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LONG TERM ELECTRICITY DEMAND FORECASTING

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FOREWORD

Electricity is one of the most important drivers for the growth and development of a country. For steering the economy on the desired growth trajectory, sufficient electrical energy generation, transmission and distribution infrastructure are to be planned well in advance, which in turn requires correct estimation of electricity demand in future. Central Electricity Authority (CEA) conducts periodic Electric Power Survey (EPS) of the country to assess the state and union territory (UT)-wise / region-wise and all-India electricity demand on medium term and long term basis. So far, 19 Electric Power Surveys have been conducted.

The electricity demand projection in 19th Electric Power Survey (EPS) was carried out by CEA by using Partial End User Method (PEUM). An exercise has now been undertaken by CEA in collaboration with KPMG for demand projection of the country by using Economatric Method. This report contains electricity demand projection in term of Energy Requirement and Peak Demand for each state/UT as well as the country. The CAGR of Energy Requirement from 2016-17 to 2036-37 with the preferred scenarios of econometric method and PEUM, are in the range of 5%, which indicates that the demand arrived at by the two different method works out to be in the similar range.

I express my sincere appreciation to all the officers of CEA and KPMG who were involved in this study for their valuable support and suggestions during the deliberations and preparation of the report. I am sure that this volume of EPS would be helpful to all the stakeholders of the power sector in the proper planning of electrical infrastructure and power procurement.

New Delhi
August, 2019

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PREFACE

The economic development of our country is dependent upon the reliable power at affordable prices to various sectors and section of the country. Demand projection is an important exercise for power procurement planning and development of the whole power sector. Central Electricity Authority (CEA) carries out Electric Power Surveys for estimating the electricity demand of all the states/ UTs, Regions and for the country.

CEA has started taking a more cautious approach to minimize the skepticism involved in any forecasting exercise. CEA is carrying out electricity demand forecasting through two entirely different approaches to minimize the degree of uncertainity in this capital-intensive power sector. The electrical forecasting with two Econometric models namely Partial Adjustment Model (PAM) and Seemingly Unrelated Regression (SUR) are covered in this report considering three GDP scenario of Pessimistic (6.5%), Business as usual (7.3%) and Optimistic (8%) for each model. Apart from enlightening about other possible scenarios that would be quite useful for the investors and planner, electricity demand forecast through Econometric method is also an attempt to review the results of 19th EPS (Electric Power Survey) – Volume-I that were arrived upon through conventional Partial End User Method (PEUM).

This report has been prepared by CEA in association with KPMG under the Technical Assistance titles “Supporting Structural Reform in the Indian Power Sector” funded by Department of International Development, UK Government. I would especially like to place on record the valuable contribution of Shri Pankaj Batra, the then Chairperson (I/C), CEA under whose guidance this work was taken up. I would also like to acknowledge the hard work and contribution of Officers of Power Survey & Load Forecasting (PS&LF) Division and KPMG in carrying out this study.

New Delhi
August, 2019

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ACKNOWLEDGEMENT

The report of Long Term Demand Forecasting with econometric method has been brought out by CEA in association with KPMG in compliance with the decision of the 19th EPS committee. Traditionally, CEA does state/UT-wise, region-wise and all-India electricity demand projection through Partial End User Method (PEUM) which is a bottom-up approach focused on end-uses of different categories of the consumers. It is basically a combination of time series analysis and End-Use Method.

In contrast, the econometric model used in this study is based on parameters such as GDP, real electricity price, weather parameters, and past electricity consumption. The input data set used in this analysis comprises of data on these key drivers of electricity demand for all the Indian states and UTs from 2002-03 to 2015-16. The monthly data of states and UTs spanning over 168 periods (14 years of monthly data) has been considered for model development.

The electric demand forecast has been worked out through two econometric models i.e. Partial Adjustment Model (PAM) and Seemingly Unrelated Regression (SUR) model and for each model, three different electricity demand scenarios corresponding to three GDP growth rate of 6.5%, 7.3% and 8% were considered. The in-sample data forecasting and comparison of the demand projection with actual electrical energy requirement during past two years suggest that PAM model under 7.3% GDP scenario is fitting better and therefore, the results obtained through that is recommended as the most preferred scenario. The report covers state-wise and all- India electricity demand projections up to the year 2036-37.

For preparing this report, I would like to acknowledge Sh. Pankaj Batra, the erstwhile Chairperson (I/C), Sh. Sanjiva Mandilwar, the then Chief Engineer (PSLF) who have provided guidance and valuable support at each and every step of the econometric analysis of electric demand projection. I would also like to appreciate the hard work and contribution of Sh. Deepak Kumar, Director(PSLF), Sh. Ishan Saran, earlier Director(PSLF), Sh. Naresh Kumar, Deputy Director PSLF, Ms Komal Dupare, earlier Assistant Director(PSLF) in shaping up this report. Last but not the least, I wish to acknowledge the excellent efforts of KPMG team working on this report, particularly Dr. Puneet Chitkara, Dr Eshita Gupta, Mr. Parteek Garodia & Ms Deeksha Pandey for their valuable contribution.

August, 2019

(B.K. Arya)

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Executive summary

Background

Projection of electricity demand is a prerequisite for power sector planning. A periodic Electric Power Survey (EPS) of the country is conducted by the Central Electricity Authority (CEA) to assess the state-wise/union territory (UT)-wise/region-wise and all-India electricity demand on medium- and long-term basis. So far, 19 Electric Power Surveys have been conducted. The 19th Electric Power Survey (EPS) Committee, constituted by the CEA in June 2015, decided that the 19th EPS would be brought out in four volumes, as detailed below:

Volume I: Discom-wise, state/UT-wise, region-wise and all-India electricity demand projection by partial end use method (PEUM).

Volume II: Electric Power Survey of National Capital Region (NCR).

Volume III: Electric Power Survey of Mega Cities.

Volume IV: Electricity demand projection by econometric method.

The Volume I of the 19th EPS Report, covering electricity demand projection of Discoms, states, UTs, regions and the all-India electricity demand using Partial End Use Method (PEUM) of electricity demand forecasting, was brought out in January 2017. Now, in line with 19th EPS Committee recommendations, the CEA and KPMG India, has carried out electricity demand forecasting by the **econometric method**.

Data used

The data set for the econometric analysis comprises data on key drivers of electricity demand for all the Indian states and UTs from 2002-03 to 2015-16. Such a cross-sectional (for all states and UTs) data over multiple time periods is called a panel data set.

Panel data analysis help by blending the inter-state differences and intra-state dynamics and this has several advantages over cross-sectional or time-series data. It improves the efficiency of econometric estimates by considering more degrees of freedom and by capturing the impact of variables those might be unobservable. Also, in a time-series model, any factor would typically be strongly correlated with its lagged value that leads to a restricted forecast. This problem may be overcome with the panel data.

The panel data set considered in this analysis has both the **dependent variable** i.e. electricity demand/requirement, and a set of **independent variables** such as state-level gross domestic product (GDP)and weather data for all the states and UTs, except Himachal Pradesh, Arunachal Pradesh, Dadar and Nagar Haveli, Sikkim, Daman and Diu, Andaman and Nicobar Islands and Lakshadweep. For these states/UTs, as weather data (temperature, rainfall, etc.) was not consistently available, it has been assumed that the growth rate of electricity demand will converge to the national growth rate in future. The monthly data of 25 states and three UTs spanning over 168 periods (14 years of monthly data) has been used for the model development.

Models for electricity demand forecasting

Electricity demand across states is likely to be dependent on time, i.e. it is natural to expect electricity demand in any given year to be dependent on its previous value, especially as the overall electrical equipment determining electricity demand can be considered as fixed in the short-run. Electricity demand is a derived demand that arises from demand of energy services such as space conditioning, cooking and lighting, for which we require investment in electric equipment. However, adjustment takes time as investment in electric equipment is not immediate. The dynamics arise as a result of the demand stickiness prevalent in electricity consumption because of its capital-intensive nature.

This inertia in demand is captured by including lagged dependent variables in the model which helps in computing dynamic impacts of key drivers on electricity demand and hence improve upon static models where such impacts are not captured. Such an economic model which distinguishes between short-run and long-run electricity responses to its key drivers is known as **Partial Adjustment Model (PAM)**. This model is dynamic as it does not assume an instantaneous adjustment to new equilibrium values when any independent variable (such as price or income) changes. It is assumed that the household can change the rate of utilisation of the existing stock of appliances, but not the existing capital stock with variations in prices or income, so that the short-run and long-run elasticities are not same. These adjustments, however, can vary by regions in India and partial adjustment framework at the regional level provides useful insight into how demand would grow in various regions. The partial adjustment framework has been widely applied in the past for estimating short-run and long-run electricity demand elasticities as well as for obtaining future forecasts of electricity demand.

The PAM model estimates electricity demand (in MU and MW) within regional panel framework which assumes that all the states within a region will have same response for key socio-economic variables included in the model. Thus to estimate differential response of each state with respect to change in key drivers, the state-specific model is also estimated using regional **seemingly unrelated regression (SUR) model**. This model estimates state-specific regression model but takes advantage of the panel data structure to improve overall efficiency of state-level parameter estimates. It pools panel data observations within a region and accounts for correlation in the errors across states within a region.

Selection of the preferred model

The best model for energy requirement/demand at all-India is selected as the one which **minimizes out-sample mean absolute percentage error**[1] (MAPE) for the year 2015-2016 and has the **least average deviation** from the actual observed demand for the two recent years 2016-17 & 2017-2018. For selecting the best model, first estimation is done using data till 2014-15 and then out sample MAPE is calculated for the year 2015-16 as the complete set of independent variables were available for this year in the sample data frame. The regional partial adjustment model (PAM) performs best in terms of forecasting performance by both these measures. The forecasted electricity requirement/demand from the PAM model matches very closely with the actual electricity requirement for the year 2015-16 with minimum out-sample mean absolute percentage deviation in errors amongst the all estimated models. At the same time, it has the least average deviation from the actual observed demand for the two recent years 2016-17 & 2017-2018 as compared to all other estimated models.

Although, it is found that the partial adjustment model (PAM) has a better forecasting accuracy at all-India level with a relatively lower mean absolute percentage error (MAPE) in out-of-sample data and lower average deviation in two recent years as compared to the seemingly unrelated regression (SUR) model, but for few states, electricity requirement forecasts in the long-run seemed better from the SUR model as compared to the PAM model and thus electricity demand forecasts are obtained from both these models for comparison and better understanding of the future scenario under state-specific demand transitions.

Partial Adjustment Model – The Model & Its Significant findings

The panel partial adjustment model has been estimated using data for 25 states and three UTs in all the five regions — north, west, south, east and north-east. The monthly data used for the model development in the current study is long panel with 25 states and three UTs spanning over 168 periods (14 years of monthly data) in all the five regions. The dependent variable is the logarithm of monthly state electricity requirement between 2002-03 and 2015-16.

The independent variables include logarithm of state electricity requirement lagged by one and 12 months respectively, logarithm of GDP lagged by 12 months, logarithm of real electricity prices, cooling degree days (CDD), heating degree days (HDD), rainfall, state by month fixed effect (accounting for factors particular to a state that are distinct in every month) and dummies for incorporating structural break between time periods.

The partial **adjustment model** describes change in electricity requirement from one month to the next as some proportion of the difference between the current level of monthly demand and desired/equilibrium long-run monthly demand. The key assumption of the model is that consumers try to bring their actual level of monthly consumption in line with the equilibrium level but they are only partially successful in every period to close this gap. The estimated **speed of adjustment** of short-run deviation from the long-run equilibrium path is about 31% per annum at the all-India level. This implies that the short-run will converge to the long-run equilibrium in 3.2

[1] Error is defined as a difference between actual and forecasted electricity requirement/demand.

years. The speed of adjustment turns out to be the highest for the northern region at 42% per annum or 2.4 years and lowest for the eastern region at 22% per annum or 4.5 years.

The PAM model distinguishes between short-run and long-run, and thus estimates both short-run and long-run **income elasticity (as measured by GDP elasticity)**. The long-run income elasticity of Electrical Energy Requirement at the all-India level is 0.74, which is more than three times the short-run elasticity. As expected, the elasticity turns out to be lowest for developed region of western India (0.48), which comprises two developed and big states of India - Gujarat and Maharashtra. The elasticity is the highest in the relatively less-developed eastern region (0.91). The relatively slower growth in electricity demand has been observed in developed states and relatively faster growth in electricity demand has been observed in developing states, indicating convergence in demand and living standards over time.

As in the case of income, the model estimates both short-run and long-run **price elasticity** of electricity demand. A 1% increase in real electricity price results in a small 0.02% decrease on an average in the state Electrical Energy Requirement in the short-run at the all-India level. The long-run price elasticity of -0.06 at the all-India level is three times the short-run elasticity. This reinforces that electricity price increase will have much greater impact on electricity demand in the long-run. This is expected as people are likely to adjust more to electricity price increases over time by switching to alternate sources of energy, primarily renewables. An examination of the coefficients of region-specific partial adjustment model shows that the price elasticity is relatively higher than the all-India average in the southern region (-0.12 in the short-run and -0.38 in the long-run) and western region (-0.07 in the short-run and -0.26 in the long-run). This can possibly be explained by relatively higher average real price in western region and the greater captive generation in the industrial sector in western and southern regions, making utility electricity requirement to be more sensitive to price changes.

The estimated long-run impact of CDDs at the all-India level is about 0.19% increase in Electrical Energy Requirement per one-degree Celsius increase in the CDD. The short-run impact of the CDD is about 0.06% increase in Electrical Energy Requirement per one-degree Celsius increase in the CDD. The long-run impact is estimated to be higher in relatively hot and developed regions in India — west (0.26%) and south (0.22%).

In the short-run, a one unit (100 mm) increase in **rainfall** results in 6% reduction in Electrical Energy Requirement when rainfall is between 0-50 mm, 4% reduction when rainfall is between 50-100 mm, 3% reduction when rainfall is between 100-150 mm and 2% reduction when rainfall is above 200 mm. In India, higher rainfall generally occurs during summer when temperature and humidity are high. While higher rainfall in summers brings down temperature and electricity demand but the associated increase in humidity dampens the impact of rainfall on electricity demand to some extent. As the humidity effect is absent in winters, an increase in rainfall during summer may reduce demand (in percentage terms) lesser as compared to winter. Also in winter, the agricultural demand is very high in many states. Higher rainfall in winter can significantly reduce the agricultural load due to pumps. The estimated impact of rainfall turns out to be the highest in the northern region due to high agricultural load. The estimated average long-run impact at the all-India level in all four rainfall categories is 12% reduction in electricity demand with one unit (100 mm) increase in rainfall.

Forecasts based on the regional PAM model

All-India electricity requirement forecasts as based on the regional PAM model under three different GDP scenarios-baseline or business-as-usual (BAU) scenario, optimistic scenario and pessimistic scenario are discussed below:

The BAU case assumes that GDP at the all-India level will continue to grow at the average compound annual growth rate (CAGR) of about 7.3% obtained during 2000-01 to 2017-18 and there will be no significant deviations from these past trends. In the optimistic growth scenario, the all-India GDP is assumed to grow at 8% for all future years during 2018-19 to 2036-37. In the pessimistic growth scenario, the all-India GDP is assumed to grow at 6.5% for all future years during FY 2018-19 to FY 2036-37.

An overview of Electrical Energy Requirement (BU) and CAGR (%) for various scenarios is shown in Table 1 and Table 2 respectively:

Table 1: Electrical Energy Requirement (in BU) from PAM

Year	7.3% GDP (BAU scenario)	8% GDP (optimistic scenario)	6.5% GDP (pessimistic scenario)	Projection by PEUM
2016-17	1152.4	1152.4	1152.4	1160.4
2021-22	1471.5	1477.5	1443.5	1566.0
2026-27	1886.9	1905.4	1776.9	2047.4
2031-32	2378.7	2458.9	2186.7	2530.5
2036-37	2976.3	3175.4	2691.07	3049.4

**All forecasts are reported for average weather conditions. See details of each scenario.*

Table 2: Electrical Energy Requirement CAGR (%) from PAM

Year	7.3% GDP (BAU scenario)	8% GDP (optimistic scenario)	6.5% GDP (pessimistic scenario)	Projection by PEUM
2016-17 to 2021-22	5.01	5.10	4.61	6.18
2021-22 to 2026-27	5.10	5.22	4.24	5.51
2016-17 to 2026-27	5.05	5.16	4.43	5.84
2026-27 to 2036-37	4.66	5.24	4.24	4.06
2016-17 to 2036-37	4.86	5.20	4.33	4.95

In the BAU scenario of 7.3% GDP growth, Electrical Energy Requirement is projected to increase at a CAGR of 4.86% for the period FY 2016-17 to FY 2036-37. Energy Requirement is projected to increase from 1152.4 BU in

2016-17 to 1886.9 BU in 2026-27, 2378.7 BU in 2031-32 and 2976.3 BU in 2036-37. Under the baseline scenario, Electrical Energy Requirement is likely to increase 2.58 times between FY 2016-17 and FY 2036-37.

In the optimistic scenario of 8% GDP growth, Electrical Energy Requirement is projected to increase at a CAGR of 5.2% for the period FY 2016-17 to FY 2036-37. Energy Requirement is projected to increase from 1152.4 BU in 2016-17 to 1905.5 BU in 2026-27, 2458.9 BU in 2031-32 and 3175.4 BU in 2036-37. Under the optimistic scenario, Electrical Energy Requirement is likely to increase 2.75 times between 2016-17 and 2036-37.

In the low growth scenario of 6.5% growth, Electrical Energy Requirement is projected to increase at a CAGR of 4.33% for the period FY 2016-17 to FY 2036-37. Energy Requirement is projected to increase from 1152.4 BU in 2016-17 to 1776.9 BU in 2026-27, 2186.7 BU in 2031-32 and 2691.07 BU in 2036-37. Under the low growth scenario, Electrical Energy Requirement is likely to increase 2.33 times between 2016-17 and 2036-37.

An overview of Peak Electricity Demand (MW) for various future periods is shown in Table 3:

Table 3: Peak Electricity Demand (in MW) from PAM

Year	7.3% GDP (BAU scenario)	8% GDP (optimistic scenario)	6.5% GDP (pessimistic scenario)	Projection by PEUM
2016-17	158,994	158,994	158,994	161,834
2021-22	201,481	202,330	195,133	225,751
2026-27	255,911	259,628	239,299	298,774
2031-32	319,794	333,152	293,462	370,462
2036-37	398,172	427,497	359,882	447,702

**All forecasts are reported for average weather conditions. See details of each scenario.*

Forecasts based on the SUR model

All-India electricity requirement forecasts as based on the regional SUR model under three different GDP scenarios-baseline or business-as-usual (BAU) scenario, optimistic scenario and pessimistic scenario are discussed below:

An overview of Electrical Energy Requirement (BU) and CAGR (%) for various scenarios is shown in Table 4 and Table 5:

Table 4: Electrical Energy Requirement (in BU) from SUR

Year	7.3% GDP (BAU scenario)	8% GDP (optimistic scenario)	6.5% GDP (pessimistic scenario)	Projection by PEUM
2016-17	1188.2	1188.2	1188.2	1160.4
2021-22	1550.0	1558.3	1488.2	1566.0
2026-27	2056.4	2095.7	1884.5	2047.4
2031-32	2685.1	2836.8	2395.4	2530.5
2036-37	3517.4	3878.2	3066.8	3049.4

**All forecasts are reported for average weather conditions. See details of each scenario.*

Table 5: Electrical Energy Requirement CAGR (%) from SUR

Year	7.3% GDP (BAU scenario)	8% GDP (optimistic scenario)	6.5% GDP (pessimistic scenario)	Projection by PEUM
2016-17 to 2021-22	5.46	5.57	4.61	6.18
2021-22 to 2026-27	5.82	6.1	4.83	5.51
2016-17 to 2026-27	5.64	5.84	4.72	5.84
2026-27 to 2036-37	5.51	6.35	4.99	4.06
2016-17 to 2036-37	5.58	6.09	4.86	4.95

In the BAU scenario of 7.3% GDP growth, Electrical Energy Requirement is projected to increase at a CAGR of 5.58% for the period FY 2016-17 to FY 2036-37. Energy Requirement is projected to increase from 1188.2 BU in 2016-17 to 2056.4 BU in 2026-27, 2685.1 BU in 2031-32 and 3517.4 BU in 2036-37. Under the baseline scenario, Electrical Energy Requirement is likely to increase 2.96 times between FY 2016-17 and FY 2036-37.

In the optimistic scenario of 8% GDP growth, Electrical Energy Requirement is projected to increase at a CAGR of 6.09% for the period FY 2016-17 to FY 2036-37. Energy Requirement is projected to increase from 1188.2 BU in 2016-17 to reach 2095.7 BU in 2026-27, 2836.8 BU in 2031-32 and 3878.2 BU in 2036-37. Under the optimistic scenario, Electrical Energy Requirement is likely to increase 3.26 times between 2016-17 and 2036-37.

In the low growth scenario of 6.5% growth, Electrical Energy Requirement is projected to increase at a CAGR of 4.86% for the period FY 2016-17 to FY 2036-37. Energy Requirement is projected to increase from 1188.2 BU in 2016-17 to reach 1884.5 BU in 2026-27, 2395.4 BU in 2031-32 and 3066.8 BU in 2036-37. Under the low growth scenario, Electrical Energy Requirement is likely to increase 2.58 times between 2016-17 and 2036-37.

An overview of Peak Electricity Demand (MW) for various future periods is shown in Table 6:

Table 6: Peak Electricity Demand (in MW) from SUR

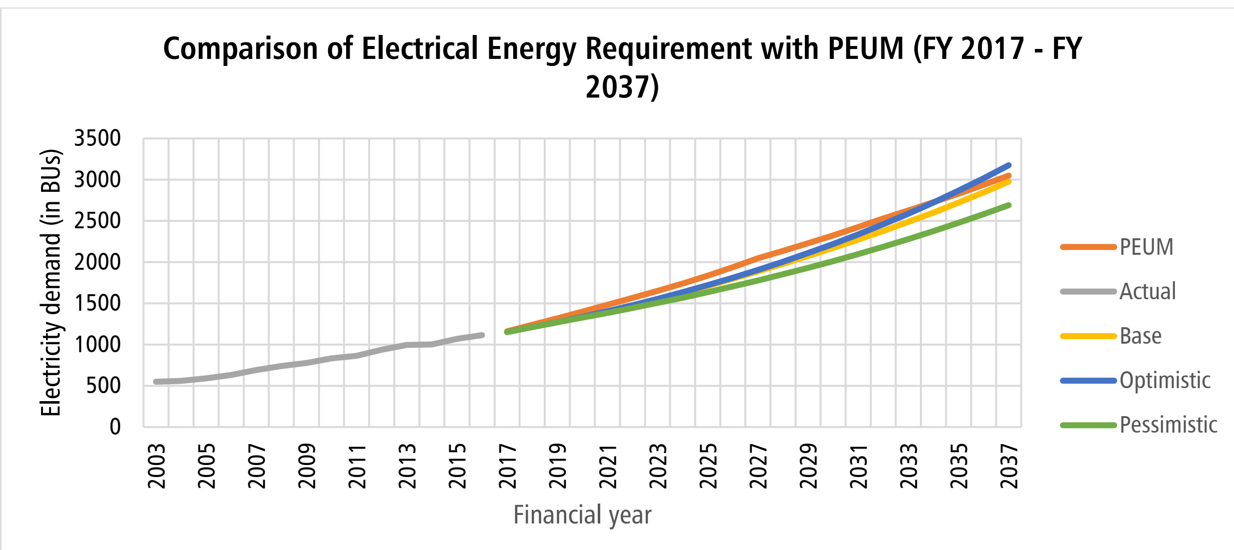
Year	7.3% GDP (BAU scenario)	8% GDP (optimistic scenario)	6.5% GDP (pessimistic scenario)	Projection by PEUM
2016-17	163,148	163,148	163,148	161,834
2021-22	212,828	213,972	204,340	225,751
2026-27	282,361	287,751	258,747	298,774
2031-32	368,683	389,512	328,904	370,462
2036-37	482,950	532,495	421,081	447,702

**All forecasts are reported for average weather conditions. See details of each scenario.*

Comparison between 19th EPS forecast by PEUM and econometric method forecast

The difference in the forecast of Electrical Energy Requirement between 19th EPS forecast by PEUM and econometric method forecast from PAM for 2016-17 to 2036-37 is shown in Figure 1.

Figure 1 Comparison of Electrical Energy Requirement under PAM with PEUM (FY 2017 – FY 2037)



An analysis of the differences between the econometric forecasts under PAM and the 19th EPS forecasts by PEUM yields that the 19th EPS forecasts by PEUM are higher than both the BAU and the higher GDP growth scenario till the year 2031-32. The implied GDP growth rate in BAU is 7.3% whereas in the optimistic scenario it is around 8%. For the years beyond 2031-32, the econometric method forecasts under the BAU and the higher growth scenario compare favourably to the 19th EPS forecast by PEUM.

