Dynamics of Electricity Demand: Analysis and Forecasting for Bhutan

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Received: 14th April 2025 Revised: 9th June 2025; Accepted: 12 July 2025, Published:17 August 2025

Abstract
Bhutan is endowed with abundant renewable energy sources to generate electricity from hydro, solar, and wind. Bhutan achieved over 99% electrification in 2016, well ahead of its year 2020 target. This paper provides a comprehensive overview of Bhutan's electricity demand, a country experiencing significant economic growth and accelerated energy demand growth. This study aims to assess current trends and project future electricity demand. Bhutan's electricity demand has been growing over the years, reaching 9,167 kWh per capita in 2024, with a 12% CAGR over two decades. The industrial sector dominates consumption, accounting for over 88% of total demand, while residential, institutional, and commercial consumers contribute just over 12%. Electricity demand follows seasonal patterns, peaking in winter due to heating needs. To forecast low voltage demand, the Holt-Winters method was used, a time series forecasting technique incorporating trend and seasonality. This model effectively captures demand fluctuations, which are influenced by economic growth and seasonal variations. The forecast for the existing and upcoming high voltage industries are based on the contract demand, demand factor and load factor of existing industries. Using the Holt-Winters forecasting method for low voltage and contract demand for industries, the study projects a 15.05% CAGR in electricity demand over the next five years, with 94% demand from energy-intensive loads. As demand outpaces supply, strategic planning, capacity expansion, and policy actions are critical for ensuring reliable energy to support Bhutan's socio-economic development. The projections suggest that there is a need to enhance firm generation capacity to be able to ensure energy security and meet the increasing demand and eliminate winter power deficits.
Key Words: *Bhutan, electricity demand, forecasting, renewable energy, hydropower.*

1. INTRODUCTION

Electricity was first introduced in Bhutan in early 1960s sourcing through a diesel generator to light the bordering town. The first mini-hydropower plant was constructed in 1967 to light the capital city, while the first major hydropower plant, the 336 MW Chhukha plant, was commissioned in the 1980s. Within the next four decades, more than 99% of Bhutanese had access to electricity and hydropower became a major source of revenue and driver for the economy.

The demand for electricity in the country has been growing rapidly over the years keeping in pace with the economic development. Over the last two decades, the per capita demand has increased to 9,167 kWh in 2024 with a 12% CAGR within last two decades.

Electricity demand is mostly from the manufacturing industrial sector with the largest share while the demand pattern is driven by the residential and commercial sectors with distinct patterns in time-of-use. In 2024, the industrial sector, which are supplied at 66kV or higher voltages had the highest share of demand with more than 88% of the total electricity demand followed by low voltage (LV) consumers, that are mostly residential, institutional and commercial, attributing to just over 12% of the total demand. Medium voltage consumers, which are mostly small and medium scale industries attributed to around 3% of the total demand.

Electricity demand in Bhutan is highly seasonal with peak demand during the winter months, which is mainly due to the increase in space heating needs.

On the supply side, Bhutan is endowed with rich renewable energy sources, which is mostly hydro, but also included solar, wind and biomass. The study has shown over 33GW (Energy, 2019), 12GW and 0.7GW (Agency, 2019, p. 4) potential of hydro, solar and wind respectively. Today, a little over ten percent (3,464 MW installed capacity including 1020 MW Punatsangchhu-II hydroelectric plant) of the hydropower potential is harnessed from eight major hydropower plants generating more than 10 TWh of energy annually. Electricity generation from solar is also gaining the traction recently. The first utilityscale solar PV plant with installed capacity of 22.38 MW is currently under construction at Sephu, Wangduephodrang.

However, due to inherent limitations of the run-of-river scheme of hydropower plants, electricity generation is seasonal and highly dependent on the river inflow. Therefore, the current total firm capacity is much lesser than the peak demand. With the growing demand far outpacing the capacity additions, energy security is under threat. Therefore, this study aims to study the trend of demand in the coming years.

The literature review shows not many studies related to the long-term electricity demand forecasting.

2. ELECTRICITY DEMAND TREND

Bhutan achieved close to 100% electrification by 2014 (Bhutan Power Corporation Limited, 2015), before its target of 2020 (Japan International Cooperation Agency , 2005). Electricity is a major driver and enabler of economy, continuing to be among the largest revenue generator contributing close to 11.61% of the total Gross Domestic Product in 2023 (National Statistic Bureau, 2024).

