VASUDHA FOUNDATION
Green ways for a good earth!

AN OUTLOOK OF

INDIA'S ELECTRICITY DEMAND

ANALYSIS AND PROJECTIONS TO THE NEXT DECADE

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About Vasudha Foundation

Vasudha Foundation is a non-profit organisation set up in 2010. We believe in the conservation of Vasudha, which in Sanskrit means the Earth, the giver of wealth, with the objective of promoting sustainable consumption of its bounties. Our mission is to promote environment-friendly, socially just and sustainable models of energy by focusing on renewable energy and energy-efficient technologies as well as sustainable lifestyle solutions. Through an innovative approach and data- driven analysis, creation of data repositories with cross-sectoral analysis, along with outreach to ensure resource conservation, we aim to help create a sustainable and inclusive future for India and Mother Earth.

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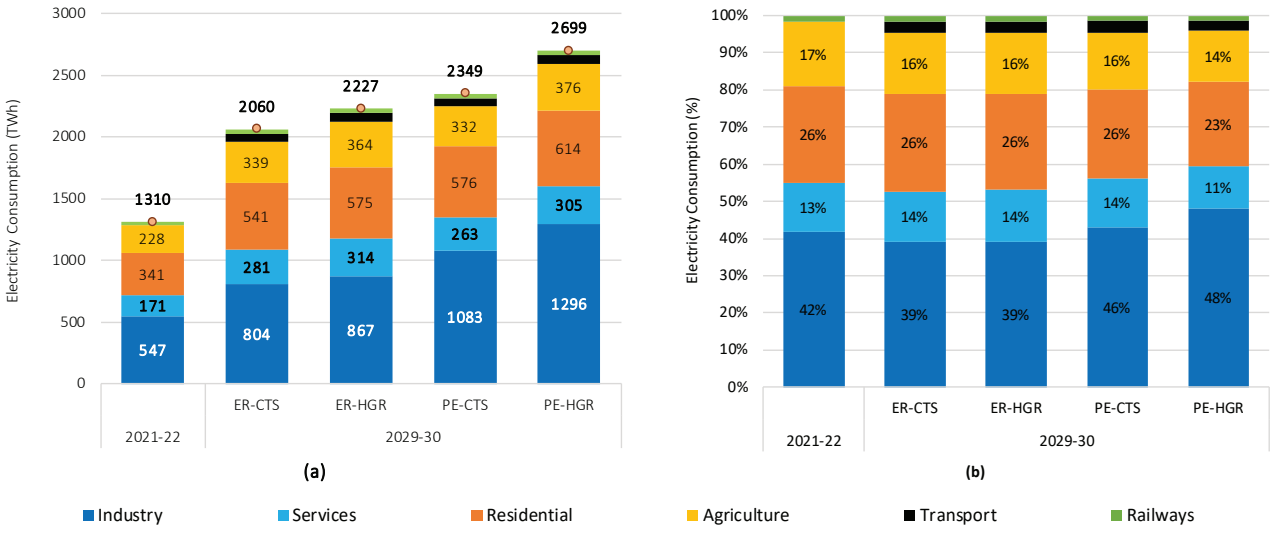
EXECUTIVE SUMMARY

Electricity demand forecasting is an integral part of a robust power system planning, which helps to ensure affordable and reliable power to all. India's electricity demand will grow multifold in the coming years and will experience a continuous growth supported by post pandemic economic recovery, electrification of the transport sector, higher penetration of residential end use appliances, and manufacturing growth with indigenisation supported by various central government policies.

This report provides an extensive analysis of electricity demand projections for both national and sub-national level over the next decade. The analysis is based on historical data, current trends in electricity consumption, demographic changes, and various economic growth indicators. Two overarching methodologies- Econometric Regression (ER) Method and Partial End-Use Method (PEUM)- are adopted to assess the electricity demand. The result of these two methodologies are further analysed for two scenarios: Current Trajectory Scenario (CTS) and High Growth Rate (HGR) Scenario.

1. National Electricity demand set to rise two folds by 2030

By 2030, the total electricity demand in the country, including captive demand (excluding T&D losses) is projected to be 2,060 – 2,699 TWh. The utility level demand including T&D losses would likely be in the range of 2,039-2,454 TWh. The wide range of projections within the scenarios indicate the underlying uncertainties in each sector. With a 6 percent growth from the current level, the industrial sector is expected to be the biggest contributor (~40 percent) to the increasing electricity demand, followed by the residential and commercial sectors. Furthermore, the projections for 2037 suggests a rise in ex-bus electricity requirement to 2,936-3,175 TWh, which is in line with the Central Electricity Authority's (CEA) projection of 3,095 TWh.



ES1. (a) Projected Electricity demand (including captive) across scenarios in India for FY 2029-30, (b) Share of sectors in demand mix

Year	Vasudha Scenarios				CEA 20th EPS
	ER-CTS	ER-HGR	PE-CTS	PE-HGR	
FY 2026-27	1758	1831	1668	1782	1907
FY 2029-30	2039	2191	2215	2454	2279
FY 2036-37	2936	3175	NA	NA	3095

ES2. Ex-Bus Electricity requirement (TWh) in all scenarios and comparison with other studies.

2. Sectoral Outlook

Industry

Throughout the next decade, the industrial sector continues to drive the surge in the electricity demand, which will comprise about 40 percent of the total electricity demand mix. Therefore, it is anticipated that the Industrial electricity demand would reach 804-1296 TWh across the scenarios studied by 2030.

Policy mandates towards fuel switching along with rise in industrial production (255 MT steel production by 2030, as compared to 120 MT as of today) are expected to augment an additional 175-250 TWh electricity requirement by 2030, in line with the target to boost domestic manufacturing capacity and a growing impetus for green hydrogen as a fuel and feedstock in heavy industries (5 MT green hydrogen production by 2030). Thus, based on the PEUM forecast the industry electricity demand will rise to 1,083-1,296 TWh by 2030.

Residential

Across the scenarios evaluated, the residential electricity demand is anticipated to rise to 542-614 TWh by 2030. Space cooling will account for the largest share of ~67 percent in the residential electricity consumption. Due to rapid urbanisation and intensifying heat stress, the residential air conditioning stock is expected to reach ~240 million units, thus resulting in a total electricity consumption of 268-310 TWh for residential cooling by 2030. This represents almost a two-fold rise in penetration of residential cooling in households as compared to the current situation. A new residential electricity demand for electronic appliances is also emerging thus increasing electricity consumption for the sector to 135-141 TWh for 2030, which is 110 percent higher as compared to 2021. However, the growth of decentralised agricultural pumps and solar rooftops will result in a reduction of 61-80 TWh from the gross consumption forecast.

Transport

Road transport registrations are expected to reach 521-538 million in 2030 from 349 million in 2022. The private ownership of four wheelers is expected to rise to 51-57 vehicles per 1000 capita in 2030, which is double the current levels. By 2030, the road transport electrification is anticipated to be

significantly driven by both private and public transport, thus creating new electricity demand for the sector and occupying 3-4 percent share of the total electricity demand at 61-65 TWh. Overall, road and railways electrification are expected to contribute ~110 TWh to the electricity demand by 2030.

Services

The services sector is expected to witness a rapid growth predominantly due to rising electricity demand from increasing commercial floor space area and higher air conditioning requirement in the financial, IT and retail sectors. By 2030, the floor space area is anticipated to increase by twofold to 1,555-1,600 million sq.m. as compared to 2017 while the electricity demand for air-conditioned commercial cooling space is projected to increase to 201-240 TWh. However, the non-air-conditioned spaces would account for only a third of the services electricity demand.

3. Efforts to strengthen end use modelling

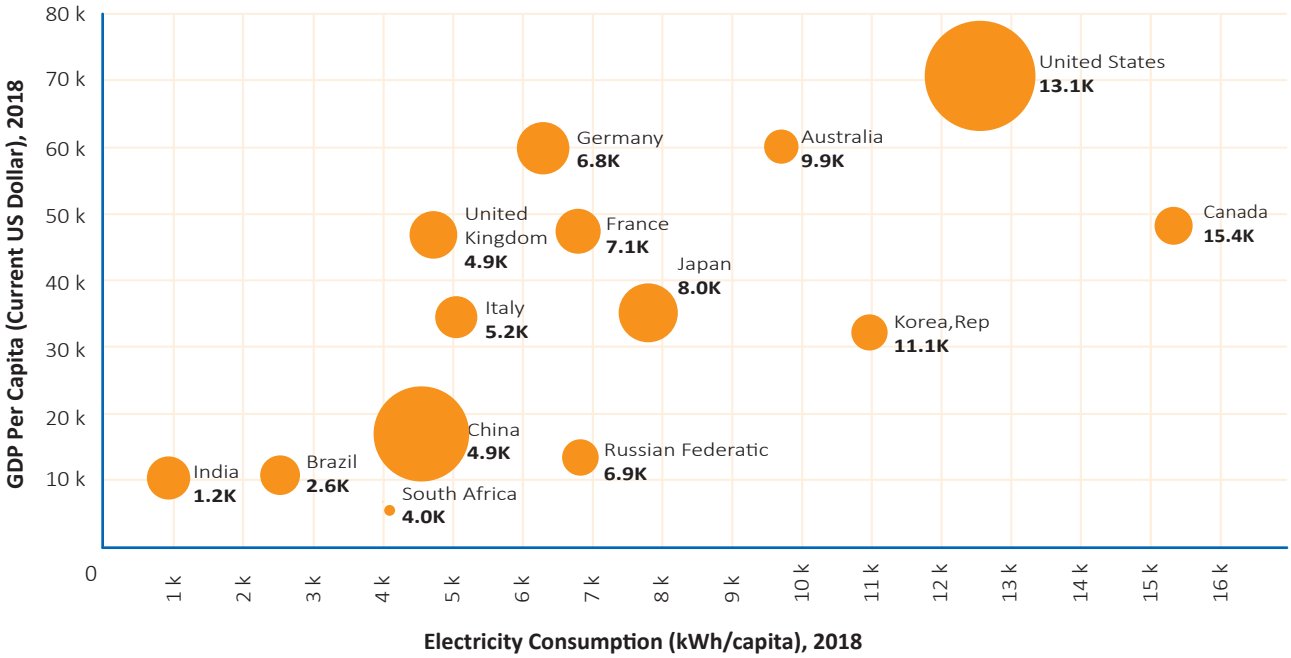
According to all the scenarios discussed in the study, the ex-bus electricity requirement is expected to increase from 2,030 to 2,454 TWh by 2030. The use of different forecasting methodologies and underlying assumptions can, however, result in a wide range of potential outcomes. This highlights the importance of having access to accurate and comprehensive end-use demand data, including information regarding appliance penetration, industrial production, and building stock across different demographic groups. Unfortunately, such data is currently limited in India. This lack of data poses a challenge for forecasting electricity demand and planning for optimal electricity supply in the near to mid-term. To address this issue, more efforts should be made to promote transparency and data dissemination at both the state and national levels, which will help improve the accuracy of future electricity forecasts and support better planning for meeting India's electricity requirements.

1

INTRODUCTION

Following independence, electricity consumption has increased from a mere 16 kWh per capita in 1947 to 1208 kWh in 2020 (Hindustan Times, 2020) indicative of economic growth, increased electricity access due to provision of affordable electricity to all households, reduced electricity shortages, and continued transition to the use of emerging technologies. The changing economic landscape has further led to structural changes of the Indian electricity demand. Residential electricity consumption, which has overtaken industrial consumption, now accounts for more than a third of total consumption, resulting in daily and seasonal electricity demand patterns.

As compared to other global economies, the per capita electricity consumption in India remains fairly low. This can be gauged from Figure 1. showing the comparison of electricity consumption per capita versus Gross Domestic Product (GDP) per capita for developed as well as emerging market and developing economy (EMDE) countries. India's per capita electricity consumption is almost one tenth of the developing countries and a fifth of EMDE countries. The varied margin indicates that India is likely to experience electricity growth in the years to come.



The bubble size contrasts the country GDP, however the value next to the bubble is electricity consumption per capita.

Figure 1 : An inter country comparison of GDP per capita, electricity consumption per capita

Despite being one of the most complex and largest networks in the world, the Indian power grid has been tested for resilience during extreme events. The most predominant event was the onset of the Covid-19 pandemic which caused unprecedented drop in electricity demand across the country. In March 2020, during the week following lockdown when economic activities especially in industry and services sector were hampered, the peak electricity demand plummeted by 28 percent (Saur Energy, 2020). However, the impact of the pandemic in agricultural and residential electricity consumption was not significant due to resumption in agricultural activities and work from home measure being practiced widely. During the first wave of the pandemic in 2020, electricity consumption saw a decline of 5.4 percent and 2.7 percent in services and industry sectors, respectively, while it grew at 5.2 percent for the agriculture and 4.9 percent for residential sector.

Even though Covid -19 impacted the overall economic growth in the past two years, the Indian economy is recovering. The projected real GDP growth for the current year is 6.8 – 7 percent (Business Standard, 2022) and for the next decade it is expected to be in the range of 6- 7 percent. According to the International Monetary Funds (IMF), India will be on par with the covid recovery, boosted by domestic consumption and capital investments. However, rising interest rates, higher inflation, and slowing global growth may impact the economic activities and result in a slower overall economic growth. Sectors like services and industry, in particular, are likely to see a higher growth trajectory, as the macroeconomic drivers are strongly correlated with the Indian electricity demand. This further depends on the ambitious policies and programmes that aim to promote energy efficiency and reduce the overall energy intensity.

In addition, as discussed above, the Covid-19 pandemic, economic slowdown etc, have impacted the electricity consumption in the country and necessitates a reassessment of the electricity needs in the coming decade. In this direction, this report attempts to assess the quantum of electricity demand foreseen comprehensively. The approach and methodology would be discussed in the following sections, however to this end, it is worth mentioning that this report brings out a broad range of scenarios anticipating Indian electricity demand as it grows with emerging technologies and underpinning policies, thus electrifying new end-use sectors.

2 METHODOLOGY AND SCENARIOS

This report covers the electricity demand forecasts for 2030, along with a brief outlook for the FY 2036-37, considering two varying methodologies. Figure 2 illustrates the framework used in this report. Firstly, we estimate the forecasts based on econometric regression methodology (both a univariate and multivariate) for which a top-down approach is considered by forecasting the state level electricity demand aggregated at national level. This also includes forecasting transmission & distribution losses and calculating ex-bus demand (for utilities demand) for 2030. Secondly, in the partial end use method, we assess the electricity demand of all the demand sectors/drivers (existing and new) at the national level considering in detail the stock of appliances, industrial processes, material intensities, other policy mandates etc. The end use sectors covered are residential, services, agriculture and Industry. We further project the demand separately for public lighting and emerging demand sectors including electrification of road transportation as well as Indian railways and green hydrogen usage in heavy industry.

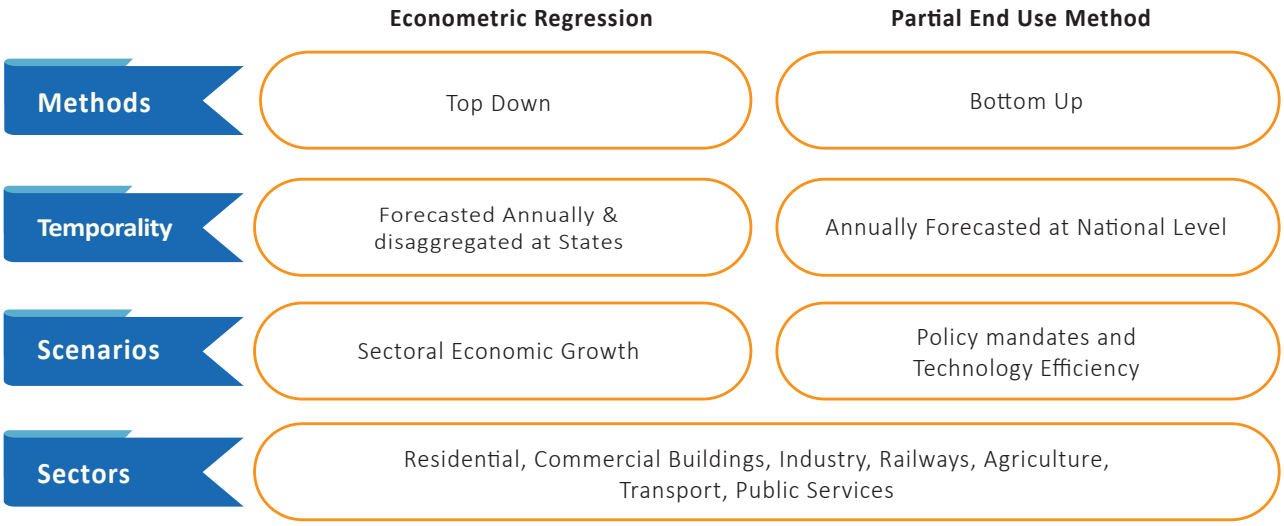


Figure 2 : Demand Forecasting Framework

Scenarios

In this report, we cover scenarios which are broadly aligned to the anticipated growth of the Indian economy by 2030. We consider macroeconomic forecast indicators aligning with current growth rate and an estimate for a higher growth range scenario. There are two scenario categories considered namely Current Trajectory Scenario (CTS) and High Growth Rate scenario (HGR). Taking into account

the macroeconomic forecasts, we assume a pre-covid growth in the CTS for independent variables and a percentage point increase in the HGR. While the underlying principle guiding these scenarios in Econometric and Partial-End use scenarios remains the same (i.e., the economic growth), the methodology for devising individual parameters remains different. In econometric forecasts, the electricity demand is a broad function of macroeconomic growth rates, whereas in the partial end-use method, it is dependent on the rate of adoption of end-use (for example industrial production, appliance usage, floor space area, etc.).

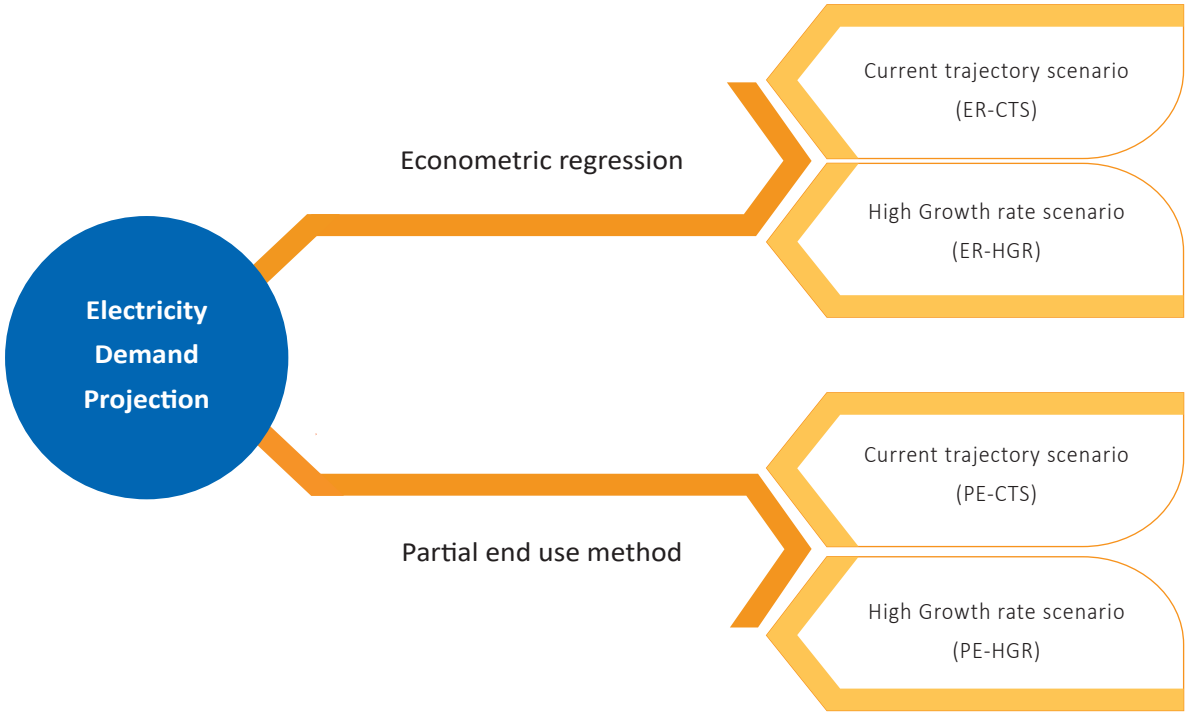


Figure 3: Scenarios Framework

3

DEMAND PROJECTIONS USING ECONOMETRIC REGRESSION

In this section, we present a comprehensive analysis of the electricity demand projections for 2030 using econometric regression. Furthermore, we explored various econometric parameters that could affect the broad sectoral forecasts in the Indian states. The projections include majority of the states, except for a few Union Territories where we have estimated the demand using a compounded annual growth method, given the non-uniformity in economic data and its correlation with respect to end use sectors.