The actual Electrical Energy Requirement in India in the year 2016-17 and 2017-18 was 1142.9 BU and 1213.3 BU respectively. It is observed that the econometric method forecasts are closer to the actual Electrical Energy Requirement observed during both these years. The econometric method forecasts from PAM are higher than the actual Electrical Energy Requirement in 2016-17 (by 0.8%) and almost equal to the actual Electrical Energy Requirement in FY 2017-18 (with deviation of 0.03%)

The econometric method forecasts from SUR are higher than the actual Electrical Energy Requirement in FY 2016-17 (by 3.96%) and in FY 2017-18 (by 2.43%).

Introduction

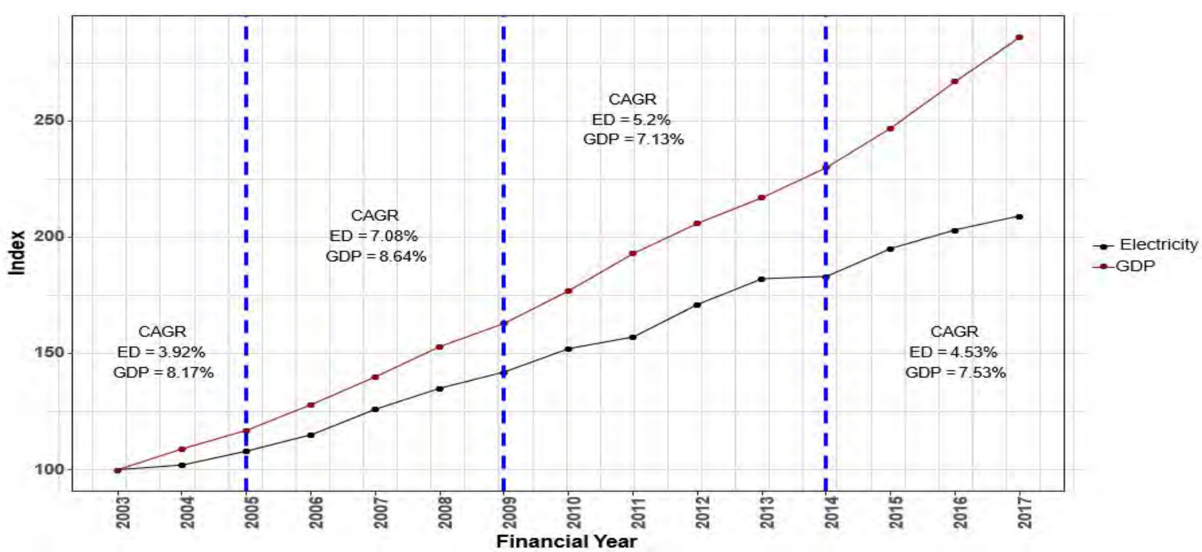
1

1. Introduction

India has witnessed profound social, economic, cultural and demographic changes, most of which have accelerated in the last decade. In the past decade, Electrical Energy Requirement in India increased steadily at a CAGR of 5.42% from 546 BUs in 2002-03 to 1,143 BUs in 2016-17. During the same period, the Indian economy experienced rapid modernisation and economic development with GDP increasing with a CAGR of 7.78% and population increasing with a CAGR of 1.45%. Figure 1.1 shows that India's GDP Index increased 2.8 times from the year 2002-03 to 2016-17 with a corresponding increase in Electrical Energy Requirement of approximately 2.1 times. Apparently, there is a strong positive relationship between income and Electrical Energy Requirement. However, the historical trends depicted in Figure 1.1 imply that the income elasticity of electricity requirement is falling over time. Between the years 2013-14 and 2016-17, the CAGR for GDP was almost double the CAGR for Electrical Energy Requirement. According to the annual report of the Planning Commission on the working of State Power Utilities & Electrical Departments (2014), the elasticity of electricity consumption vis-à-vis GDP has declined from 5.04 in the period 1960-61 to 1965-66 to 1.04 in the period 2006-07 to 2011-12.[2]

The varying relationship between income and Electrical Energy Requirement further highlights the need to understand the causes of these trends in the past, which, forms the basis of the future trajectory of Electrical Energy Requirement.

Figure 1.1 Trends in all-India GDP and Electrical Energy Requirement (utility)



In addition to rapid growth and development, many other macroeconomic factors, climatic factors, technological

[2] Report: http://planningcommission.nic.in/reports/genrep/rep_arpower0306.pdf

As accessed on 1st April 2019

changes, consumer preferences, alternative energy sources, state-specific factors and energy policies are expected to impact Electrical Energy Requirement both in the short-run and long-run. For instance, on the one hand, policies and schemes such as Make in India, Dedicated Freight Corridor, Power for All are likely to increase electricity consumption dramatically; on the other hand, roof-top solar programme, Perform, Achieve and Trade (PAT), Bachat Lamp Yojana (BLY) and Star and Labelling programme are likely to reduce electricity demand on the grid. Furthermore, other advanced technologies such as electric vehicles could alter demand. Also with increasing global concerns due to climate change, there has been increasing focus on gradually reducing dependence on fossil fuels and increasing the share of renewable energy sources in the energy mix. The share of off-grid renewables such as solar pumps is expected to decrease demand for grid electricity in the future, as a result of numerous policies and programmes being recently implemented by the Ministry of New and Renewable Energy. Specifically, relatively slower growth in Electrical Energy Requirement during 2013-14 to 2016-17 can be attributed to increasing energy efficiency, rising captive generation and increasing share of off-grid renewables.

Central Electricity Authority (CEA) has been carrying out periodic electricity demand forecast for India by conducting National Electric Power Surveys. The basic objective of electricity demand forecasting has been to provide reliable inputs for carrying out long-term generation expansion planning along with commensurate transmission and distribution facilities. Many government and private organisations have been using the electricity demand forecast for various purposes.

Several methods of forecasting are available which vary from simple extrapolation of the past demand to sophisticated econometric models involving a number of variables and parameters. The earliest indicators used for energy forecasting were simple measures such as growth rates, elasticities, and energy intensity (ratio of Energy requirement to GDP). Over time, sophisticated techniques have been developed to determine electricity demand ranging from econometric models, time series co-integration models, end-use models, hybrid models (that combine features of economic and engineering models), systemic dynamic models, semi-parametric models, scenario approaches, decomposition models, process models, input-output models and artificial neural networks.

Table 1.1 summarises different models that have been used in past studies for forecasting long-term electricity demand.

Table 1.1 Models for electricity demand forecasting

Model	Explanation of the approach
Time series	A forecasting model is developed based on the previously observed values of demand. Models for time series data represent different stochastic processes — autoregressive models, integrated models and moving average models.
Multivariate regression	Electricity demand is modelled as a function of a number of independent variables such as income, price and weather-related factors. The most common method used is least squares regression.

Model	Explanation of the approach
Non-parametric/Semi-parametric analysis	Model structure is not fixed as in case of parametric models but determined from data. Extensively used in the past to study the non-linear relationship between electricity demand and its key explanatory variables such as temperature, income and price. A common method used is generalised additive model.
Panel data analysis	A panel data set is one where there are repeated observations on the same unit such as states, households and countries. Fixed effect model allows for unit-specific unobserved factors that are constant over time. A dynamic panel, through inclusion of lagged electricity demand terms, can allow for a dynamic adjustment process of electricity demand when there is a change in the determinants of electricity demand. The adjustment process arises as there is inertia which slows adjustment process in response to changes in economic variables such as GDP. A dynamic panel can also enable us to distinguish between short- and long-term elasticities of electricity demand.
Co-integration analysis	These models are used due to non-stationary nature of electricity consumption, real energy prices and income variables. If the variables are found to be co-integrated, the electricity demand is modelled using the vector error-correction (VECM) framework to estimate short-run and long-run income, price and temperature elasticities.
End-use approach	The end-use approach focusses on end uses or final needs at a disaggregated level. The method aggregates the electricity demand in the economy by consumer categories — residential, industrial, commercial and agriculture. The electricity demand for each category is calculated on the basis of the use of various electric appliances. This method allows incorporation of the energy efficiency improvements in the economy, changes in the energy-mix and other efficiency measures.
Hybrid approach	These models attempt to reduce the methodological divergence between the econometric and engineering models by combining the features of the two traditions.
Input-output models	These models provide a framework that is able to capture the direct as well as indirect energy demands through inter-industry transactions. This approach is highly data-intensive.

Model	Explanation of the approach
Machine learning	Artificial intelligence-based techniques include neural networks, support vector machine, wavelet networks and fuzzy logic.
Scenario approach	This approach involves the development of plausible scenarios that could capture structural changes, emergence of new economic activities or disappearance of activities.

CEA uses the PEUM to forecast the electricity demand. PEUM is a 'bottom-up' approach focusing on end uses or final electrical energy needs of different categories of consumers such as domestic, commercial, irrigation, industries and railway traction. In addition to this method of demand forecasting, CEA has been using simple/multiple regression techniques to validate the forecast of various electric power surveys from time to time.

CEA, in its 18th EPS report in collaboration with Indian Statistical Institute (ISI), had published the forecast of electricity demand using econometric method in April, 2014. The forecast was made using multiple regression techniques on panel data through selection of independent econometric variables with state fixed effect technique using past data. The projection of the future had been made by selecting appropriate growth rates for various independent variables and through a set of scenarios. In literature, there exist numerous studies that applied different variants of panel data models to estimate long-term electricity demand at the national/international level.

Electricity demand forecasting models have typically been developed using its key drivers. While electricity demand can be explained by past trends alone (univariate analysis), it is also typically influenced by a combination of drivers that may be broadly categorised as economic, demographic, behavioural and meteorological factors. Some factors have a greater impact on annual electricity demand, while others on monthly electricity demand. GDP, population, and urbanisation are some socio-economic factors that impact electricity demand at an annual level. At a monthly level, the effect of changes in temperature on electricity demand can be significant. Other climate variables such as rainfall, wind and cloud cover also play a role in determining electricity consumption, especially in states where majority of the load is used for domestic and agricultural purposes. These latter variables are typically used in short-term demand forecast (typically day ahead or intra-day forecasts). Some of these drivers are listed in Table 1.2 from past studies.

Table 1.2 Summary of panel data studies on electricity demand

S.No.	Paper/Report name	Authors and year of the study	Period under study	Temporal granularity	Spatial granularity	Dependent variables	Independent variables under consideration
1	Causal relationship between energy consumption and GDP growth revisited: a dynamic panel data approach (2008)	Bwo-Nung Huang, M.J. Hwangc, C.W. Yang	1972-2002	Annual energy consumption	82 countries	Log of energy consumption	• Log of energy consumption • Log of per capita real GDP • Log of the share of capital formation to GDP to represent capital stock • Log of population to represent labour force Log of GDP deflator
2	The effect of development on the climate sensitivity of electricity demand in India (2016)	Gupta, Eshita	2005-2009	Daily electricity demand	28 Indian states	Log of daily electricity demand	• Gross domestic product per capita • Population • HDD and CDD • Sector-wise electricity price • Pump sets • Rainfall
3	Residential electricity demand in Spain: new empirical evidence using aggregate data (2013)	Leticia Blázqueza, Nina Boogenb and Massimo Filippini	2000-2008	Annual electricity demand of residential sector	47 Spanish provinces	Log of residential electricity demand	• Price • Income, i.e. net disposable income (real) • Weather conditions • Population (province-wise) • Household size • Natural gas penetration/proxy for gas price: measured as the number of gas consumers divided by number of houses CDD/HDD
4	18th Electric Power Survey	Central Electricity Authority and Indian Statistical Institute	1980-2010	Annual electricity demand	All Indian states	Log of electricity demand	• Real State Domestic Product per capita • State population rate of urbanisation • Percentage of population electrified

S.No.	Paper/Report name	Authors and year of the study	Period under study	Temporal granularity	Spatial granularity	Dependent variables	Independent variables under consideration
							• Poverty head count ratio • Wholesale Price Index of electricity (all India) Structure of state (measured by share of agriculture, industry and service in state's domestic product)
5	Seasonal temperature variations and energy demand: a panel cointegration analysis for climate change impact assessment (2013)	Enrica De Cian, Elisa Lanzi, Roberto Ros on	1978-2000	Annual energy demand	31 OECD and non-OECD countries	Log of residential electricity demand	• Average seasonal temperature • Lagged dependent variable • Alternative energy prices Real per capita GDP
6	Modelling Ontario's regional electricity system demand using a mixed fixed and random coefficients approach*(198 9)	Cheng HSIAO, Dean C. MOUNTAIN and M.W. Luke CHAN, Kai Y. TSUI	1967-1982	Monthly municipal peak and kilowatt-hour demand	Ontario — 9 municipaliti es	Monthly peak demand	• Income • Price of the relevant electricity commodity • Since an income variable was not directly available by municipality, it was approximated by the product of average weekly earnings of the industrial composite and a composite index number of employment for urban areas • Region-specific factors • 12 regional monthly dummies to represent the regional- and seasonal-specific factors CDDs and HDDs
7	A PES of the US electricity	Anthony Paul, Erica	1990-2006	Monthly demand	USA, state-level (48	Electricity	• Annual disposable income per capita

S.No.	Paper/Report name	Authors and year of the study	Period under study	Temporal granularity	Spatial granularity	Dependent variables	Independent variables under consideration
	demand by region, season, and sector (2009)	Myers, and Karen Palmer		estimated for each of the three customer classes and nine US census divisions	states and district of Columbia)	consumption per capita per consumer for residential and commercial classes	for the residential class and gross annual state product for the commercial and industrial classes • Average retail electricity price; it varies by customer class • HDD and CDD • Number of minutes of daylight in the capital of each state on the 15th day of each month, which varies across months but not across years • The retail price for delivered natural gas that is included only for the residential class FE that are state-level fixed effects
8	The non-linear link between electricity consumption and temperature in Europe: a threshold panel approach (2008)	Marie Bessec, Julien Fouquau†	1985-2000	Monthly electricity consumption	15 European countries	Electricity consumption	• Temperature • Summer holiday dummy • Cubic trend • Population • Production in total manufacturing • Monthly dummy variables

In the current study, the long-term electricity demand has been forecast both at the state and all-India level. The model has been estimated based on the monthly electricity demand data of 25 states and three UTs during the period 2002-03 to 2015-16, within panel framework for each of the five regions — north, south, east, west and north-east. The states included in different regions for estimating regional panel data models are listed in Table 1.3. The key advantage of using regional panel data analysis is that it allows to control for heterogeneity across differentiated Indian states within a given region and enables to account for state-specific unobserved factors that are constant over time. For states and UTs(other than Lakshadweep[3]) not included in the panel model, the future Electricity Requirement and Peak Demand forecast has been obtained based on all-India CAGR of 5%. These states/UTs contributed just 1.65% of the total India's Electrical Energy Requirement in FY 2016. Himachal Pradesh has not been included in the analysis due to non-availability of weather data. Weather data for Shimla was available only post FY 2014-15, that was insufficient for the purpose of our analysis

Electricity demand forecast of Telangana is included in the forecast of Andhra Pradesh as its substantial data was not available separately for the past years.

Table 1.3 States selected in different regions for regional panel data analysis

Region	States
North	Delhi, Haryana, Rajasthan, Uttar Pradesh, Uttarakhand, Jammu and Kashmir, Punjab, Chandigarh
South	Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Puducherry
East	Bihar, Jharkhand, Odisha, West Bengal
West	Chhattisgarh, Gujarat, Madhya Pradesh, Maharashtra, Goa
North East	Assam, Manipur, Tripura, Meghalaya, Mizoram, Nagaland
Others (forecast on the basis of all-India average rate of growth of 5% per annum)	Himachal Pradesh, Arunachal Pradesh, Dadar and Nagar Haveli, Sikkim, Daman and Diu, Andaman and Nicobar Islands, Lakshadweep

[3] In case of Lakshadweep, while Electricity Requirement has been obtained at 5% growth as done for other states but Peak Demand has been considered constant during our forecasting period because almost constant Peak Demand was observed during period FY2011-FY2016.

Methodology for econometric forecasting

2

2. Methodology for econometric forecasting

This chapter discusses the modelling techniques used for electricity demand forecasting by econometric method using panel data.

2.1 Methodology

2.1.1 Panel data

Panel data typically refers to data containing time-series observations of a number of states. Therefore, observations in panel data involve at least two dimensions; a state-level or cross-sectional dimension and time dimension. Panel data blends the inter-state differences and intra-state dynamics. This leads to several advantages over only cross-sectional or time-series data. Important benefits of panel data estimation are:

2.1.1.1 It is a more accurate inference of model parameters. Panel data usually contains more degrees of freedom and more sample variability than cross-sectional data which may be viewed as a panel of only one-time period, or time-series data for only one state, hence improving the efficiency of econometric estimates.

2.1.1.2 Panel data controls for omitted variables. A panel model can control for the state-specific, time-invariant factors through the use of state-specific intercepts or "fixed effect". These fixed effects, in essence, capture the impact of variables that are time-invariant and unobservable to the econometrician (such as, the innate preferences of the consumers regarding restricted use of electricity demand. These intrinsic tendencies of consumers would not be expected to change during the time span of roughly 15 years over which the analysis is conducted.)

2.1.1.3 The fixed-effect estimation method is carried out by demeaning each of the variables i.e. the variable is transformed by subtracting the mean value of the variable over time (the temporal dimension). Demeaning the variables along the temporal dimension would eliminate the heterogeneous fixed effects (idiosyncrasies that are assumed to be stable). Demeaning variables 'within-subject' implies that the mean value for each variable (over time) is subtracted from each observed value of the variable. Hence, within each subject, all the demeaned variables have a mean of zero. For time-invariant variables, the demeaned variables will have a value of zero for every case, and since they are constants, they will drop out of any further analysis. This removes all the between-subject variability (which may be diluted by the presence of omitted variable bias) and leaves only the within-subject variability to analyse.

2.1.1.4 In a time-series model, any factor would typically be strongly correlated with its lagged value. With panel data, we can rely on the inter-state differences to reduce the collinearity between current and lag variables to estimate unrestricted time-adjustment patterns.

2.1.1.5 Panel data arrives at more accurate predictions for individual state outcomes by pooling the data rather than generating predictions of individual state outcomes using the data on the individual state in question. If the electricity demand of each state is similarly dependent on certain variables, panel data provides the possibility of learning an individual state's behaviour by observing the behaviour of others. Thus, it is possible to obtain a more accurate description of an individual state's behaviour by supplementing observations of the individual state in question with data on other states.

Two variants of fixed effect model, the long panel model (adopted in 18th EPS) and partial adjustment model (PAM), are estimated. In addition to the two fixed effect models, one state-specific model is estimated using seemingly unrelated regression estimation (SURE) approach. All three models are discussed below in detail.

2.1.2 Long panel model

Electricity demand across states is likely to be dependent on time, i.e. it is natural to expect electricity demand in any given year to be dependent on its previous value, especially as the overall capital stock governing electricity supply can be considered as fixed in the short-run. The monthly data used for the model development in the current study is long panel, with each state spanning over 168 periods (monthly data spanning over 14 years).

The most commonly used method of panel data is ordinary least squares (OLS) estimation. OLS is a statistical technique for estimating changes in a dependent variable (such as electricity demand) which is in linear relationship with independent variables (such as GDP, real electricity price etc.). It is named so because, in its computation, the sum of the squared deviations of the predicted values from the observed (past) values of the variables is minimised.

The long time-series-cross-section data may have correlation in electricity demand across states in the same period (known as contemporaneous correlation) as these cross-sectional units are subject to spill overs from economy wide shocks. In addition, there is a correlation of electricity demand with its lagged values within states (known as serial correlation) and non-constant variance of the electricity demand (known as heteroscedasticity) across the ranges of values of the independent variables (that predict it). However, OLS regression requires that there is no contemporaneous correlation in electricity demand across states and no serial correlation within states, and that electricity demand should have constant variance across different ranges of independent variables.

The long-panel fixed effect model transforms the error term associated with the data using the Prais-Winsten[4] regression, so that the assumption requiring no serial correlation in electricity demand or errors is not violated. In this method, coefficient of correlation between the error terms (called rho), is estimated from the data by regressing the OLS residuals on the lagged residuals. This estimated rho is then used to transform both electricity demand and all the independent variables such that the correlation in electricity demand and its one period lagged value is accounted in the estimation.
It also estimates panel-corrected standard errors (PCSE) to account for correlation across units (year-specific shocks) and non-constant variance of the electricity demand. The fixed effect panel data model is estimated in

[4] This methodology is explained in the appendix in detail.[5] The theory of partial adjustment model is explained in detail in the appendix.

the current dataset observations on cross-section units which are repeated over long time periods. This model was also estimated in the 18th EPS to forecast future electricity demand at the all-India level. The long panel model has been estimated using data for 25 states and three UTs in all the five regions — north, west, south, east and north-east. The estimated model is:

$$logY_{State,t} = \beta_1 log(GDP)_{t-12} + \beta_2 log(REP) + \beta_3 CDD + \beta_4 HDD + \sum \beta_5 Rainfall + \sum \beta_{s,TP}\ Dummy\ + \sum \beta_{s,m}\ Dummy + \varepsilon_{s,t}$$

The dependent variable is the monthly state Electrical Energy Requirement between 2002-03 and 2015-16. The independent variables used include GDP lagged by 12 months, real electricity prices, CDDs, HDDs, rainfall, state by month fixed effect (accounting for factors particular to a state that are distinct in every month) and dummies for incorporating structural break between time periods.

2.1.3 Partial adjustment model (PAM)

Electricity demand is a derived demand that arises from demand of energy services such as space conditioning, cooking and lighting, for which we require investment in electric equipment. However, adjustment takes time as investment in electric equipment is not immediate. The dynamics arise as a result of the demand stickiness prevalent in electricity consumption because of its capital-intensive nature.

Specifically, the partial adjustment model has been used in a fixed effects framework to incorporate the dynamics of electricity demand behaviour and hence improve upon simple "long panel" static models where such impacts are not captured. This inertia in demand is captured by including lagged dependent variables in the model[5]. Thus, this model is dynamic as it does not assume an instantaneous adjustment to new equilibrium values (as in the long panel model) when any independent variable (such as price or income) changes. It is assumed that the household can change the rate of utilisation of the existing stock of appliances, but not the existing capital stock with variations in prices or income, so that the short-run and long-run elasticities are not same. While the long panel model only estimates long-run elasticities, the partial adjustment model estimates both short-run and long-run elasticities. These adjustments vary by regions in India and this provides a useful insight into how demand would grow in various regions. As in the case of the long panel model, the fixed effect PAM has been estimated using data for 25 states and three UTs in all the five regions — north, south, east, west and north-east. The estimated model is:

$$logY_{State,t} = \beta_1 log(ED)_{t-1} + \beta_2 log(ED)_{t-12} + \beta_3 log(GDP)_{t-12} + \beta_4 log(REP) + \beta_5 CDD + \beta_6 HDD + \sum \beta_7 Rainfall + \sum \beta_{s,TP}\ Dummy\ + \sum \beta_{s,m}\ Dummy + \varepsilon_{s,t}$$

The dependent variable is the monthly state Electrical Energy Requirement or Peak Electricity Demand between the years 2002-03 and 2015-16. The independent variables used include electricity demand lagged by one and 12 months, respectively, GDP lagged by 12 months, real electricity prices, CDDs, HDDs, rainfall, state-specific time dummies in order to account for structural breaks over time and state-specific month dummies to account for state-specific seasonality.

[5] The theory of partial adjustment model is explained in detail in the appendix.

The above two models (long panel and PAM) estimate electricity demand (in MU and MW) within regional panel framework which implicitly assumes regional convergence in electricity demand over time. The assumption of regional convergence may turn out to be wrong if an individual state takes on its individual path. Thus, for comparison purposes, the state-specific model is estimated using regional seemingly unrelated regression (SUR) model.

2.1.4 Seemingly unrelated regression estimation (SURE)

The SUR model estimates a state-specific model for electricity demand. But instead of estimating each state equation separately, as in the case of OLS, it exploits the additional information from the error structure of other states that are linked by the fact that their disturbances or the error terms are correlated in the same period. The correlation among the equation disturbances can come from many sources like correlated shocks to the macro economy.

As it is reasonable to expect contemporaneous correlation in electricity demand of different states within a region, pooling temporal cross-sectional observations in the form of Zellner's SUR model help to improve the efficiency of the estimates of state-specific parameters. As a first step, presence of contemporaneous correlation is checked using the Breusch-Pagan test. There was evidence of strong correlation between the error terms of states at the regional level (i.e. between states in each of the five regions considered). Thus, the region-specific model allows to obtain state-specific coefficients adjusted for inter-dependencies in electricity demand, in the same time-period among states in each region. The model is estimated as a system of equations for all states (s) within each region with stacking of observations over's':

$$logY_S = X_s\beta_s + \varepsilon_s$$

For s = 1……M. M is the number of states in each region. Y_S and ε_s are N-vectors and X_s is N x K_s matrix, where K_s =dim (β_s). The dependent variable is the monthly state Electrical Energy Requirement between 2002-03 and 2015-16. X represents the set of independent variables used for explaining electricity demand such as GDP, price, rainfall, population etc. The chosen specific independent variables vary across states according to what variables best explain as electricity demand in each state (for example: HDD has been considered for states that experience winters such as northern states while dropped for states that do not experience winters such as southern states).