Electricity demand has been steadily increasing over the years driven by the economic growth, urban and industrial growth, and greater accessibility. Over the two decades, the electricity demand grew by 12% (CAGR). The demand rose by 64% year-on-year in 2023, fueled by growth in energy intensive high voltage consumers. The number of high voltage consumers increased by 15% to 22 in 2023 compared to previous year's 19. During the same year the overall number of consumers connected to the grid increased by 5% year-on-year to 243,285 (Bhutan Power Corporation Limited, 2023, p. 2).

Energy intensive consumers, those with capacity demand of 2 MW and above, play a major role in shaping the demand profile. In 2024, 88% of the total demand was from the energy intensive consumers. The medium voltage category made 3% of the total demand.

The demand from low voltage category is seasonal in nature, with higher demand during the winter months. In 2024, 12% of the total demand was from low voltage category. The peak demand in 2024 was recorded 1026 MW in the month of December.

2.1 DEMAND TREND ANALYSIS

a. Year-on-Year Demand

The electricity shows correlation with the GDP growth trend as shown in **Fig. 1**. The yearly demand shows a major dip in demand in 2020 compared to previous year. In 2019 the year-on-year demand growth was (-2%) and in 2020, the demand growth further plummeted to (-14%). However, not much impact was seen on electricity demand due to financial crisis in 2008 with the domestic demand mainly attributable to increase in number of high voltage industries from four in 2007 to nine in 2008 and 11 in 2009 (Bhutan Power Corporation Limited , 2016, p. 17). Nevertheless, a (-2%) dip in the demand in 2016 coincides with the global economic turmoil such as the Brexit, Chinese market crash, OPEC oil production cut, among others.

b. Month-wise Demand

The demand for electricity by the low voltage consumers shows variation in month-to-month, which are largely influenced by the seasonal changes. During the winter months, the demand surges mainly attributable to the rise in space heating requirements and decreases during the summer months. The month-wise demand share of the annual demand for three years (average of 2022 to 2024) is shown in Fig. 2. The winter LV load increases by around 50 MW as compared to the summer load.

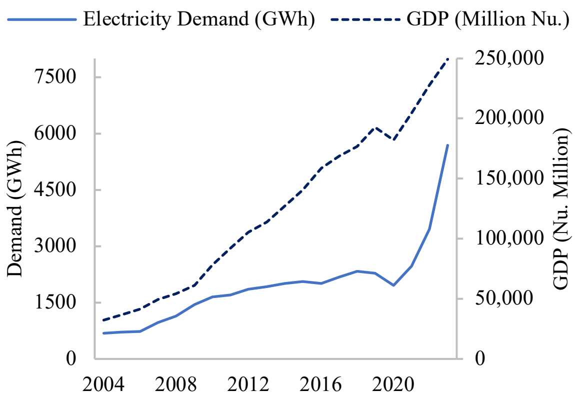

Fig. 1: Yearly electricity demand.

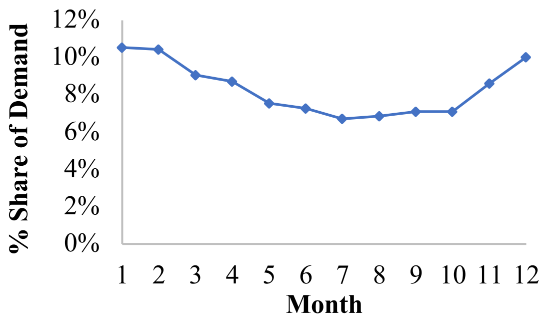

Fig. 2: Month-wise variation in demand.

c. Load Curve

The typical daily load curve of summer and winter both for week days and weekends are shown in Fig. 3. The daily load curve represents the variation of demand over a period of 24 hours in a day influenced by usage of electrical load connected to the system.

The consumption pattern shows distinct patterns for summer and winter months whilst showing similarities in term of day-time peaking of demand.

During the winter month the morning demand peaks at around 0800 hours and evening demand peaks at 1800 hours. However, during the summer months, the demand during the morning hours remains mostly constant after 0700 hour till noon with a slight dip in the afternoon hours before peaking at around 2000 hours.