With the objective to cover the impact of COVID contraction on electricity demand for further projections, the base year was chosen as FY 2021-22. Thus, the econometric projections not only serve as a forecasting method, but are also an underlying metric to investigate electricity intensity of sectors that may be affected in near to mid-term. In light of this, we try to investigate underlying growth in each sector and consider elasticity of demand as one of the metrics to understand the electricity demand growth.

There are several independent variables that influence the electricity demand, varying from climatic conditions, demography, structure of the economy etc. It is quite evident from the past experiences across the globe that countries evolving from developing status to developed go through a structural change with sectors evolving in the process (IMF, 2013). Thus, it is crucial to understand this transition that eventually shapes the electricity demand.

Broader assumptions for econometric forecasts

We have undertaken the econometric regression analysis using both Univariate and Multivariate[1] regression methods. However, we did not find a substantial change in either of the analyses and therefore, we refer to all scenarios hereby as multivariate regression analysis, unless otherwise mentioned separately. The multivariate regression has been formulated under various machine learning methods based on python language, and are analysed endogenously. Figure 4 shows the independent and dependent variables used in the econometric forecasts for each end use sector. As seen in Figure 4, the sectoral electricity demand is the major dependent variable driver, while the other variables mentioned in the sectoral box represent all the independent variables.

In order to understand the impact of various independent variables on overall electricity consumption, data was collected from multiple sources including CEA General Review report while the macro-economic data such as GDP, Sectoral Gross Value Added (GVA), Gross Irrigated Area, etc., were sourced from the Reserve Bank of India (RBI). In the econometric analysis, we have ensured to fit the model with data availability to a maximum extent and as exhaustively possible obtain the historical trend of various input data closely. We have considered FY 2015-16 as our first year of data availability and although this may not represent a long history of data related to the sector; it eliminates in consistency.

1 Multivariate regression considers more than 1 independent variable to forecast linearly whereas Univariate considers a single independent variable.

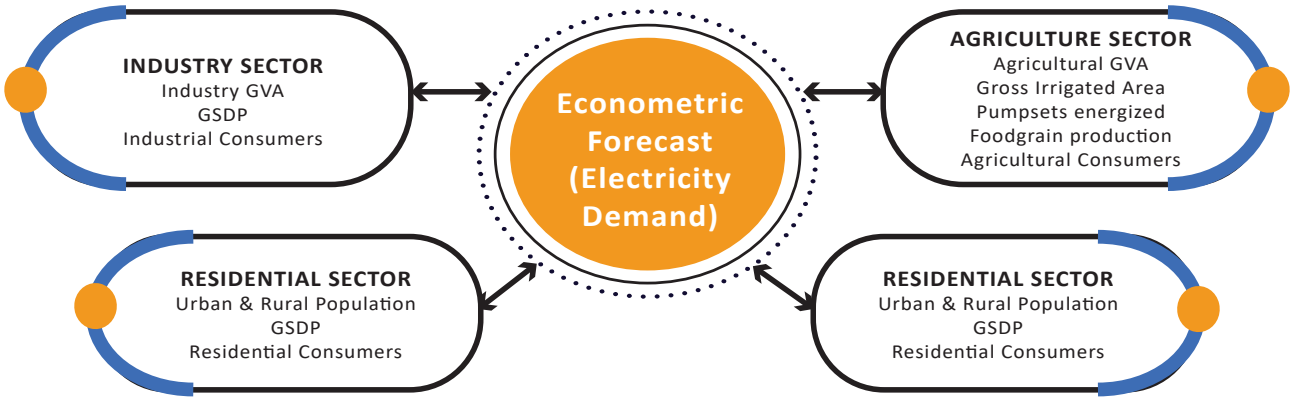


Figure 4 : Econometric variables considered for demand projections

If certain variables are not calibrated correctly, econometric forecasts are bound to contain error particularly the temporal horizon, consistency of data and so on. Moreover, multiple independent variables shaping the electricity demand may distort the forecasts. Thus, it is important to maintain uniformity and clarity in forecasts. This can be verified by performing a number of tests including multicollinearity, homoscedasticity, linearity and comparison of correlation coefficients between independent and dependent variables. Furthermore, we explored different supervised regression models such as multiple linear regression, support vector regression etc. and adopted the one that best fit to the test data. In the subsequent sections, we will discuss in detail the individual sectors and demand projections results.

Agriculture Sector

In the last decade, the agriculture sector has contributed to ~15 percent of the total value added (VA) and almost a half of the country's workforce, predominantly contributes to a large-scale informal workforce (RBI, 2023a). As countries transition to developed economies, the share of agriculture in overall GDP decreases. As for India, it has seen a decline from a third of the country's VA share in 1980 to less than a fifth of the country's VA currently. In addition, the sector is relatively less electricity intensive when compared to other sectors. The electricity intensity of the sector rose from 7.2 kWh/Rs1000 (constant FY 2011-12) in FY 2000-01 to ~11 kWh/Rs1000 in FY 2020-21 (CEA, 2022). This can be gauged from two factors: First, with improved access to electricity, there has been an increased reliance on irrigation for groundwater pumping while the share of diesel pumps has reduced substantially owing to government's focus on phasing out diesel pumps across the country. Although, the Electricity intensity, as seen in the table is on a decline between 2015-22 owing to improving efficiency in irrigation pumping. Secondly, over the last two decades, due to a growth of 0.2 percent land under cultivation (net sown area) year-on-year, foodgrain yield per hectare has grown at a rate of 2 percent, implying a higher cropping intensity (number of times a given area has been sown in a given year). Consequently, the cropping intensity increased from 1.28 in FY 2001-02 to 1.44 in FY 2019-20 (DA&FW, 2022). Thus, taking into account the historical trends, it is expected that the cropping intensity is bound to increase in the coming years, with increased accessibility to irrigation.

Table 1 : Agriculture statistics in India

Parameter	FY 2015-16	FY 2021-22	CAGR (FY 2015-16 to FY 2021-22)
Cumulative Pumpsets energized (Millions)	20.4	25.3	3.6%
Total Foodgrain Production (MT)	251	315	4.0%
Gross Irrigated Area (Million hectares)	97	118	4.0%
GVA (Real) (Trillion Rs)#	16.2	21.5	4.9%
Share of Agriculture in Total GVA (%)	15.4	15.5	0.1%
Electricity Intensity (kWh/1000Rs)	10.7	10.6	-0.2%
Cropping Intensity[2]	1.38	1.43	0.7%
Yield per hectare (kg/ha)	1.2	1.4	
Sectoral Demand Elasticity [3]	0.98		

Agricultural GVA here refers to GVA from Agriculture, forestry and fishing.

Source: (CEA, 2022; DA&FW, 2022; RBI, 2023a)

In order to forecast electricity demand from the agricultural sector, we have used the Correlation Coefficient (CC) to highlight key statistics emerging from the states. Table 2 shows the number of states with a correlation fit of independent variables against the dependent one, that is the electricity consumption. We have observed that the CC varies with independent variables across the states, so we only consider those variables that have a strong correlation (>90 percent) with the electricity consumption. In case of a weaker correlation, we neglect those variables and consider univariate forecasts having the highest correlation. For few states with a higher growth in certain years, although this might prove to be an outlier in states with smaller population and thus, for datasets such as these we have placed a growth constraint over such independent variables (at 7 percent in line with the national GDP growth).

2 Cropping Intensity determines the number of times a field was sown in a year. It is a ratio of gross irrigated area to net sown area.

3 Ratio of Change in Electricity demand to change in Value added. It signifies the sensitivity of electricity demand to a dependent parameter, here which is value added.

Table 2: Number of States and their independent correlation parameters with electricity consumption

Parameters	Number of States having	
	>80 percent correlation	>90 percent correlation
Agricultural GVA	16	12
GSDP (Real)	12	8
Gross Irrigated Area	26	6
Pumpsets Energized	21	5
Production of foodgrains	7	18
Number of Consumers	5	3

Source: Author's Analysis

Econometric projections for agricultural electricity demand

In accordance with the econometric forecasts, it is projected that the aggregate electricity consumption of the agricultural sector in the country will reach 338 and 364 TWh in the ER-CTS and ER-HGR, respectively by 2030. Figure 5 illustrates these projections from 2015 to 2030. It is important to note, that commensurate with agriculture's real GVA growth of 3.1 percent by 2030, the electricity consumption from the sector is expected to rise at the rate of 5.1 percent which is 2-3 percent faster than sectoral value added. On the other hand, the electricity consumption in the ER-HGR is expected to grow at 5.8 percent from 2022 onwards. It is in line with the baseline projections, which estimate that the sectoral demand elasticity to value added will rise to 1.21-1.22, compared to 0.98 in 2015 to 2021. Owing to increase in irrigation requirements, the sector's electricity intensity is also expected to increase in the range of 12.5-15 kWh/1000Rs (as per 2011 constant prices).

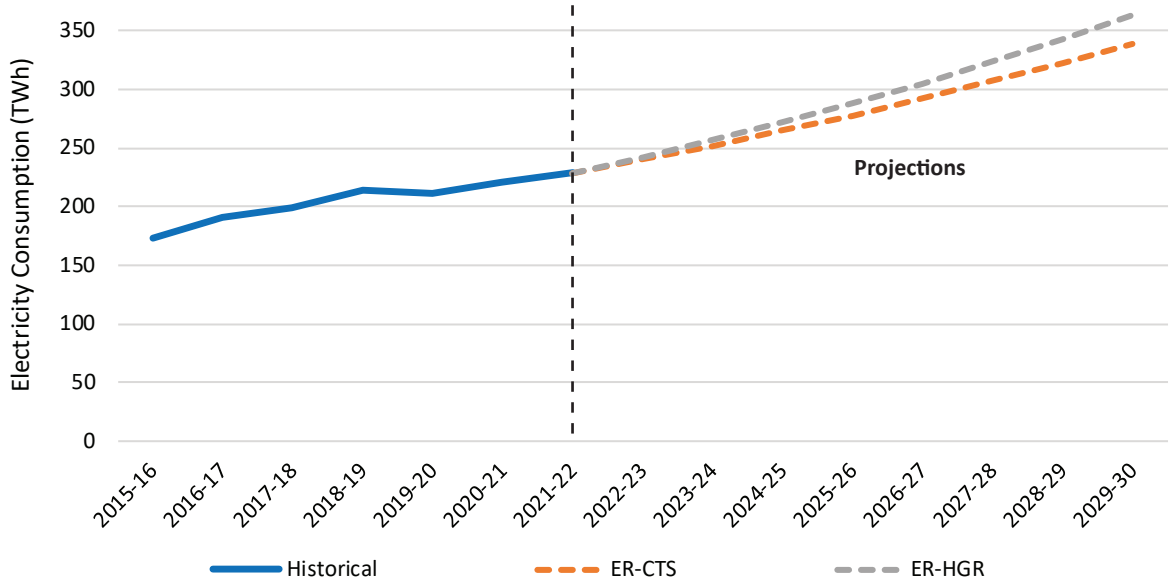


Figure 5 : Agricultural Electricity Consumption in ER-CTS and ER-HGR by FY 2029-30

By 2030, the total number of pump sets is anticipated to rise from 21 million in FY 2020-21 (CEA, 2022) to a range of 33-34 million, representing a growth rate of ~4 percent per annum. This is discussed in more detail in the PEUM section where we have assessed the impact due to agricultural pumping. In order to understand the state level impact on agricultural electricity demand in the ER-CTS, we present insights from the major consuming states in the Exhibit 1. However, the state level projections for all the states are included in the annexures.

Exhibit 1: Top eight agricultural value adding states that contribute to 78 percent of the agricultural demand

By 2030, eight states, namely Punjab, Karnataka, Maharashtra, Tamil Nadu, Rajasthan, Madhya Pradesh, Telangana and Uttar Pradesh, are expected to contribute 82 percent of the agricultural electricity demand and 73 percent of the country's agricultural GVA. Table 3 provides comparison of the key parameters within these states. It has been observed that the electricity intensity of these states is higher than the national average (16 kWh/1000 Rs). Furthermore, as compared to 2022, these major states will be electricity intensive by 2030 indicative of a higher electricity consumption than the GVA growth. Despite higher pumping demand, we see an overall contraction in the GVA, moderately slower than electricity consumption. In our econometric model, we have not taken into account an additional efficiency improvement other than the existing ones which are based on the historical trend. However, our end use section delves into the impact of higher efficiency improvement, considering the impact of pumpset usage patterns and consumption. Interestingly, these states have improved cropping patterns as the gross irrigated area[4] as a percentage of net sown area has increased by 165 percent, compared to the national average of 144 percent. This implies that access to irrigation directly impacts yield per hectare thereby increases electricity consumption.

Table 3: Agricultural intensive states consumption statistics by FY 2029-30

State	Electricity Consumption FY 2021-22 (TWh)	Electricity Consumption FY 2029-30 (ER-CTS) (TWh)	Electricity Intensity FY 2021-22 (kWh/1000Rs)	Electricity Intensity FY 2029-30 (kWh/1000Rs)	% Contribution in Agricultural GVA (FY 2029-30)	Demand elasticity (2021-2030)
MH	36.3	58.7	15.0	15.2	12%	1.03
RJ	28.8	44.6	19.2	20.1	7%	1.09
MP	26.5	42.2	11.4	11.7	11%	1.04
TG	22.2	34.9	30.8	29.3	4%	0.92
KA	21.9	29.5	16.5	16.2	6%	0.95
UP	19.0	29.3	6.5	6.3	14%	0.95
TN	13.4	21.7	14.3	13.7	5%	0.93
PB	12.6	17.1	14.7	14.6	4%	0.98

4 Gross irrigated area as % of net sown area denotes the % incremental amount of time in the year where the land was sown more than once

Impact due to the PM KUSUM scheme: Aiming to solarise the agricultural sector (component B & C), the PM KUSUM scheme envisages reduction in electricity dependence on the grid through a range of interventions that includes installation of solar pumps and feeder solarisation. A detailed discussion of the comprehensive impact due to policy mandates of pump solarisation would be done in the end use section, however to this end, it is important to note that as per the Government of India's policy to install 1.75 million decentralised solar pumps by 2030 (PIB, 2022b)approximately 41 TWh (14 percent of the agricultural consumption) of the electricity demand will be off the grid, as a result of solar agricultural pumping. This would provide the dual advantage of reducing T&D losses on the grid as well as liability to the distribution utilities in terms of purchasing power to the agricultural sector, which is heavily subsidised today.

Services Sector

There is a rapid economic growth of the services sector in India and it currently contributes to ~60 percent of the country's total value added (RBI, 2023a). As compared to its overall share of GDP of 54 percent, the sector's share of final energy consumption is higher, accounting for 59 percent of the energy use (IEA, 2021). Moreover, the sector contributed ~16 percent of the total electricity demand in the past years. From FY 2015-16 to FY 2021-22, the electricity consumption in the sector grew at ~3 percent CAGR owing to COVID induced contraction in Indian economy. The post liberalisation era opened up avenues for the services sector primarily in the financial, IT and retail spheres. This has led to a rapid rise in the electricity consumption due to increased commercial floor space area and higher demand for air conditioning. The highlights of India's services sector are shown in Table 4.

Table 4: Services sector statistics in India

Parameter	FY 2015-16	FY 2021-22	Growth during this period
Electricity Consumption (TWh)	148.7	170.9	2.3%
GVA BAU (Rs Trillion) (Real)	52.6	69.4	4.7%
Electricity Intensity (kWh/1000Rs)	2.5	2.3	-1.4%
Demand Elasticity	0.54		NA
Sector Employment(Millions)	151	186	4.2%

Source: (ICED, 2023), (RBI, 2023a), (RBI, 2023b)

In the pre-covid period (2016 to 2020), the electricity consumption grew by ~5.8 percent, whereas the GVA grew at 7.3 percent at a moderately faster rate. The electricity intensity of the sectoral GVA stood at 2.23 kWh/1000 Rs in FY 2021-22, compared to 2.5 kWh/1000 Rs in FY 2015-16. With the compliance of BEE norms for Energy Efficiency in Commercial Spaces with regard to space cooling and energy conservation measures, the energy intensity has dropped down marginally. Further, the COVID-induced lockdown resulted in an increase in online service activities while reducing electricity

consumption in the commercial sector. It is anticipated that an increase in air conditioning needs in building spaces will increase electricity consumption in the next decade, driven by increased purchasing power and heatwave intensity. Higher economic output, however, would keep the electricity intensity at a marginal increase. We will examine the need for higher cooling demand in commercial spaces in greater detail in the end use section.

Econometric projections for services electricity demand

Based on our estimates of the ER-CTS and ER-HGR the electricity consumption of the services sector is expected to grow to ~281 and 304 TWh, respectively by FY 2029-30. It is projected to grow at a rate of 6.4-7.5 percent annually as compared to 4.9 percent during the period 2015 to 2022.

According to the econometric forecasts, the electricity consumption has a strong correlation with the sectoral value added (R^2=0.97). Continuing to account for 17-18 percent of country's total electricity demand, the sectoral trend does not appear to have a drastic change, and is just a few percentage points higher than the current demand. Even though the electricity consumption is expected to grow by 2020, the electricity intensity remains moderately similar in the range of 2.7-2.83. The Exhibit 2 compares the electricity intensities of some of the Indian states during FY 2015-16 with that of FY 2029-30.

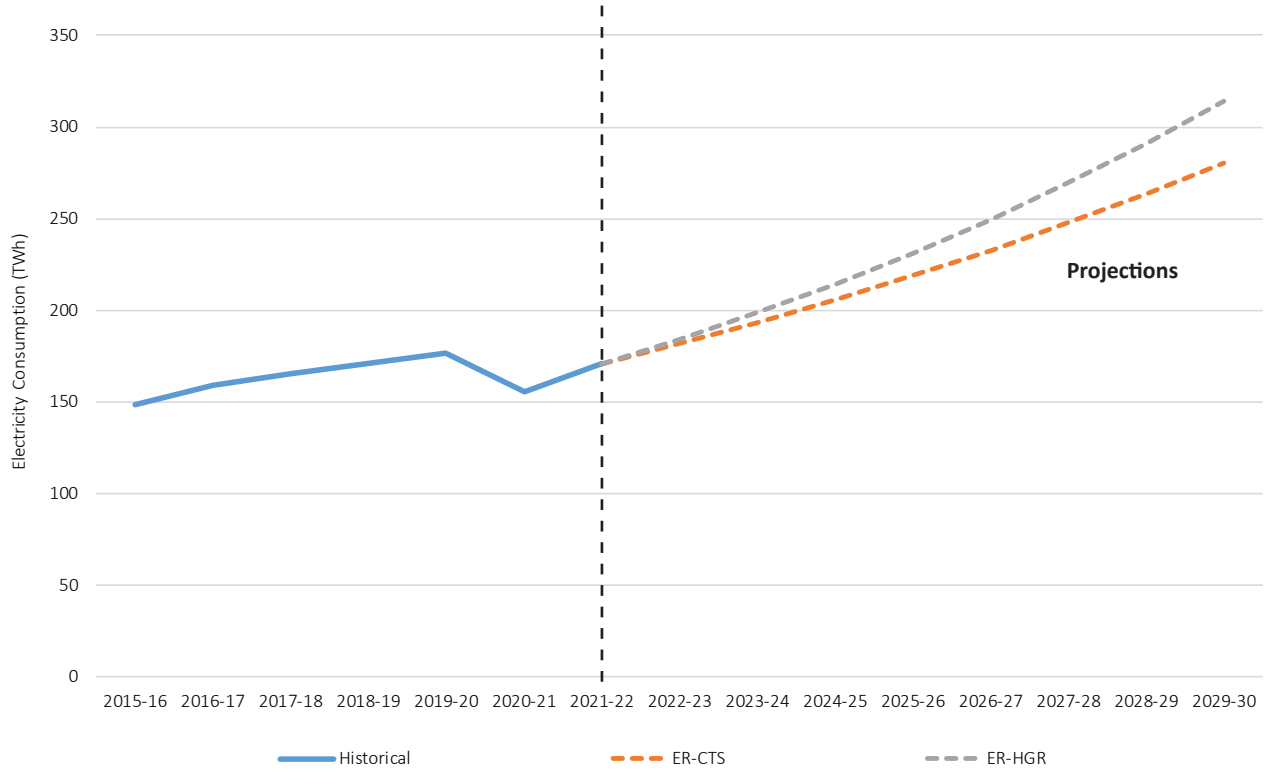


Figure 6 : Services Electricity consumption in ER-CTS and ER-HGR by FY 2029-30

Exhibit 2: Which states are electricity intensive and what factors contribute to this rise?