The model assumes that, within each state, the error terms can be dependent on each other over time (electricity demand in a state at any given period will be closely related to previous period values because of the inertia in electricity demand). The error terms across states can be related only in the same year and not over time. Therefore, the errors can be serially correlated within each cross-sectional unit but allows only contemporaneous correlation across cross-sectional units. Furthermore, the magnitude of this contemporaneous correlation across states does not change over time[6].

[6] There is no time heterogeneity, i.e. $E(E_{it}E_{jt}) = \sigma_{ij}$

2.2 Data used

The dependent variable in all the models is monthly Electrical Energy Requirement or Peak Electricity Demand in a state/India depending on the model under consideration. The monthly Electrical Energy Requirement is measured in Million Units (MU) and monthly Peak Electricity Demand is measured in Megawatts (MW). Key explanatory variables in the proposed forecasting models are categorised into two groups — weather variables i.e. temperature and rainfall, and socio-economic variables i.e. GDP (in billion rupees), population (in numbers), per capita income (in rupees) and sector's share of GDP (in %). All the weather-related variables are available at the monthly or daily level. These monthly driver variables are captured either at a monthly frequency or constructed by taking monthly totals or averages over daily level data. Annual variables, on the other hand, are those variables captured at the end of every financial year.

A key summary of the variables used in the analysis is given in Table 2.1:

Table 2.1 Variables used in analysis

Variables used	Description	Period
Agriculture	Share of agriculture in GDP of the state	FY 2002-03 to FY 2015-16
Mining	Share of mining in GDP of the state	FY 2002-03 to FY 2015-16
Electricity	Share of electricity in GDP of the state	FY 2002-03 to FY 2015-16
Industry	Share of industry in GDP of the state	FY 2002-03 to FY 2015-16
Construction	Share of construction in GDP of the state	FY 2002-03 to FY 2015-16
Trade	Share of trade in GDP of the state	FY 2002-03 to FY 2015-16
Banking	Share of banking in GDP of the state	FY 2002-03 to FY 2015-16
Public services	Share of public services in GDP of the state	FY 2002-03 to FY 2015-16
Transport	Share of transport in GDP of the state	FY 2002-03 to FY 2015-16
Manufacturing	Share of manufacturing in GDP of the state	FY 2002-03 to FY 2015-16
Services	Share of services in GDP of the state	FY 2002-03 to FY 2015-16
Gross irrigated area	Gross area units of irrigated area in the state	FY 2002-03 to FY 2015-16
Gross unirrigated area	Gross area units of unirrigated area in the state	FY 2002-03 to FY 2015-16
Annual rainfall	Annual rainfall received	FY 2002-03 to FY 2015-16
CDDs	Cooling degree days	FY 2002-03 to FY 2015-16
HDDs	Heating degree days	FY 2002-03 to FY 2015-16

Monthly rainfall	Monthly rainfall received	FY 2002-03 to FY 2015-16
Structural change	Political party at the centre	FY 2002-03 to FY 2015-16
Per capita	Per capita income of the state	FY 2002-03 to FY 2015-16
GDP	GDP of the state	FY 2002-03 to FY 2015-16
GDP per capita	GDP per capita of the state	FY 2002-03 to FY 2015-16
Lagged electricity demand	Electricity demand lagged by 12 months	FY 2002-03 to FY 2015-16
Electricity prices	State-wise annual real electricity prices	FY 2002-03 to FY 2015-16
Urbanisation	State-wise annual urbanisation rate	FY 2002-03 to FY 2015-16
Villages electrified	State-wise annual percentage of villages electrified	FY 2002-03 to FY 2015-16
Total pump sets	State-wise annual number of pump sets	FY 2002-03 to FY 2015-16
Index of industrial production	Annual all-India index of industrial production	FY 2002-03 to FY 2015-16

All the variables listed in Table 2.1 were tested in the model. However, only those variables that were statistically significant and that improved the fit of the model were included in the final model. To reiterate, the variables that were statistically insignificant or not improving the explanatory power of the model were dropped. Some of the primary reasons for dropping these variables were:

Collinearity of variables with GDP: Some variables such as population, rate of urbanisation and rate of poverty were highly correlated with GDP. This is because higher level of economic growth measured by higher GPD values is positively related with the rate of urbanisation and rate of poverty. In a way, one predictor variable can be used to predict the other and this introduced redundant information in the model. Because of the inter-relationships of these variables with GDP, the inclusion of these variables in the model, along with GDP, would affect how GDP singularly affects the electricity demand (by altering the coefficient of the GDP term by making it insignificant or negative). Therefore, to avoid the problem of collinearity, all collinear variables have been removed from the model, except GDP.

Issues of changes in data methodologies: Complete data was available for variables such as village electrification and total pump sets used in agriculture. The data methodology adopted for calculation of village electrification was changed multiple times during the period of analysis. Due to change in computation methodologies, the data could not be relied upon as there appeared to be arbitrary fluctuations in the estimates.

Insignificance of variables: As discussed above, variables that did not improve fit of the model were excluded to keep the model parsimonious, i.e. to maximise explanatory power of the model using the minimum amount of data. Variables such as the index of industrial production (IIP), structure of the economy, gross irrigated area and gross unirrigated area were statistically insignificant when introduced in the model and were, thus, excluded from our analysis.

Specifically, the variables that have been incorporated in the final version of the models, after multiple iterations, are as given in Table 2.2:

Table 2.2 Variables used in the final model

Independent variables	Description	Rationale
GDP	State-wise GDP estimates	To capture structural features of the state
Lagged electricity demand (1 month lag)	State-wise electricity demand estimates	1. To capture structural features of the state 2. To capture short-term dynamics of electricity demand
Lagged electricity demand (12 month lag)	State-wise electricity demand estimates	1. To capture structural features of the state 2. To capture long-term dynamics of electricity demand
HDDs	Heating degree days	To capture weather dynamics of the state
CDDs	Cooling degree days	To capture weather dynamics of the state
Rainfall	Monthly estimates for state-wise rainfall	To capture weather dynamics of the state
Period breaks	Dummy variable reflecting variation in demand due to change in government	To capture structural time break
State fixed effects	Fixed effect for each state	Capture state-specific time invariant factors that impact electricity demand in the state but are unobservable to the econometrician
Month fixed effects	Fixed effect for each month	Capture seasonal factors that impact electricity demand in the state but are unobservable to the econometrician

Historical trends of variables

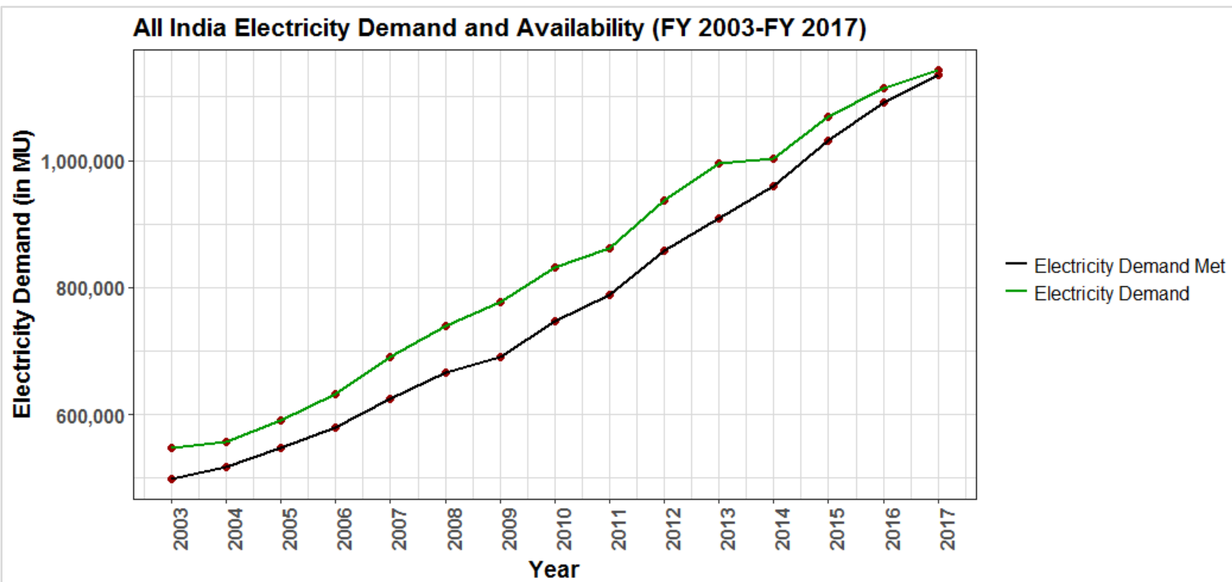
3

3. Historical trends of variables

3.1 Trends in electricity demand

Overall, India has seen a rise in Electrical Energy Requirement and electrical energy met over the years. Figure 3.1 maps the change in the country's Electrical Energy Requirement and electrical energy met during the years 2002-03 to 2016-17. The electrical energy not met as measured by the gap between these two electricity measures has been decreasing over the years.

Figure 3.1 Trends in electrical energy requirement and electrical energy met



The CAGR of electricity energy requirement over this period has been 5.4%. Growth over the period may be attributed to factors such as economic development, growing population, rise in standard of living coupled with greater electrical appliance penetration, poverty alleviation, urbanisation etc.

Figure 3.2 presents state-wise CAGR of total Electrical Energy Requirement between 2002-03 and 2015-16. Some less developed states with low base Electrical Energy Requirement in the year 2002-03, such as Bihar, Arunachal Pradesh and Chhattisgarh, have witnessed a significant rate of growth during the period 2002-03 to 2015-16.

Figure 3.2 State-wise CAGR of Electrical Energy Requirement

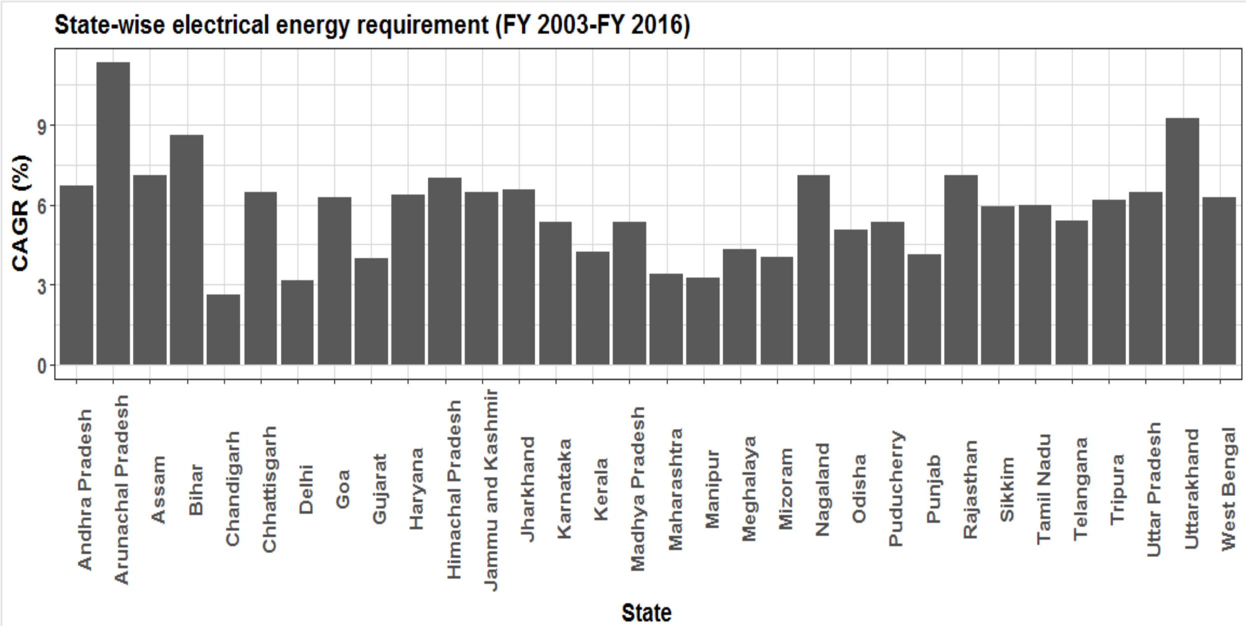
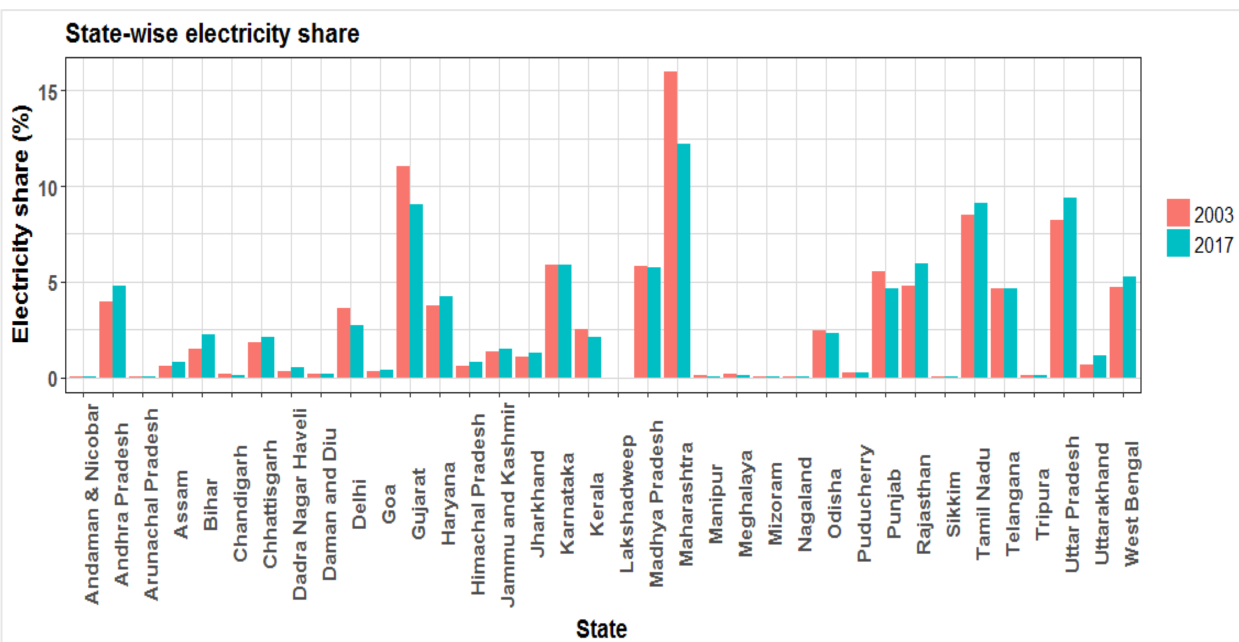


Figure 3. 1 State wise

Figure 3.3 plots each state's share in total Electrical Energy Requirement of India. It is observed that 17 states — Maharashtra, Tamil Nadu, Uttar Pradesh, Gujarat, Punjab, Karnataka, Rajasthan, Madhya Pradesh, Andhra Pradesh & Telangana (bifurcated on a 49:51 basis), West Bengal, Haryana, Delhi, Odisha, Chhattisgarh, Bihar and Kerala account for 92.4% of Electrical Energy Requirement in FY 2015-16.

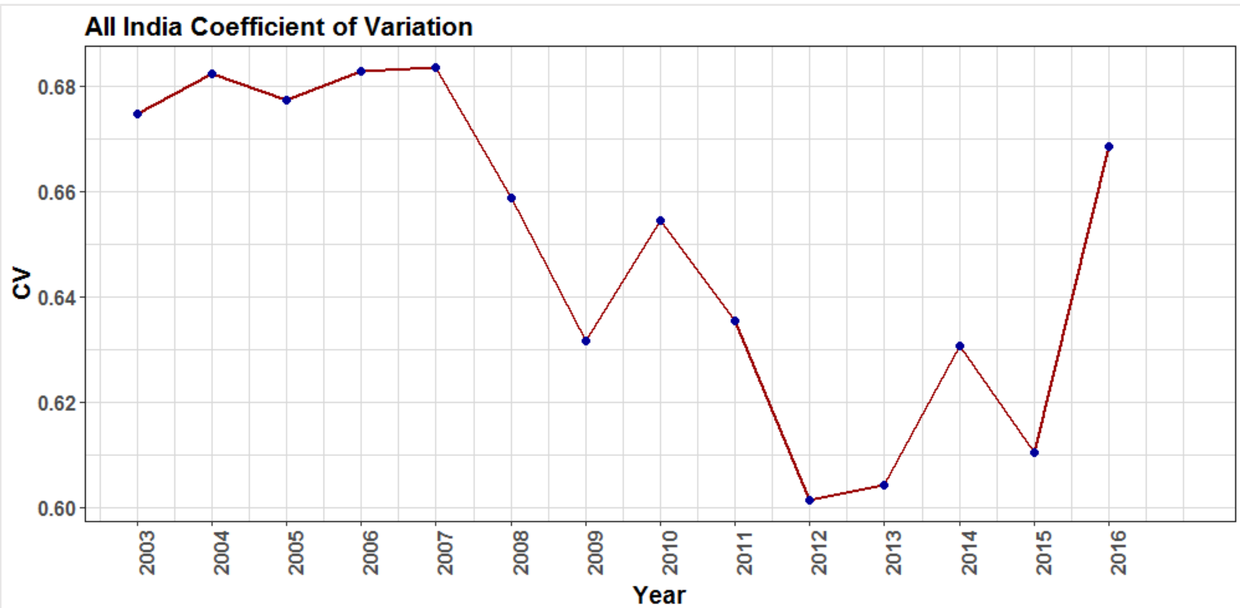
Figure 3.3 State-wise electricity shares



Between FY 2002-03 and FY 2011-12, there seems to be a trend of sigma convergence[7] in the per-capita electricity consumption between states, with a decline in the dispersion in per-capita electricity consumption between states. However, this trend of convergence seems to have reversed post 2011-12 and there appears to be a recent spike in disparity in inter-state per capita electricity consumption in the year 2015-16, as can be seen in Figure 3.4. The dispersion is measured by computing a coefficient of variation (CV) for each financial year, where:

$$CV = \frac{\text{(Standard deviation of per capita electricity consumption across states)}}{\text{(Mean per capita electricity consumption across states)}}$$

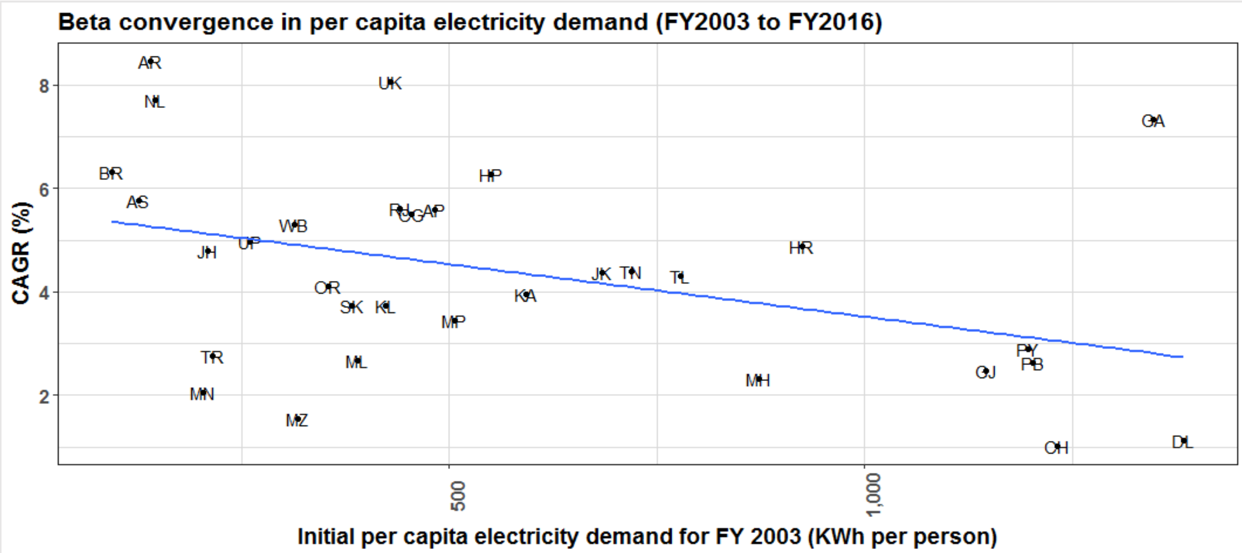
Figure 3.4 Coefficient of variation



However, states with lower initial per capita electricity demand in the year 2002-03 seem to be growing faster when compared to states with higher initial per capita electricity demand in the year 2002-03. Figure 3.5 indicates that all states are converging towards the same equilibrium in terms of electricity demand per capita and growth rate, which is known as beta convergence.

[7] Sigma convergence refers to a decline in relative difference or 'dispersion' over time of per capita values of any variable (such as income or electricity demand) across economies.

Figure 3.5 Beta convergence



Furthermore, electrical energy not met or electricity shortage is mapped at an all-India level and at a state level (Figure 3.6 and Figure 3.7). The country's prevailing trend over the years is declining shortage over the years 2008-09 to 2016-17. Relatively less developed states such as Jammu and Kashmir, Uttar Pradesh and Bihar seem to record greater shortage during the year 2016-17. This may be on account of development seen in these states during the same period; higher pace of development is likely to put additional pressure on requirement for electrical energy.

Figure 3.6 All-India electrical energy not met

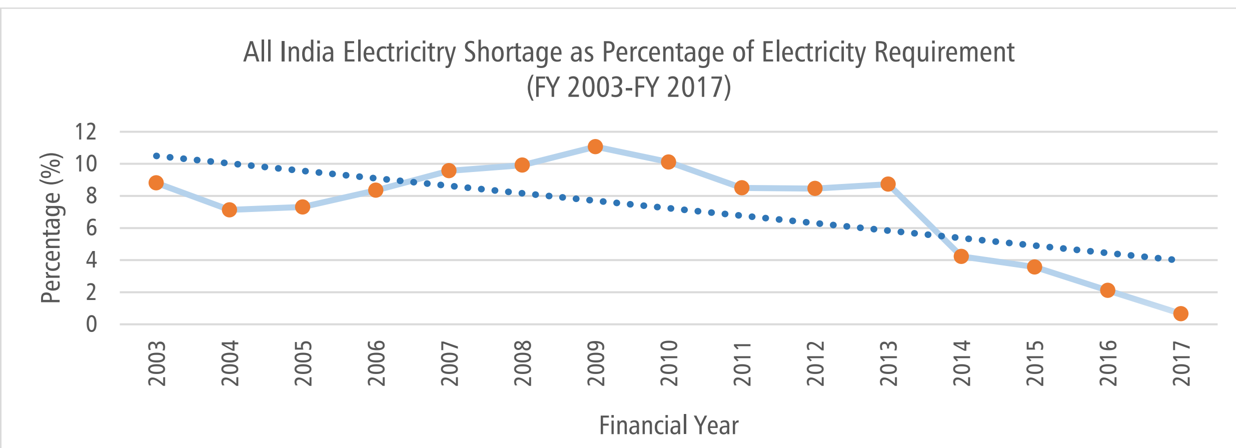


Figure 3.7 State-wise electrical energy not met in FY 2017

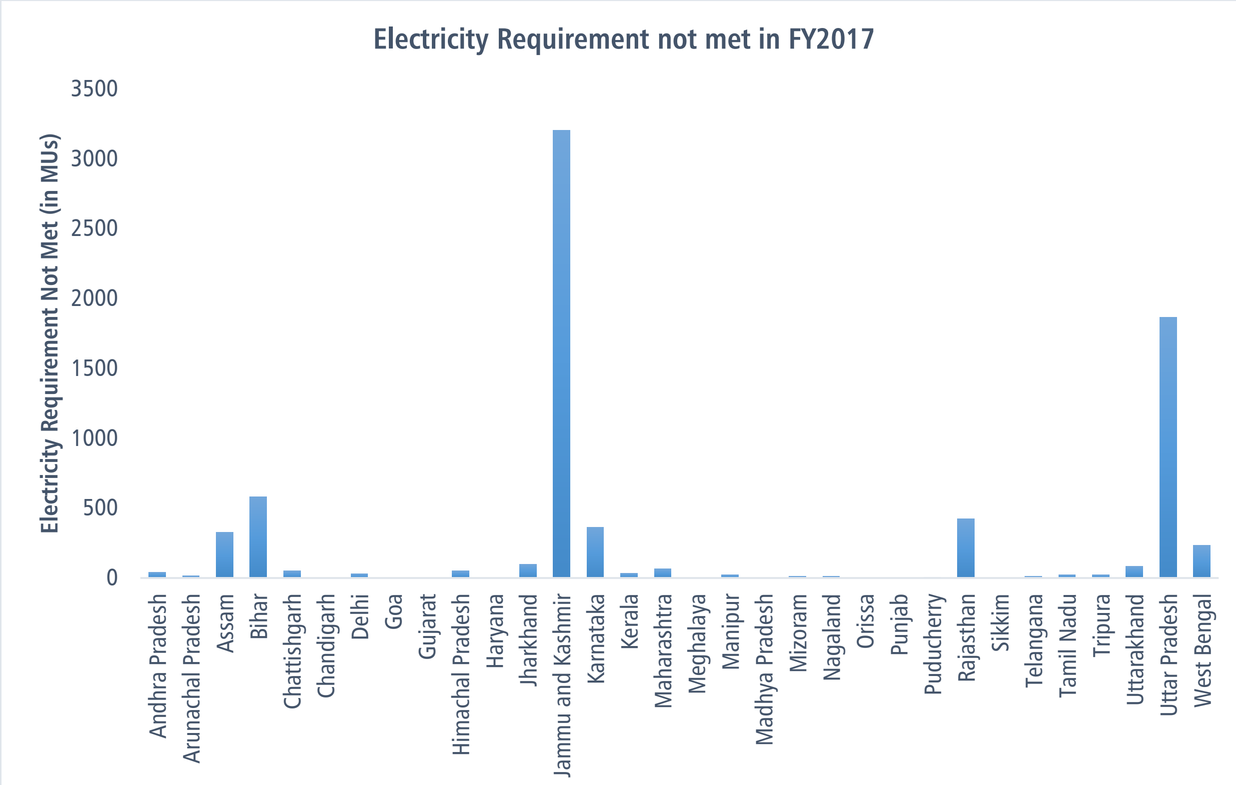


Figure 3.8 presents the data on annual Peak Electricity Demand at the all-India level. Annual Peak Electricity Demand in India has seen a consistent rise over the period 2002-03 to 2016-17. At the same time, Peak Electricity Demand not met has shown a downward trend. Figure 3.9 shows that states like Maharashtra, Uttar Pradesh, Gujarat, Tamil Nadu and Madhya Pradesh have the highest Peak Electricity Demand in the year 2016-17.

