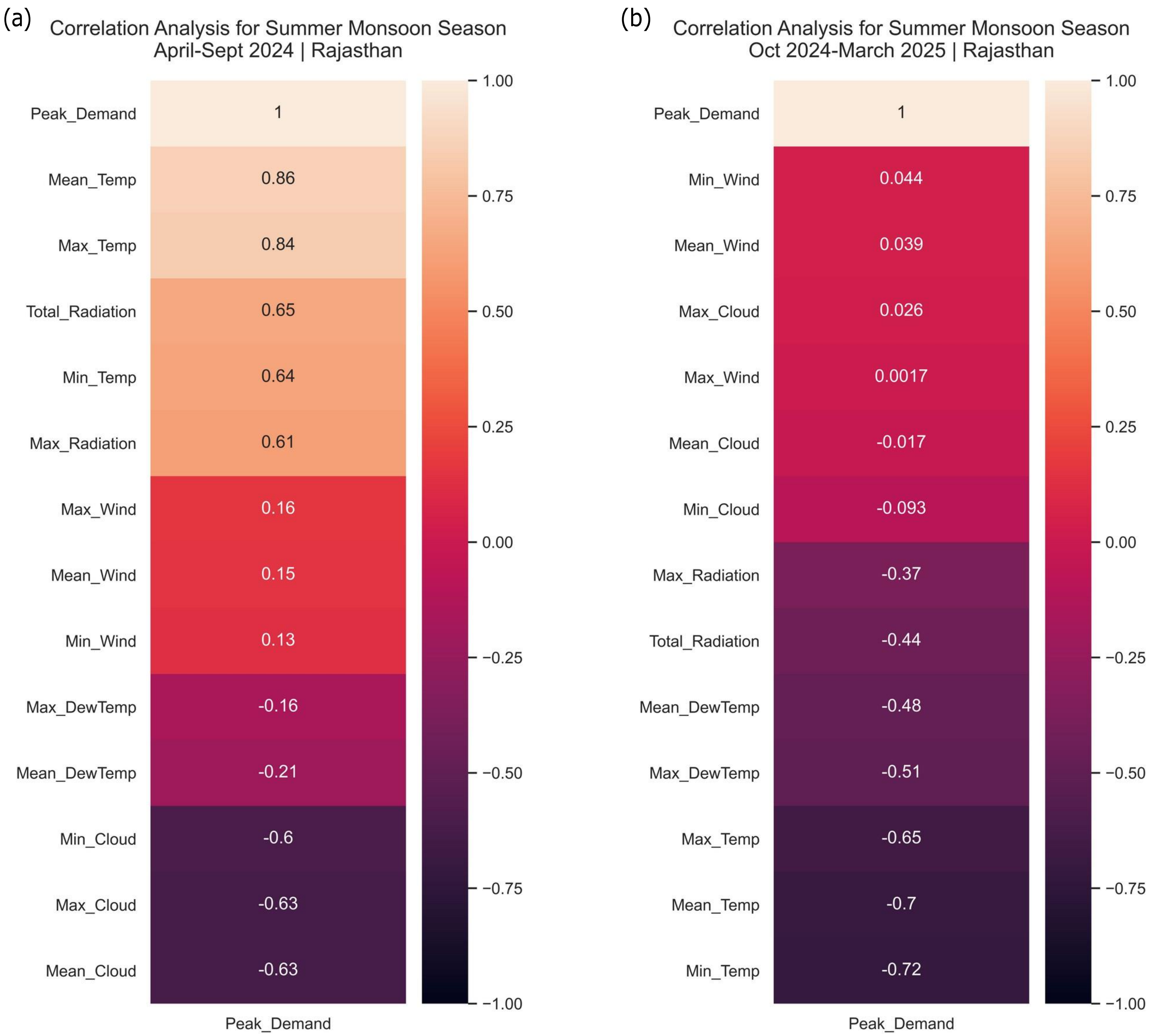
Policy implications for Delhi NCR

1. **Introducing ToU tariffs:** South Asia's largest 20 MW (40 MWh) Battery Energy Storage System (BESS) was commissioned at Kilokari, South Delhi, which will help in enhancing grid flexibility and overall grid management, especially during peak hours of electricity consumption. Time-of-Use Tariffs enable the price of electricity to fluctuate throughout the day depending on the time of day. The prices will be relatively lower for solar hours (8 hours of daytime) and will be relatively higher during peak hours (after office hours and nighttime cooling). Hence, during peak hours, consumers can switch to alternatives such as BESS technology to reduce electricity bills.
2. **Expanding PM Surya Ghar-Muft Bijli Yojana:** Delhi has already set an example by setting up rooftop solar panels for efficient grid management. To make sure that daytime and evening loads are better managed, this scheme can be further enhanced by including storage systems. This would not only enhance grid stability but also boost consumer savings.

Rajasthan

In this section, we will be analysing the relationship between peak electricity demand in Rajasthan and climate variable aggregates for two different scenarios. The first set spans six months, from April 2024 to September 2024, and the second set includes months from October 2024 to March 2025. We have taken this approach for a better understanding of the trends and what climate factors affect the peak electricity demand for the particular period.