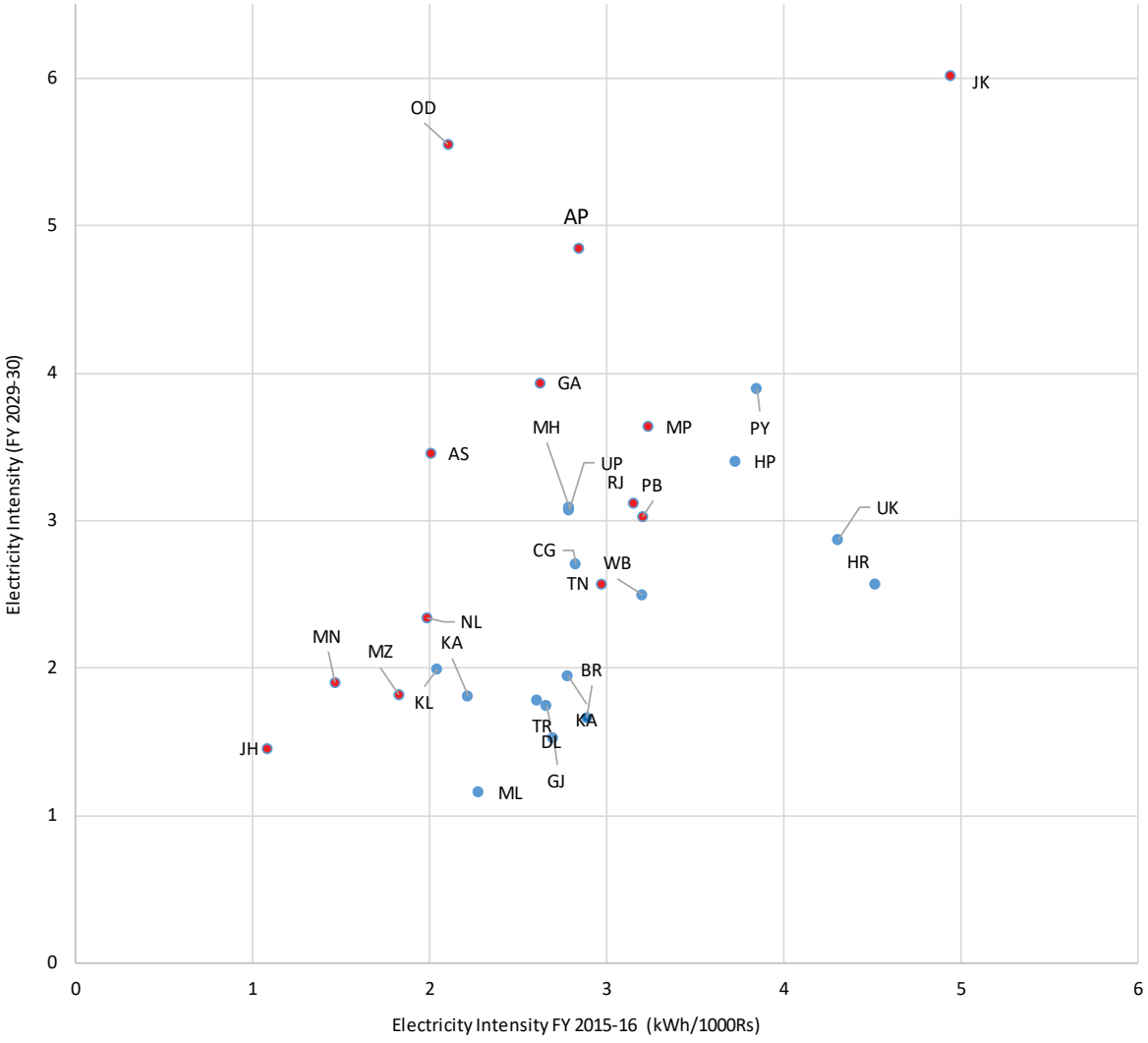
Table 5 presents the results of electricity demand forecasts for the eight key states which have significantly contributed to the services value added across the country. As shown in the table, Maharashtra, Karnataka, Tamil Nadu, Uttar Pradesh, Andhra Pradesh, West Bengal, Rajasthan, and Telangana collectively contribute to ~61 percent of the total services value added by 2030. This trend is almost identical to the past growth level, with the exception of a few percentage point adjustment. However, electricity consumption in these states contributes to 62 percent of the total services electricity consumption and it is interesting to note that not all states have observed an increase in electricity intensity. The services sector is highly elastic to change in its economic value added, therefore, states like Karnataka and Rajasthan are able to improve by reducing the electricity intensity at the rate of 5 percent by 2030. On the contrary, we observe that few of the states showcase a moderate improvement or even exceeded their electricity intensity when compared to the current level. The average energy intensity of these eight states in 2030 is 2.9 kWh/1000Rs (Real FY 2011-12) versus the national average of 2.74 kWh/1000 Rs (Real FY 2011-12)

Table 5: Services intensive states consumption statistics by FY 2029-30

State	Electricity Consumption (TWh) (FY 2021-22)	Electricity Consumption (TWh) (FY 2029-30)	Electricity Intensity (kWh/1000 Rs) (FY 2021-22)	Electricity Intensity (kWh/1000 Rs) (FY 2029-30)	% Contribution in Services GVA (FY 2029-30)	Demand elasticity (2022-30)
MH	19.09	32.81	1.91	1.95	0.15	1.03
UP	16.39	28.16	3.04	3.07	0.08	1.01
TN	15.32	24.41	2.53	2.57	0.09	1.03
KA	12.13	20.69	1.82	1.81	0.10	0.99
TS	10.65	18.29	3.09	3.10	0.05	1.01
AP	10.29	17.68	4.25	4.85	0.03	1.24
WB	9.38	14.95	2.47	2.49	0.05	1.02
RJ	8.86	14.66	3.23	3.12	0.04	0.95

The scatter plot in Figure 7 further illustrates the comparison of electricity intensity with reference to services sector across all the Indian states for FY 2015-16 and FY 2029-30. The decline in electricity intensity is represented in blue (i.e. improvement), whereas an increase is marked in red. As per the plot, by 2030, although most of the states show a decline in the services electricity intensity, we observe

that only a few states show a substantial increase (marked in red). States like Tamil Nadu, Andhra Pradesh are anticipated to have a much higher electricity consumption growth than the current growth rate in service sector, indicative of a boost in commercial floor space area in finance, retail and IT sectors which are highly electricity intensive.



(a) The abbreviation for states are as per road transport office code. (b) States coloured as red signifies increase in electricity intensity while blue signifies the decrease in electricity intensity.

Figure 7 : Services Electricity Intensity change between FY 2015-16 to FY 2029-30 (ER-CTS)

Industry Sector

In India, industry is one of the most electricity-intensive sectors, and it consumes electricity from both utilities and captive sources, resulting in a diverse electricity consumption pattern. Between 2015 to 2022, the industrial production contributed to ~23 percent of the country's gross value added (RBI, 2023a). Accounting for 70-75 percent of the sectoral employment (RBI, 2022), the sector is also a major contributor to semi and unskilled labour. The key statistics of electricity consumption

and associated parameters for India's industry sector are presented in Table 6. During the period 2015-2022, the economic output from the industrial sector advanced at a rate of ~5 percent, however, the electricity consumption grew at a slower pace at 4.2 percent as compared to the sectoral value added. In FY 2020-21, several factors, including COVID-19 lockdown and energy efficiency policy measures by the Bureau of Energy Efficiency's (BEE) Perform Achieve and Trade (PAT), resulted in a marginal reduction of 0.8 percent in the electricity intensity. In comparison to the pre-covid year, the industrial electricity consumption dropped by 3 percent during the first wave of the COVID pandemic.

Table 6: Industry Sector Statistics in India

Parameters	FY 2015-16	FY 2021-22	Growth (%)
Electricity Consumption (TWh) (BAU)	429.36	547.34	4.13%
GVA BAU (Rs Lakh) (BAU) (Real)	332933	446259	5.00%
Electricity Intensity (kWh/1000Rs) (BAU)	12.90	12.27	-0.83%
Demand Elasticity (BAU)	0.85		

Source: (ICED, 2023), (RBI, 2023a)

Furthermore, to provide reliable electricity output for large scale industrial production, the sector also substantially contributes to the overall captive consumption. Figure 8 depicts the total electricity consumption and the captive share of that consumption. There has been a fairly constant share of captive consumption within the sector, which stands at 32- 38 percent throughout the years, even though it has a diverse base in the sector. The total installed captive capacity accounts for ~77 GW with steel industry having the largest share of 19 percent, aluminium 9 percent, cement 8 percent while other industries make up the rest. For our econometric projections for 2030, we have not considered a fixed captive share of the total electricity consumption, rather we forecast utilities and non-utilities electricity consumption separately and then calculate the captive share accordingly for each year.

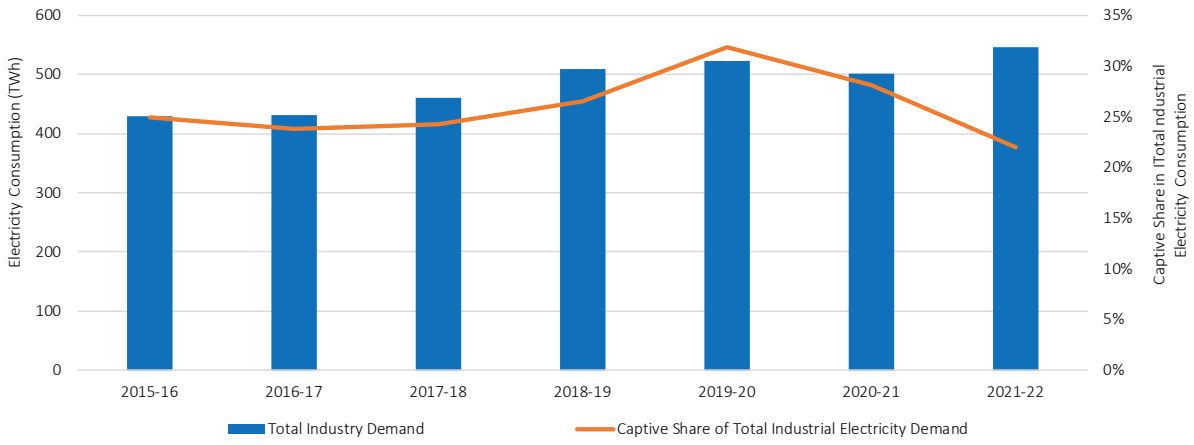


Figure 8 : Historical Industry demand and share of captive consumption

Econometric projections for industry electricity demand

In the ER-CTS and ER-HGR, by 2030, the electricity demand (utilities and non-utilities) will reach 804 TWh and 867 TWh, respectively, compared to 547 TWh in 2021-22. We observe a strong correlation between electricity consumption and Industrial GVA (R^2=0.98) and GSDP (R^2=0.96). In spite of the slowdown in growth during the pandemic, it has been predicted that amidst the post recovery period leading to 2030, the industrial electricity consumption would grow at 4.6 percent and 5 percent in the ER-CTS and ER-HGR, respectively, while the electricity intensity is bound to improve during this period According to our econometric forecasts, the electricity intensity in the industry sector is anticipated to reach 12.3-12.6 kWh/1000 Rs by 2030. This indicates towards higher electricity consumption in electricity intensive sectors including aluminium and steel. As a point of note, the projections are based on current economic growth and existing energy efficiency measures in the post-pandemic economic recovery setting, and do not assume additional improvements in energy efficiency or material intensity. The section pertaining to material intensity and industrial production linked to independent sectors is further discussed in the PEUM section.

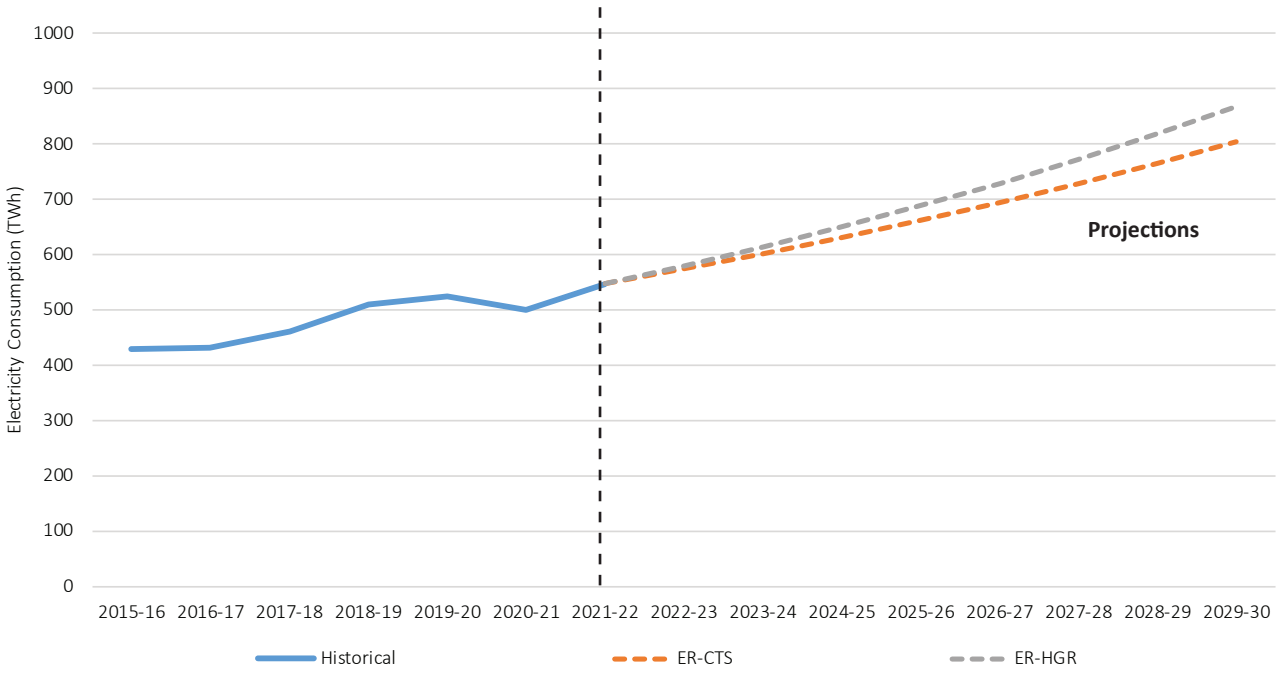


Figure 9 : Industry Electricity Demand in ER-CTS and ER-HGR by FY 2029-30

Exhibit 3: Which states are industry electricity intensive and are they likely to remain so?

Post liberalization, while many states witnessed an upsurge in private investments in both heavy and medium scale industries, only a few have been able to actually improve their energy efficiency measures. Table 7 lists the top eight contributors to the industry based on their GVA. As foreseen, by 2030, these states will collectively contribute ~55 percent of the country's total industrial GVA which is almost equal to the current GVA contribution. However, we note that the growth in the GVA and the electricity consumption varies significantly across the states. For few states like Chhattisgarh, Andhra Pradesh, Gujarat, and Tamil Nadu although there is an improvement in the electricity intensity, but it still remains higher than the national average. In contrast, heavy industry dominant states such as Maharashtra, Rajasthan, and Odisha have seen a marginal increase in electricity intensity. Here, we would like to emphasize the electricity intensity nature of these states, especially in the industry sector, which cannot be assessed as the sole metric to show a compatible growth in terms of electricity consumption. Some sectors are highly sensitive to electricity requirements while others are not. For instance, fertiliser, steel, textiles, and a few others require more thermal energy than electrical energy. Moreover, MSME profiles differ across the states, and their estimation are complex due to lack of data on energy use and type. As technological improvements and digitalisation aid in lowering the production costs, especially by reducing electricity consumption, electrification will play a crucial role in heavy industry. Thus, it would be quite interesting to witness a shift towards electrification of industrial processes in the future. We will discuss a few of these measures in the PEUM section.

Table 7: Industry intensive states consumption statistics by FY 2029-30

State	Electricity Consumption (FY 2021-22) (Utilities and Non-Utilities Consumption)	Electricity Consumption (FY 2029-30) (Utilities and Non-Utilities Consumption)	Electricity Intensity (kWh/1000 Rs) (FY2021-22)	Electricity Intensity (kWh/1000 Rs) (FY 2029-30)	% Contribution in Industry GVA (FY 2022-30)	Demand elasticity (2021-30)
GJ	86	137	14.9	13.8	14.89%	0.89
OD	63	100	35.0	36.3	4.65%	1.03
MH	60	82	11.3	12.2	10.12%	1.31
TN	45	66	10.5	9.0	10.98%	0.76
RJ	27	43	15.9	20.3	3.17%	1.94
CG	28	39	22.6	18.0	3.23%	0.64
AP	27	36	16.1	14.7	3.72%	0.81
HR	20	34	12.5	12.9	3.99%	1.05

Industrial captive forecast

In India, the captive electricity consumption accounts for 32-38 percent of the total industrial electricity consumption, as discussed previously. Based on the econometric projections, it has been observed that by 2030 the captive electricity consumption will be 250-269 TWh, while the utility consumption will be 553-597 TWh. Although, the captive share is expected to decrease in the coming years, but our econometric forecasts are in line with the existing trend. The reason for this is twofold, first, the forecasts with a shorter temporal horizon does not lead to a substantial change in the macroeconomic parameters. Second, any new policy regime can provide a shift in captive consumption only in the medium term, and therefore the current captive share in total consumption remains fairly consistent with past captive shares.

Residential Sector

Between 2015 to 2022, the residential electricity consumption grew at a rate of 6.1 percent (fastest amongst all the sectors), while GDP per capita increased at 5.6 percent (The World Bank, 2023) in this period. Along with this, the sector accounted for nearly 30-32 percent of the total electricity consumption suggesting an emerging demand for residential appliances driven by rising consumption expenditure budgets in Indian households during the period. It is further anticipated that the rising electricity demand will continue to surge in the coming decade due to the expected two-fold (United Nations, 2018b) increase in urbanisation rate by 2030 resulting in higher residential consumption demands and an increase in cooling demand for mitigating heat stress in South Asian emerging economies, which is unprecedented and may escalate domestic air conditioning requirements.

In Table 8, we present the residential electricity demand statistics till date and divide the residential population on the basis of urban and rural demography to carry out the econometric forecasts. Based on the historical data, it has been observed that the electricity consumption is correlated with the GDP per capita with an R^2 value of 0.96 and urban population with an R^2 value of 0.92.

Table 8: Residential Sector Statistics in India

Parameters	FY 2015-16	FY 2021-22	Growth during this period
Electricity Consumption (TWh)	239	341	6.1%
GDP per capita (PPP) (Constant) (2011-12)	1732	2277	4.7%
Correlation of electricity consumption to GDP per capita (R2)	0.96		
Correlation to Urban Population	0.92		

Source: (ICED, 2023), (RBI, 2023a)

Econometric projections for residential electricity demand

The residential electricity demand in the ER-CTS and ER-HGR is anticipated to reach 581 TWh and 575 TWh, respectively. Also, the aggregated electricity consumption in the sector is expected to increase by 5.9- 6.6 percent by 2030 in comparison to the pre-pandemic growth of nearly 6.1 percent. The recovery from the pandemic resulted in a marginally slower demand in few sectors barring the residential sector. However, it is interesting to notice that the effect remains short lived because of vigorous growth in electricity consumption during the second half of the decade with extensive economic growth domestically and export led policies.