Figure 3.8 All India Peak Electricity Demand

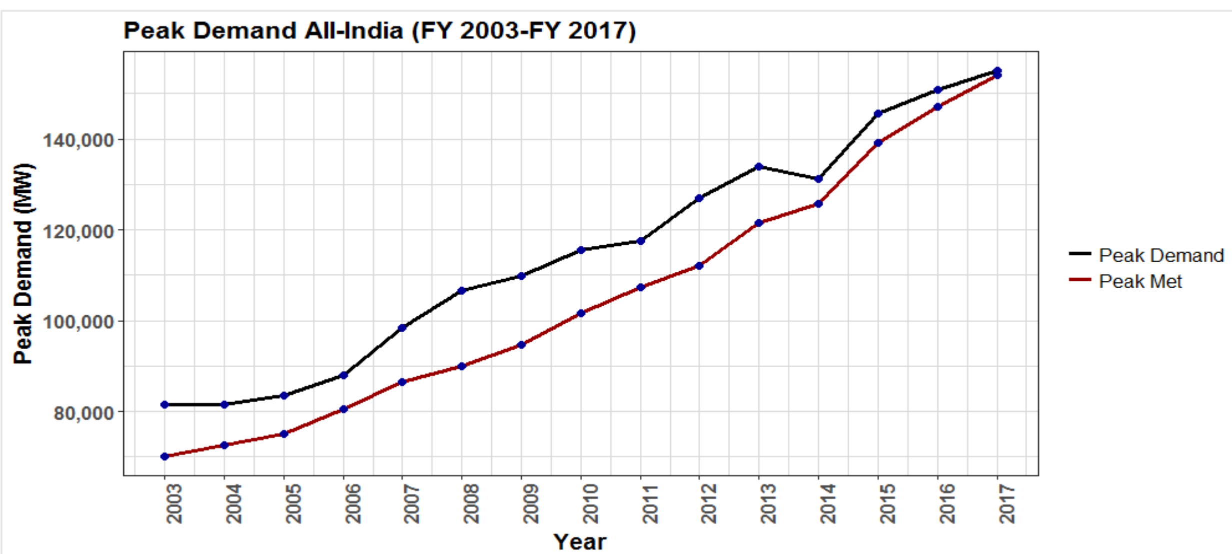
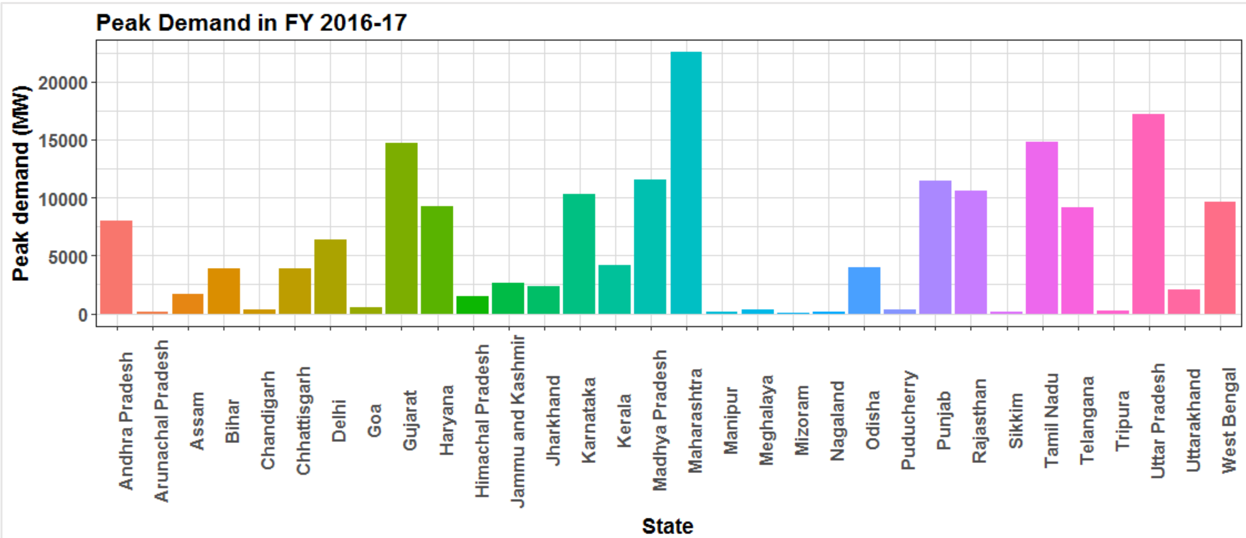


Figure 3.9 Peak Electricity Demand in FY 2016-17

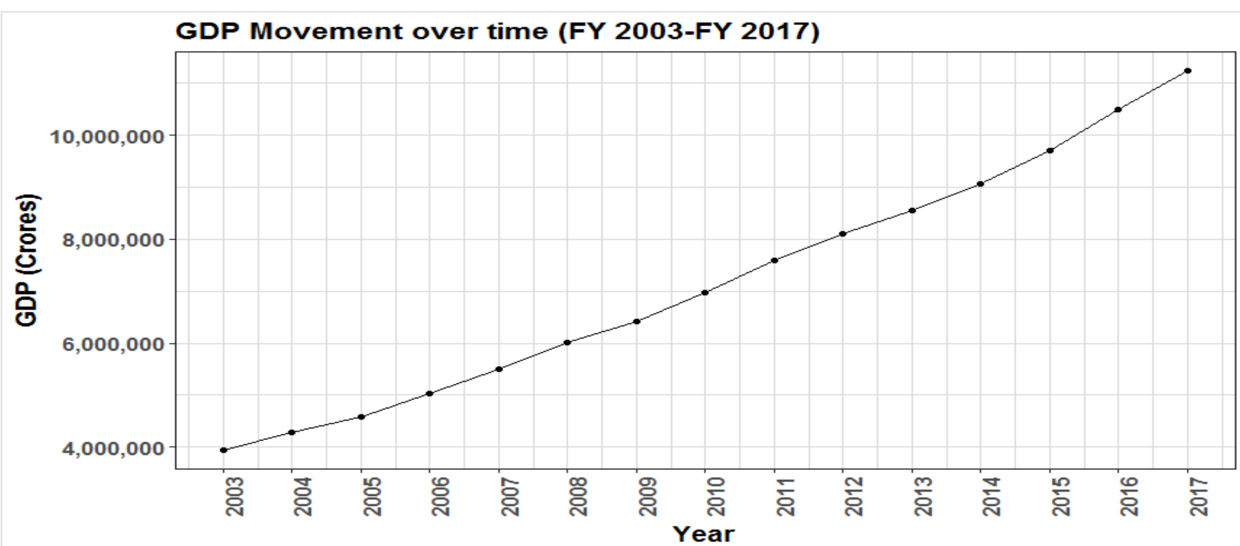


3.2 Drivers of electricity demand

3.2.1 GDP

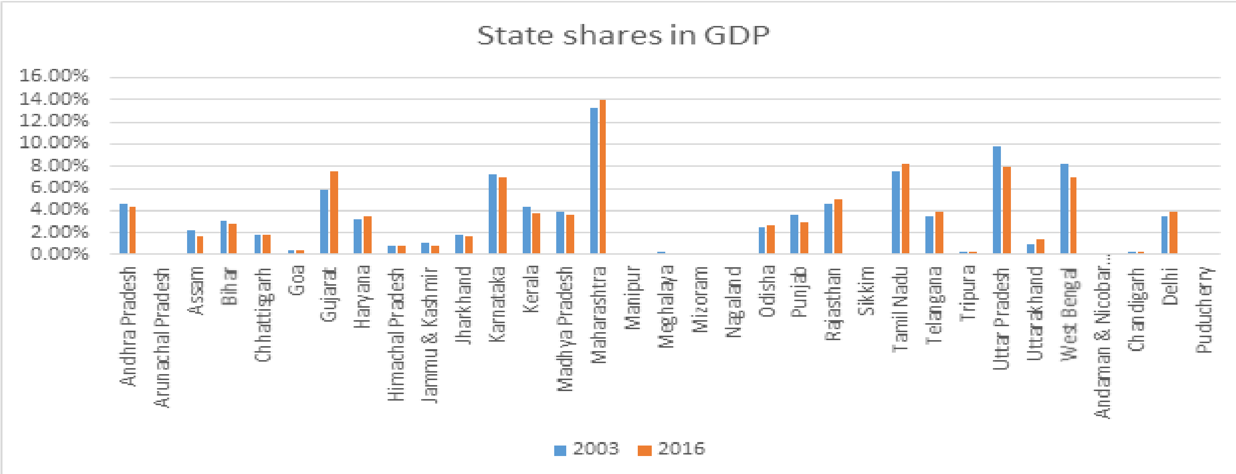
As seen in Figure 3.10, India's GDP has more than doubled during FY 2002-03 to FY 2016-17. Figure 3.11 presents data at the state level.

Figure 3.10 GDP movement over time



At the state-level, it is observed that the states such as Maharashtra, Uttar Pradesh, Tamil Nadu, Karnataka, Madhya Pradesh, West Bengal, Gujarat, Kerala, Andhra Pradesh, Telangana and Rajasthan account for the major portion of the country's GDP.

Figure 3.11 State shares in GDP

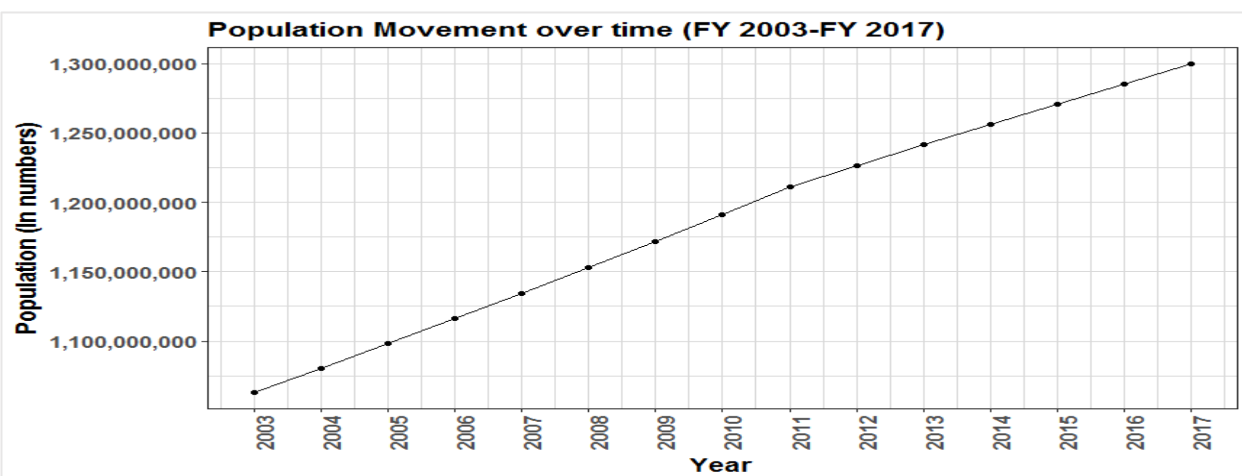


A likely shift in the position of states when compared on the basis of electricity demand growth rate and GDP shares is anticipated to take place. The GDP share of relatively less developed states is expected to increase in future with relatively faster growth as compared to the more developed states. This shift can be attributed to development, rising standards of living and latent demand that are likely to exist in many states on account of insufficient T&D infrastructure, technology penetration, among other factors.

3.2.2 Population

As seen in Figure 3.12, India's population has increased by a CAGR of 1.45% during the period 2002-03 to 2016-17. Some states with relatively lower population are seen to have greater electricity demand as compared to states with larger populations. Delhi, Haryana and Punjab have higher electricity demand as compared to states such as Jharkhand, Kerala and Odisha. This difference in state demands can be attributed to the consumer-segment break-up, industrialisation and per capita income. States such as Haryana and Punjab have a greater segment of their demand arising from the industrial and agricultural consumers, while Kerala and Odisha have a consumption pattern skewed towards domestic consumption.

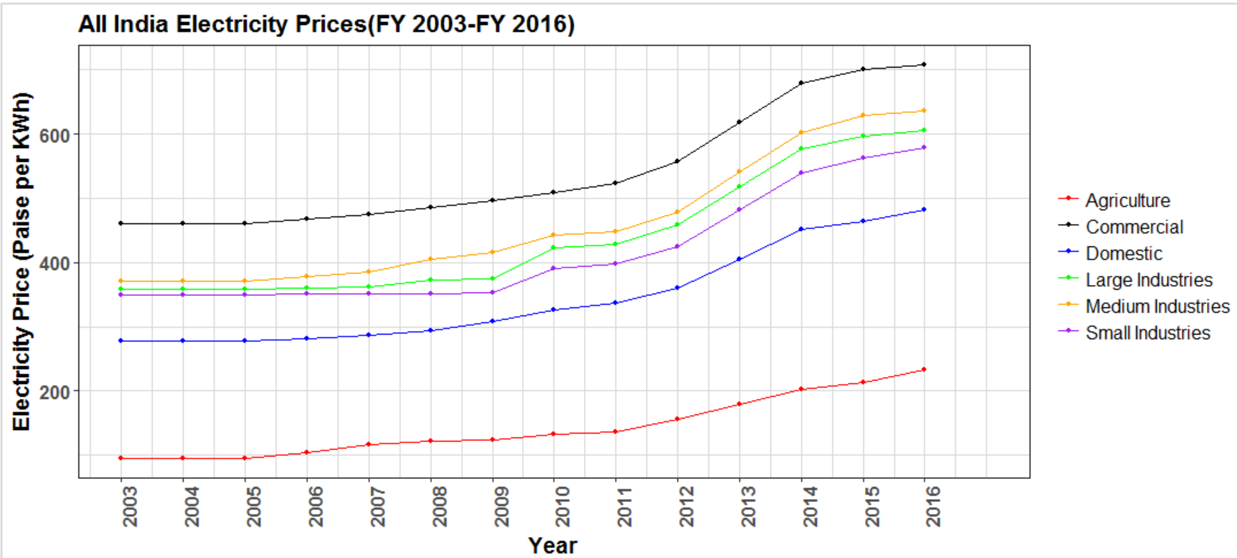
Figure 3.12 Population increase over time



3.2.3 Electricity price

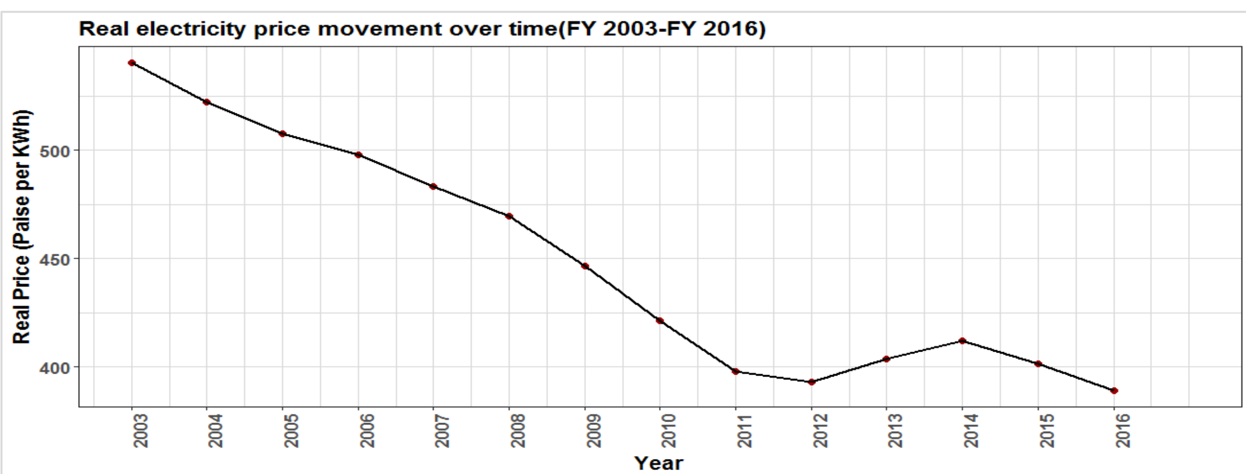
In theory, the electricity price is expected to impact electricity demand negatively. Unlike other goods, consumers of electricity do not face a single price, but rather a price schedule that specifies block pricing across different segments of usage- Agriculture, Commercial, Domestic, Industrial (Large, Medium and Small industries.)

Figure 3.13 Trends in electricity prices



While the nominal electricity prices across all usage segments have consistently increased over time (Figure 3.13), there is a declining trend for the average real price movement (Figure 3.14). This indicates that the effective price that the consumer pays for electricity, after the adjustment for inflation, has decreased between FY 2002-03 to FY 2015-16. But during FY 2011-12 to 2013-14, it is observed that there was a sharp increase in nominal prices for all the categories. The real price during this period increases as the percentage increase in the nominal price is greater than the percentage increase in the price index during this period.

Figure 3.14 Real electricity price movement



Note: Base year for real price calculation is FY 2012

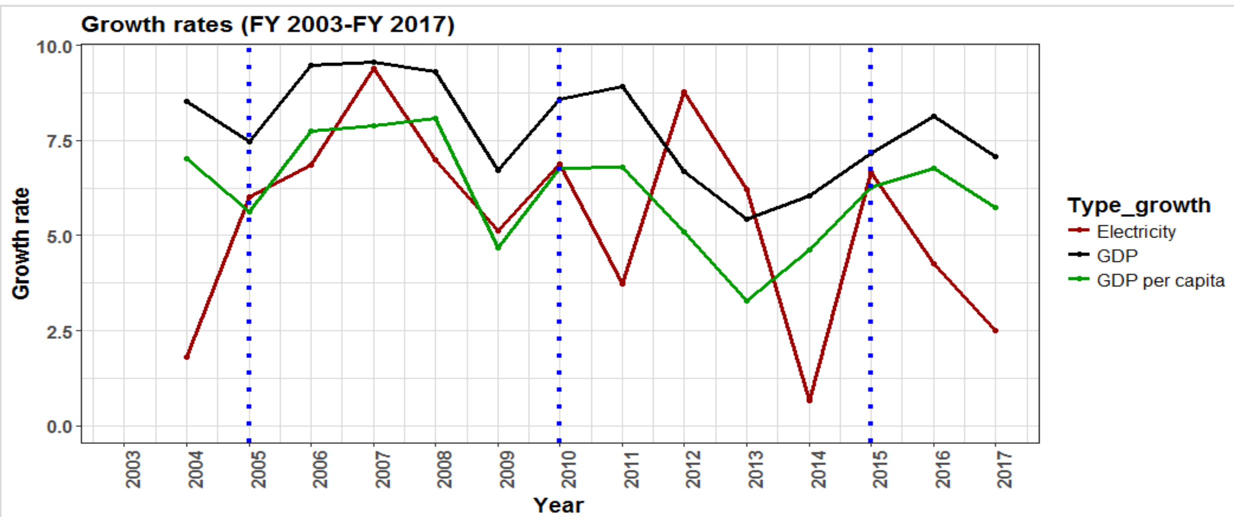
3.2.4 Time periods of structural change

For our analysis, we have divided the time period between FY 2002-03 to FY 2015-16 into four distinct time periods, according to the political scenario. It was observed from the data that a distinct pattern of growth seemed to emerge in the year 2015-16. There was a general increasing electricity demand trend for all states prior to the year 2014-15. However, the change of government at the centre in the year 2014-15 coincided with a change in pattern of electricity demand — there was very high growth for states such as Bihar, Goa and the north-eastern states compared to stagnant growth for states such as Delhi or Haryana.

It seems that a change of government at the centre brings about a change in policy regime and can be perceived as a structural time break. Therefore, the time periods of structural change have been defined on the basis of election years as: FY 2002-03 to FY 2003-04, FY 2004-05 to FY2008-09, FY 2009-10 to FY 2013-14 and FY 2014-15 to FY 2016-17.

The year-on-year growth rates for Electrical Energy Requirement, GDP and population during these periods are shown in the graph below:

Figure 3.15 Growth rates of Electrical Energy Requirement, GDP and population



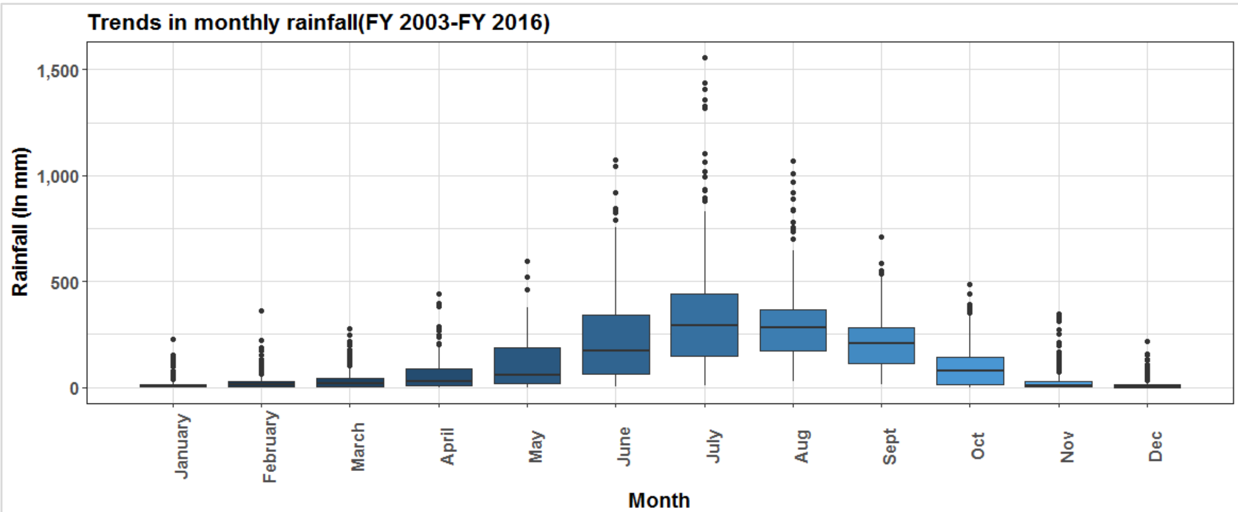
It is important to note that our model used for analysis in this report is at the level of the state and electricity is a state subject. While changes at the centre do influence electricity demand, equally critical would be the changes at the state level. Thus, the econometric model estimated in this study allows for a different response of electricity demand for different time periods for each state. This has been incorporated in the model by including state-specific time period dummies.

3.2.5 Monthly rainfall

As regards rainfall, electricity demand is expected to have a negative relationship with rainfall, i.e. as rainfall increases, demand is likely to fall. This is because we would expect rainfall to create more favourable weather conditions in most states, thereby reducing demand of electricity for cooling. In agricultural states, rainfall would reduce the use of irrigation pumps.

Thus, the dominant consumer segment in each state plays an important role in this relationship. Climate variables have a greater impact on demand in states where a significant portion of electricity consumption is attributed to domestic, commercial and agricultural consumers.