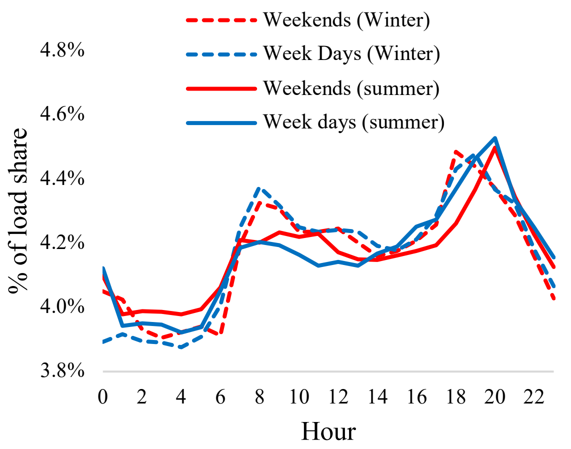

Fig. 3: *Daily load curve of total demand.*

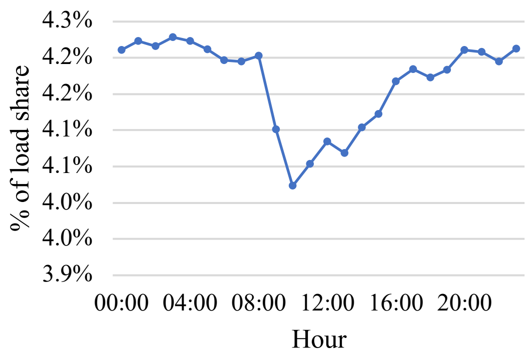

Fig. 4: *Load curve of Industry load.*

The flat morning peak and a later evening peak in summer peak are mainly due to warmer temperatures and longer daylight hours during summer. The daylight period during summer months is longer compared to the daylight period in winter months by more than two hours.

The industry load curve shown in the Fig. 4 shows trough at 10:00 hours. The industrial load during this hour drops by close to an average of 20 MW.

3. ELECTRICITY DEMAND FORECAST

Electricity generation in Bhutan fluctuates seasonally due to variation in river inflow. Domestic generation is maximum during the summer months and drops to less than 20% of the total installed capacity during the winter months. Similarly, the demand for electricity also has seasonal variations, however, in contrast to the generation profile, demand surges in winter. The firm electricity generation capacity which is currently around 437 MW falls far short of meeting the peak demand. Consequently, to meet the supply shortage in winter, Bhutan has been importing power from India during the lean generation period since 2022. Therefore, a robust and accurate forecasting of demand and generation, both in the short-term and long-term is of paramount importance to adequately plan and address energy security imperatives.

Overall, the national electricity demand is heavily driven by the industrial sector, which is responsible for over 88.30% [2024] of the total demand. The demand growth and consumption patterns of the industrial load and low voltage consumers differs. The demand peaks during the winter months for the low voltage consumers, where as demand from the industrial load does not varies much. Therefore, demand forecast for industrial load and low voltage load are carried out separately as described in the ensuing sections.

3.1 Industrial demand forecast

Over the last two decades, the industrial demand increased by 13% CAGR in 2024 compared to 2004 and 30% CAGR compared to pre-COVID period.

Therefore, the forecast for the existing and upcoming high voltage industries are based on the contract demand, demand factor (which is the ratio of maximum demand of the system at particular period to the total connected load on the system) and load factor (which is the ratio of average load over a period to the maximum load during a given period) of existing industries.

In the coming years (2025-2027) close to 800 MW industrial load are expected to be connected to the system at Jigmeling (Lamsang, 2024) and Norbugang Industrial Park (Choden, 2023). Considering the current firm power constraints and further owing to lack of data, it is assumed that there will be no additional industrial load from 2027 through 2029.

The demand factor and load factor as computed and used for the forecasting are shown in the Table 1.

With the implementation of Grid Discipline Mechanism (GDM – a commercial imbalance settlement mechanism aimed at enabling energy-intensive consumers and generators to accurately forecast demand and supply while adhering to planned schedule), the analysis shows an improvement in the load factor from 2022 to 2024. Therefore, the load factor shown in Table 1 is reasonable.

Table 1: *Demand factor and load factor for industrial load*

Type of Industry	DF	LF
MV Industries	59.7%	35.9%
HV Industries	93.9%	91.9%

a. Result And Finding

By the end of 2029, the industrial demand is expected to see a CAGR of 16.04% compared to 2024 as shown in the **Fig. 5**.