From the current level of 179 kWh/capita, the residential electricity consumption is expected to increase almost two-fold to 347-374 kWh/capita. While the empirical evidence indicates that cooling will majorly dominate the residential electricity demand in the coming decade, we will comprehensively examine how various electricity demand sub-categories are expected to contribute to the existing share of electricity consumption mix in the residential sector in the upcoming sections.

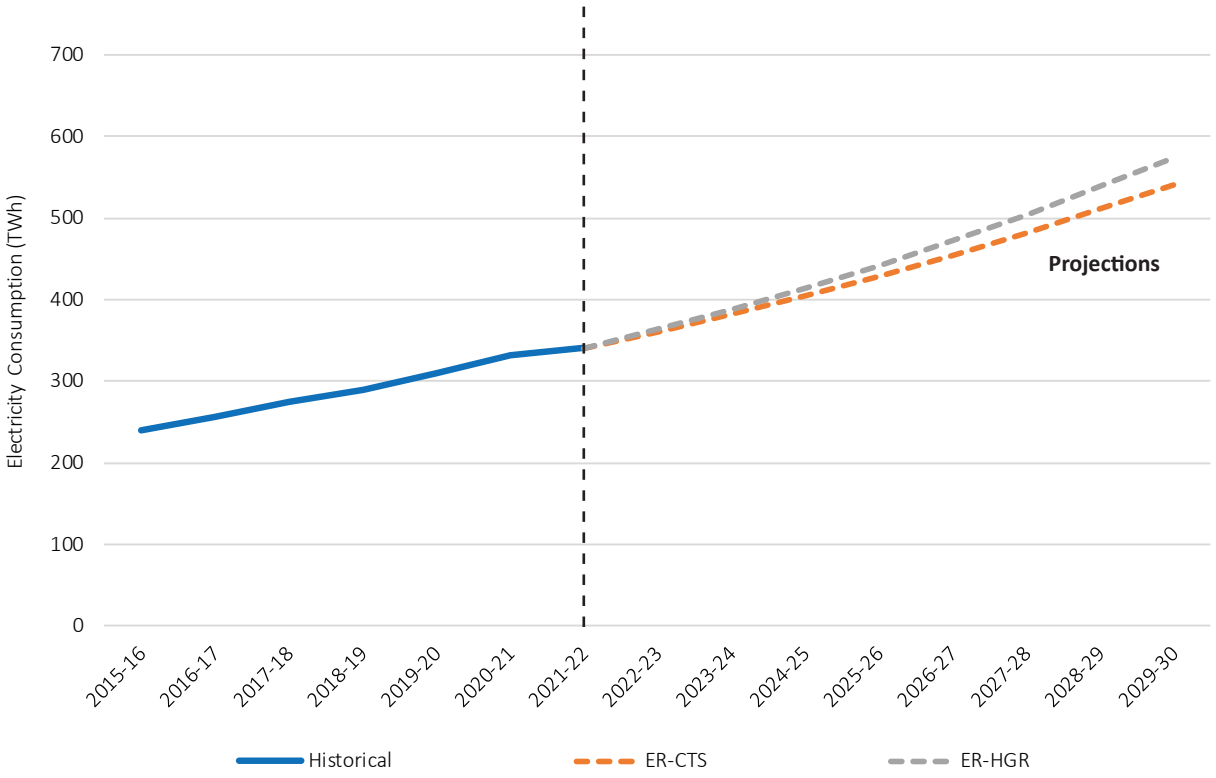


Figure 10 : Residential Electricity consumption in ER-CTS and ER-HGR by FY 2029-30

Exhibit 4: How intensive are the top residential electricity consuming states in terms of per capita demand?

In Table 9, we compare the top eight residential electricity consumption states based on a number of key parameters. Several critical insights emerge on comparing the consumption based on absolute value and consumption per capita for the years 2021 and 2030. Firstly, we observe that these eight states account for 59 percent of the total electricity consumption in the residential sector with Uttar Pradesh, Tamil Nadu and Maharashtra constituting a third of this consumption. Secondly, the residential consumption trend is similar to the current level, however, it is not uniform across the states. For Delhi, Tamil Nadu and Maharashra the residential electricity per capita consumptions are higher than their counterparts, moreover, as compared to the national average the GDP per capita is also higher for these four states (a comprehensive analysis of GDP per capita and residential electricity consumption per capita shows an R^2 correlation of 0.733, suggesting a strong correlation between both). Owing to the rising urbanisation rate by 2030, it is expected that these states will further intensify their residential electricity consumption in absolute terms as well as on a per capita basis.

Table 9: High Residential Electricity Consuming states statistics by FY 2029-30

State	Electricity Consumption (GWh)			Domestic Consumption per capita (kWh/capita)		
	FY 2021-22	FY 2029-30 (BAU)	FY 2029-30 (HGR)	FY 2021-22	FY 2029-30 (BAU)	FY 2029-30 (HGR)
UP	44.5	76.4	81.1	191	301	324
TN	34.0	55.0	58.4	443	705	878
MH	30.7	49.0	52.0	245	569	667
MP	17.3	29.7	31.5	202	319	339
BR	17.0	29.1	30.9	136	209	304
WB	18.2	25.8	27.4	185	254	307
DL	16.5	25.3	26.9	786	1050	1241
PB	14.8	24.5	26.0	488	567	612

Source: Author's Analysis

Aggregation and Key highlights of the electricity demand as per the econometric forecasts

In this section, we summarise the insights derived from the econometric forecasts discussed comprehensively in the previous sections. Table 10 outlines the electricity consumption for agriculture, services, industry and residential sectors. It also mentions the transport and railways electricity

consumptions for ease of overall estimation, although they have only been forecasted through end use methodology. Also, please note that the PEUM section will discuss the electricity consumption from agricultural pumping, solar rooftops, fleet electrification, green hydrogen in heavy industry etc and an aggregate of the estimation of total ex-bus electricity requirement will be presented at the end of this report.

Table 10: Key Summary results from Econometric forecasting scenarios (All values in TWh)

Sectors	FY 2021-22	ER-CTS		ER-HGR	
		FY 2026-27	FY 2029-30	FY 2026-27	FY 2029-30
Industrial	556	695	804	729	867
Services	171	233	281	250	314
Residential	339	455	541	472	575
Agriculture	228	292	339	305	364
Transport*	0	15	61	18	73
Railways*	22	31	34	31	34
Total Consumption	**1316**	**1721**	**2060**	**1805**	**2227**

*The projections for transport and railway consumption are discussed in transport section

According to the table 10, the total electricity consumption (which includes transport and railways sectors) in the ER-CTS and ER-HGR is expected to increase to 2060 and 2227 TWh, respectively, by 2030. While the industrial, commercial and agriculture consumptions collectively occupy nearly 70 percent of the share, the residential consumption account for a quarter of the total electricity consumption.

4

DEMAND PROJECTIONS USING PARTIAL END USE METHOD

The previous sections have delved into scenarios and results emerging out of the econometric regression methodology. Although macroeconomic parameters allow us to project electricity demand by correlation with various activity variables in midterm, however it is important to acknowledge dynamic nature of demand structure, technological improvement, and system efficiency within the Indian economy. These changes have been rapidly observed due to policy push for electrifying end uses. Consequently, it is important to examine this growth through an end use approach. This allows us to forecast electricity demand in future through a lens of changing technological landscape and policy changes. This section focuses on end use projections to next decade considering underlying sections discussed earlier along with new demand drivers like green hydrogen and EV sales.

Agriculture Sector

With a 4.3 percent growth, the agriculture sector's share in the electricity consumption has been relatively slower than other sectors, nevertheless, by showing a 5.2 percent increase over the past couple of years, it was the only sector next to residential to witness a growth during the COVID wave. This can be attributed to reverse migration as a result of COVID and revival of agricultural activities in rural India. It is to be noted that, since 1990, the agricultural workforce has decreased significantly from 70 percent to 40 percent owing to a substantial shift of the workforce to services and industry sectors. In the past decade, the agriculture sector has largely relied on the southwest monsoon for cultivation of major kharif crops but in order to provide perennial supply of food, irrigation became increasingly important. As of 2021, the net irrigated area (total area under cultivation irrigated once in a year) makes up 49 percent of the sown area, of which 60 percent relies on groundwater pumping, and the remainder on canal irrigation (Union Budget, 2022).

Figure 11(a) and (b) show the corresponding growth in parameters related to agricultural production during FY 2015-16 and FY 2019-20. The period is marked by a significant growth in agricultural production. This could be understood by two facts. First, with access to groundwater irrigation, area under irrigation as a share of total sown area increased tremendously. Second, with higher yield variety seeds and irrigation, cropping season extended. Figure 11(b), shows an R^2 correlation of 0.89 between gross irrigated area and pump sets energised during the last decade. This is an important metric to gauge, since gross irrigated area indicates how many times that area has been sown throughout the year. A surge of 14 percent is observed in India's cropping intensity, which represents a slight increase over the previous decade. This is anticipated to continue growing faster in the coming decade, for ensuring India's food security and boosting exports of foodgrains. In the upcoming subsection, we will discuss how the cropping intensity is bound to grow through 2030 and how this will impact the electricity requirements for irrigation.

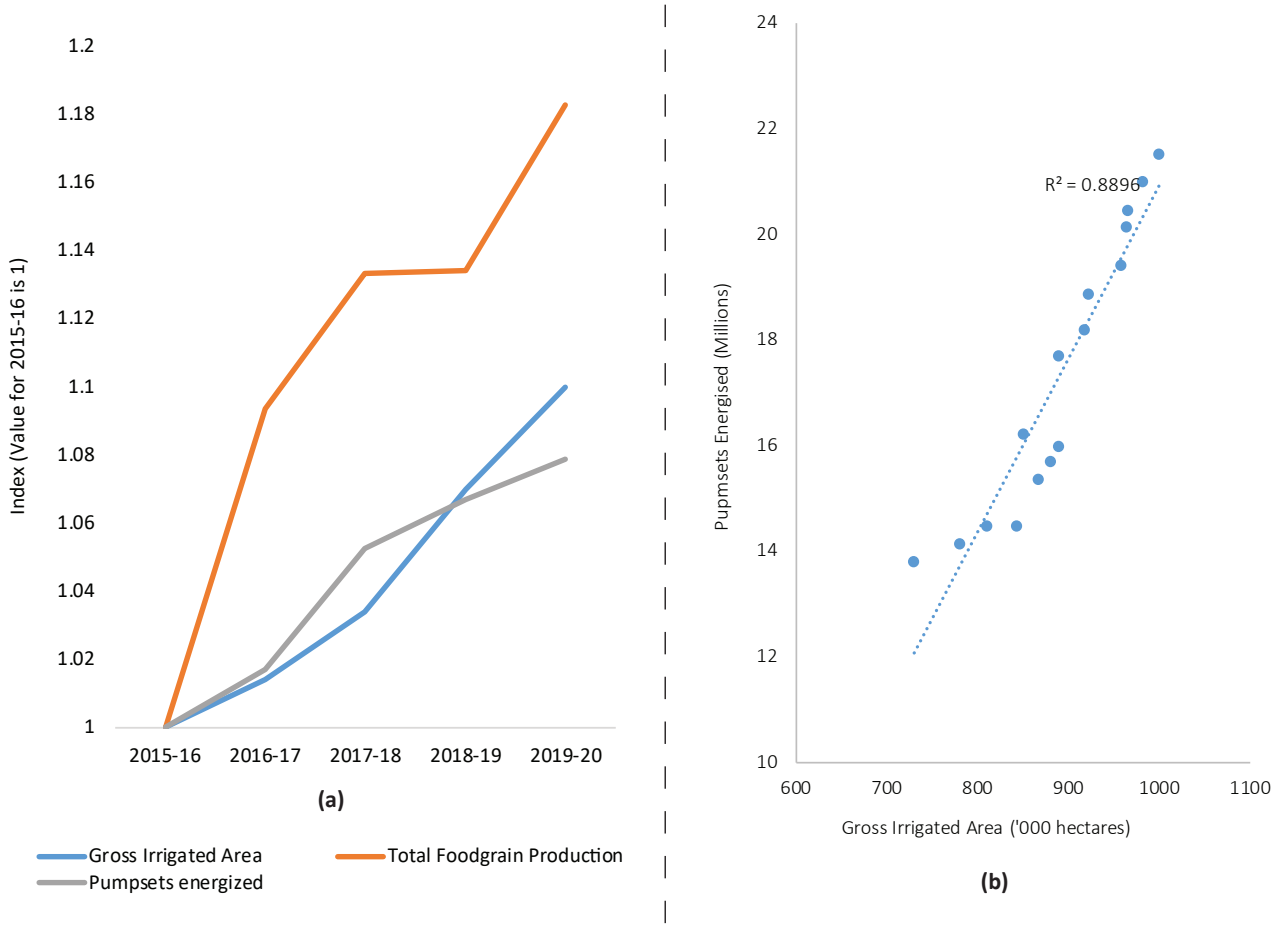


Figure 11: (a) Index of Agricultural Statistics, (b) Correlation between pump sets energised and gross irrigated area (from 2005 to 2020)

Methodology for agriculture sector

In the previous paragraph, we have discussed that the number of pump sets energised in the last decade has increased significantly and is strongly correlated with gross irrigated area. This underlines the dependence on irrigation to maintain continuous agricultural production throughout the year. As seen in figure 11(a), a strong correlation could be gauged between electricity consumption and associated parameters. Electricity consumption has a R^2 correlation of 0.953 in case of pump sets energised and an 0.934 in case of gross irrigated area.

Thus, to forecast the future growth of electricity consumption, we estimate the new Electric pump sets by 2030. We estimate the growth in gross irrigated area based on rise in cropping intensity by 2030, which assumes an average growth of foodgrain production in India. Accordingly, we bifurcate the irrigation pump sets based on their usage capacity, efficiency, and type. It is seen that the pump sets (~70 percent) are generally used during the kharif and rabi seasons with typically lower usage hours of 0-200 hours (DoWR, RD & GR, 2017). Furthermore, 65 percent of the total pump sets are sized between 5 to 7.5 hp while a few (5 percent) are limited to 20 hp and above (Shakti Foundation, 2018). However, we adjust the number of usage hours to consider a moderate growth due to groundwater depletion. We aggregate the total Electricity consumption for all the pump sets energized.

Partial end use projections for agriculture electricity demand

Agricultural electricity consumption is expected to rise from 295 to 334 TWh (net electricity consumption considering decentralised solar pumping adoption), entailing an overall growth of 6.45 percent over the current electricity consumption. During the period of 2020-2030, the total stock of pump sets is expected to reach 33-35 million, with an overall growth rate of 4-4.8 percent. This, in turn would improve the cropping intensity to 1.6-1.62 by 2030, which is at 1.47 at present. Therefore, it is anticipated that by 2030 the solar pump sets will constitute 11 percent of the total stock, in line with the ambitious target set under the PM KUSUM scheme to broaden the scope of solar pumping.

Table 11: Agricultural Gross and Net Electricity consumption by FY 2029-30

Scenario	Year	Gross Consumption (TWh)	Net Consumption (TWh)	Total Solar Pumps (Millions)	Pump Sets Energised (Millions)	Cropping Intensity
PE_CTS	FY 2024-25	269	250	1.5	27.8	1.53
	FY 2029-30	332	295	3.5	33.5	1.60
PE_HGR	FY 2024-25	312	290	1.9	28.4	1.55
	FY 2029-30	376	335	3.7	34.2	1.62

Services Sector

Over the past few years (from 2015 to 2022), the services sector has contributed to nearly 16 percent of the total electricity consumption, with consumption growing at three percent over its GVA which grew at two percentage points higher. In addition, the air-conditioned commercial spaces contributed around 26 percent in the services sector, which is expected to further increase to 43 percent by 2030. However, the energy intensity has been reducing in the sector proportionately, as a result of policy mandates set forth by the BEE's Energy Conservation Building Code (ECBC) to achieve energy efficiency performance standards in commercial building design and space cooling requirements.

As of 2017, the country's total floor space area for commercial buildings was 1096 million square metres (Kumar, 2018). In the Indian context, however, subclassification of commercial buildings based on their type and use is limited, as commercial buildings are usually benchmarked based on their connected loads. Thus, benchmarking electricity consumption becomes challenging across various sub-sectors. Therefore, the lack of an existing database presents a trivial setback in estimating India's electricity consumption.

Methodology for service sector

To estimate the current and future stock of buildings by their end use, we have adopted the methodology and base year data (2017) for the classification of commercial building end uses based on the comprehensive study (Kumar, 2018). Commercial spaces are sub-categorised as hospital, hotel, retail, office, educational, assembly and transit, while the residual floor space is considered as a separate non-specified category, even though it represents a marginal representation in the total

stock. The growth in floor space areas is forecasted in each of the building categories up to 2030 in accordance with their historical shares and future growth trends. This is illustrated in Figure 12. Given the higher share of growth among the commercial spaces over the last five years, finance, retail and office spaces are considered to have a higher precedence in growth rate. By 2030, the total air-conditioned space in each category is expected to exponentially increase based on growth till date. The Energy Performance Index (EPI) benchmarks for each of building category are derived from BEE standards and existing literature. EPI serves as an important indicator since different building stock has varying levels of energy consumption depending on their cooling, appliance and lighting requirements.

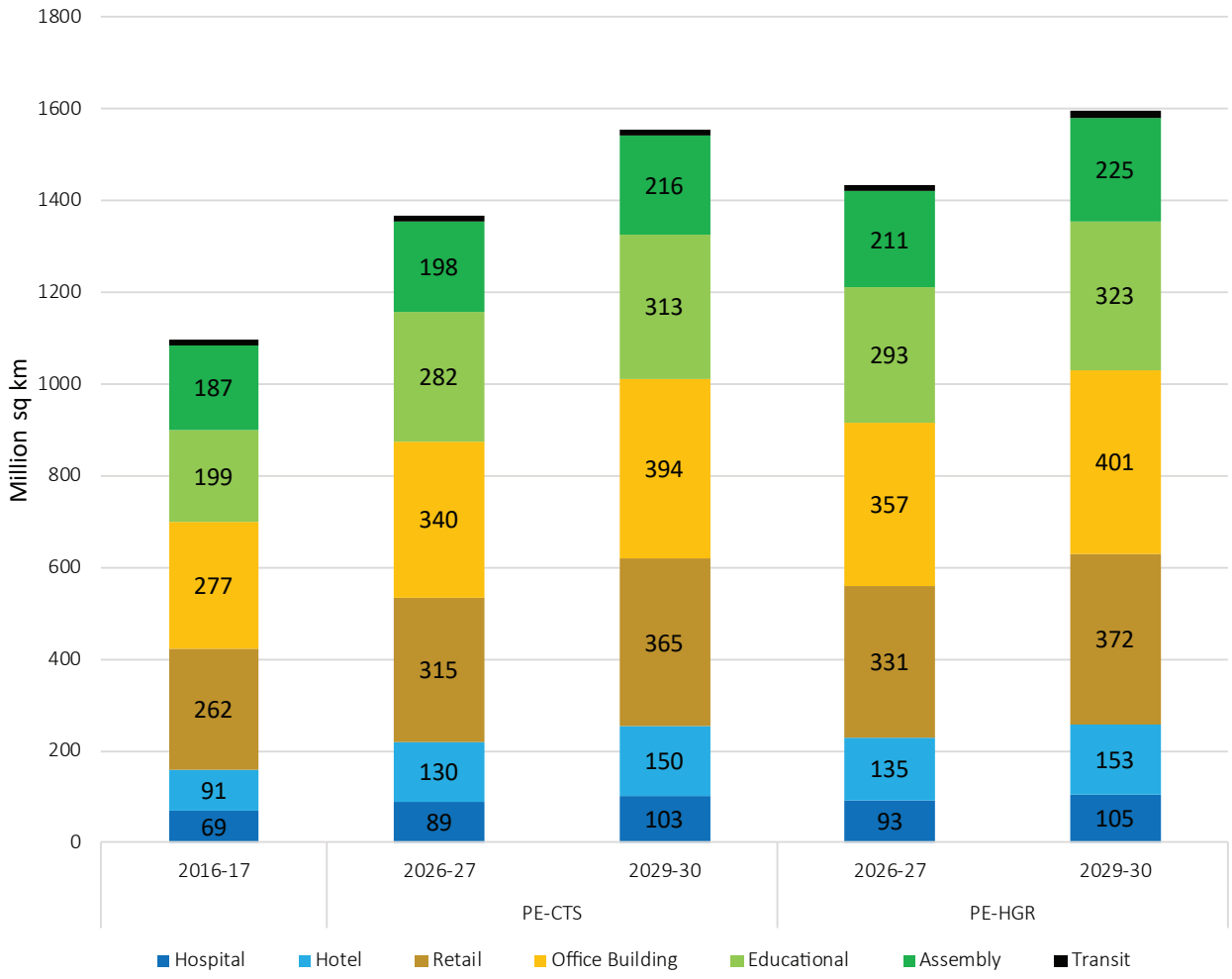


Figure 12: Commercial floor space area projections by FY 2029-30

Partial end use projections for services electricity demand

As per our end use projections, electricity consumption for the commercial buildings is expected to increase to 263-305 TWh by 2030 and the share of air-conditioned spaces in the total services electricity consumption is anticipated to rise from 60 percent in 2017 to 76 percent in 2030 in both PE-CTS and PE-HGR, as shown in Figure 13. Furthermore, office space, retail and educational buildings continue to account for 75 percent of total electricity consumption.