Figure 3.16 Trends in monthly rainfall

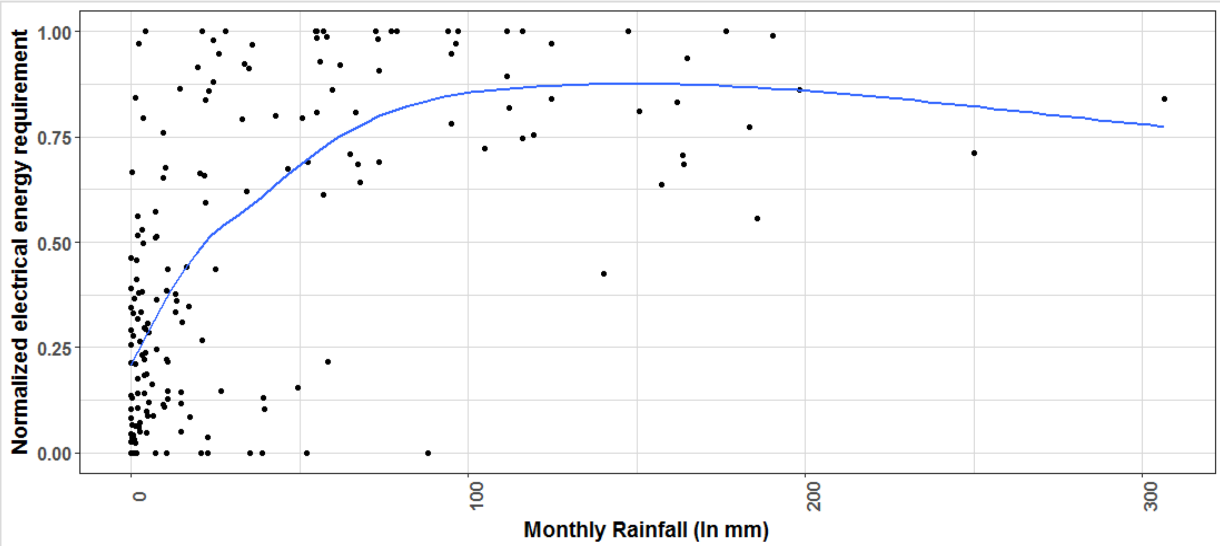


As can be observed in Figure 3.16, the monsoon months of June–Sept consistently receive the highest levels of rainfall, with the maximum rainfall being received particularly in July in terms of an all-India average.

The impact of rainfall on electricity demand varies by season, temperature, humidity and the level of rainfall. Figure 3.17 plots normalised electricity demand and monthly rainfall in Delhi as an illustrative case. The Electrical Energy Requirement is normalised by subtracting the yearly minimum observed value of demand in the respective year and dividing it by the observed yearly range (maximum demand minus minimum demand) of the Electrical Energy Requirement.

For rainfall levels less than 50 mm, the relationship seems relatively weak with high rainfall associated with both high and low electricity demand. At higher levels of rainfall, the relationship seems to be negative. In India, generally, higher rainfall is experienced during summer and thus associated with higher temperature and humidity. To estimate the non-linear impact of rainfall on electricity demand, rainfall variable is categorised into four different groups: rainfall between 0-50 mm, 50-100 mm, 100-200 mm and above 200 mm. The estimated electricity demand model discussed in the next chapter estimates different electricity demand responses for these categories.

Figure 3.17: Normalised Electrical Energy Requirement and monthly rainfall for Delhi (FY 2016)



3.2.6 Temperature variables: HDDs and CDDs

To capture the non-linear impact of temperature on electricity demand, degree day approach has been adopted. Monthly HDDs/CDDs represent the number of days in a month on which the temperature is respectively below/above the threshold cooling/heating point and by how many degrees. The threshold is a point over or under which the heating or cooling appliances will be switched on. HDD, CDD and threshold points are all measured in degree Celsius. It is important to note that electricity equipment penetration is an important factor for the impact of high HDD/CDD to translate into higher electricity demand. If there is minimal penetration such that heating or cooling equipment are not available to the people during low and high temperature, respectively, then electricity demand will not be very sensitive to these weather variables.

Daily HDD and CDD may be defined as follows:

$\boldsymbol{HDD_d}$ = max (0, $T*-Tt$)

$\boldsymbol{CDD_d}$ = max (0, $Tt-T*$)

Where, d is a specific day in a particular month, T* is the threshold temperature of cold or heat, and Tt the observed temperature on day t. This provides the sum of daily HDD and CDD in a given month. Monthly HDD and CDD, which represents the number of days in each month where the temperature is below or above the threshold, are computed as follows:

$\boldsymbol{MHDD} = \Sigma HDD_{dm}$

$\boldsymbol{MCDD} = \Sigma \boldsymbol{CDDd}$m

All references to CDD and HDD here forth will imply monthly HDD and CDD (MHDD and MCDD).

With reference to the analysis conducted in the research study by Gupta (2016)[8], the threshold temperature for India has been assumed to be 21°C for the construction of monthly CDD and HDD for all states. Figure 3.18 and Figure 3.19 give trends in CDD and HDD for all state-level temperature observations for the period FY 2002-03 to FY 2015-16.

Figure 3.18 Trends in CDD

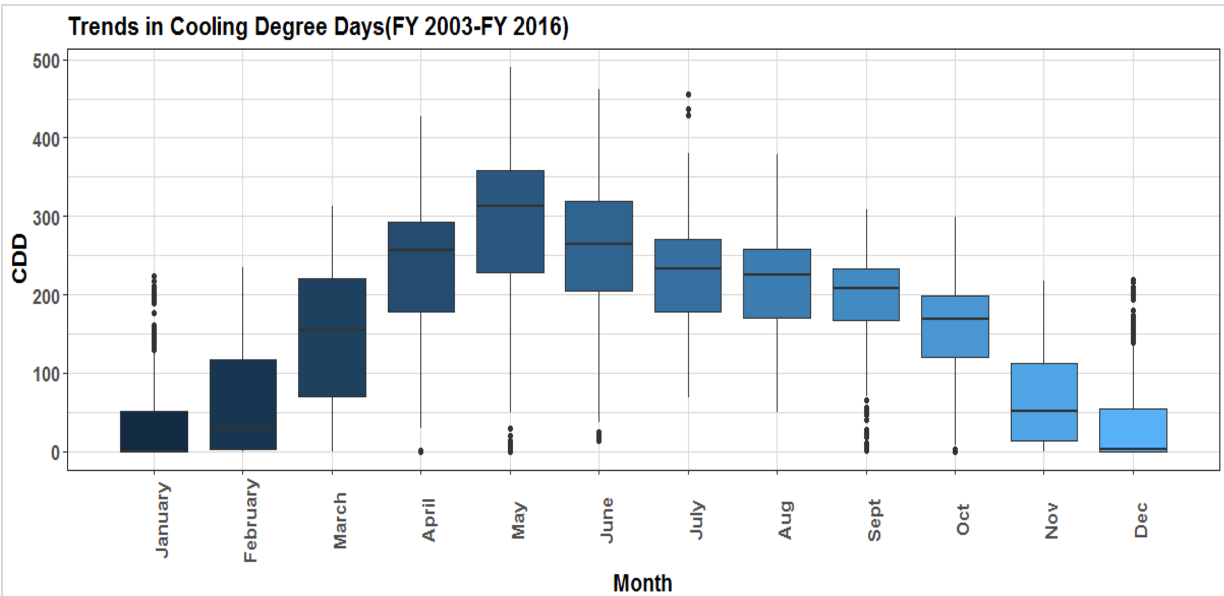


Figure 3.19 Trends in HDD

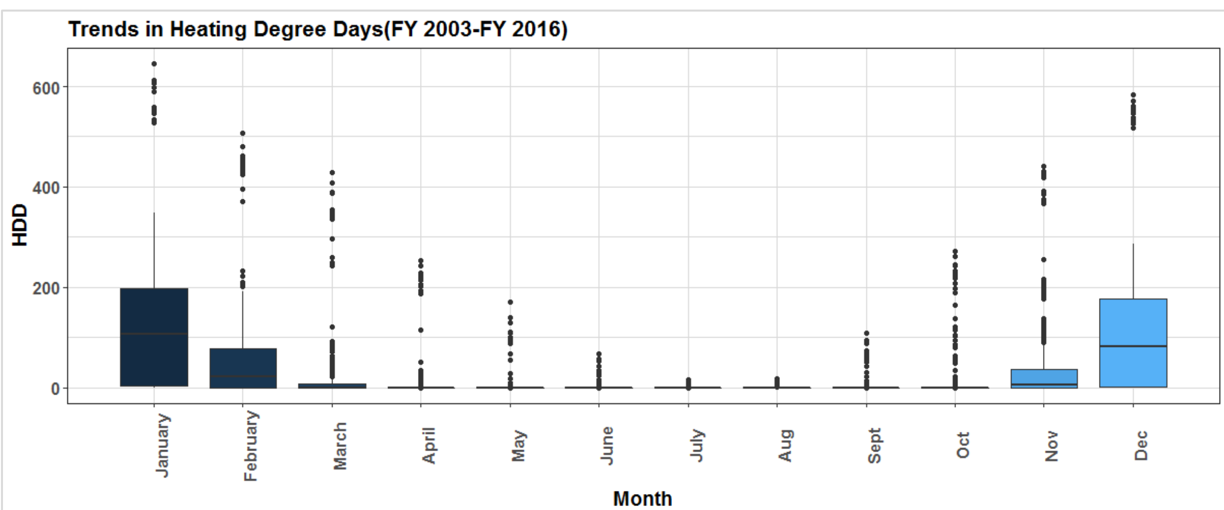


Table 3.1 shows that there is a significant difference in mean CDD across states. While Andhra Pradesh, Rajasthan, Tamil Nadu, Kerala and Telangana have mean monthly CDD above 200, other states such as

[8] Gupta, E., 2016. The effect of development on the climate sensitivity of electricity demand in India. *Climate Change Economics*, *7*(02), p.1650003.

Uttarakhand, Manipur, and Jammu and Kashmir clock mean monthly CDDs under 100. For majority of the states, however, CDD ranges between 150 and 200. Furthermore, variance in CDD differs even more drastically in some states over the others. This effectively means that a change in meteorological variables in these states will likely impact electricity demand more than other states which record lower variance. States with high standard deviation (>122.5) include Delhi, Haryana, Punjab, Rajasthan, Bihar and Uttar Pradesh.

HDD, on the other hand, also varies across states; however, the mean and variance, in this case, are as anticipated lower than CDDs. Jammu and Kashmir has the highest mean HDD in India. Variance, in this case, was also noted as significant. Uttarakhand, Punjab and Haryana also record HDD above 50 on average.

Table 3.1 State-wise trends in HDD, CDD and rainfall (FY 2003 - FY 2016)

State	HDD (degree Celsius)		Rainfall (mm)		CDD (degree Celsius)	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Andhra Pradesh	0.00	0.00	74.95	72.31	228.31	76.08
Arunachal Pradesh			201.43	175.33		
Assam	22.51	41.96	188.81	177.09	122.10	95.19
Bihar	27.61	55.51	93.71	117.52	179.47	128.15
Chhattisgarh	9.87	20.36	104.01	137.00	150.65	109.92
Chandigarh	69.96	105.01	39.97	54.99	144.33	133.33
Delhi	45.30	76.92	39.97	54.99	181.64	148.29
Goa	0.00	0.00	265.24	395.10	195.99	41.87
Gujarat	3.01	8.59	69.48	118.07	196.92	98.58
Himachal Pradesh			84.96	82.05		
Haryana	53.95	89.42	39.97	54.99	186.99	157.56
Jharkhand	21.09	39.51	98.01	117.48	147.39	108.43
Jammu and Kashmir	244.95	205.14	94.05	68.99	20.02	34.37
Karnataka	0.02	0.14	147.91	168.69	126.38	55.65
Kerala	0.00	0.00	241.89	236.78	209.15	30.51
Maharashtra	0.37	1.32	122.53	170.59	176.13	83.75
Meghalaya	22.51	41.96	188.81	177.09	122.10	95.19
Manipur	56.49	78.52	145.74	132.89	68.09	61.30
Madhya Pradesh	24.30	46.57	85.19	126.84	165.73	132.17
Mizoram	18.56	38.89	145.74	132.89	145.91	91.54
Nagaland	56.43	78.55	145.74	132.89	68.04	61.31
Orissa	4.54	11.03	125.03	147.21	185.29	106.70
Punjab	69.96	105.01	43.32	53.66	144.33	133.33
Puducherry	0.00	0.00	80.45	76.22	217.31	61.09
Rajasthan	28.15	53.77	39.49	63.06	207.92	153.34

State	HDD (degree Celsius)		Rainfall (mm)		CDD (degree Celsius)	
Sikkim			208.16	212.11		
Telangana	0.76	2.71	74.95	72.31	201.77	108.65
Tamil Nadu	0.00	0.00	80.45	76.22	217.31	61.09
Tripura	18.56	38.89	145.74	132.89	145.91	91.54
Uttarakhand	71.29	99.70	127.51	162.48	93.73	89.99
Uttar Pradesh	40.76	74.82	93.51	122.09	172.64	137.03
West Bengal	10.80	24.34	166.64	168.66	182.95	104.43

For the entire period FY 2003 to FY 2016, the national CDD average stands around 160 while the HDD average is about six.

The above degree-day approach estimates the non-linear relationship between electricity demand and temperature by a piece-wise linear function using two segments: one for the summer where the temperature is above the predetermined threshold temperature, and another one for winter where the temperature is below the same threshold temperature. This non-linear relationship between weather variables (CDD, HDD) and electricity demand is illustrated using the data for Delhi in Figures 3.20 and 3.21. The Electrical Energy Requirement is normalised by subtracting the yearly minimum observed value of demand in the respective year and dividing it by the observed yearly range (maximum demand minus minimum demand) of the Electrical Energy Requirement.

Figure 3.20 Normalized Electrical Energy Requirement and CDD (degree Celsius) for Delhi

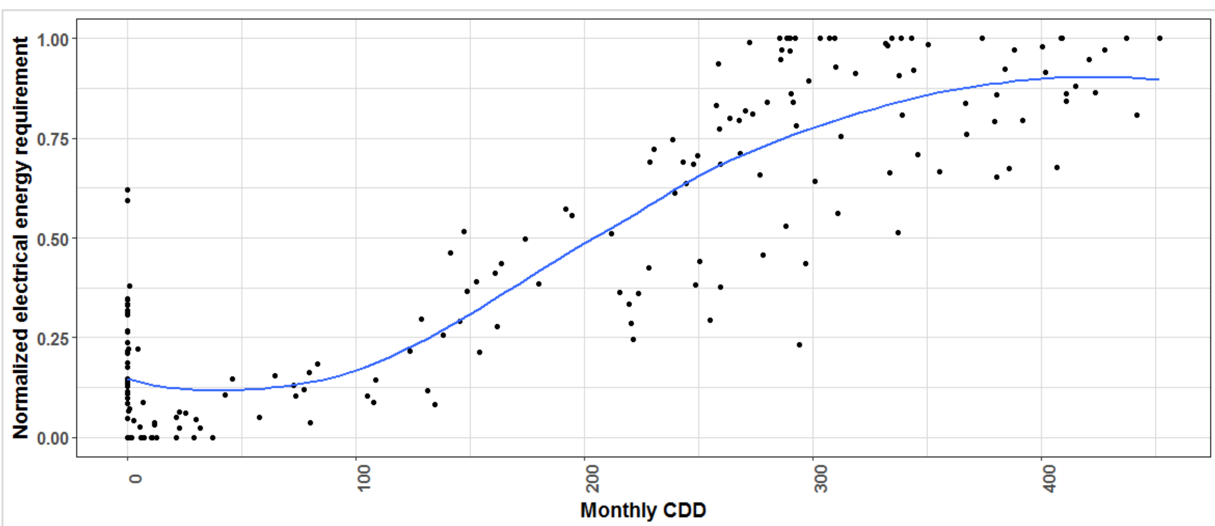
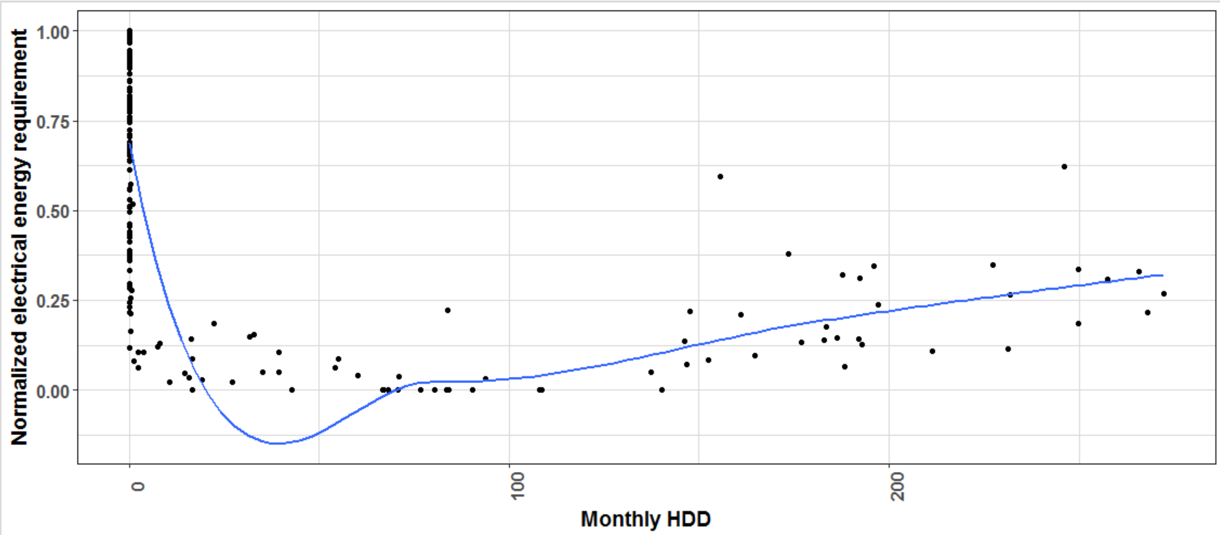


Figure 3.21 Normalized Electrical Energy Requirement and HDD (degree days) for Delhi



Choice of model for forecasting electricity demand and estimation of results

4

4. Choice of model for forecasting electricity demand and estimation of results

The details of estimation results of the various models estimated in Chapter 2 are discussed in this chapter. The most appropriate model is selected based on the criterion of out-sample prediction.

4.1 Estimation results

The estimated coefficients and associated standard errors for different electrical energy forecasting models (long panel, PAM and SUR) are shown in Tables (A3.1) – (A3.5) of Annexure 3. For long panel and PAM, six equations are estimated, one for each region and one for the all-India level. For the SUR model, 28 equations are estimated, one for each state.

R-square or coefficient of determination represents the proportion of the variance for a dependent variable explained by all the independent variables. It is a commonly used measure of goodness of fit of a linear model. The R-square of all the estimated models is high indicating that selected independent variables well explain electricity demand. All independent variables have expected signs (i.e., the impact of any variable to increase/decrease of the overall Electrical Energy Requirement or Peak Electricity Demand is as expected) and turn out to be statistically significant in all models except HDD. A change in one unit of the log of a variable[9] is approximately equal to a 1% change in its value. It is observed that the impact of different variables varies over time, regions and states. The impact of different variables on electricity demand from all models is discussed below.

4.1.1 Lagged electricity demand

Both electricity demand lagged by period one and electricity demand lagged by period 12 have positive and significant impact in PAM models. According to PAM for the total electricity requirement (Table A3.1), at the all-India level, the coefficient of electricity requirement lagged by period one is 0.61 and the coefficient of requirement lagged by period 12 is 0.08. This means that a 1% increase in the previous period Electrical Energy Requirement increases Electrical Energy Requirement in the current period by 0.61% while a 1% increase in Electrical Energy Requirement lagged by 12 periods increases Electrical Energy Requirement by 0.08%. The speed of adjustment for the model is obtained using the two coefficients corresponding to Electrical Energy Requirement lagged by 1 and 12 months. The short-run and long-run elasticities are related according to the following equation:

$$E_{LR} = \frac{E_{SR}}{1 - \beta_1 - \beta_{12}} = \frac{E_{SR}}{\Lambda}$$

[9] The logarithmic form of the variables have been used as the dependent variable and explanatory variables to run the model

The term $\frac{1}{\Lambda}$ indicates the fraction of the gap between the current electricity consumption and the equilibrium level of consumption that is closed every year. Therefore, the number of years required to bridge this gap towards the equilibrium value is indicated by Λ.

The estimated speed of adjustment of short-run deviation from the long-run equilibrium path is about 31% per annum at the all-India level. This implies that the short-run demand values will converge to the long-run equilibrium in 3.2 years. The speed of adjustment turns out to be the highest for the northern region at 42% per annum or 2.4 years and the lowest for the eastern region at 22% per annum or 4.5 years.

According to PAM for all-India Peak Electricity Demand (Table A3.5), at the all-India level, the coefficient of Peak Electricity Demand lagged by period one is 0.62. This means that a 1% increase in the previous period Peak Electricity Demand increases Peak Electricity Demand in the current period by 0.62%.

This result is very close to the result obtained for the total Electrical Energy Requirement. The estimated speed of adjustment of short-run deviation from the long-run equilibrium path is about 38% per annum at the all-India level. This implies that the short-run demand values will converge to the long-run equilibrium in 2.6 years.

4.1.2 Gross domestic product

Income has a positive sign in all models and has a statistically significant impact on the dependent variable (at 1% level of significance in all models). According to PAM model estimated for all-India panel for Electrical Energy Requirement, a 1% increase in the previous year's gross state domestic product results in about 0.23% increase in state’s Electrical Energy Requirement in the current period on an average. Since the short-run GDP elasticity is well below unity, GDP growth, just by itself, with everything else held constant, results in a much less than proportional increase in electricity demand. As expected, the elasticity turns out to be the lowest for western India, which comprises two rich and big states of India — Gujarat and Maharashtra. The elasticity in all other regions vary between 0.2 and 0.3.

The long-run elasticity level at all-India turns out to be same from both panel data models — PAM and long panel. The long-run elasticity of GDP at the all-India level is 0.74, which is more than three times the short-run elasticity of GDP. The elasticity is the lowest in the western region (0.48–0.49) and the highest in the eastern region (0.91–0.92).

Figure 4.1 and Figure 4.2 show that the state-level income (as measured by GDP or GDP per capita in SUR model) elasticities as estimated from the SUR model are in line with the above estimates from the two panel data models. High income elasticity of over 1 has been found in states such as Bihar, West Bengal and Chhattisgarh. As discussed in Chapter 3, relatively slower growth in electricity demand per capita has been observed in developed states and relatively faster growth in electricity demand per capita has been observed in developing states, indicating convergence in living standards over time. Figures A4.1–A4.4 in the appendix plot sectoral shares of electricity consumption for all states over time. For all the states with high income elasticity of demand, the share of the domestic consumption has increased significantly over time due to electrification of new households. Thus, the higher growth in electricity demand (due to expansion of rural electrification in the past) relative to growth in income during the same period resulted in high income elasticity for these states. In most of these states, commercial sectors such as, real estate and hotels have further contributed significantly to the increased demand over the period of analysis.