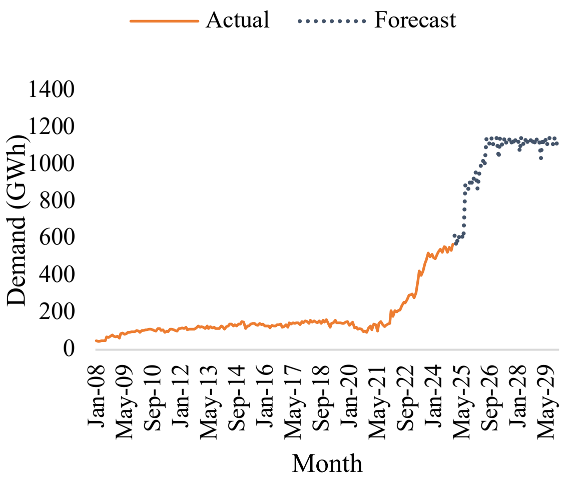

Fig. 5: *Monthly HV industries demand.*

3.2 Low voltage demand forecast

The low voltage demand shows seasonal variations in a year and a year-on-year increasing trend. Therefore, a time series model, the Seasonal Holt-Winters method is used to forecast the demand.

The Holt-Winters method, also known as exponential smoothing, is a forecasting technique used for time series data, particularly when the data exhibit trends and seasonality. The demand data of Bhutan exhibits a trend and seasonal pattern with increasing amplitude over the period. Therefore, multiplicative Holt-Winters is chosen for forecasting the low voltage demand. The demand (Y_{t+1}) is forecasted using the equation shown below (Al-Hafid, 2012).

$$Y_{t+1} = (L_t + (k)T_t) * S_{t+1-m} \quad (1)$$

$$L_{t+1} = \alpha\left(\frac{Y_{t+1}}{S_{t-m}}\right) + (1-\alpha) * (L_t + T_t) \quad (2)$$

$$T_{t+1} = \beta(L_{t+1} - L_t) + (1-\beta) * T_t \quad (3)$$

$$S_{t+1} = \gamma(Y_{t+1}/L_{t+1}) + (1-\gamma) * S_{t-m} \quad (4)$$

Where:

Y_{t+1} is forecast value at time $(t+1)$, L_t is level value, T_t is trend value and, S_t is seasonal value, at time t. $\alpha, \beta, and\ \gamma$ are smoothing constant of level, trend and seasonal respectively between 0 and 1. m is the number of months in a year, where m=12, in this study. k is period to be forecast into the future.

The initial value of level (L_0), trend (T_0) and seasonal factors $S_1, S_2, S_3, \dots \dots . S_m$ are computed as follows

$$L_0 = \frac{\sum_{t=1}^{m} Y_t}{m} \quad (5)$$

$$T_0 = \frac{1}{s}\sum_{t=1}^{m}\frac{Y_{s+t}-Y_t}{m} \quad (6)$$

$$S_t = \frac{Y_t}{L_t}, \text{ where t= 1,2….m} \quad (7)$$

where Y_t is actual observed demand at time t.

The accuracy of the model is measured through Mean Absolute Percentage Error (MAPE) which is given by

$$\text{MAPE} = \frac{\sum_1^N \left|\frac{Y_t - Y_f}{Y_t}\right|}{N} * 100\% \quad (8)$$

Where;

Y_t is actual demand

Y_f is forecasted demand

N is the number of forecasted values

The analysis is carried out in Microsoft Excel using the monthly demand data recorded by Bhutan Power Corporation Limited from January 2008 to December 2024 to forecast the electricity demand for the next five years (2025-2029). The detailed process is as shown in the flowchart depicted in Fig. 6.

a. Result and findings

The smoothing components and MAPE are shown in the Table 2. A MAPE of 3.97% was achieved indicating high accuracy in forecasting. The results indicate that the low voltage demand i.e., demand from residential, institutional and commercial sectors will grow at 4.38% CAGR over the next five years as shown in the Fig. 7, while the industrial sector will be growing at 16.04% CAGR in the same period. Cumulatively, the national load is projected to grow at 15.05 % CAGR resulting in a demand of close to 2,000 MW in 2029, a steep increase from 1,490 MW in 2025.