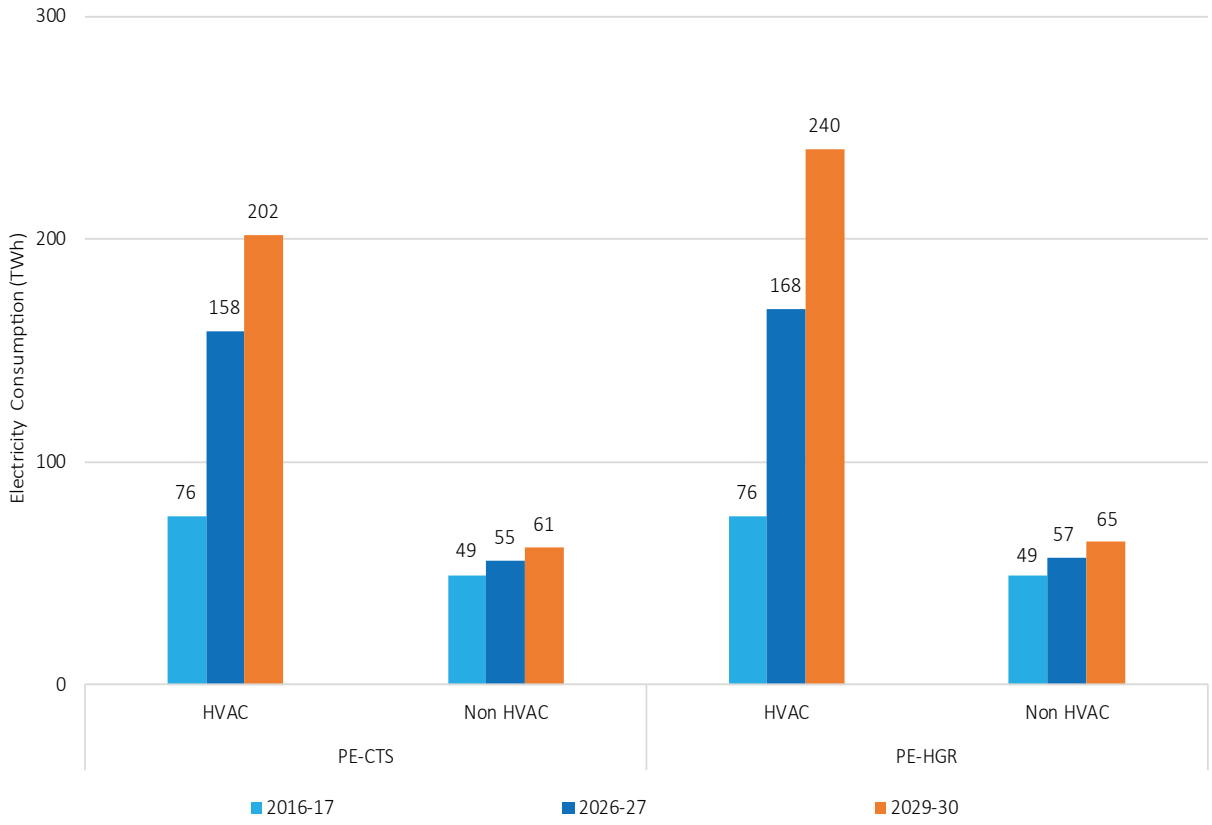


Figure 13: Electricity consumption projections by FY 2029-30 in Services Sector

Industrial Sector

In India, the industrial electricity consumption occupies substantial share only next to residential sector, however it has a contribution both in terms of utilities and non-utilities demand in order to meet the demand for industrial production in a reliable manner. In the previous section on econometric projections, we comprehensively assessed the captive demand which represents almost 30-32 percent of the total electricity demand. Moreover, the heavy industries together with MSME have experienced a robust growth in recent years, through export led policies and push for indigenous manufacturing. Thus, the sentiments for energy growth in industry remains extremely positive. Several policy interventions supported by the BEE's Perform Achieve and Trade (PAT) scheme have resulted in significant energy savings. As part of the PAT scheme, specific energy consumption targets are established for heavy to medium industries, and the progress is monitored every five years. By doing so, industries are encouraged to exceed their goals and sell those credits as Energy Saving Certificates (ESCerts). Table 12 provides an overview of industrial production by major Indian industries in FY 2019-20 and their share of value addition to the industrial sector.

Table 12: Industrial Production and outlook statistics

Sector	Total Production (FY 2019-20) (MT)	Total Production target (FY 2029-30) (MT)	% contribution in the total industrial GVA
Iron and Steel	96	255	13%
Cement	299	600	9%
Aluminium	4.02	10	14%
Olefins (Petrochemicals)	11.8	NA	6%*
Chlor-Alkali	3.5	NA	7%#
Pulp and paper	23	NA	2%
Fertilizer	38	NA	4%

Source: India KLEMS, * All Petrochemicals, #All Chemicals

Exhibit 5: Robust policies targets for driving industrial production by 2030

Indian exports are dominated by steel and heavy engineering goods sector, ranking among the top five nations across the globe. To indigenise the industrial value chain and further boost exports, the government has set ambitious industrial production targets which are determined by policy mandates and long-term vision plans from various ministries. As part of its 2030 (Ministry of Steel, 2020) steel production target, the Ministry of Steel is aiming to increase capacity to produce 255 million tonnes per annum (MTPA) of steel from the current 114 MT of finished steel production and to increase the per capita consumption of steel to 160 kg from 65 kg at present, which is fairly low than the current global averages. Moreover, the ministry is also exploring the potential of using green hydrogen to decarbonise the hard-to-abate steel sector. Similarly, the fertiliser sector has set a target to be self-sufficient by 2025 and export-dominated by 2030, with a two fold increase resulting from a strong policy push and significant boost in agricultural production (PIB, 2022c). The aluminium production is expected to rise threefold by 2030 to 10 MTPA with a push towards exports and domestic consumption (United News of India, 2019). On the similar lines, the cement industry is anticipating a rise to 600 MTPA by 2030 due to strong signals from the real estate sector and a surge in commercial building spaces. Therefore, it is expected that such policy-based targets will provide accountability for heavy industry decarbonisation and boost capital investments.

Methodology for industry sector

The estimation of industrial electricity demand on the basis of its end use approach is complex. Although electricity consumption in energy intensive industries can be assessed by analysing the industrial output, however, estimating non-PAT sectors (which contribute ~60 percent to total industrial electricity consumption) is more challenging since the data for end use production and electricity consumption are unavailable.

By adopting a hybrid approach (policy-based and growth-based) to assess industrial production, we have estimated industrial electricity consumption based on the end use methodology. This is due to a lack of policy-based targets for 2030 in the mid-term for certain industries, such as cement, aluminium and steel. Those sectors that do not have policy mandates their industrial production is assessed by correlation to sub-sectors' value added to 2030 (RBI, 2022). This approach is especially relevant to industries such as chloralkali, fertilisers, petrochemicals and pulp and paper.

The residual (non-PAT) industrial consumption of industries that are non-specified, i.e. sectors that are not covered by the PAT scheme, is estimated based on the historical consumption share. We cover the same sectors for assessment and estimate the residual demand.

The PE-CTS and PE-HGR scenarios assume a similar level of material and energy intensity but the electricity consumption is assessed based on the change in industrial production in these scenarios. Since, the energy intensive industries are efficient and comply with global specific energy consumption (SEC) standards, there is a limited scope for improving energy efficiency in these industries. Although the energy efficiency potential exists for MSME and non-PAT sectors, estimation of the same is a challenge and therefore, we have not considered further energy efficiency improvements in the overall industrial sector. The role of energy efficiency and potential savings are, however, discussed in in residential sectors.

The SEC for each of the processes in the sub-sectors mentioned above is derived from multiple case studies, BEE Monitoring and Verification documents, secondary literature and expert opinions. Furthermore, we examine recent policy mandates relating to fuel switching, including the use of green hydrogen in the fertiliser and steel industries, along with the potential for deep electrification.

Partial end use projections for industrial electricity demand

The electricity consumption in FY 2026-27 and FY 2029-30, separated by PAT and non-PAT consumption is shown in Figure 14, indicating moderate to high industrial production growth by 2030. In the PE-CTS and PE-HGR, the electricity consumption is estimated to reach to 1058-1260 TWh (including the captive demand) which is a threefold increase from the current level. Consequently, the industrial electricity consumption is ~30-40 percent higher than the econometric projections. This increase in the end-use estimation could be attributed to the uncertainty in the non-PAT sector, new demand from the green hydrogen production, and unaccounted improvements in specific energy consumption by 2030, which remains factored out for the ER-CTS and ER-HGR scenarios.

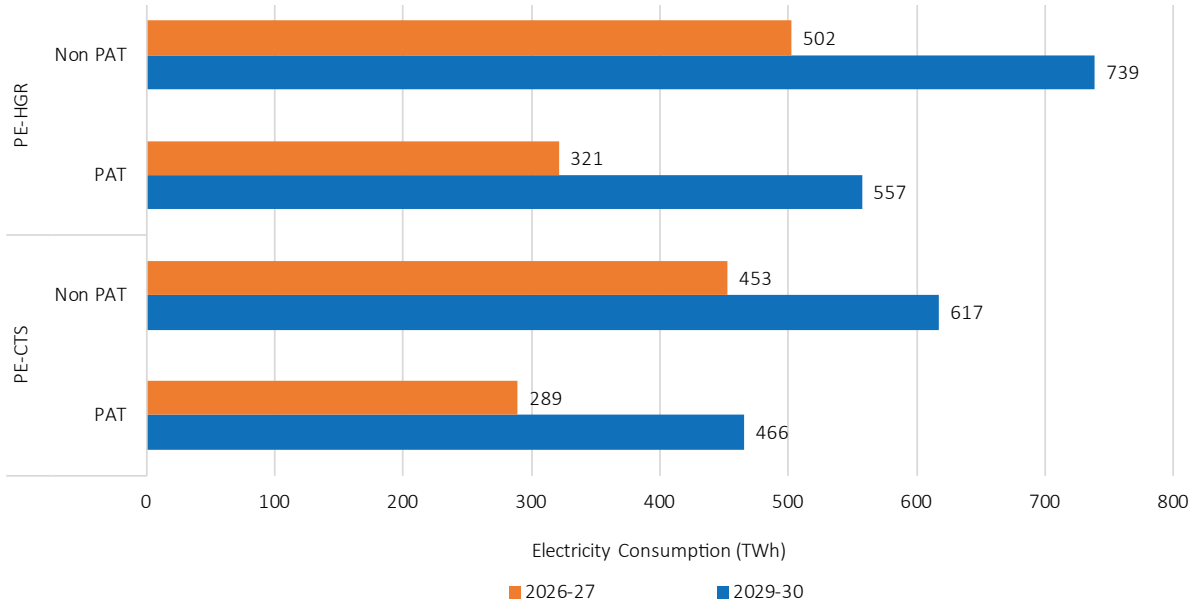


Figure 14: Industrial electricity projections in PAT, non-PAT and captive sectors by FY 2029-30

Figure 15 illustrates in more detail the breakdown of electricity consumption by 2030 as compared to 2020. While the PAT dominating electricity intensive sectors consume 53 percent of the total industrial electricity consumption, the non-PAT sectors account for 43 percent of this consumption. Further, there has been a shift in share within the PAT sectors with refineries, fertilisers and steel having a marginally higher share due to an uptake of green hydrogen. Thus, between 2020 and 2030, these three PAT sectors' electricity consumptions rise from 42 percent to 62 percent of the total PAT consumption. Moreover, we consider a uniform share of captive consumption of total Industry electricity consumption as per the current trend. However, we marginally adjust the captive share in electricity demand based on an equal distribution of green hydrogen production through captive and utility-based electricity sales. Further, a significant portion of non-PAT consumption share as shown in the figure is attributed to the lack of sub sectoral data at the granular level.

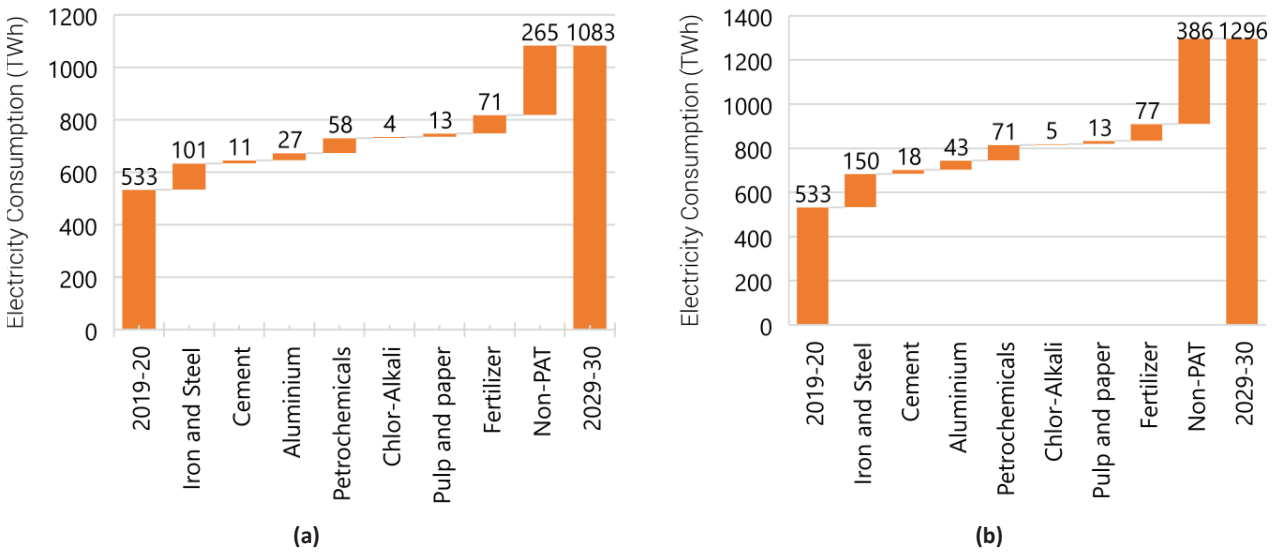


Figure 15: Share of Sub sectoral electricity consumption in Industries from FY 2019-20 to FY 2029-30 (a) PE-CTS (b) PE-HGR

Exhibit 6: Scope for Green Hydrogen in industrial decarbonisation.

With the launch of the National Green Hydrogen Mission, the mandate for production of 5 MTPA green hydrogen by 2030 is a positive development for heavy industries (MNRE, 2022b). This is especially crucial considering the existing demand for hydrogen predominantly within the fertiliser, petrochemicals and the steel sector. Further, there is a push to replace natural gas with green hydrogen in DRI-based steel production and urea-based Haber Bosch units, although at present, there is no direct mandate for demand pull for green hydrogen in these industries. Using the end use approach, we have estimated green hydrogen consumption based on two scenarios - 3.5 and 5 MTPA. By 2030, the use of green hydrogen in urea production and petrochemicals is 40 percent each, while its usage in DRI-based steel production is 20 percent, resulting in a total natural gas savings of 41-59 mmscmd and an incremental electricity demand of 175-250 TWh owing to the replacement of electricity with natural gas. This incremental demand will likely be captive in nature in order to avoid transmission charges that may be incurred if procured through the state grid. Further, the current carbon intensity of the Indian grid would make utility scale production of green hydrogen unsuitable. Our projections estimate the linear consumption of green hydrogen to 2030 and its usage based on the manufacturing output in the PE-CTS and PE-HGR. Consequently, PE-CTS and PE-HGR scenarios occupy a higher estimate of electricity consumption as compared to ER scenarios. It would be worthwhile to observe the increase in electricity consumption in the near-term with the rapid implementation of the mandates for green hydrogen consumption.

Residential Sector

Residential sector is the second highest consumer of electricity in the country with a total electricity consumption of 30-32 percent, which has grown at 6.1 percent CAGR from 2015 to 2022. Due to rapid urbanisation of Indian cities coupled with an expected migration of approximately 120 million population to cities by 2030, the electricity demand from residential sector is anticipated to rise at a faster rate by the next decade (United Nations, 2018a).

Residential floorspace area is expected to increase by almost 30 percent from 2010 to 2030 with a total area of 52,000 million sq.m (IEA, 2021). As per the data from the Ministry of Statistics and Programme Implementation (MoSPI) and the National Sample Survey Office (NSSO), there is a significant increase in the ownership of electricity intensive appliances, particularly for cooling. The domestic ownership of air conditioners and air coolers raised from 17 percent in 2015 (MoHFW, 2017) to 25 percent in 2021 (MoHFW, 2022), with urban areas accounting for ~65 percent of this ownership. In addition, new demands for electrical appliances such as refrigerators, electric cooking, and others has been emerging as can be seen in Table 13 which illustrates the growth in residential appliance ownership from 2010 to 2020.

A comparison of domestic appliance penetration in urban and rural demography helps identify the past trends as well as the future outlook in the coming decade. It is to be noted that the data for the past

decade is robustly sourced from NSSO and government surveys, however, the appliance details for FY 2019-20 have been derived from primary surveys conducted by various organisations and secondary literature. With almost 100 percent coverage in both demographics, there has been a tremendous growth in LED usage in the last decade primarily due to the Government of India's UJALA scheme. Moreover, air conditioning has experienced a significant uptake in the cooling segment, although its penetration is uneven across the states with 74 percent in Delhi, 70 percent in Punjab and single digit percentage use in eastern and north-eastern states. In the Indian context, usage of electricity for heating purposes is very limited and it primarily pertains to water heating. The use of refrigerators, televisions and washing machines in both rural and urban areas has increased substantially in the recent years and the projections for 2030 foresee an enormous uptake in the electrical appliances segment. Furthermore, with India's rapid urbanisation, there is a boost in the use of mobile phones, tablets and laptops with the penetration of mobile phone to the extent of 90-100 percent in both urban and rural households.

Table 13: Rise in Appliance Ownership in Urban and rural geographies

Appliance category	Sub-Category	Appliance Ownership (% of household)				Growth in appliance stock	
		Rural	Urban	Rural	Urban	10 Year CAGR	10 Year CAGR
		2010		2020		Rural	Urban
Lighting	Incandescent	61%	49%	100%	100%	7%	12%
	CFL	15%	27%	100%	100%	25%	20%
	LED	0%	0%	86%	91%	105%	121%
Space Cooling	Fan	55%	91%	90%	97%	7%	4%
	Coolers	11%	11%	37%	51%	16%	23%
	Air Conditioning	1%	3%	3%	17%	22%	31%
Heating	Geyser	0%	3%	3%	8%	6%	15%
	Space Heating	0%	1%	1%	9%	18%	32%
Appliances general use	TV	42%	76%	58%	87%	5%	5%
	Induction cooking	0%	0%	3%	10%	4%	73%
	Refrigerator	7%	39%	25%	63%	17%	9%
	Washing Machine	2%	20%	9%	36%	21%	11%
	PC/Laptop	1%	10%	4%	19%	21%	12%
	Mobile Phone	51%	79%	92%	97%	8%	6%

Source: IRES, 2022

Methodology for residential sector

The ownership pattern of major electricity-intensive and non-electricity intensive appliances across rural and urban demographics in India is used to estimate the electricity consumption in the residential sector, as shown in Table 13. Given a shorter time horizon to 2030, we prefer to consider the current stock of appliances still in operation rather than creating a stock model to identify the total number appliance currently in use. We have further divided each of the appliance penetration in both rural and urban segments, assuming a higher level of penetration as per the PE-HGR scenario.