Figure 4.1 Income (GDP) Elasticity of Electrical Energy Requirement

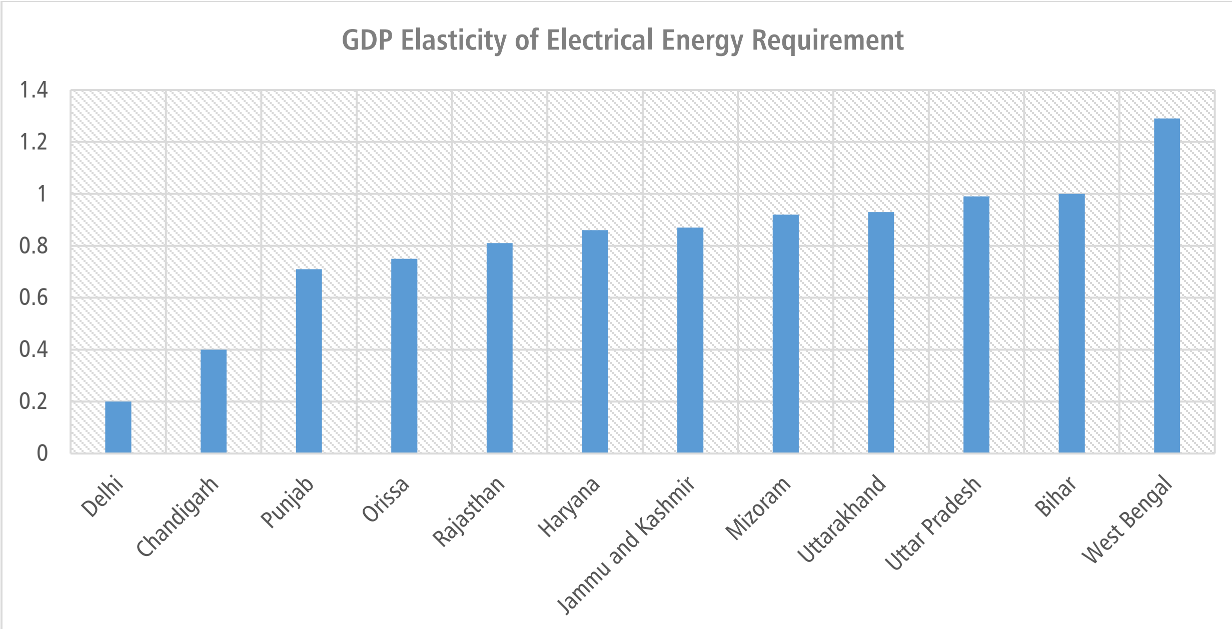
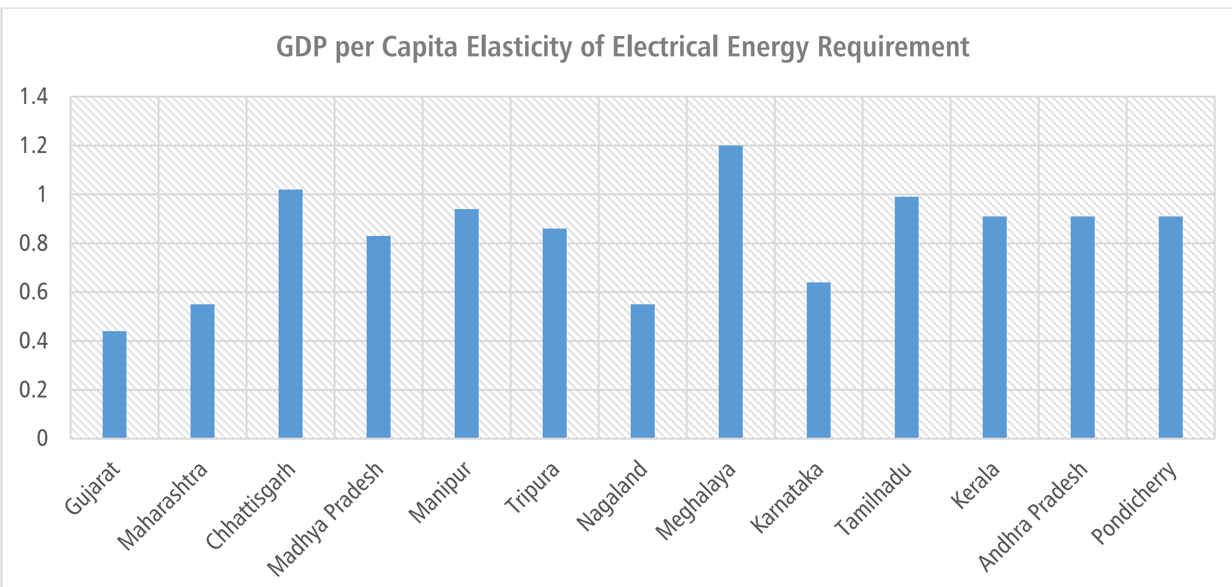


Figure 4.2 Income (GDP per Capita) Elasticity of Electrical Energy Requirement



According to PAM for all-India Peak Electricity Demand (Table A3.5), the coefficient of GDP is 0.25. This means that a 1% increase in GDP increases Peak Electricity Demand by 0.25% in the short-run. The estimated long-run Peak Electricity Demand elasticity at 0.66 is 2.6 times the short-run elasticity. As per state-level regional PAM (Table A3.4), the short-run GDP elasticity of Peak Electricity Demand at 0.09 turns out to be the lowest for the western region. For all other regions, it is between 0.17 and 0.21.

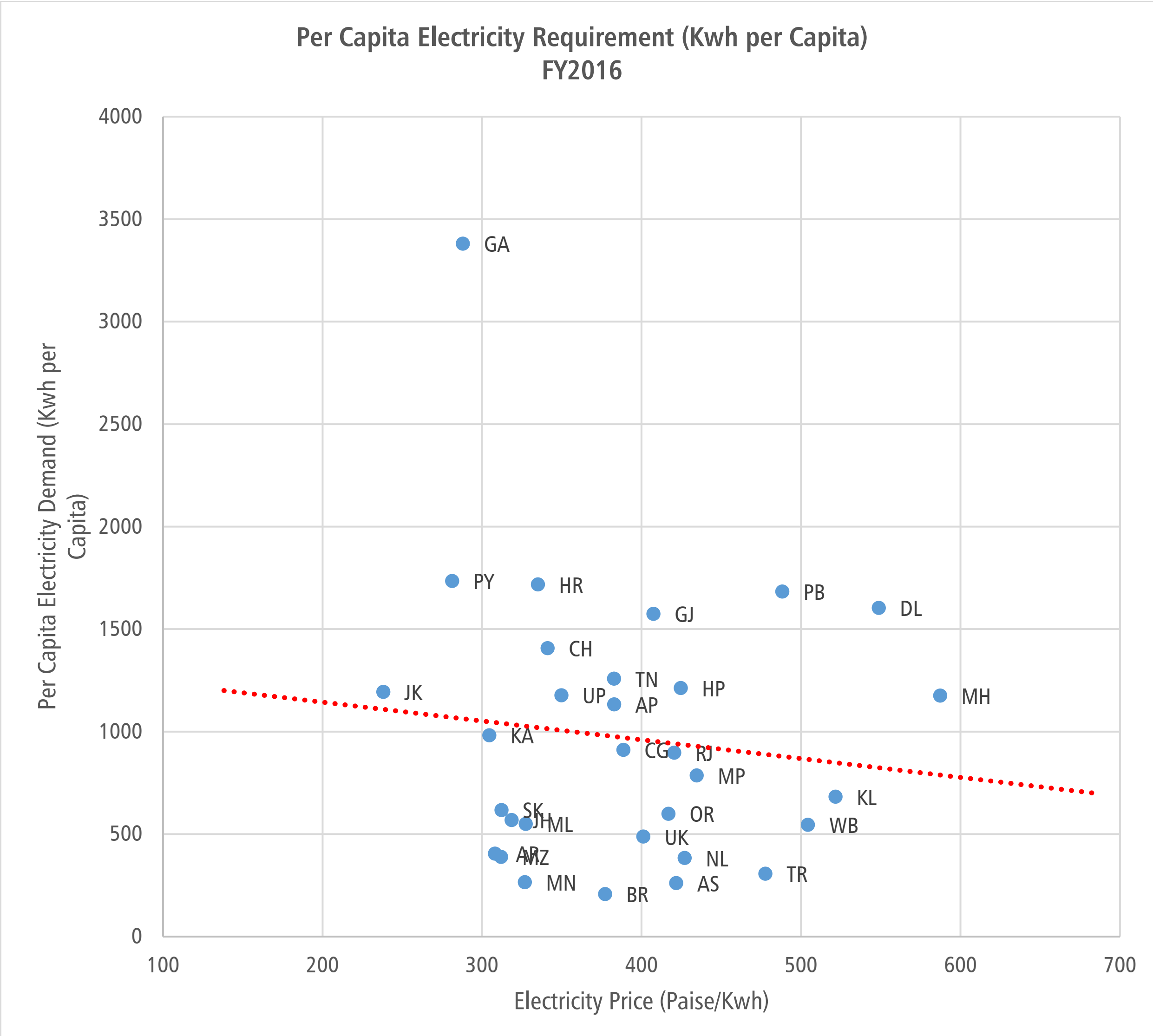
4.1.3 Real electricity price

As expected, real electricity price has a negative impact on electricity demand in all models. A 1% increase in real electricity price results in a small 0.02% decrease in the Electrical Energy Requirement at 15% level of significance in the short-run at the all-India level as estimated from PAM (Table A3.1). The long-run price elasticity at the all-India level at 0.06% is more than three times the short-run elasticity. A 1% increase in real electricity price results in about 0.06% decrease in Electrical Energy Requirement in the long-run vis-à-vis 0.02% in the short-run. This reinforces that electricity price increases will have much greater impact on lowering electricity demand in the long-run. This is expected as people are likely to adjust more to electricity price increases over time by switching to more energy efficient alternatives, alternative sources of energy (primarily renewables) and captive generation. Electricity demand is typically price inelastic for residential, small and medium industrial and commercial consumers; however, agriculture consumers and large industrial consumers would shift to solar-based pumps and captive generation, respectively.

Investments in solar pumps/captive generation are long-run decisions and impact grid electricity demand in the long-run — hence long-run elasticities are higher than short-run elasticities (the consumers are not able to respond very systematically to changes in retail electricity prices in the short-run).

Relatively small estimated impact of electricity price can be further inferred from the fact that electricity retail prices are 'regulated' and not discovered through a market mechanism, hence, the typical strong negative relation between price and demand may not be observed – the marginal utility from consumption of electricity by most consumers may be greater than the regulated prices (this is expected because electricity has typically served social objectives of the various governments). The negative and 'low' value of elasticity seems to be driven not so much by the 'response' to real electricity price by each state individually, but the model seems to be inferring it from the relationship across states. This is illustrated in Figure 4.3:

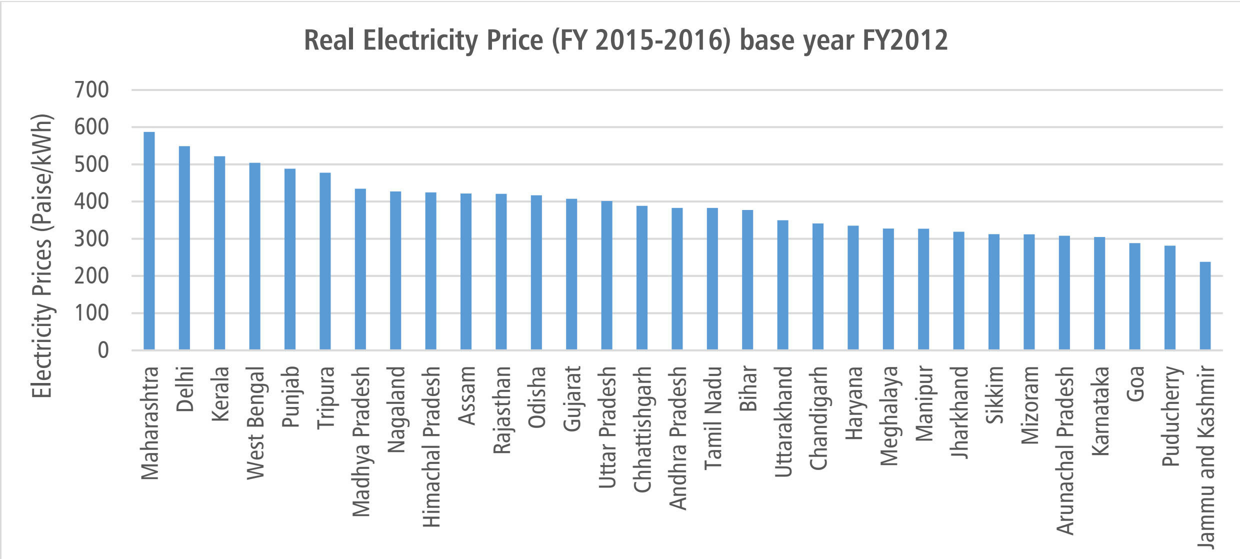
Figure 4.3 Per Capita Electrical Energy Requirement and Electricity Price (FY2016)



Note: Base year for real price calculation is FY 2012

An examination of the coefficients of region-specific models show that the price elasticity in short run is relatively higher than the all-India average in the southern (0.12) region and western region (0.07). This can possibly be explained by the relatively higher average real price in the western region (Figure 4.4). In addition, the greater captive generation in the industrial sector in the western and southern regions makes utility electricity demand more sensitive to price changes.

Figure 4.4 State Average Electricity Price

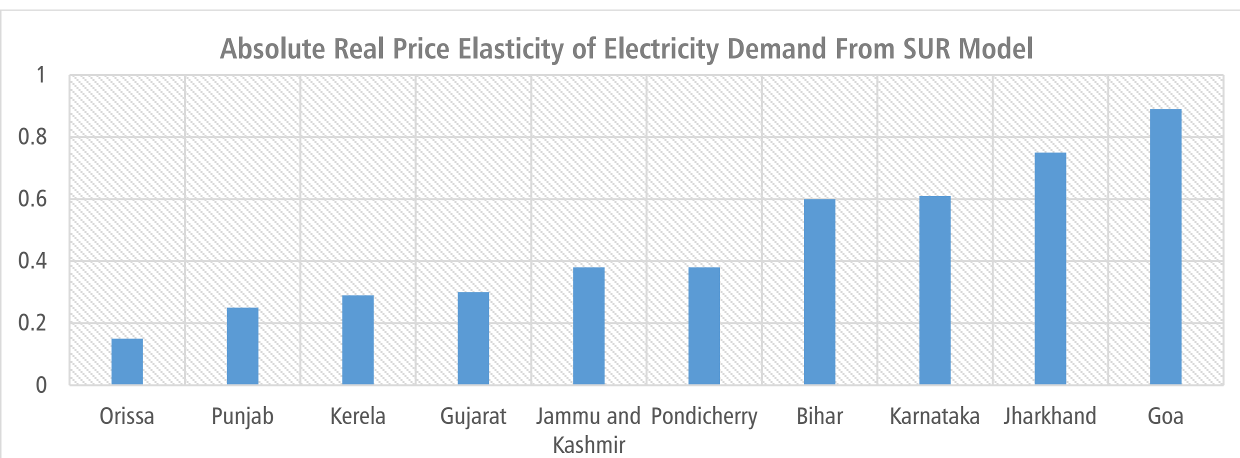


Note: Base year for real price calculation is FY 2012

As in the case of short-run price elasticities, the long-run elasticities also vary across regions (0.02–0.38) and states.

The state-level long-run price elasticities as estimated from the SUR model are plotted in Figure 4.5. High price elasticity has been found in states such as Bihar (-0.6), Jharkhand (-0.75), Karnataka (-0.61), Goa (-0.89).

Figure 4.5 Price Elasticity of Electrical Energy Requirement

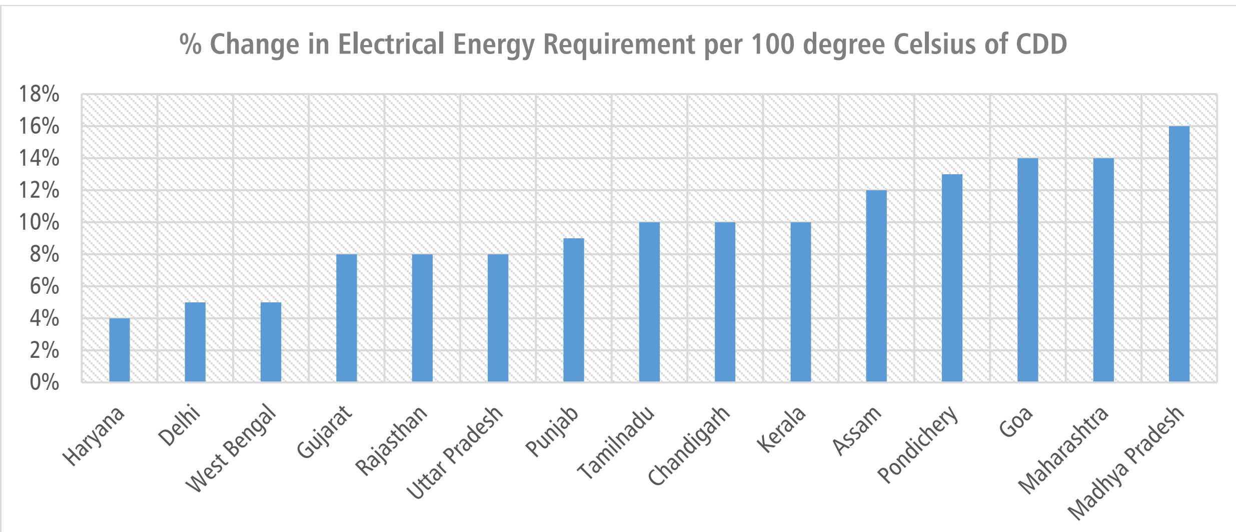


4.1.4 Cooling degree days (CDD)

The impact of CDD is positive and significant in most models. The estimated coefficient is 0.06 in short run. This implies that Electrical Energy Requirement increases by 6% per 100-degree Celsius increase in CDD in the short-run at the all-India level as per PAM (Table A3.1). The impact estimated is higher in relatively hot and rich regions in India — North (7%), West (7%) and South (7%).

The estimated long-run impact at the all-India level is higher from PAM (19.3% per 100 degree Celsius) than the long panel model (7% per 100 degree Celsius). Both models account for state-specific month dummies, which are correlated with temperature. This indicates that the month dummies absorb some impact of CDD in these models and make CDD coefficient relatively small. Dropping the month dummies is not advisable since they also capture many other omitted variables. From the SUR model, CDD has relatively higher impact in hot and rich states/UTs such as Maharashtra (14% per 100 degree Celsius), Gujarat (8% per 100 degree Celsius), Tamil Nadu (10% per 100 degree Celsius), Chandigarh (10% per 100 degree Celsius) and Punjab (9% per 100 degree Celsius) (Figure 4.6). In case of Assam higher percentage increase of demand per 100 degree Celsius can be attributed to higher share of domestic demand while in the case of Madhya Pradesh it can be attributed to higher share of agricultural sector and hot and humid temperature.

Figure 4.6 Impact of CDD on electricity demand



According to PAM for all-India Peak Electricity Demand (Table A3.5), the coefficient of CDD is 0.04 in short run. This means that Peak Electricity Demand increases by 4% in the short-run and 10% in the long-run every 100-degree Celsius increase in CDD. As per regional PAM (Table A3.4), the CDD impact on Peak Electricity Demand vary between 4% and 5% in the short-run for every 100-degree Celsius increase in CDD across different regions.

4.1.5 Heating degree days (HDD)

The impact of HDD is positive but insignificant in most models.

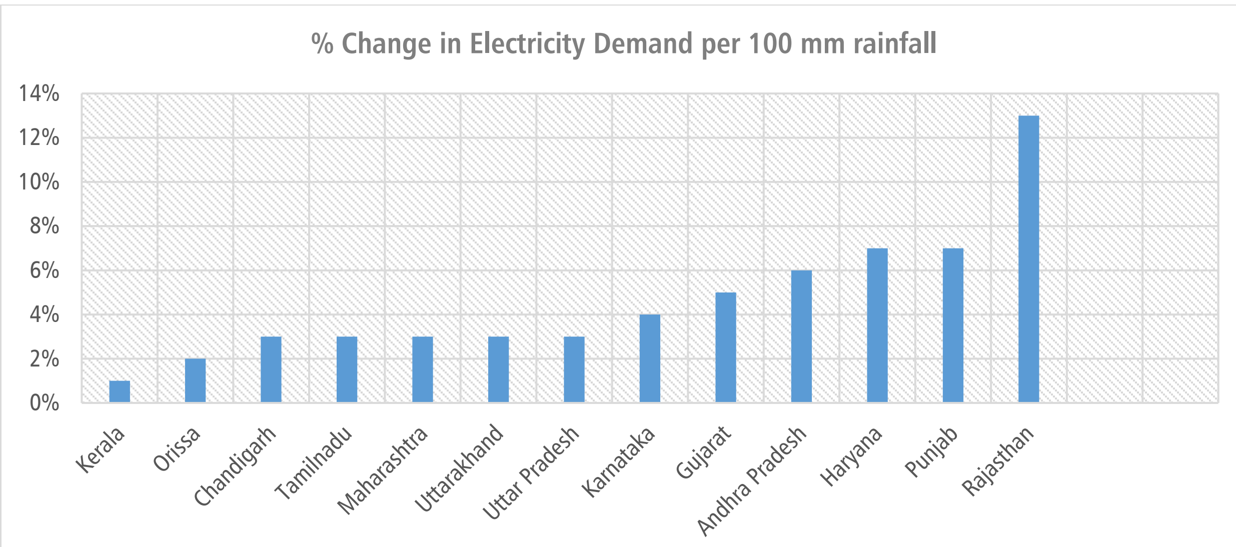
4.1.6 Rainfall

The impact of rainfall is negative and significant in most models. At the all-India level, the estimated impact of rainfall varies across different rainfall categories (as discussed in Chapter 2). It is observed that the reduction in electricity demand is higher when the level of rainfall is lower. A one unit (100 mm) increase in rainfall results in 6% reduction in demand when rainfall is in the range of 0–50 mm, 4% reduction when rainfall is in the range of 50–100 mm, 3% reduction when rainfall is in the range of 100–150 mm and 2% reduction when rainfall is above

200 mm (Table A3.1). In India, higher rainfall generally occurs during summer when temperature and humidity are high. Thus, an increase in rainfall during summer may reduce load lesser than in winter. In addition, the agricultural load is very high in many states during winter. Higher rainfall during winter can significantly reduce the agricultural load due to pumps. The estimated impact of rainfall turns out to be the highest in the northern region due to the high agricultural load.

The estimated average long-run impact at the all-India level in all four categories is 12% reduction in electricity demand with one unit (100 mm) increase in rainfall. The impact of rainfall varies across states (Figure 4.7). The results from the SUR model confirms the above findings as the highest impact of rainfall is observed in the northern agricultural states such as Rajasthan (13% per 100mm), Punjab (7% per 100mm) and Haryana (7% per 100mm).

Figure 4.7 Impact of Rainfall on Electrical Energy Requirement



According to PAM for all-India Peak Electricity Demand (Table A3.5), a one unit (100 mm) increase in rainfall results in 5% reduction when rainfall is in the range of 50–100 mm, 5% reduction when rainfall is in the range of 100–150 mm and 4% reduction when rainfall is above 200 mm.

4.2. Out-sample prediction and choice of the model

In the section above, the relationships between different variables are reported. However, a forecasting exercise is not just about explaining relationships but models also need to be tested on whether they are good in terms of using historical relationships to project into the future. One method to do this is to assume that one has data till, for example, FY 2014-15 and estimate the models using data from FY 2002-2003 to FY 2014-2015. Thereafter, forecasts for the period FY 2015-16 are made based on the estimated model and the one that fits the actual data for the period best, is the best model used for forecasting beyond FY 2015-16. It is found that PAM gives the lowest mean absolute percentage error at the all-India level and thus forecasts obtained from this model are the most recommended scenario (see Figure 4.8). Two versions of PAM were estimated — all-India panel model and regional level panel model. As the average Mean Absolute Percentage Error (MAPE) for PAM-all India is very close to PAM at the regional level, PAM at the regional level is selected as it performs better when we compare deviations of forecast demand (keeping weather and other explanatory variables same in both models) from actual demand at the all-India level during 2017 and 2018 (See Figure 4.8 and Figure 4.9). Figure 4.10, which plots the predicted Electrical Energy Requirement from PAM (regional) with actual Electrical Energy Requirement during FY 2002-03 to FY 2015-16, shows that the model fits the actual Electrical Energy Requirement quite closely.