FIGURE 6| CORRELATION HEATMAP - FEATURES CORRELATING WITH PEAK DEMAND

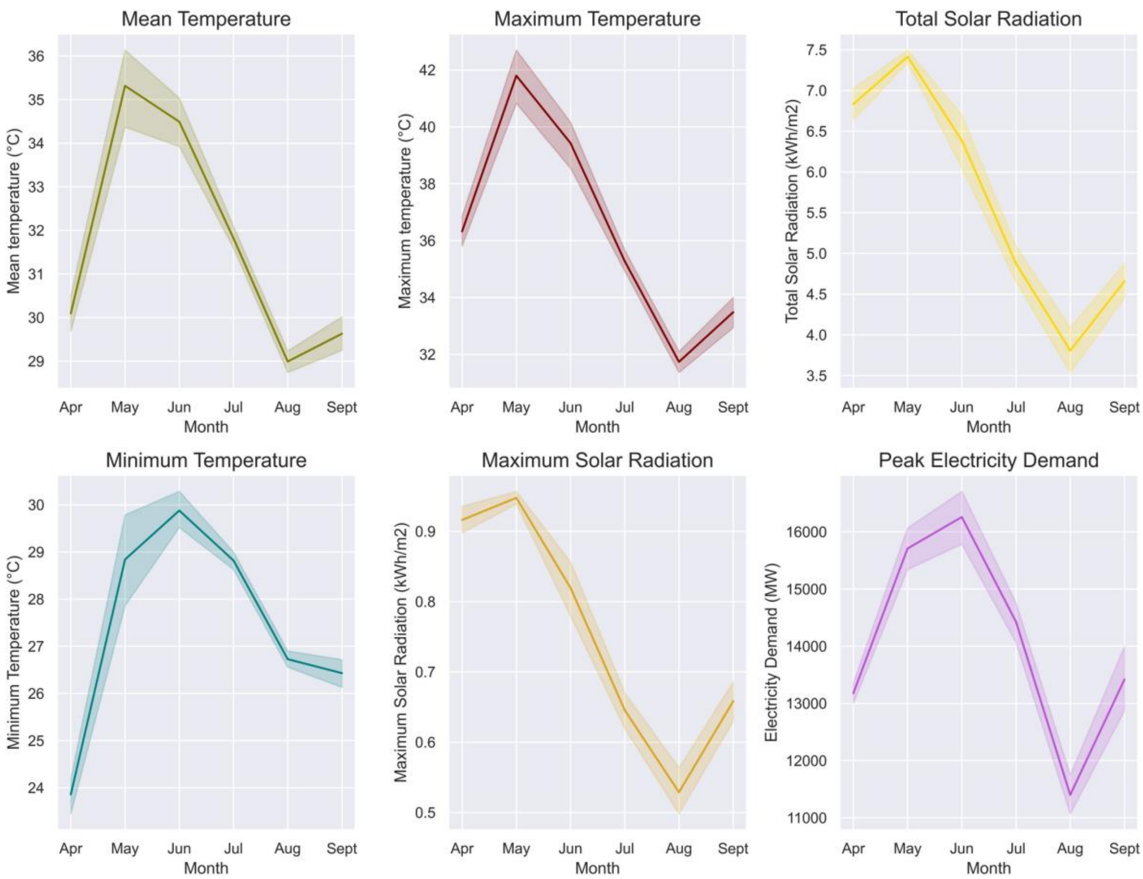


RESULTS

Figure 6(a) shows a correlation heatmap between peak electricity demand and climate aggregates for the months April to September 2024 for the State of Rajasthan. The demand shows strong positive correlation coefficients (α> 0.5) with mean temperature (0.86), maximum temperature (0.84), total solar radiation (0.65), minimum temperature (0.64), and maximum solar radiation (0.61) throughout the day for the months considered. This indicates a strong influence of the solar radiation and temperature in the region for the months April-September. As these variables increase, it reflects an increase in peak electricity demand.

Figure 6(b) shows a correlation heatmap between peak electricity demand and climate aggregates for the months October 2024 to March 2025 for the State of Rajasthan. Unlike Figure (a), which shows strong positive correlation coefficients, this set of months shows strong negative correlation (α< -0.5) with minimum temperature (-0.72), mean temperature (-0.7), maximum temperature (-0.65), and maximum dew point temperature (-0.51). One can interpret that temperature and humidity are the binding factors of an increase in electricity demand for the months of October-March in the State. A significant decrease in these variables during October-March can result in higher electricity demand in Rajasthan.

FIGURE 7 | CLIMATE VARIABLE AGGREGATES AND ELECTRICITY DEMAND APR-SEPT 2024 | RAJASTHAN



RESULTS

Figure 7 shows the time series of peak electricity demand and climate variable aggregates, including mean temperature, maximum temperature, total solar radiation, minimum temperature, and maximum solar radiation for the months April-September 2024. The figure clearly indicates similar trends between all the variables. As the temperature and solar radiation increase for months April, May, and June, the electricity demand also increases. There is a sharp decline in electricity demand as the temperature and solar radiation decrease in mid-July and August, and a sharp increase in September.