We have applied a different method of estimation for air cooling, since it consumes significant amount of electricity. The forecasting methodology and associated results are elaborated in Exhibit 7. The datasets from NSSO, NFHS and primary surveys conducted by other institutions are used to estimate the appliance penetration. In addition, we have incorporated the policy settings affecting appliance penetration, rather than relying solely on projected growth of appliances. For example, we have considered a complete phaseout of incandescent point lighting by 2030 as well as the minimum three-star rating appliances for all demographic segments.

Moreover, we have calculated efficiency savings primarily in the cooling sector, which has a highly energy-intensive nature, and thus, enable us to estimate potential savings in the residential sector.

Partial end use projections for residential electricity demand

The results of residential electricity demand for 2027 and 2030 in the baseline and high growth scenarios are shown in Table 14. Based on the PEUM methodology, we have estimated electricity demand to rise to 576-614 TWh in the PE-CTS and PE-HGR scenarios by 2030. The highest growth in residential electricity demand is attributed to cooling, as discussed in previous subsections. The estimated cooling demand by 2030 follows the similar demand trend as the residential sector and is projected to reach 392-411 TWh in the PE-CTS and PE-HGR scenarios, accounting for the majority (~66 percent) of total electricity demand.

Table 14: Electricity demand (TWh) in Residential sector by Appliance in FY 2026-27 and FY 2029-30

Category	PE-CTS		PE-HGR		Share of Individual category
	FY 2026-27	FY 2029-30	FY 2026-27	FY 2029-30	
Lighting	34	34	35	35	6%
Space Cooling	266	379	279	411	66%
Heating	29	33	30	34	6%
Appliances	100	130	104	135	23%
Total	**430**	**576**	**448**	**614**	**100%**

Exhibit 7: Residential cooling demand to dominate the residential electricity consumption by 2030

With intense heat waves and rapid urbanisation, India's cooling demand is rising exorbitantly. As per the meta study of emerging economies, a rise in 100 Cooling Degree Day (CDD) would result in an increase of 3-7 percent of air conditioning penetration in households, with most Indian states vulnerable to extreme heat stress and therefore, their cooling demand is bound to increase (Nature Communications, 2021). Compared to the world average of 252 kWh, India's per capita cooling demand in 2020 was 69 kWh, although residential cooling is anticipated to grow to 280 million TR by next decade, representing 71 percent of total cooling demand for the country (MoEFCC, 2021).

In our end use analysis, we have projected cooling demand based on the historic share of air conditioner stocks and underlying forecasts for 2030. Using demography (both rural and urban), volume (1,1.5 and 2 TR), type (window and split), energy consumption (3-star and 5-star) and hours of usage (considering impact of CDD increase to 2030 on hours of usage), we determine the stock of air conditioning penetration. By 2030, the residential air conditioning stock is estimated to rise to 216-243 million units in the PE-CTS and PE-HGR scenarios. This comprises of 162-175 million units in urban and 54-68 million units in rural segment. The total electricity consumption from air conditioning is estimated to increase to 262-308 TWh in PE-CTS and PE-HGR scenarios by 2030. Further, we assess a high efficiency scenario in air conditioning, to estimate potential savings in the residential sector. This assumes a higher share of 5-star air conditioning penetration in the urban households. Thus, electricity consumption of 232-278 TWh is estimated from space cooling, thus yielding a 26-37 TWh energy savings from the residential space cooling itself.

The outlook for rooftop solar (RTS) in India

India has installed 11.1 GW of solar rooftop capacity by November 2023, as against the target of 40 GW of solar rooftop installation by March 31, 2026 (revised from December 2022) (MNRE, 2022a). This capacity addition is primarily concentrated in the commercial and industrial segment (with 78 percent share), while the penetration of solar into the residential segment so far is limited. Nevertheless, the government is promoting reforms in terms of extending the solar rooftop programme with upfront capital subsidies. Consequently, considering the current growth in solar rooftop and policy push, we anticipate that by the end of 2030, the cumulative capacities in PE-CTS and PE-HGR scenarios will rise to 16 GW and 24 GW, respectively. This corresponds to a growth rate of 9-14 percent by 2030. Thus, the rooftop solar generation resulting from residential, industrial, and commercial sectors is estimated to be in the range of 25 TWh to 38 TWh by 2030.

Transport Sector

Road transport currently contributes to 87 percent of the total passenger-based transport and 60 percent of the freight traffic movement (MoRTH, 2023a). Further, India's road transport has contributed to 68 percent of country's total transport emissions in 2022 and 8 percent of the total CO_2-eq emissions (IEA, 2021). In terms of energy consumption, the transport sector has contributed to ~9 percent of the final energy consumption in the country (MoSPI, 2023). With the increasing household consumption expenditure, the share of private vehicles in the total fleet is growing rapidly (Kamboj, 2022). From 1990 to 2019, private ownership of vehicles (both 2-wheeler and 4-wheeler) has increased from 11 percent to 38 percent (MoRTH, 2021), albeit only 8 percent Indian households possess a car while 48 percent owns a 2-wheeler (NFHS, India, 2021). It is estimated that by the next decade, the uptake of private vehicles will result in decrease in public transportation use. This indicates the importance of electrification of private road transport to abate the CO_2 emissions from the sector. The per capita vehicle ownership from 2012 to current fiscal year is shown in Figure 16. It can be observed that the growth of 2-wheelers in India is staggering, comparable to the current trend of developing economies in the South and South East Asia. Despite a growth in the number of privately owned cars, ownership is still only a quarter of the average ownership rate in other developing economies.

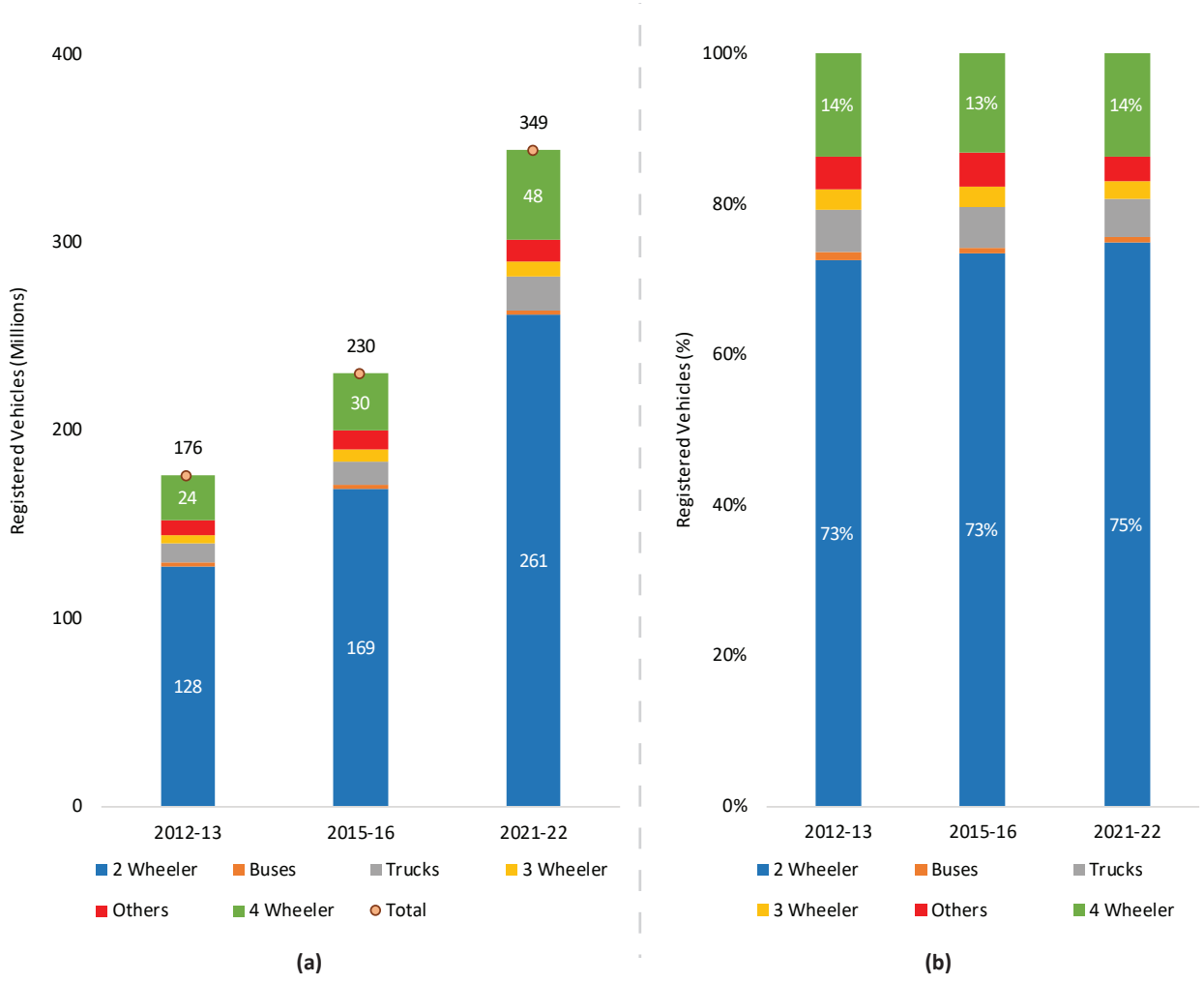


Figure 16: Total Registered Vehicles (a) in Millions, (b) Percentage;

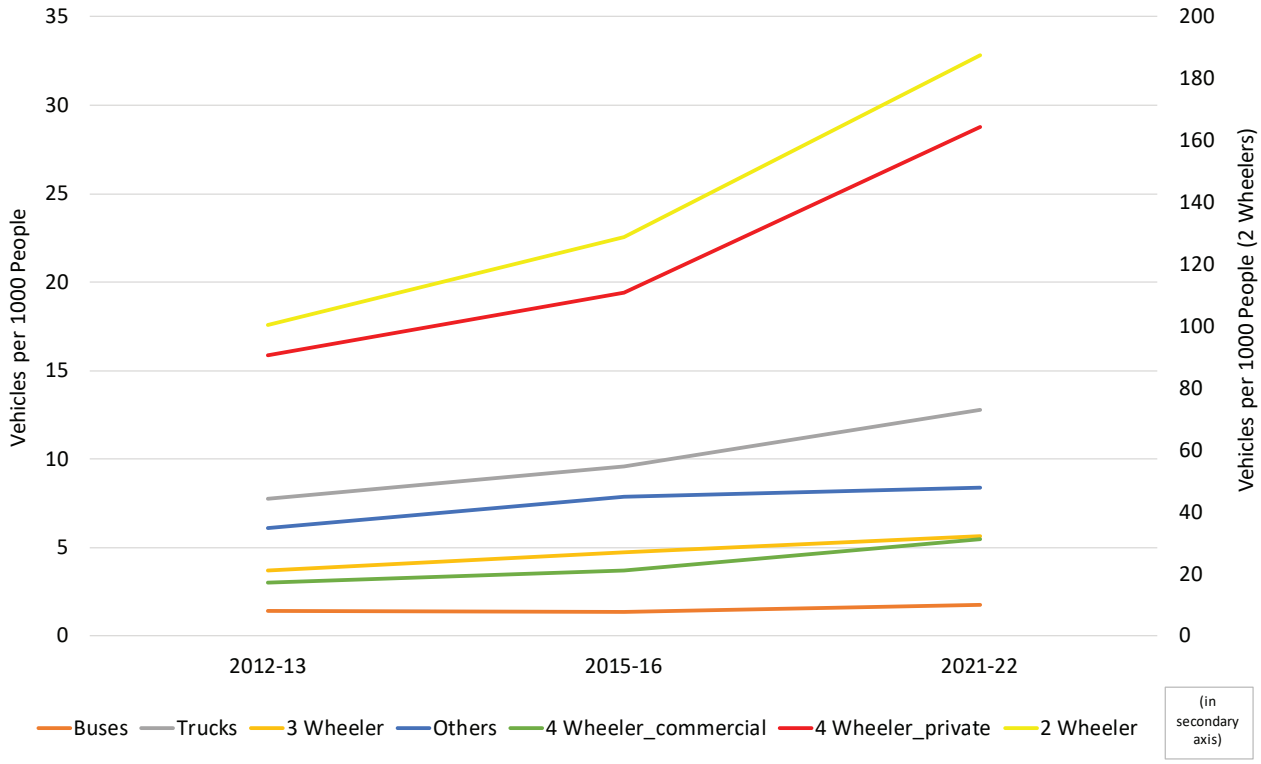


Figure 16: (c) Vehicle Motorization Index (Vehicles/1000 people)

With the government focussing on the uptake of electric vehicles through upfront subsidies on capital costs, it is imperative to understand the outlook for fleet electrification by 2030 for both electrified fleet as well as the overall growth in road transport. As a result, helping us understand the role of EVs in overall national electricity demand by 2030.

Methodology for estimation of category-wise vehicle registrations till 2030

Passenger road transport has a diverse segment base with ownership characteristics varying across the fleets. To forecast the registration of transport vehicles until 2030, we assess the historical ownership patterns, if any, over the last decade, as a result of shifts from public to private transport. Relying solely on econometric or end use approach could potentially deviate the forecasts, thus, we employ the partial end-use method to forecast the increase in the number of vehicles of respective categories. Using the data from the latest available repository from MORTH yearbook (MoRTH, 2018) and VAHAN dashboard (MoRTH, 2023b), we projected the new vehicle registration (segment-wise) econometrically based on GDP per capita and GVA from the transport sector. We further mapped the current stock of electric vehicles added till date from the same database and captured the projected ambitious fleet electrification targets as per the existing policy announcements. For estimating the electrification requirement from EVs, we derive a couple of scenarios that allow us to foresee an outlook for fleet electrification rather than a single deterministic number for 2030. The PE-CTS considers scenarios derived from a previous study (NITI Aayog & Rocky Mountain Institute, 2019), whereas PE-HGR takes into account a higher growth in fleet electrification. Table 15 summarises the category-wise penetration targets considered by 2030.

Table 15: EV Penetration of new sales in the scenarios considered

Vehicle Category	PE-CTS	PE-HGR
2-wheeler	80%	90%
3-wheeler	80%	100%
Public Buses	40%	50%
Commercial 4-wheeler	70%	80%
Private 4-wheeler	30%	40%

Exhibit 8: Recent trends in adoption of EV

There is a boost in EV adoption in the Indian market since the policy interventions and regulatory frameworks help overcome various hurdles that includes exemption from EV registration tax, income tax rebate, capital subsidy etc. From 2012 to 2022, the overall EV fleet grew by 86 percent CAGR, bringing its total stock to ~14 lakh, from a mere 0.6 lakh prior to the commencement of the FAME scheme (MoRTH, 2023b). However, the adoption of private versus commercial vehicles exhibits a sharp difference. The 3-wheelers and 2-wheelers segment comfortably picked up in the market owing to the last mile connectivity they provide. Both fleets represent ~60 percent of the new EV sale, as seen in Figure 17. In the current FY, the 2-wheelers are gaining momentum in terms of higher share in registrations while the private 4-wheelers have seen a growth only in recent years and their uptake continues to remain slow, primarily due to range anxiety, limited charging infrastructure, limited supply options as well as higher capital costs. Therefore, per capita ownership of EV remains discrete, as depicted in Figure 17.

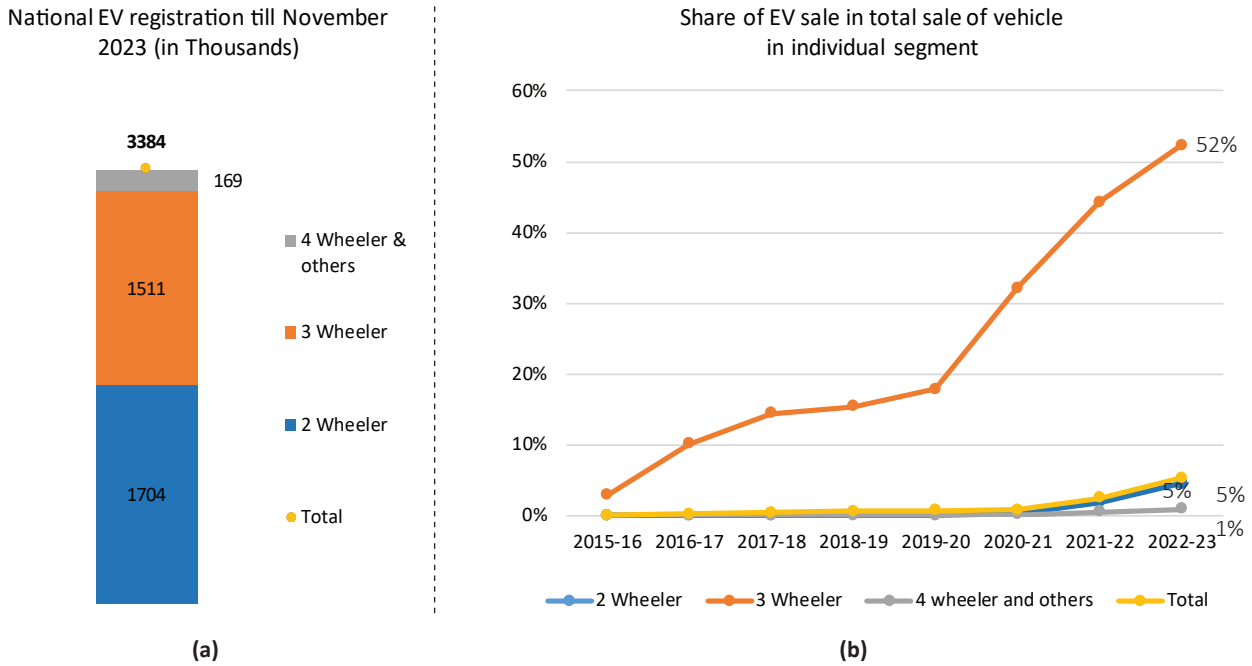


Figure 17. (a) Total EV Registrations, (b) Share of EV in total Vehicle segments

Partial end use projections for transport electricity demand

Figure 18 shows the growth in overall road-based transport registrations by 2030. India's total road-based transport registrations are expected to increase from 349 million in 2022 to 521-538 million by 2030 in the PE-CTS and PE-HGR scenarios, indicating an annual increase of 4.8 percent CAGR over the current registrations. By 2030, private 4-wheelers share is expected to reach 73-81 million, a growth of over ~5 percent CAGR from the current fiscal. However, we have observed that the share of public transport remains fairly constant, since the boost in public buses at a rate of 4 percent is rather slow, thus their share isn't exorbitant. India has one of the lowest bus availability rates at 1.7 per 1000 people, and our forecast suggests a marginal rise of only 2.1-2.3 bus/1000 person by 2030. Our model does not take behavioural changes into account in terms of uptake of new fleets and preference to public transport, but there might be a possibility of higher uptake of public transport than the current growth rate. However, the 4-wheeler ownership is expected to reach 51-57 vehicles per 1000 capita by 2030, a twofold rise from the current rate.