Figure 4.8 Comparing MAPEs at All-India for all Estimated Models (%)

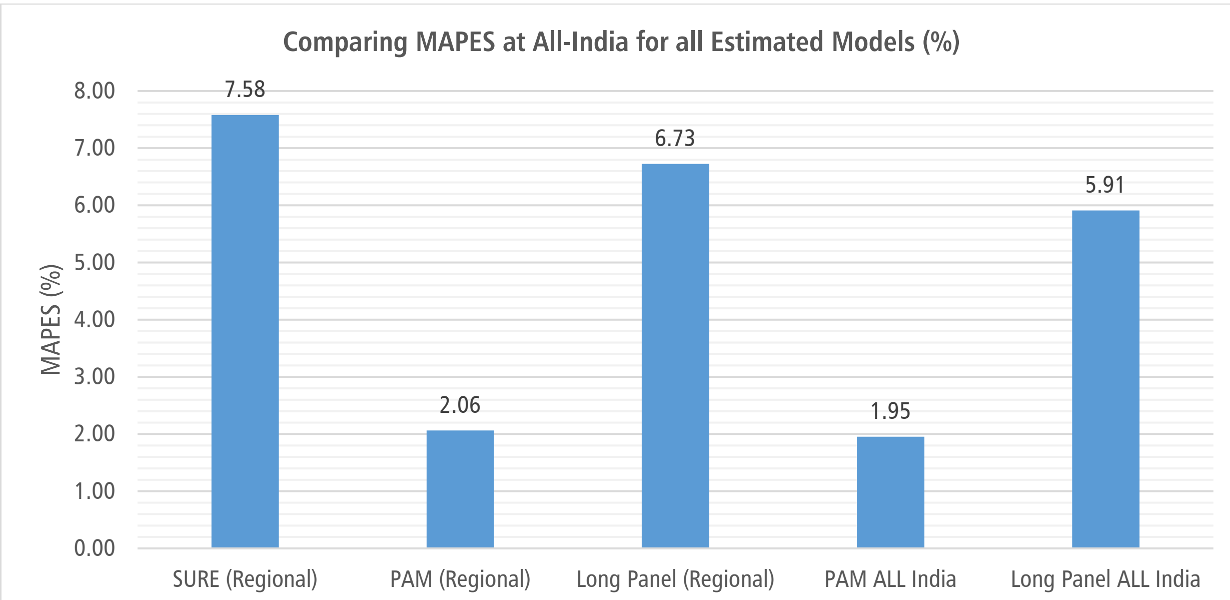


Figure 4.9 Comparison of All-India forecasts (PAM All India, PAM Region) with Actual

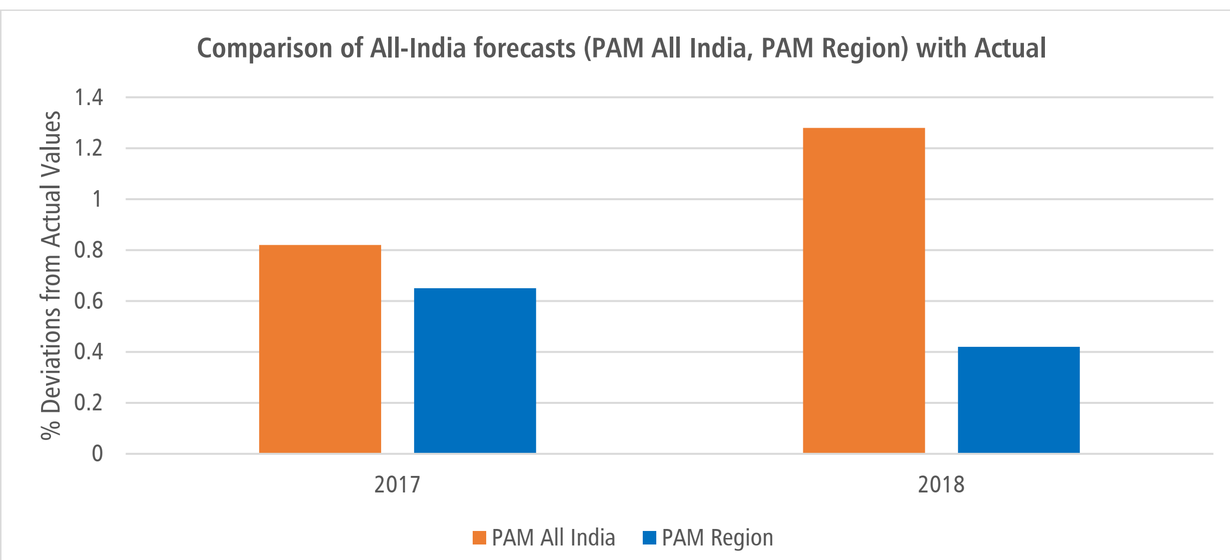
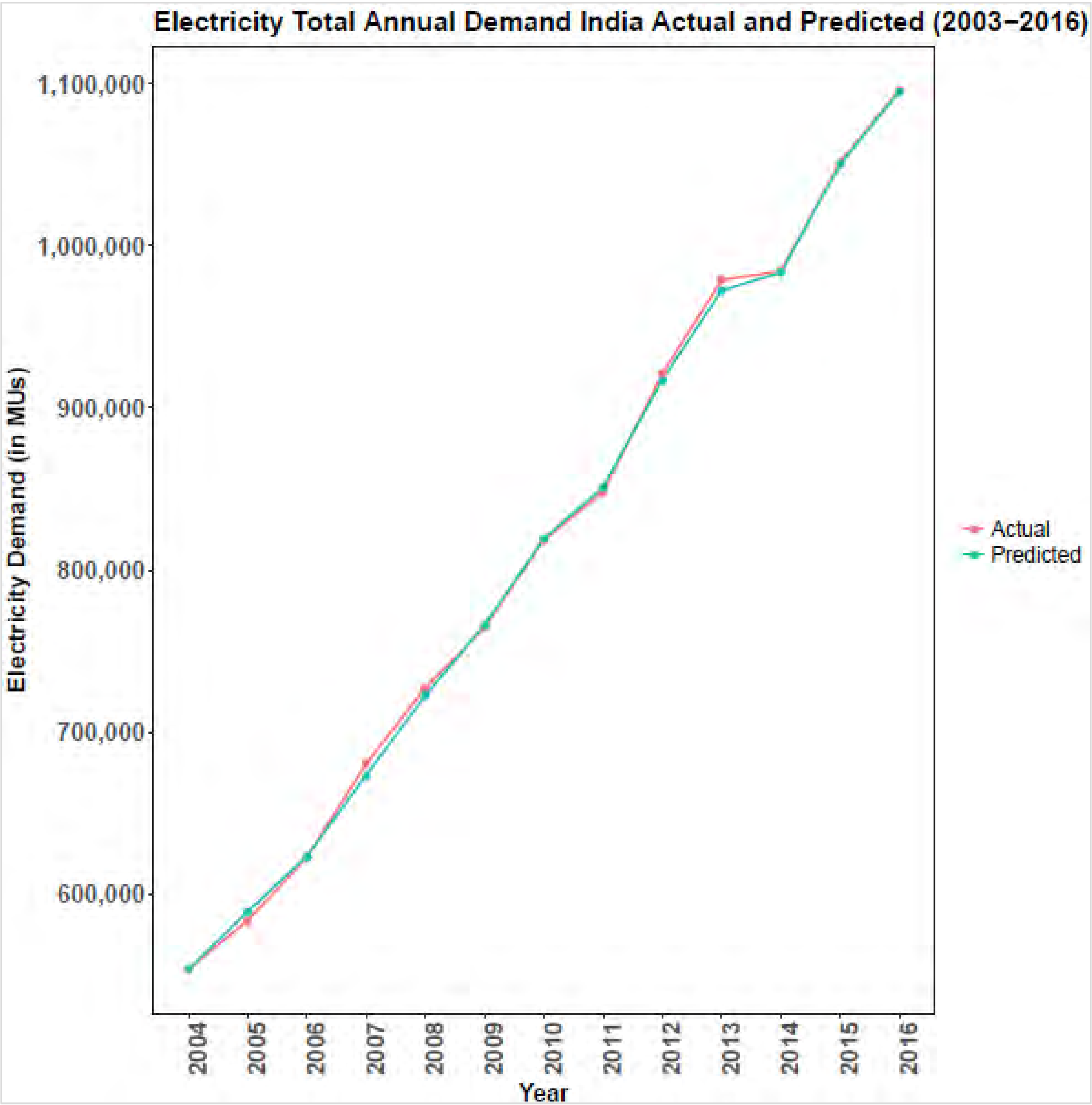
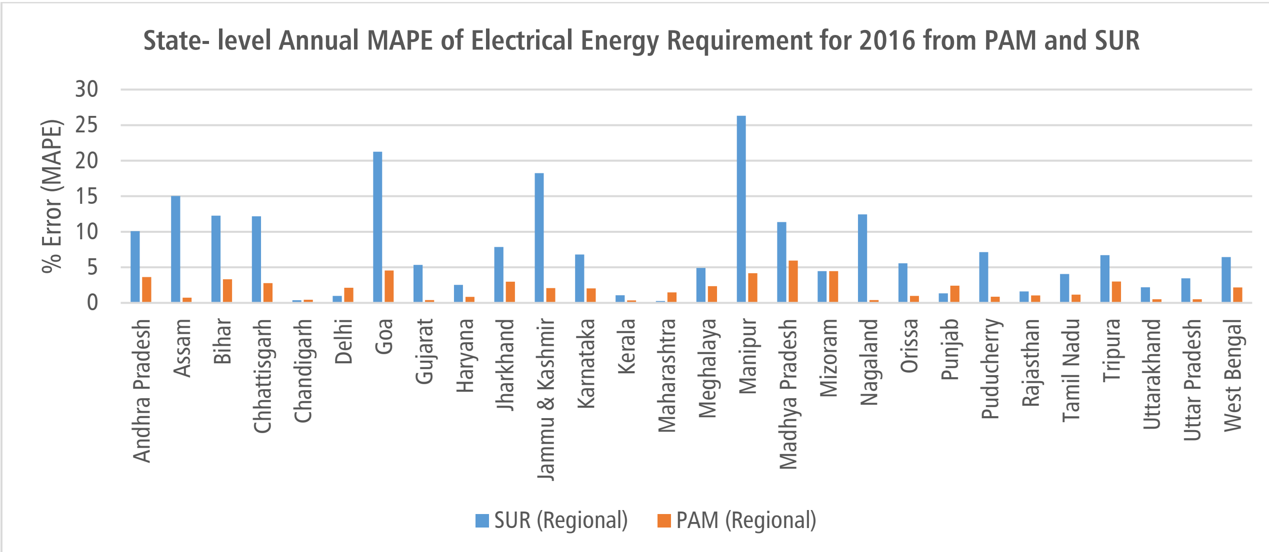


Figure 4.10 Electricity Total Annual Demand India Actual and Predicted from PAM (2003-2016)



For each state, two forecasts are obtained — one from regional PAM and another from the SUR model. While PAM estimates the future demand assuming regional convergence in the standard of living over time, the SUR model estimates state demand based on state-specific path observed in the previous period under study. Figure 4.11 shows that for many states PAM at the regional level outperforms the SUR model in terms of out sample MAPE for 2016. However, for some states/UTs such as Chandigarh, Delhi, Punjab and Maharashtra, the SUR model has lower MAPE as compared to PAM.

Figure 4.11 State-level Annual MAPE of Electrical Energy Requirement for 2016 from PAM and SUR



Electricity demand forecasts from FY 2016-17 to FY 2036-37

5

5. Electricity demand forecasts from 2016-17 to 2036-37

In this chapter, India's electricity demand (in terms of Electrical Energy Requirement and Peak Electricity Demand) is projected under three different GDP scenarios (Business As Usual, Optimistic and Pessimistic) and 14 different weather scenarios from Regional PAM (henceforth termed as "PAM" only) & SUR model.

In all future scenarios, it has been assumed that real electricity prices will remain constant at the 2015-16 level. On one hand, future electricity prices are expected to fall with increasing supply from renewables. On the other hand, prices are expected to increase with expected increase in transmission and distribution costs associated with renewables. Overall, the two effects in opposite direction are likely to offset each other and hence constant real prices have been assumed in future.

In all the future scenarios, population at the all-India level are expected to grow as per the medium growth scenario of the United Nations Development program (UNDP) (see Table A5.1 in the Annexure 5).

In all scenarios, for FY 2016-17 and FY 2017-18, the actual or provisional estimates of GDP are used. For FY 2016-17, the actual GDP (at constant prices) growth rate of 7.1% is obtained from the Ministry of Statistics and Programme Implementation (MOSPI). For FY 2017-18, the provisional estimate of GDP (at constant prices) growth rate of 6.6% is obtained from the MOSPI. For subsequent years, a different rate of growth for GDP has been assumed for different scenarios.

5.1 Business-as-Usual (BAU)

The **BAU** case assumes that GDP at the all-India level, used in the above model to forecast the future Electrical Energy Requirement and Peak Electricity Demand till the year 2036-37, will continue to grow at the average CAGR of about 7.3% obtained during FY 2000-01 to FY 2017-18, and there will be no significant deviations from these past trends. This may be considered as the most likely scenario. Under this scenario, for FY 2018-19, the expected growth rate of 7.5% in GDP has been taken from Niti Aayog. It is assumed that GDP rises gradually from 7.5% in FY 2018-19 to 8% till FY 2022-23, declines slowly to 7% in FY 2029-30 and thereafter grows at 7% per annum till FY 2036-37 (See Table A5.1 in the Annexure 5 for year-specific growth rate assumptions).

5.2 Scenario for faster growth of GDP

Niti Aayog aims to achieve relatively faster growth of 8% as compared to 7.3% achieved during FY 2000-01–FY 2017-18. Attaining the growth rate of 8% per annum on the sustained basis in the future would require concerted internal reforms to transform the structure of India's economy as well as favourable global environment. Policy reforms such as 'Make in India' can increase the stagnant share of the manufacturing sector and provide employment to a large pool of unskilled labour who are currently unemployed or partially employed.

5.3 Scenario for lower growth of GDP

The low growth scenario assumes that GDP rises by 6.5% every year between FY 2018-19 and FY 2036-37. In the recent years, there has been deceleration in the growth rate of GDP below 7%. The low growth scenario assumes this lower growth rate 6.5% to continue in future.

5.4 Forecast of Energy Requirement through PAM Model

In the BAU scenario for PAM, Electrical Energy Requirement is projected to increase at a CAGR of 4.86% for the period FY 2016-17 to FY 2036-37. Energy Requirement is projected to increase from 1152.4 BU in 2016-17 to 1886.9 BU in 2026-27, 2378.7 BU in 2031-32 and 2976.3 BU in 2036-37. Figure 5.1 and Table A5.2 present the total electricity requirement forecast for India from FY 2016-17 to FY 2036-37. Under the baseline scenario, Electrical Energy Requirement is likely to increase 2.58 times between FY 2016-17 and FY 2036-37.

In the optimistic scenario of 8% GDP growth, Electrical Energy Requirement is projected to increase at a CAGR of 5.2% for the period FY 2016-17 to FY 2036-37. Energy Requirement is projected to increase from 1152.4 BU in 2016-17 to 1905.5 BU in 2026-27, 2458.9 BU in 2031-32 and 3175.4 BU in 2036-37. Under the optimistic scenario, Electrical Energy Requirement is likely to increase 2.75 times between 2016-17 and 2036-37.

In the pessimistic scenario of 6.5 % GDP growth, Electrical Energy Requirement is projected to increase at a CAGR of 4.33% for the period FY 2016-17 to FY 2036-37. Energy Requirement is projected to increase from 1152.4 BU in 2016-17 to 1776.9 BU in 2026-27, 2186.7 BU in 2031-32 and 2691.07 BU in 2036-37. Figure 5.1 and Table A5.4 present the total electricity demand forecast for India during FY 2016-17–FY 2036-37. Under the low growth scenario, Electrical Energy Requirement is likely to increase 2.33 times between FY 2016-17 and FY 2036-37.

An overview of Electrical Energy Requirement (MU) and its CAGR for various scenarios are summarized in Table 5.1a and 5.1b below:

Table 5.1a Electrical Energy Requirement (in BU)

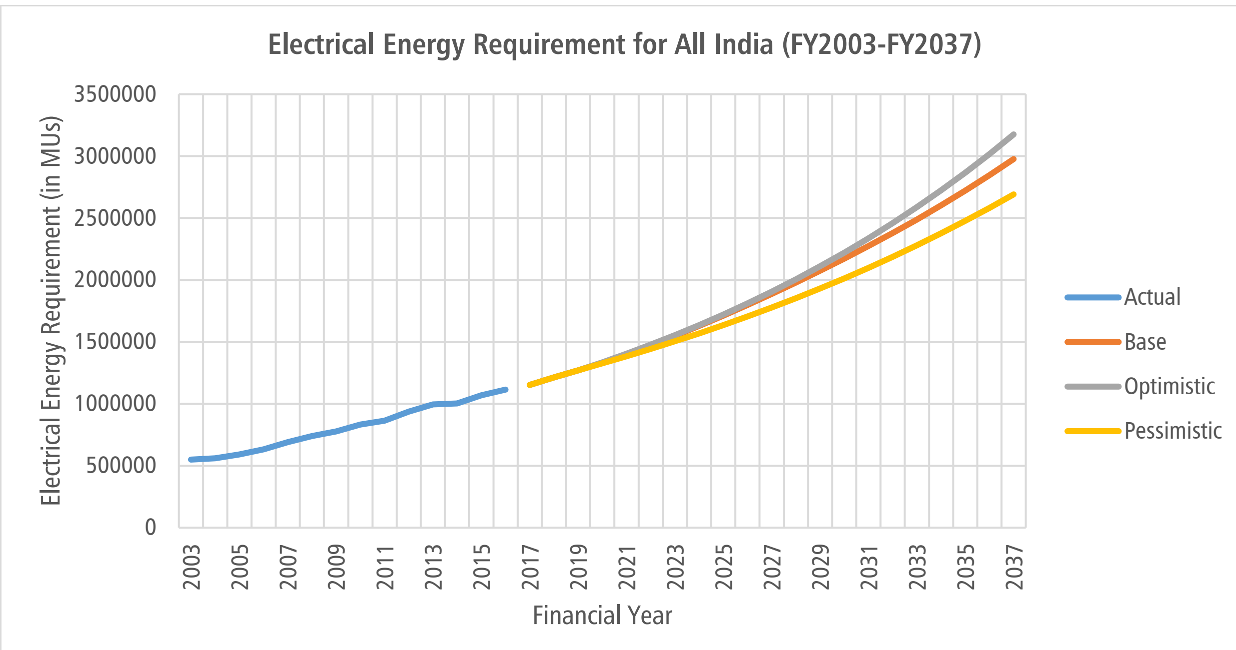
Year	7.3% GDP (BAU scenario)	8% GDP (optimistic scenario)	6.5% GDP (pessimistic scenario)	Projection by PEUM
2016-17	1152.4	1152.4	1152.4	1160.4
2021-22	1471.5	1477.5	1443.5	1566.0
2026-27	1886.9	1905.4	1776.9	2047.4
2031-32	2378.7	2458.9	2186.7	2530.5
2036-37	2976.3	3175.4	2691.07	3049.4

**All forecasts are reported for average weather conditions. See details of each scenario*

Table 5.1b: Electrical Energy Requirement CAGR (%) from PAM

Year	7.3% GDP (BAU scenario)	8% GDP (optimistic scenario)	6.5% GDP (pessimistic scenario)	Projection by PEUM
2016-17 to 2021-22	5.01	5.10	4.61	6.18
2021-22 to 2026-27	5.10	5.22	4.24	5.51
2016-17 to 2026-27	5.05	5.16	4.43	5.84
2026-27 to 2036-37	4.66	5.24	4.24	4.06
2016-17 to 2036-37	4.86	5.20	4.33	4.95

Figure 5.1 Electrical Energy Requirement under all scenarios



5.5 Forecast of Peak Electricity Demand through PAM Model

In the BAU scenario, all-India Peak Electricity Demand is projected to increase at an average annual rate of 4.7% from 158.9 GW in 2016-17 to reach 255.9 GW in 2026-27, 319.7 GW in 2031-32 and 398.1 GW in 2036-37. Figure 5.2 and Tables (A5.5–A5.7) present Peak Electricity Demand forecast for India during FY 2016-17–FY 2036-37. Under the baseline scenario, all-India Peak Electricity Demand is likely to increase 2.5 times between FY 2016-17 and FY 2036-37.

An overview of Peak Electricity Demand (MW) for various future periods is shown in Figure 5.2 and Table 5.2 below:

Figure 5.2 Peak Electricity Demand

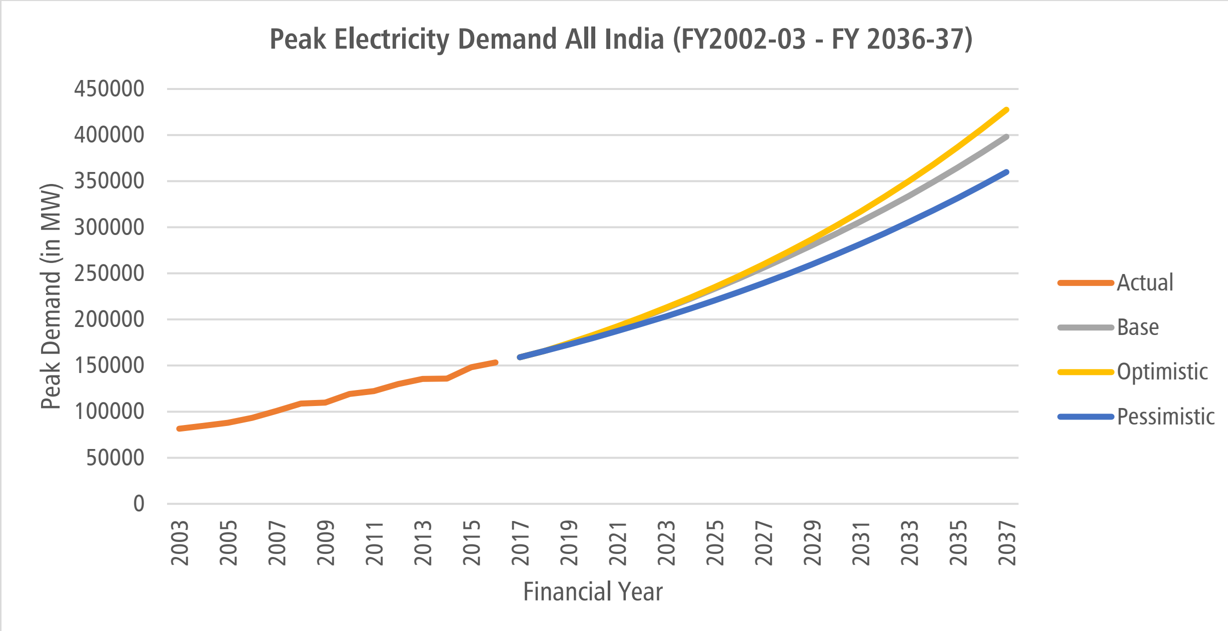


Table 5.2 Peak Electricity Demand (in MW)

Year	7.3% GDP (BAU scenario)	8% GDP (optimistic scenario)	6.5% GDP (pessimistic scenario)	Projection by PEUM
2016-17	158,994	158,994	158,994	161,834
2021-22	201,481	202,330	195,133	225,751
2026-27	255,911	259,628	239,299	298,774
2031-32	319,794	333,152	293,462	370,462
2036-37	398,172	427,497	359,882	447,702

**All forecasts are reported for average weather conditions. See details of each scenario*

5.6 Forecast of Energy Requirement through SUR Model

All-India electricity demand forecasts as based on the regional SUR model under three different GDP scenarios-baseline or business-as-usual (BAU) scenario, optimistic scenario and pessimistic scenario are discussed below:

An overview of Electrical Energy Requirement (Billion Units (BU)) and CAGR (%) for various scenarios is shown in Table 5.3 and Table 5.4 below:

Table 5.3: Electrical Energy Requirement (in BU) from SUR

Year	7.3% GDP (BAU scenario)	8% GDP (optimistic scenario)	6.5% GDP (pessimistic scenario)	Projection by PEUM
2016-17	1188.2	1188.2	1188.2	1160.4
2021-22	1550.0	1558.3	1488.2	1566.0
2026-27	2056.4	2095.7	1884.5	2047.4
2031-32	2685.1	2836.8	2395.4	2530.5
2036-37	3517.4	3878.2	3066.8	3049.4

**All forecasts are reported for average weather conditions. See details of each scenario.*

Table 5.4: Electrical Energy Requirement CAGR (%) from SUR

Year	7.3% GDP (BAU scenario)	8% GDP (optimistic scenario)	6.5% GDP (pessimistic scenario)	Projection by PEUM
2016-17 to 2021-22	5.46	5.57	4.61	6.18
2021-22 to 2026-27	5.82	6.1	4.83	5.51
2016-17 to 2026-27	5.64	5.84	4.72	5.84
2026-27 to 2036-37	5.51	6.35	4.99	4.06
2016-17 to 2036-37	5.58	6.09	4.86	4.95

In the BAU scenario of 7.3% GDP growth, Electrical Energy Requirement is projected to increase at a CAGR of 5.58% from 1188.2 BU in 2016-17 to reach 2056.4 BU in 2026-27, 2685.1 BU in 2031-32 and 3517.4 BU in 2036-37. Under this baseline, Electrical Energy Requirement is likely to increase 2.96 times between FY 2016-17 and FY 2036-37.

In the optimistic scenario of 8% GDP growth, Electrical Energy Requirement is projected to increase at a CAGR of over 6.09% from 1188.2 BU in 2016-17 to reach 2095.7 BU in 2026-27, 2836.8 BU in 2031-32 and 3878.2 BU in 2036-37. Under this optimistic, Electrical Energy Requirement is likely to increase 3.26 times between 2016-17 and 2036-37.

In the low growth scenario of 6.5% growth, Electrical Energy Requirement is projected to increase at a CAGR of over 4.86% from 1188.2 BU in 2016-17 to reach 1884.5 BU in 2026-27, 2395.4 BU in 2031-32 and 3066.8 BU in 2036-37. Under this low growth scenario, Electrical Energy Requirement is likely to increase 2.58 times between 2016-17 and 2036-37.

5.7 Forecast of Peak Electricity Demand through SUR Model

An overview of Peak Electricity Demand (Megawatt (MW) for various future periods is shown in Table 5.5 below:

Table 5.5: Peak Electricity Demand (in MW) from SUR

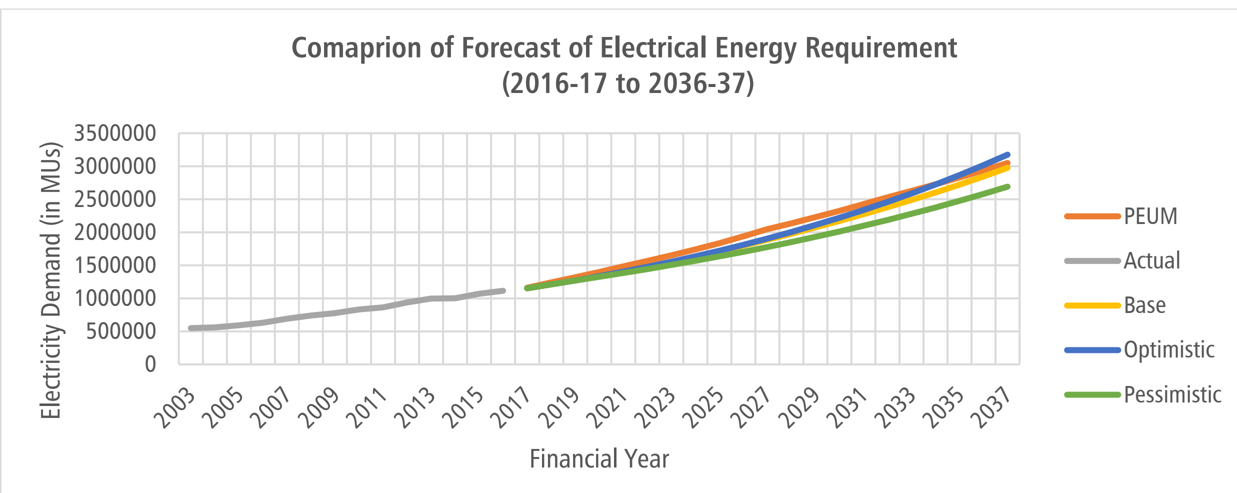
Year	7.3% GDP (BAU scenario)	8% GDP (optimistic scenario)	6.5% GDP (pessimistic scenario)	Projection by PEUM
2016-17	163,148	163,148	163,148	161,834
2021-22	212,828	213,972	204,340	225,751
2026-27	282,361	287,751	258,747	298,774
2031-32	368,683	389,512	328,904	370,462
2036-37	482,950	532,495	421,081	447,702

**All forecasts are reported for average weather conditions. See details of each scenario.*

5.8 Comparison of econometric method forecasts with 19th EPS forecasts by PEUM

The difference in the forecast of Electrical Energy Requirement by PEUM and econometric method forecast from PAM for FY 2016-17–FY 2036-37 is shown in Figure 5.3.