FIGURE 8| CLIMATE VARIABLE AGGREGATES AND ELECTRICITY DEMAND OCT-MAR 2024 | RAJASTHAN

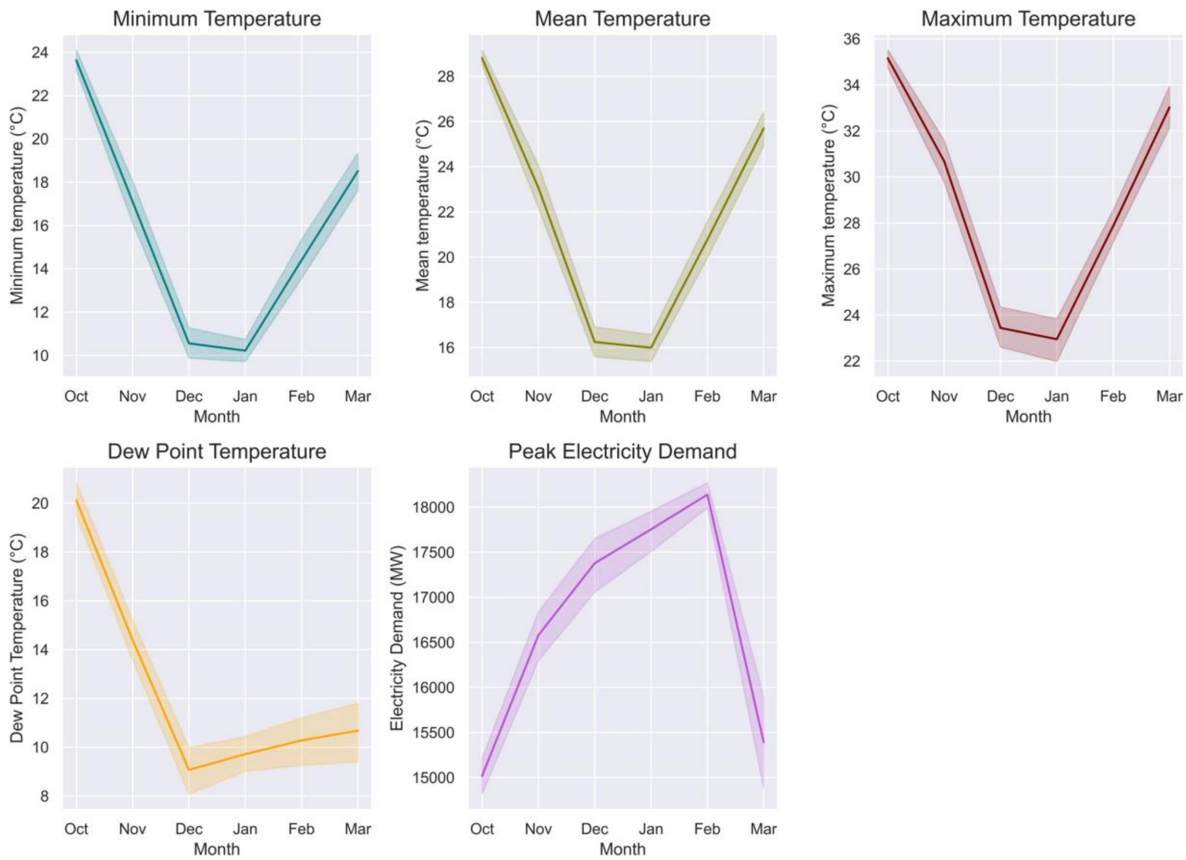


Figure 8 shows the time series of peak electricity demand and climate variable aggregates, including minimum temperature, mean temperature, maximum temperature, and maximum dew point temperature, for October 2024 to March 2025 in Rajasthan. There is a sudden increase in electricity demand from October to February, and a sudden decrease in the month of March. As the colder months (November, December, January) approach, the temperature and humidity drop significantly, thereby increasing the electricity demand. This would include an increase in the usage of heating appliances in most households in the State.

Policy insights for Rajasthan

1. **Managing peak load with seasonal tariffs**: For the months April–September, when temperature and solar radiation strongly correlate with peak demand, Time-of-Day (ToD) tariffs and real-time pricing signals can be introduced. This would encourage consumers to shift energy-intensive activities to solar hours when rooftop and grid solar output is highest, thereby using clean energy.
2. **Expanding rooftop solar with storage deployment**: Rajasthan has strong solar potential and state-level policies to support rooftop solar. Adding battery storage incentives (residential and commercial) ensures surplus solar energy can be stored during the day and used during evening peaks, reducing reliance on thermal power during high-demand periods. India would need 61 GW of storage by 2030 to achieve 500 GW of clean power capacity. Hence, expanding the rooftop solar with battery storage will go a long way in achieving the clean energy target.
3. **Demand-side incentives for summer and winter season**: Since summer demand is closely tied to high temperature and humidity, expanding programs such as the Smart Cooling Efficiency Program for high-efficiency air conditioners, EC fans, and passive cooling solutions will go a long way in managing peak load electricity expenses. For October–March 2025, negative correlations suggest that demand rises as temperatures fall. During these months, demand-side incentives for heating efficiency can be explored, and sufficient reserve margins during cold waves and low-temperature events can be ensured.

WAY FORWARD

Building on the current findings for Rajasthan, future policy bulletins will incorporate rainfall as a critical climate variable to understand its role in electricity demand fluctuations during floods, droughts, and monsoon variability. This will help identify how hydrological extremes influence agricultural pumping loads, industrial activity, and residential energy use.

Moving forward, the Energy Futures Lab will extend the electricity–meteorology framework to Tamil Nadu. By analysing climate drivers: temperature, humidity, solar radiation, and rainfall across Tamil Nadu, the next phase of research aims to deliver region-specific forecasting insights and policy measures to enhance grid resilience, manage electricity consumption and costs, promote renewable integration, and mitigate risks from climate variability.