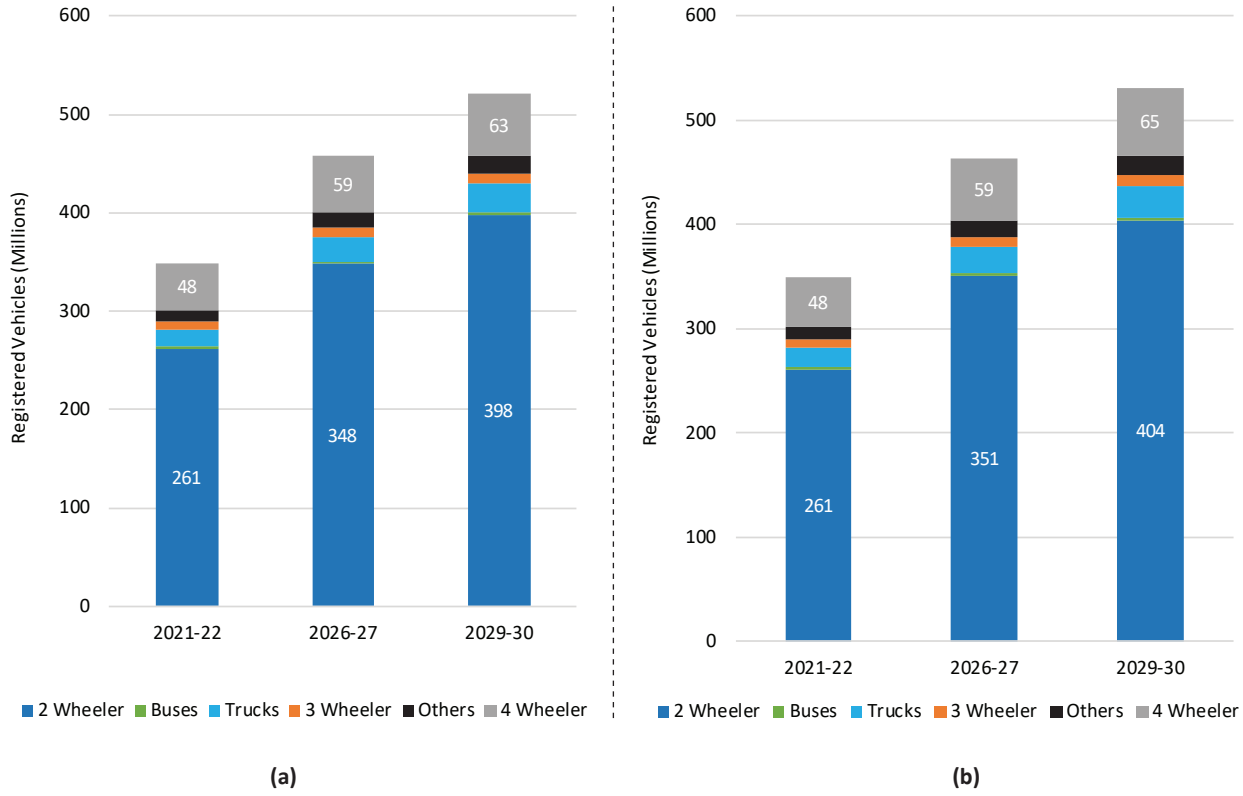


Fig 18: Total Vehicles Registered till FY 2029-30 (a) PE-CTS and (b) PE-HGR

EV penetration and electrification requirement

By 2030, the total electric vehicles in India are estimated to rise to 61-66 million in PE-CTS and PE-HGR scenarios, with 2-wheelers estimated to largely dominate, although a higher uptake is expected for 4-wheelers, only after 2025. This underpins the reduction in capital costs and high growth in charging infrastructure deployment across cities and proposed major highways. Figure 19 shows the EV stock by 2025 and 2030 according to fleet type. A huge growth is anticipated in the 2-wheeler segment

driven by both private and commercial users. As a result of the last mile delivery services, 2-wheelers sales have skyrocketed at ~135 percent growth over the last five years. Decent growth is predicted in E-buses as well. Due to the limited coverage of policy mandates for private and intercity electric buses in literature, we are only considering intra-city electric buses in our modelling. This further suggests an unorganised nature of the transport sector and unclear policy mandates beyond Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME India), which mainly focuses on public buses.

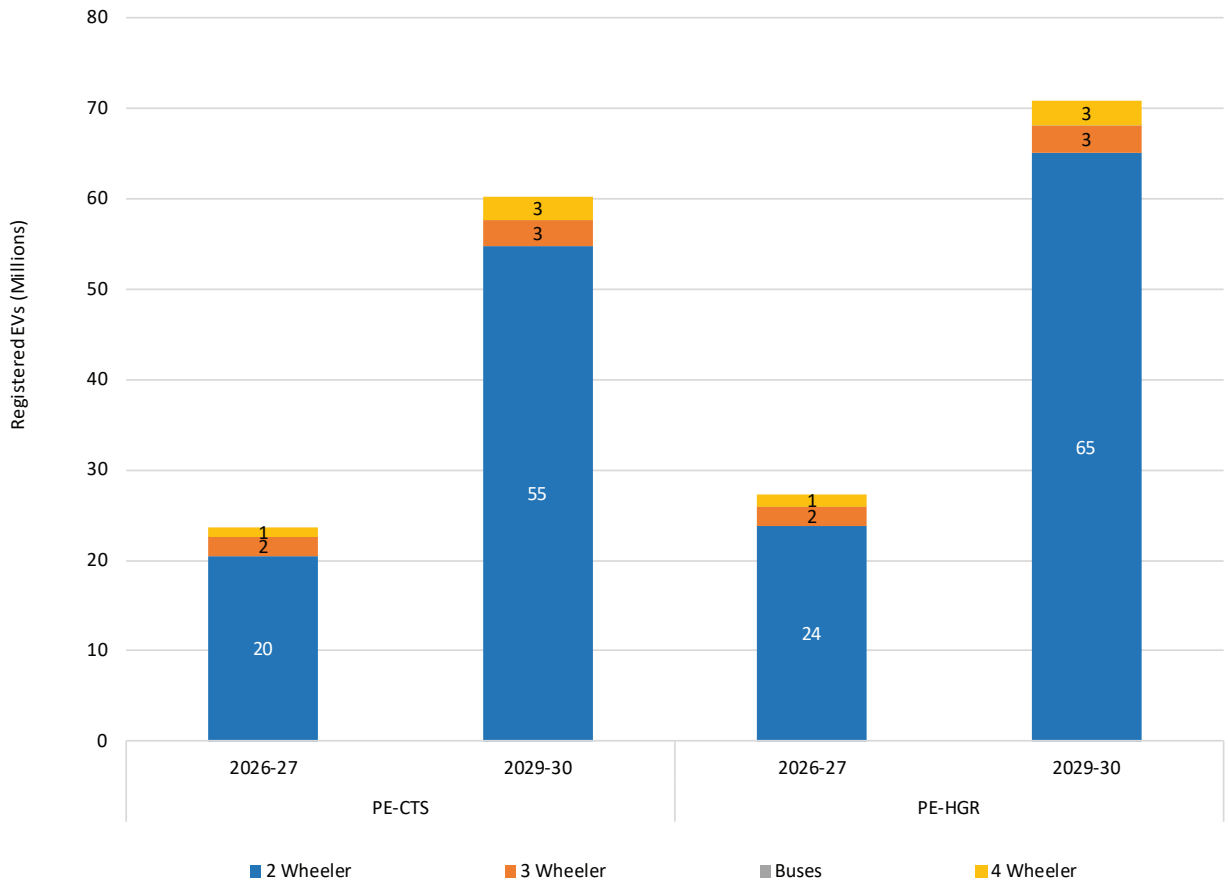
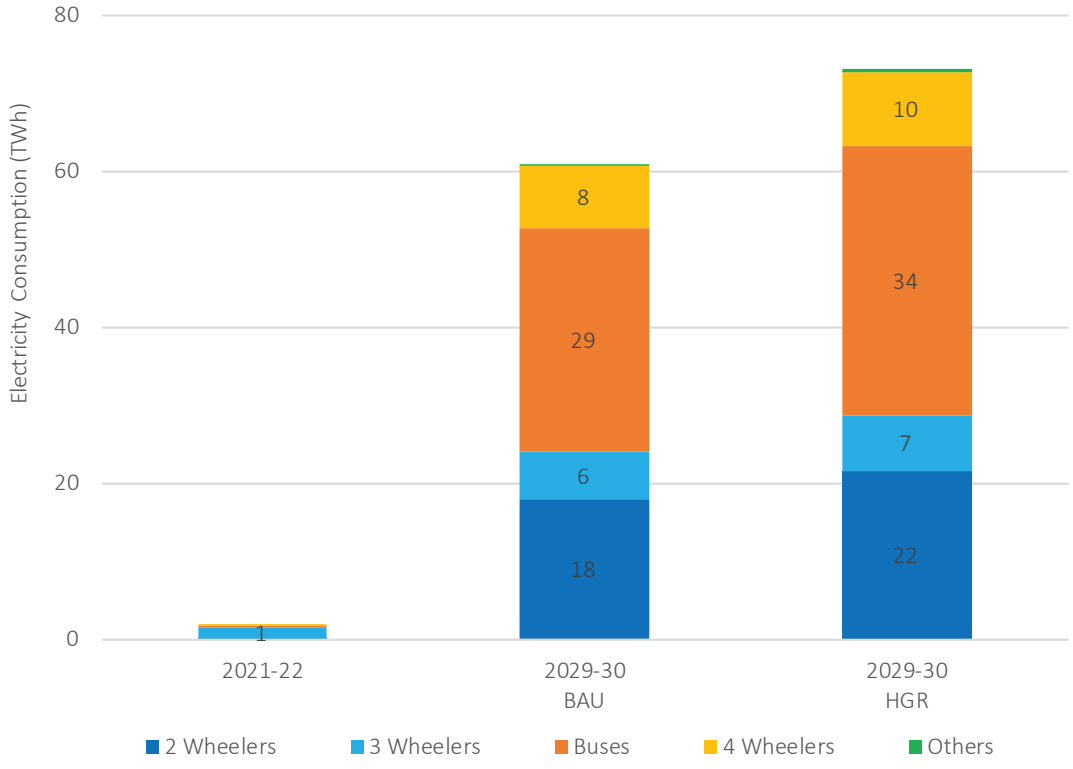


Figure 19: Category wise registered EVs by FY 2029-30

Electricity consumption estimates

In this subsection, we discuss the forecasted growth in electricity consumption from the road transport sector by 2030. According to our estimate, the total electricity consumption will rise to 57-68 TWh by 2030 and electric buses and 2-wheelers segments are estimated to consume the majority of electricity. These segments may also witness highest growth during the decadal period. It is likely that the electric buses would avail highest instantaneous power demand for opportunity charging at the depot, hinting towards higher peak demand, especially during daytime. Therefore, measures such as tariff rationalisation, optimised depot-based charging stations could result in demand response measures as well as higher utilisation of distributed solar for charging during the daytime.



(2021-22 Consumption is a calculated consumption and not actual value)

Figure 20: Electricity Consumption by EVs in PE-CTS and PE-HGR by FY 2029-30

Railways Sector

Indian Railways has the largest rail network in Asia, carrying both passenger as well as freight traffic under the purview of single management control. The network expanded vigorously from 26,125route kilometre (RKM) in 2016 to 64,689 RKM in FY 2021-22 at 15 percent CAGR (Ministry of Railways, 2021). Further, over the past 20 years, the electrification of railways significantly increased from just 24 percent in 2000 to 66 percent by 2021. The Indian railways has set an ambitious plan to electrify the traction segment completely by 2025 and become net-zero by 2030 (PIB, 2022a).

Between year 2000 and2020, the share of freight traffic in railways has reduced significantly from 45 percent to 31 percent. Firstly, this is because of the higher freight rates in Indian railways, which are among the highest in the world (Brookings India, 2018). The higher freight hauling charges to cross subsidise the railway passenger segment is depreciating the freight traffic in the railways. Secondly, due to the very long turn-around times, as both the freight and passenger trains run on the same track. In projecting the RKM and electricity consumption, we have taken into account the current measures that the government is focussing on traction as well as non-traction segment. We have calculated the kWh consumption per RKM for the traction load and estimate the same trend for the future. Given the higher share of traction load, the share of electricity consumption has remained particularly consistent between traction and non-traction segments.

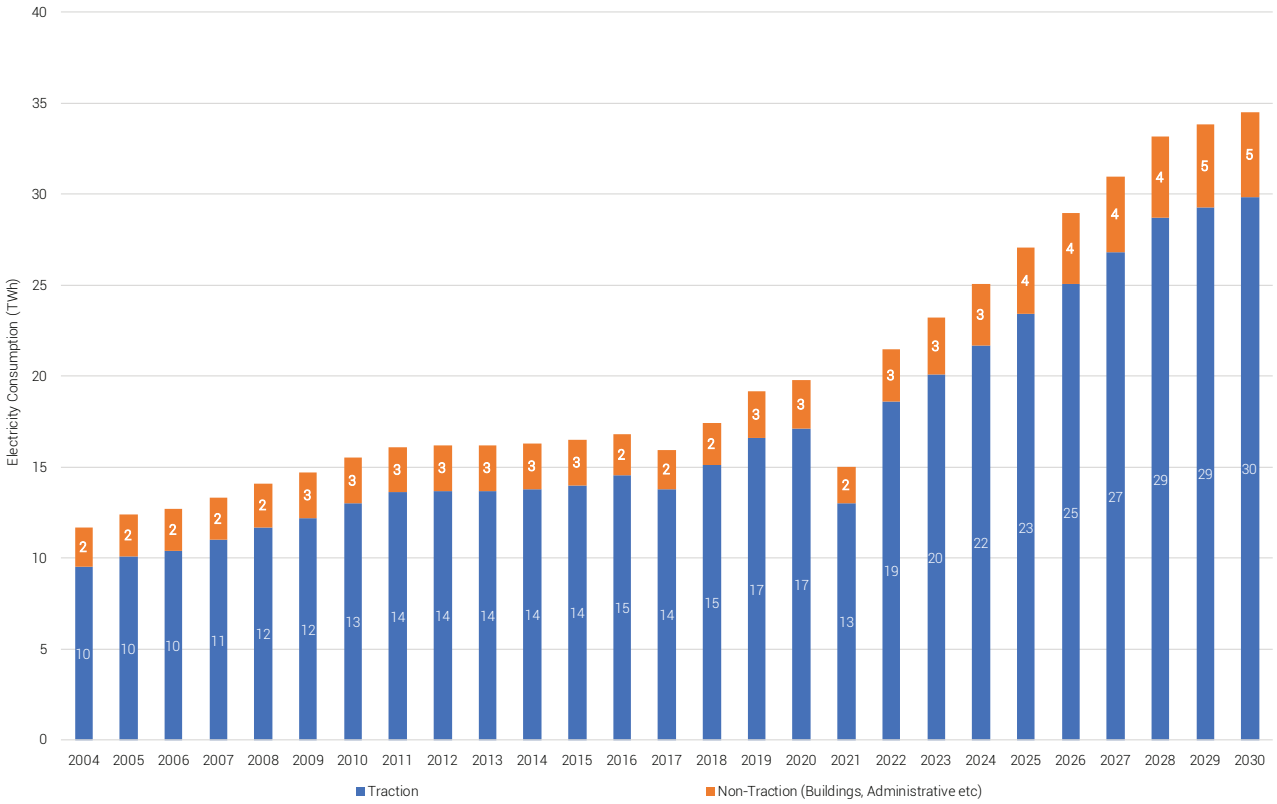


Figure 21: Electricity Consumption in Railways Traction and Non-traction segment (PE-CTS) by FY 2029-30

End use projections for railways electricity demand

Based on our end-use projections, we have indicated the total route kilometre (RKM) and electricity consumption until FY 2029-30. The total RKM is estimated to reach 74,310 RKM, a 0.6 percent per year increase from the current level. Furthermore, as compared to 2020, the electricity consumption is estimated to rise just about twofold, that is, 31-34 TWh by 2030. The percentage share contributed by traction and non-traction segments for electricity consumption by the Indian Railways is ~85-87 percent and 13-16 percent, respectively.

Aggregation and Key highlights of the electricity demand as per the partial End Use method

In this section, we summarise the key results emerging from the partial end use forecasts discussed comprehensively in the previous sections. Table 16 outlines the electricity consumption for agriculture, services, industry, residential sectors and also including Railways and Road Transport. Overall, by 2030, the total consumption is estimated to reach 2370-2723 TWh. Most noteworthy amongst all Electricity demand driver is the industry which consumes ~42% of the total consumption, this additional driver is driven by policy mandates on green hydrogen usage. Further, residential sector has a higher consumption by the end of 2030, given a higher consumer appliance penetration together with newly electrified segments in residential sector including cooking.

Table 16: Key Summary results from PEUM scenarios (all values in TWh)

Sectors	FY 2021-22	PE-CTS		PE-HGR	
		FY 2026-27	FY 2029-30	FY 2026-27	FY 2029-30
Industrial	556	742	1083	824	1296
Services	171	214	263	225	305
Residential	339	430	576	448	614
Agriculture	228	285	332	328	376
Transport	0	15	61	18	73
Railways	22	31	34	31	34
Total Consumption	**1316**	**1716**	**2349**	**1873**	**2699**

Consolidated summary of electricity projections

This section concludes and draw inferences from the results of the Econometric and Partial End Use scenarios. The insights from these scenarios will be further analysed for 2030. In addition, we have attempted to segregate the total electricity consumption from ex-bus electricity demand requirement. Table 17 illustrates the sectoral forecasts aggregated based on the two scenarios mentioned. As per the ER and PE methodologies, by 2030, the electricity demand is expected to reach 2,060 to 2,227 TWh and 2,349-2,699 TWh, respectively. This demand is expected to grow at the rate of 6.1 percent to 6.8 percent as compared to a lower growth rate of 4.9 percent between 2015 and 2022 as a result of the economic slowdown followed by pandemic restrictions.

We anticipate that the transmission and distribution losses are expected to reach 15 percent by 2030 due to the downward trajectory of 3.5-3 percent per year from the current level of ~19 percent. In contrast, our wide range of ER and PE scenarios projects that the ex-bus electricity requirement is expected to reach 2,039-2,191 TWh and 2,215-2,454 TWh by 2030.

Table 17: Consolidated results from Econometric and PEUM methodology (All values in TWh)

Sectors	Vasudha Scenarios							
	ER-CTS		ER-HGR		PE-CTS		PE-HGR	
	FY 2026-27	FY 2029-30	FY 2026-27	FY 2029-30	FY 2026-27	FY 2029-30	FY 2026-27	FY 2029-30
Gross Consumption including Captive (Utilities + Non-Utilities) - (A)								
Industrial	695	804	729	867	742	1083	824	1296
Commercial	233	281	250	314	214	263	225	305
Residential	455	541	472	575	430	576	448	614
Agriculture	292	339	305	364	285	332	328	376
Transport	15	61	18	73	15	61	18	73
Railways	31	34	31	34	31	34	31	34
Total	**1721**	**2060**	**1805**	**2227**	**1716**	**2349**	**1873**	**2699**
Captive Consumption - (B)								
Agriculture Pumping	27	36	31	42	27	36	31	42
Solar Rooftop	19	25	28	38	19	25	28	38
Railways	15	17	15	17	15	17	15	17
Industry	192	250	202	270	262	390	312	518
Total Captive Consumption	**254**	**329**	**277**	**367**	**324**	**468**	**386**	**616**
Net Consumption (Utility) (C) = (A-B)								
Net Consumption	**1467**	**1732**	**1528**	**1861**	**1393**	**1881**	**1487**	**2084**
T&D Losses								
T&D Losses (D)	291	308	303	331	276	334	295	370
Ex-bus Electricity Requirement (Utilities) (C+D)								
Total Ex-bus Electricity Requirement	**1758**	**2039**	**1831**	**2191**	**1668**	**2215**	**1782**	**2454**

In Figure 22 compares the share of electricity demand in the CTS and HGR scenarios by FY 2026-27 and FY 2029-30 along with their individual shares. According to our observations, the industrial and residential sectors would likely to have a dominant share in the electricity demand, contributing 60-64 percent of the total consumption, similar to the current situation. Moreover, the partial end use scenarios have significantly higher demand than the econometric scenarios due to two possible reasons:

Firstly, the industrial demand increases substantially in partial end use scenarios as we anticipate a shift in emerging technologies, particularly in energy intensive sectors (use of green ammonia in urea production and green hydrogen in steel production) and a higher electrification of transport fleet across light and heavy-duty segments. It is to be further noted that the usage of green hydrogen in industry is distributed equally in utility sales as well as captive consumption. ER scenarios in contrast could not capture the sectoral shift in the electricity consumption usage. Secondly, we observe an increase in the residential electricity consumption, primarily related to residential air conditioning usage as well as change in appliance ownership prevalent in urban households. Therefore, the residential sector in end use scenarios has a marginally higher forecast. On the contrary, the agriculture forecasts in PE see a marginal decline, due to efficiency improvement and adoption of decentralised solar pumping. The decline can also be attributed to solar rooftop adoption targets by 2030 (mentioned in the previous subsections) which is likely to result in a reduction of electricity demand by 25-38 TWh.