***Table 2:** Smoothing components and MAPE.*

Alpha (α)	Beta (β)	Gamma (γ)	MAPE
0.12	0.026	0.09	3.97%

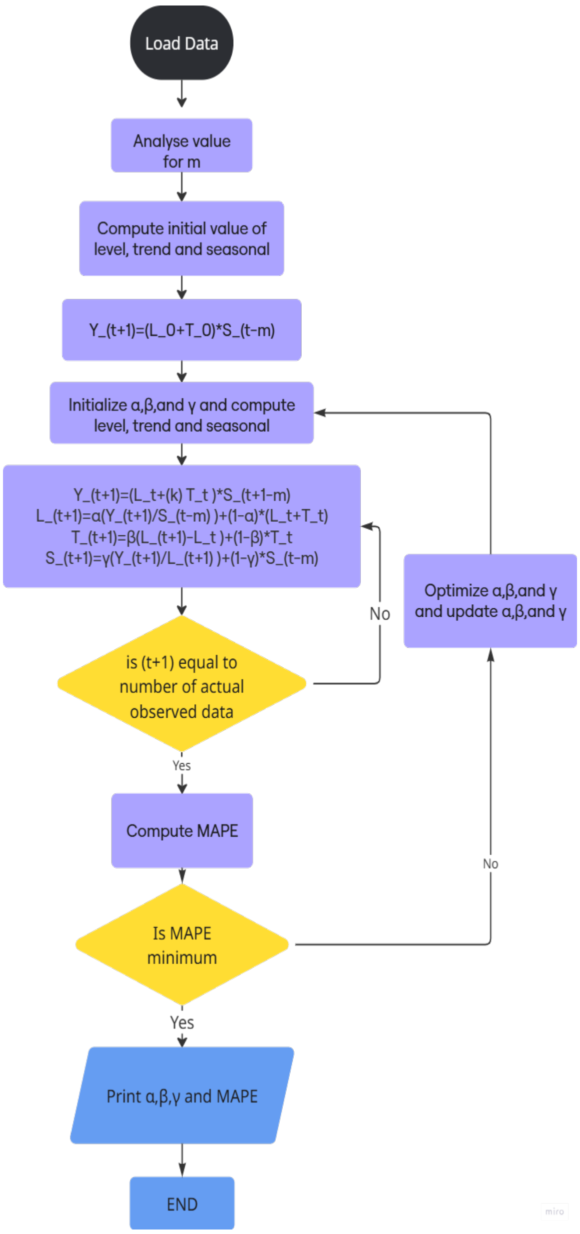

***Fig. 6:** Flow chart for Holt-Winters model.*

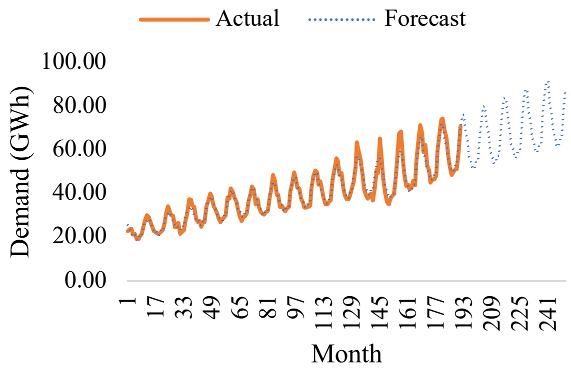

***Fig. 7:** Low voltage demand forecast.*

4. CONCLUSION

The study concludes that considering the business as usual, in the next five years, the electricity demand of Bhutan could see a rise of around 15.05% CAGR. Close to 94% of the demand will be from the energy intensive loads. Therefore, a combination of supply-side expansion and demand-side management policies as shown below are essential:

Supply side expansion

- Diversify energy sources by investing in solar, wind and biomass, which can reduce seasonal supply gaps
- Strengthening regional cooperation for electricity export/import

Demand-side management

- Implementing energy efficiency standards
- Incentivize use of efficient technologies
- Tariff reforms by introducing the time-of-use tariff and smart meters

The current study focused exclusively on forecasting long-term low voltage demand in Bhutan using the Holt-Winters. While this approach offers robust handling of trend and seasonal variations, its singular application represents a methodological limitation. Future research could benefit from exploring and comparing alternative techniques and models such as ARIMA, machine learning and advanced deep leaning architectures.

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