Figure 5.3 Comparison of forecast Electrical Energy Requirement (19th EPS using PEUM vs PAM forecast)



The table below shows the difference in percentage between 19th EPS forecast by PEUM and econometric forecast from PAM.

Table 5.6 Difference in percentage between 19th EPS forecast by PEUM and PAM forecast (Electrical Energy Requirement)

Year	7.3% GDP (BAU scenario)	8% GDP (Optimistic Scenario)	6.5% GDP (Pessimistic Scenario)
2016-17	-0.69	-0.69	-0.69
2026-27	-7.8	-6.9	-13.2
2031-32	-6	-2.8	-13.5
2036-37	-2.4	4	-11.75

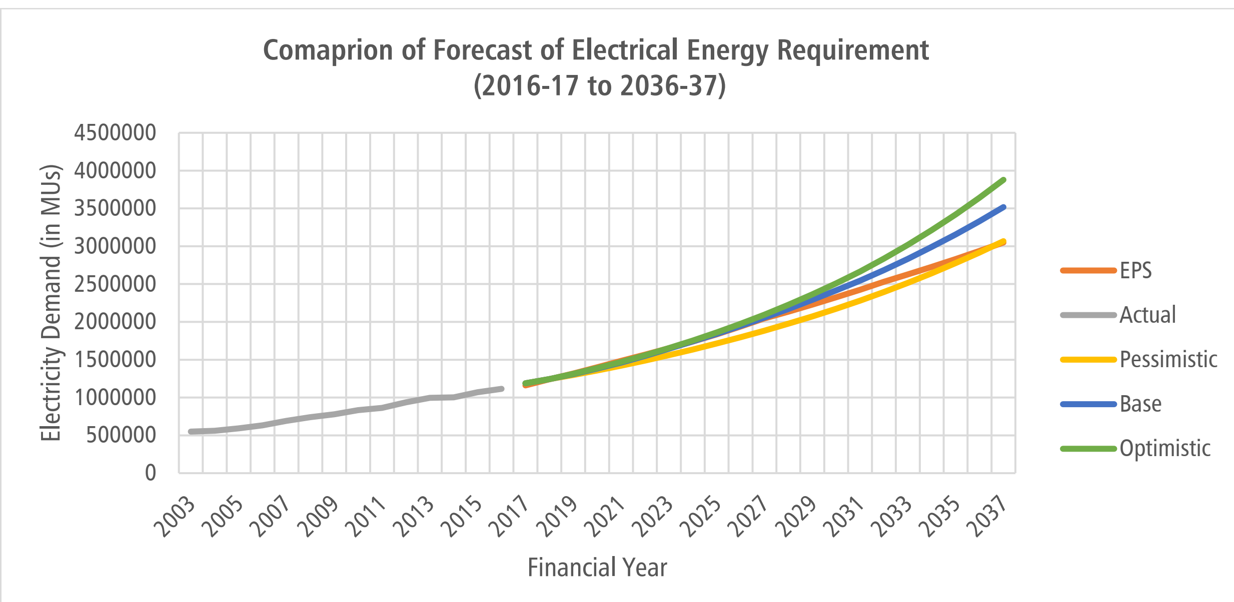
**All forecasts are reported for average weather conditions. See details of each scenario*

An analysis of the differences between the econometric forecasts and the 19th EPS forecasts by PEUM vis-à-vis PAM forecasts yields that 19th EPS forecasts by PEUM are higher than both the BAU and the higher GDP growth scenario till FY 2031-32. For the years beyond 2031-32, the econometric method forecasts under the BAU scenario and the higher growth scenario compare favourably to the 19th EPS forecast by PEUM.

An analysis of the differences between the econometric forecasts under SUR and the 19th EPS forecasts by PEUM yields that the 19th EPS forecasts by PEUM compare closely to the BAU till FY 2031-32. For the years beyond 2031-32, the econometric method forecasts by SUR under the BAU and the higher growth scenario diverge significantly from the 19th EPS forecast by PEUM and forecasts under pessimistic scenario compare favourably with the 19th EPS forecast by PEUM.

The difference in the forecast of Electrical Energy Requirement by PEUM and econometric method forecast from SURE for FY 2016-17–FY 2036-37 is shown in Figure 5.4.

Figure 5.4 Comparison of forecast Electrical Energy Requirement (19th EPS using PEUM vs SURE forecast)



The table below shows the difference in percentage between 19th EPS forecast by PEUM and econometric forecast from SURE.

Table 5.7 Difference in percentage between 19th EPS forecast by PEUM and SURE forecast (Electrical Energy Requirement)

Year	7.3% GDP (BAU scenario)	8% GDP (Optimistic Scenario)	6.5% GDP (Pessimistic Scenario)
2016-17	-2.39	-2.39	-2.39
2026-27	-0.44	-2.36	7.96
2031-32	-6.11	-12.10	5.33
2036-37	-15.34	-27.18	-0.57

**All forecasts are reported for average weather conditions. See details of each scenario*

Figure 5.5, Figure 5.6 and Figure 5.7 compare econometric forecasts under BAU scenario and the forecasts by PEUM with the actual Electrical Energy Requirement in India in FY 2016-17 and FY 2017-18. It is observed that econometric forecasts are closer to the actual Electrical Energy Requirement observed during both these years. The 19th EPS forecasts using PEUM are higher than the actual Electrical Energy Requirement in both these years (1.5% in FY 2016-17 and 2.2% in FY 2017-18). The econometric forecasts from PAM are higher than the actual Electrical Energy Requirement in FY 2016-17 (by 0.7%) and almost equal to the actual Electrical Energy Requirement in 2017-18 (with deviation of -0.06%). At the state level, it is observed that for some states econometric method forecasts are closer to the actual values of Electrical Energy Requirement, while EPS forecasts by PEUM are closer to the actual Electrical Energy Requirement (for example: Tamil Nadu and Haryana). The econometric method forecasts from SUR are higher than the actual Electrical Energy Requirement in FY 2016-17 (by 3.96%) and in FY 2017-18 (by 2.43%).

Figure 5.5 Comparison of forecasted Electrical Energy Requirement (19th EPS using PEUM vs econometric method forecasts)

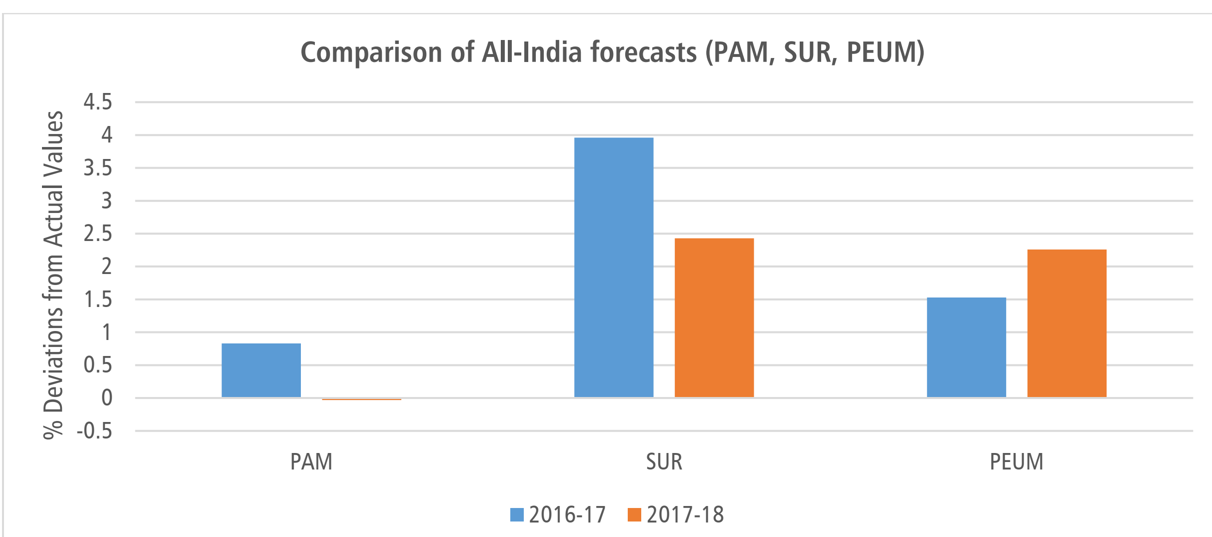


Figure 5.6 Difference in percentage between state-level forecasts and actual Electrical Energy Requirement in 2016-17

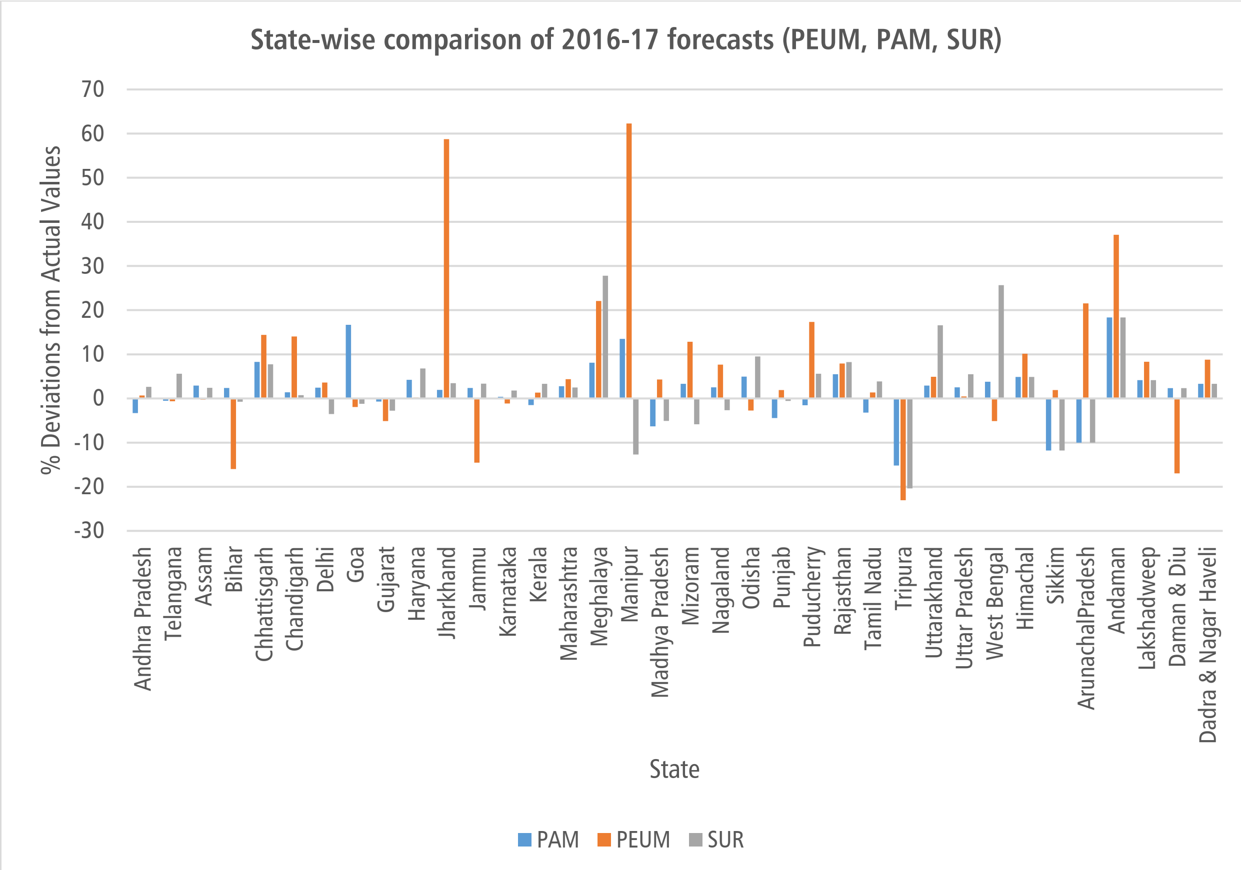
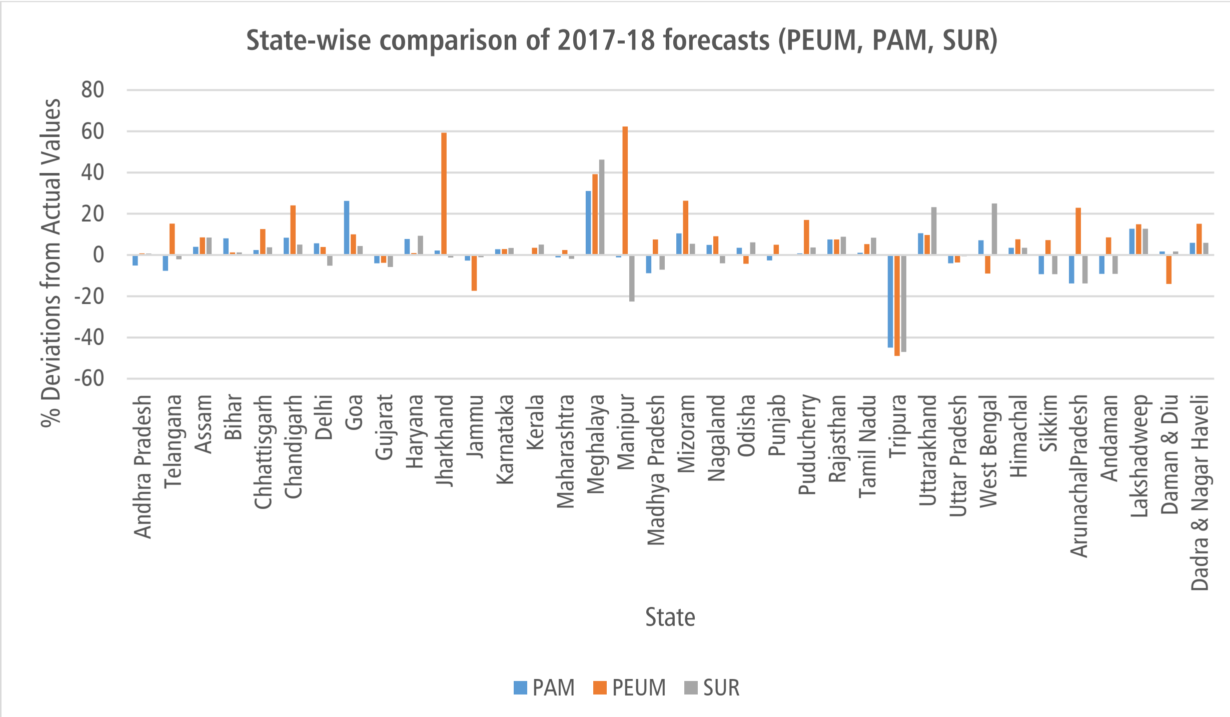
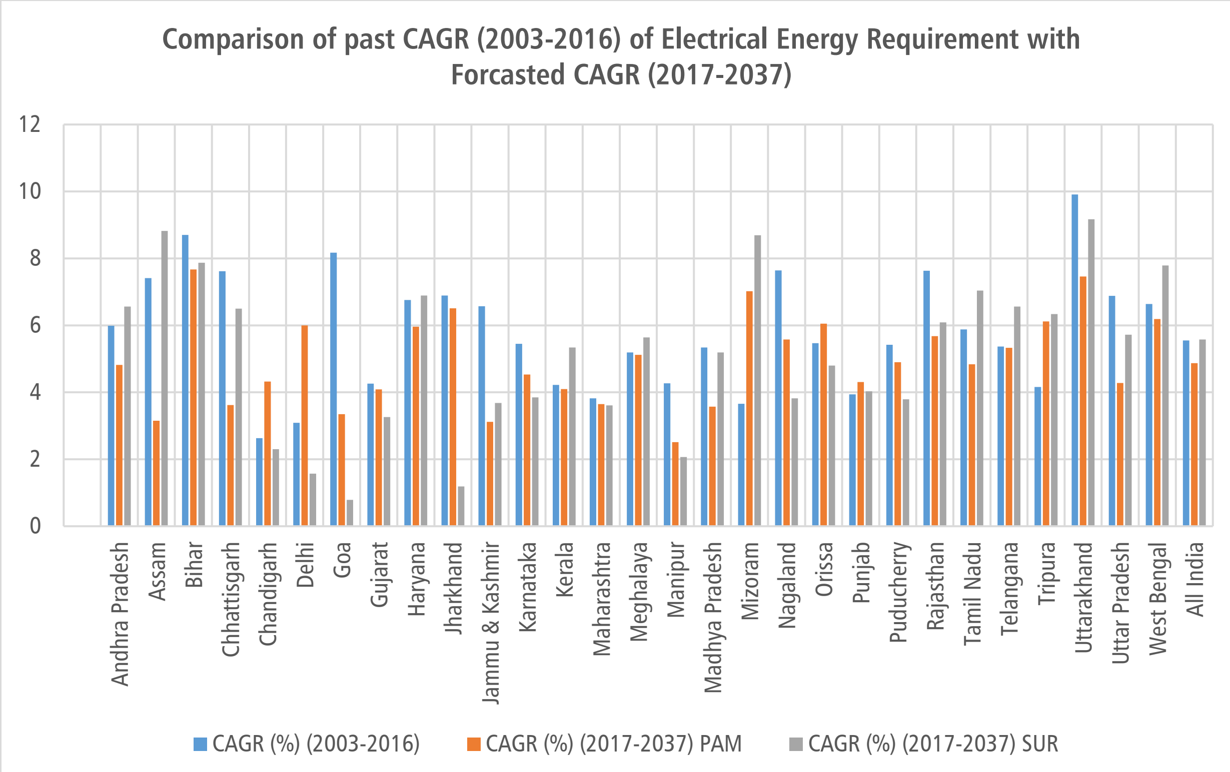


Figure 5.7 Difference in percentage between state-level forecast and actual Electrical Energy Requirement in 2017-18



It is observed that the relatively economically less developed states such as Bihar, Jharkhand, Odisha, Rajasthan, Mizoram, Tripura and Nagaland are likely to grow at a rate higher than the all-India compound annual average rate of about 4.86% during FY 2016-17—FY 2036-37. However, for few developing states such as Chhattisgarh and Madhya Pradesh, the CAGR from the PAM (which is the most preferred model at all-India) turns out to be much lower relative to their past observed growth rates. Both these states belong to the western region which also includes two most developed States-Maharashtra and Gujarat. The western region PAM results are dominated by these two states and thus depresses future growth rates of these two developing states. To address this issue, state-specific forecasts are obtained from the SUR model (See Figure 5.8 and Table A5.8). For both Chhattisgarh and Madhya Pradesh, the future rate of growth is higher than the all-India average from the SUR model and it is also aligning with their past growth rates.

Figure 5.8 Past and Future Growth rate of Electrical Energy Requirement



5.9 Impact of weather on electricity demand under baseline

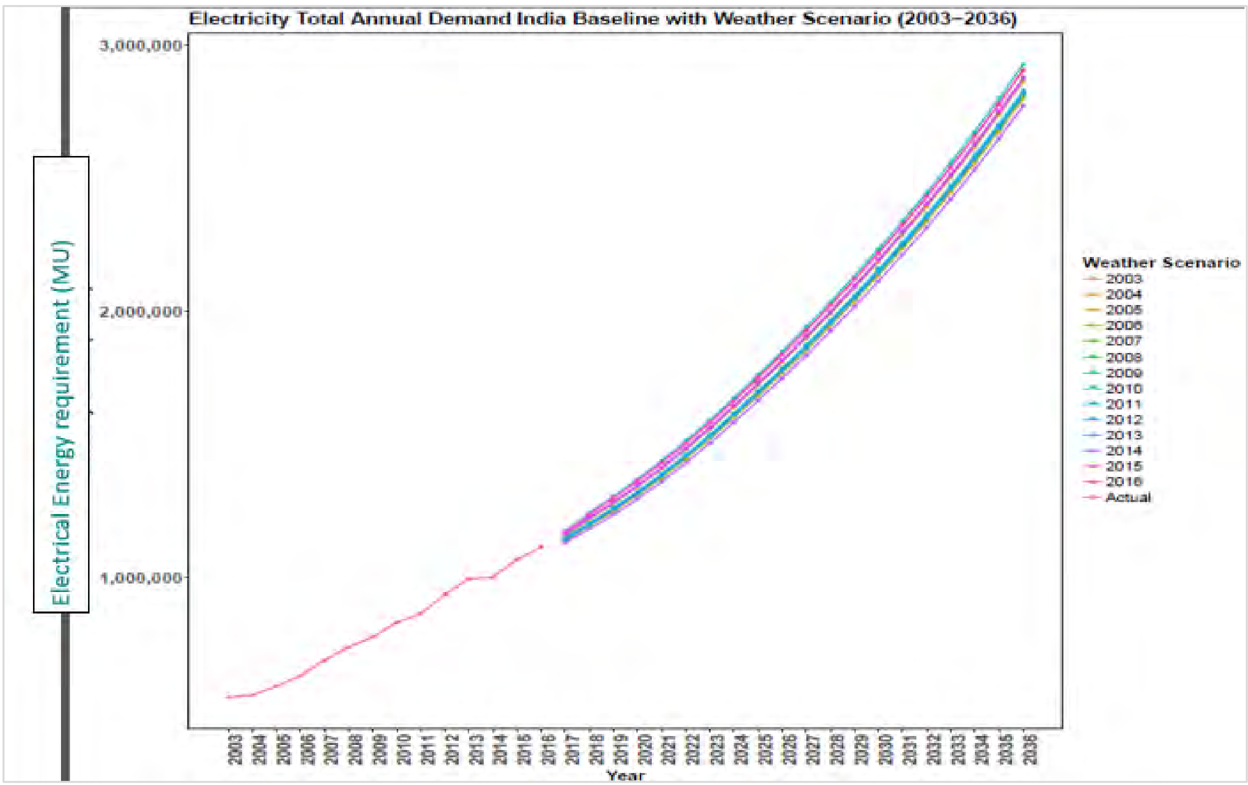
For each future year, electricity demand is forecast under 14 different weather scenarios (CDD, HDD and rainfall). Each weather scenario corresponds to a weather pattern observed during FY 2002-03-FY 2015-16. Figure 5.9 plots forecasts of electricity demand from PAM under all 14 weather scenarios for the baseline GDP growth case. It is observed that the future demand turns out to be the highest for the weather scenario corresponding to the year FY 2009-10 and the lowest for the weather scenario corresponding to the year FY 2013-14. The year FY 2009-10 is the hottest year with the highest monthly average state-level CDD of 167.5 degree days (6.23% higher than average CDD) and the lowest monthly average state-level rainfall of 97.8 mm (14% lower than average rainfall) during FY 2002-03 and FY 2015-16.

On the other hand, the year FY 2013-14 experienced the lowest monthly average state-level CDD of 150 degree days (4.36% lower than average CDD) and average monthly state-level rainfall of 115 mm which is 2.6% higher than the average monthly state-level rainfall during FY 2002-03–FY 2015-16.

In the FY 2009-10 weather scenario, Electrical Energy Requirement is projected to increase at an average annual rate of 4.9% from 1173.5 BU in 2016-17 to reach 3054.87 BU in 2036-37. As compared to the Electrical Energy Requirement obtained under the PAM baseline GDP scenario (which is the average of the forecast demand under all 14 scenarios), Electrical Energy Requirement is about 2.63% higher in this weather scenario in 2036-37 for the 2009-10 weather scenario.

In the FY 2013-14 weather scenario, Electrical Energy Requirement is projected to increase at an average annual rate of 4.83% from 1131.7 BU in 2016-17 to reach 2907.8 BU in 2036-37. As compared to the average Electrical Energy Requirement forecast obtained under the baseline GDP scenario (which is the average of the forecast demand under all 14 scenarios), electricity demand is about 2.3% lower in FY 2036-37 for the 2013-14 weather scenario.

Figure 5.9 Annual Electrical Energy Requirement under 14 past weather scenarios



Annexures