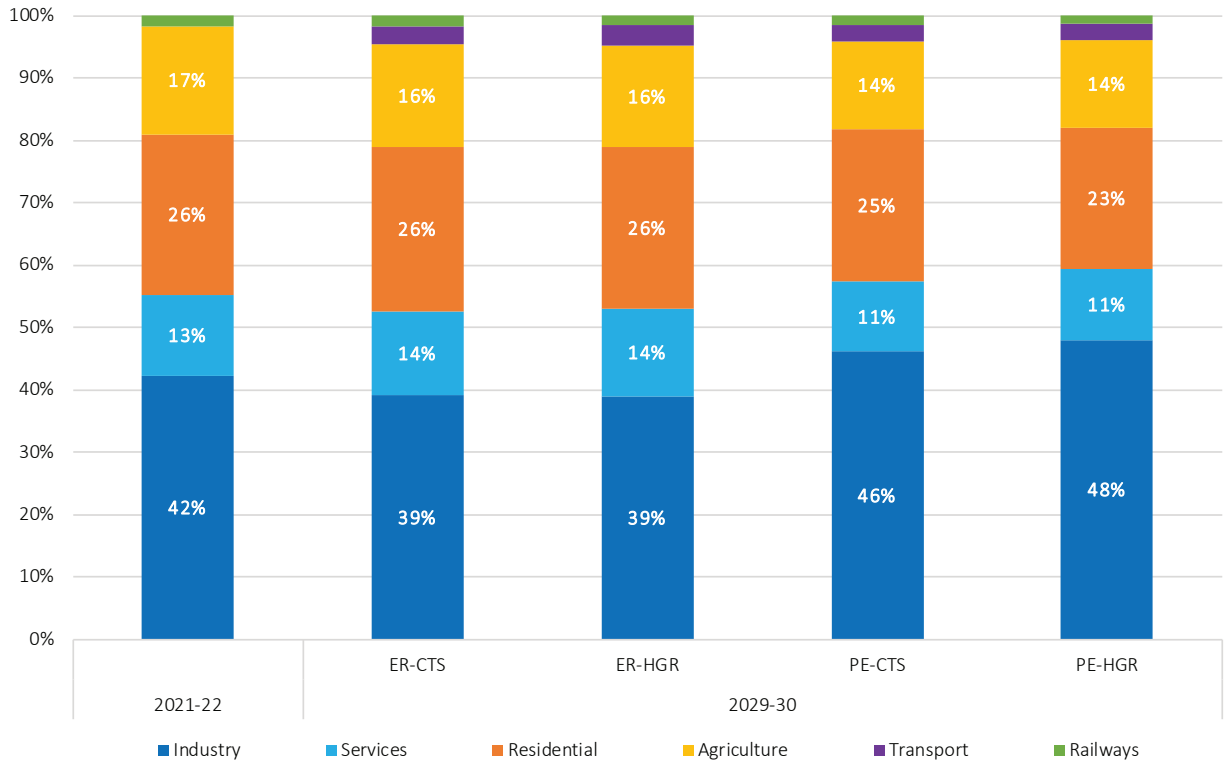


Figure 22: Comparison of Electricity consumption share by FY 2029-30 in Econometric and PEUM

How do electricity projections fare with the 20th Electric Power Survey (EPS)

In this section, we present the results from both our ER-CTS and ER-HGR scenarios for ex-bus electricity demand requirements for FY 2036-37, along with comparing the consolidated results to the recently released 20th Electric Power Survey (EPS). The survey, which is conducted by the Central Electricity Authority (CEA) provides forecasts of India's electricity demand over the medium to long-term. Although this report is not intended to be benchmarking or comparing the results with those of the central estimates, our forecasts can serve as extensions of the underlying range of future electricity forecasts that can be utilised to provide an outlook for achieving India's mid-term and long term decarbonisation goals.

In order to forecast the electricity requirement to FY 2036-37, we extend our state level econometric model to 2037 and add up the electricity requirement from new demand drivers such as EVs, railways and green hydrogen. The results from both ER and PE scenarios are summarised in Table 18.

Table 18: Ex Bus Electricity Requirement (TWh) across FY 2026-27 to FY 2036-37

Year	Vasudha Scenarios				CEA 20th EPS
	ER-CTS	ER-HGR	PE-CTS	PE-HGR	
FY 2026-27	1758	1831	1668	1782	1907
FY 2029-30	2039	2191	2215	2454	2279
FY 2036-37	2936	3175	NA	NA	3095

CONCLUSION AND WAY FORWARD

The comprehensive analysis presented in this report highlights the critical importance of electricity demand forecasting in shaping a resilient power system, especially in the context of India's dynamic and evolving energy landscape. The projections indicate a substantial growth in electricity demand over the next decade, with various sectors playing distinct roles in driving this surge.

The industrial sector emerges as a major contributor, with policies promoting fuel switching and increased industrial production likely to propel a significant rise in electricity requirements. The anticipated growth in steel production and the emphasis on green hydrogen further underscore the need for a robust and adaptive power infrastructure.

Residential electricity demand is expected to witness a substantial increase, driven by factors such as urbanization, rising heat stress, and a surge in electronic appliances. Notably, the surge in space cooling, fuelled by a considerable increase in residential air conditioning units, highlights the importance of addressing climate-related challenges in electricity planning.

The transport sector, both road and railways, is poised to undergo a transformative shift with electrification initiatives. The projected rise in road transport registrations and the surge in private ownership of four-wheelers emphasize the need for strategic planning to meet the evolving electricity demands of this sector.

The services sector, driven by growth in commercial floor space and heightened air conditioning needs, is expected to contribute significantly to the overall electricity demand. However, it is essential to note the divergence in demand between air-conditioned and non-air-conditioned spaces within this sector.

The report acknowledges the challenges posed by the lack of comprehensive end-use demand data in India. The wide range of outcomes resulting from different forecasting methodologies underscores the importance of transparency and data dissemination at both state and national levels. Addressing this data gap is crucial for enhancing the accuracy of future electricity forecasts and supporting optimal planning to meet the nation's growing electricity requirements.

As India navigates the complexities of a post-pandemic economic recovery, electrification of the transport sector, and ambitious manufacturing growth, strategic and adaptive planning becomes imperative. The insights provided by this report serve as a valuable resource for policymakers, industry stakeholders, and planners to develop robust strategies that ensure affordable, reliable, and sustainable power for the nation's continued progress.

ANNEXURES

State-wise Sectoral Electricity Projection including Captive (GWh)

Sector	ER-CTS			ER-HGR		
	2024-25	2026-27	2029-30	2024-25	2026-27	2029-30
Andhra Pradesh						
Agriculture	13,369	13,987	14,909	14,856	15,372	16,180
Services	12,609	14,436	17,684	13,146	15,476	19,768
Industry	29,873	32,310	36,345	30,743	33,894	39,236
Residential	20,248	21,748	24,210	20,720	22,601	25,746
Transport	405	455	541	412	472	578
Railways	2,255	2,581	2,874	2,322	2,659	2,960
Total	**78,757**	**85,517**	**96,563**	**82,199**	**90,473**	**1,04,468**
Assam						
Agriculture	43	43	43	59	63	69
Services	3,155	3,613	4,426	3,290	3,873	4,947
Industry	2,801	3,029	3,408	2,882	3,178	3,679
Residential	5,425	5,981	6,924	5,550	6,212	7,357
Transport	99	113	139	101	118	148
Railways	-	-	-	-	-	-
Total	**11,523**	**12,779**	**14,939**	**11,882**	**13,444**	**16,200**
Bihar						
Agriculture	1,511	1,814	2,277	1,398	1,600	1,960
Services	4,445	5,089	6,234	4,634	5,456	6,969
Industry	4,408	4,953	5,899	4,534	5,191	6,359
Residential	20,783	23,794	29,149	21,252	24,697	30,939
Transport	383	439	538	390	455	574
Railways	2,039	2,335	2,599	2,100	2,405	2,677
Total	**33,569**	**38,423**	**46,695**	**34,309**	**39,804**	**49,477**

Sector	ER-CTS			ER-HGR		
	2024-25	2026-27	2029-30	2024-25	2026-27	2029-30
Chhattisgarh						
Agriculture	6,642	7,161	8,002	6,899	7,630	8,873
Services	2,552	2,814	3,257	2,663	3,020	3,649
Industry	31,754	34,345	38,634	32,679	36,029	41,708
Residential	7,886	9,029	11,061	8,064	9,371	11,740
Transport	142	163	200	145	169	213
Railways	1,396	1,598	1,779	1,438	1,646	1,832
Total	**50,372**	**55,110**	**62,933**	**51,888**	**57,865**	**68,014**
Delhi						
Agriculture	40	43	47	39	43	51
Services	9,088	10,020	11,599	9,483	10,756	12,993
Industry	3,522	3,809	4,284	3,624	3,996	4,625
Residential	19,372	21,572	25,347	19,816	22,402	26,926
Transport	375	421	501	382	437	536
Railways	312	358	398	322	368	410
Total	**32,709**	**36,222**	**42,177**	**33,666**	**38,002**	**45,541**
Goa						
Agriculture	42	47	56	38	44	53
Services	716	820	1,004	747	879	1,123
Industry	2,398	2,593	2,917	2,467	2,720	3,149
Residential	1,439	1,557	1,751	1,473	1,617	1,862
Transport	27	28	30	28	29	32
Railways	-	-	-	-	-	-
Total	**4,622**	**5,045**	**5,758**	**4,752**	**5,290**	**6,219**

Sector	ER-CTS			ER-HGR		
	2024-25	2026-27	2029-30	2024-25	2026-27	2029-30
Gujarat						
Agriculture	13,406	13,359	13,337	15,070	15,988	17,471
Services	8,811	9,530	10,720	9,198	10,237	12,021
Industry	1,02,162	1,14,790	1,36,716	1,05,081	1,20,307	1,47,382
Residential	19,082	20,838	23,780	19,524	21,648	25,276
Transport	391	448	549	399	465	586
Railways	992	1,135	1,264	1,021	1,169	1,302
Total	1,44,845	1,60,100	1,86,366	1,50,293	1,69,815	2,04,037
Haryana						
Agriculture	10,715	10,997	11,428	10,769	12,028	14,197
Services	7,892	8,701	10,072	8,235	9,340	11,282
Industry	24,426	27,965	34,259	25,117	29,297	36,905
Residential	16,326	18,691	22,898	16,695	19,401	24,304
Transport	283	324	397	288	336	423
Railways	545	623	694	561	642	715
Total	60,185	67,302	79,747	61,664	71,043	87,826
Himachal Pradesh						
Agriculture	74	78	83	87	88	90
Services	1,870	2,022	2,275	1,952	2,172	2,551
Industry	6,901	7,464	8,396	7,102	7,830	9,064
Residential	2,639	2,767	2,971	2,701	2,877	3,162
Transport	53	58	67	54	60	72
Railways	-	-	-	-	-	-
Total	11,537	12,389	13,793	11,896	13,028	14,939

Sector	ER-CTS			ER-HGR		
	2024-25	2026-27	2029-30	2024-25	2026-27	2029-30
Jammu and Kashmir						
Agriculture	388	409	442	426	464	527
Services	3,708	4,246	5,201	3,866	4,552	5,814
Industry	1,650	1,889	2,314	1,696	1,978	2,492
Residential	6,839	7,977	10,049	6,992	8,277	10,660
Transport	52	58	68	53	60	73
Railways	32	37	41	33	38	42
Total	12,669	14,616	18,115	13,068	15,370	19,609
Jharkhand						
Agriculture	324	380	478	218	250	306
Services	1,672	1,914	2,345	1,743	2,052	2,621
Industry	24,471	26,468	29,773	25,184	27,765	32,142
Residential	7,254	8,305	10,174	7,418	8,620	10,799
Transport	137	153	181	139	159	193
Railways	1,418	1,624	1,808	1,461	1,672	1,862
Total	35,276	38,844	44,758	36,163	40,518	47,922
Karnataka						
Agriculture	24,955	26,267	28,342	25,071	27,406	31,324
Services	14,820	16,936	20,689	15,453	18,158	23,128
Industry	27,902	30,179	33,948	28,715	31,658	36,648
Residential	16,333	18,007	20,846	16,709	18,704	22,151
Transport	323	356	412	329	369	440
Railways	196	224	250	202	231	257
Total	84,530	91,969	1,04,486	86,479	96,527	1,13,948

Sector	ER-CTS			ER-HGR		
	2024-25	2026-27	2029-30	2024-25	2026-27	2029-30
Kerala						
Agriculture	490	540	620	471	540	661
Services	6,836	7,681	9,149	7,131	8,240	10,237
Industry	6,285	6,539	6,940	6,472	6,866	7,503
Residential	14,757	16,270	18,834	15,097	16,899	20,013
Transport	263	279	305	268	290	326
Railways	457	524	583	471	539	601
Total	29,089	31,833	36,430	29,910	33,375	39,341
Madhya Pradesh						
Agriculture	31,384	35,245	42,188	32,301	36,839	44,867
Services	8,895	10,184	12,476	9,275	10,919	13,946
Industry	20,779	23,347	27,807	21,372	24,469	29,976
Residential	21,188	24,258	29,717	21,667	25,178	31,542
Transport	430	492	603	438	511	643
Railways	3,129	3,582	3,988	3,222	3,689	4,107
Total	85,804	97,108	1,16,779	88,276	1,01,605	1,25,081
Maharashtra						
Agriculture	36,583	38,419	41,194	44,412	50,847	62,290
Services	23,391	26,781	32,807	24,389	28,711	36,672
Industry	67,627	73,145	82,278	69,596	76,730	88,824
Residential	36,600	41,123	48,979	37,435	42,699	52,015
Transport	692	778	926	705	808	989
Railways	3,759	4,304	4,791	3,872	4,433	4,935
Total	1,68,652	1,84,549	2,10,975	1,80,409	2,04,227	2,45,726

Sector	ER-CTS			ER-HGR		
	2024-25	2026-27	2029-30	2024-25	2026-27	2029-30
Manipur						
Agriculture	4	5	5	9	10	12
Services	241	271	323	252	291	361
Industry	38	43	51	40	45	55
Residential	537	571	626	550	594	666
Transport	10	12	14	10	12	15
Railways	-	-	-	-	-	-
Total	**831**	**902**	**1,019**	**860**	**952**	**1,110**
Meghalaya						
Agriculture	0	0	0	0	0	0
Services	208	233	278	217	250	311
Industry	790	855	962	813	897	1,038
Residential	736	788	872	753	819	928
Transport	11	11	13	11	12	13
Railways	-	-	-	-	-	-
Total	**1,745**	**1,888**	**2,124**	**1,795**	**1,978**	**2,290**
Mizoram						
Agriculture	**0**	**0**	**0**	**0**	**0**	**0**
Services	208	234	279	217	251	312
Industry	24	26	30	24	27	32
Residential	554	623	742	567	647	788
Transport	7	7	7	7	7	8
Railways	-	-	-	-	-	-
Total	**794**	**891**	**1,059**	**816**	**933**	**1,141**

Sector	ER-CTS			ER-HGR		
	2024-25	2026-27	2029-30	2024-25	2026-27	2029-30
Nagaland						
Agriculture	0	0	0	0	0	0
Services	302	346	424	315	371	474
Industry	50	57	70	51	60	76
Residential	469	508	572	480	528	608
Transport	9	10	11	9	10	11
Railways	-	-	-	-	-	-
Total	830	920	1,076	856	968	1,168
Odisha						
Agriculture	**849**	**1,001**	**1,246**	**957**	**1,096**	**1,343**
Services	8,323	9,528	11,673	8,677	10,215	13,048
Industry	74,965	84,231	1,00,321	77,107	88,280	1,08,147
Residential	12,042	13,786	16,889	12,314	14,309	17,926
Transport	185	212	260	189	220	277
Railways	2,083	2,384	2,654	2,145	2,456	2,734
Total	**98,447**	**1,11,144**	**1,33,043**	**1,01,389**	**1,16,577**	**1,43,475**
Puducherry						
Agriculture	66	68	71	67	71	78
Services	375	430	527	391	461	589
Industry	1,855	1,987	2,204	1,910	2,085	2,380
Residential	934	1,030	1,192	955	1,069	1,267
Transport	18	19	21	18	20	22
Railways	-	-	-	-	-	-
Total	**3,249**	**3,534**	**4,014**	**3,342**	**3,707**	**4,335**

Sector	ER-CTS			ER-HGR		
	2024-25	2026-27	2029-30	2024-25	2026-27	2029-30
Punjab						
Agriculture	12,907	13,226	13,676	14,432	15,821	18,161
Services	7,387	8,300	9,886	7,705	8,904	11,062
Industry	25,189	27,245	30,647	25,923	28,580	33,085
Residential	17,866	20,264	24,478	18,272	21,037	25,988
Transport	302	314	334	308	327	358
Railways	365	418	465	376	430	479
Total	**64,017**	**69,767**	**79,486**	**67,015**	**75,100**	**89,133**
Rajasthan						
Agriculture	38,209	44,605	55,965	35,302	40,417	49,512
Services	10,704	12,140	14,665	11,162	13,020	16,401
Industry	32,351	36,213	42,886	33,277	37,957	46,238
Residential	16,524	18,392	21,597	16,903	19,100	22,942
Transport	356	408	499	363	423	533
Railways	540	618	688	556	636	709
Total	**98,684**	**1,12,376**	**1,36,300**	**97,563**	**1,11,553**	**1,36,335**
Tamil Nadu						
Agriculture	16,175	17,320	19,080	16,460	18,845	23,086
Services	18,244	20,499	24,415	19,030	21,991	27,319
Industry	52,222	57,246	65,703	53,732	60,032	70,894
Residential	40,694	45,897	54,974	41,621	47,652	58,375
Transport	704	762	857	718	792	916
Railways	1,373	1,572	1,750	1,415	1,620	1,803
Total	**1,29,413**	**1,43,296**	**1,66,778**	**1,32,975**	**1,50,931**	**1,82,394**

Sector	ER-CTS			ER-HGR		
	2024-25	2026-27	2029-30	2024-25	2026-27	2029-30
Telangana						
Agriculture	27,206	29,360	32,732	26,868	30,551	37,043
Services	13,041	14,931	18,291	13,598	16,007	20,446
Industry	21,720	23,947	27,721	22,347	25,109	29,905
Residential	15,425	17,006	19,686	15,780	17,663	20,919
Transport	319	351	407	325	365	435
Railways	1,110	1,271	1,415	1,144	1,309	1,458
Total	**78,822**	**86,866**	**1,00,252**	**80,061**	**91,005**	**1,10,205**
Tripura						
Agriculture	43	45	47	48	55	67
Services	395	452	554	412	485	619
Industry	52	55	61	54	58	66
Residential	698	738	803	714	767	854
Transport	11	12	14	12	13	15
Railways	-	-	-	-	-	-
Total	**1,199**	**1,303**	**1,479**	**1,239**	**1,378**	**1,622**
Uttar Pradesh						
Agriculture	24,525	27,463	32,115	23,223	26,587	32,571
Services	20,081	22,991	28,165	20,938	24,648	31,483
Industry	29,412	31,203	34,096	30,277	32,747	36,836
Residential	54,490	62,386	76,425	55,722	64,753	81,118
Transport	1,050	1,202	1,472	1,069	1,247	1,571
Railways	2,380	2,725	3,033	2,451	2,807	3,124
Total	**1,31,938**	**1,47,970**	**1,75,307**	**1,33,679**	**1,52,790**	**1,86,704**

Sector	ER-CTS			ER-HGR		
	2024-25	2026-27	2029-30	2024-25	2026-27	2029-30
Uttarakhand						
Agriculture	176	138	73	527	603	739
Services	2,539	2,853	3,397	2,648	3,060	3,802
Industry	8,682	9,572	11,081	8,932	10,037	11,954
Residential	4,112	4,708	5,768	4,205	4,887	6,122
Transport	81	93	114	83	96	121
Railways	41	47	52	42	48	54
Total	**15,631**	**17,411**	**20,485**	**16,438**	**18,732**	**22,792**
West Bengal						
Agriculture	1,368	1,342	1,303	1,500	1,718	2,104
Services	11,173	12,554	14,952	11,654	13,468	16,731
Industry	27,396	29,918	34,141	28,191	31,377	36,844
Residential	20,717	22,624	25,818	21,197	23,503	27,442
Transport	293	317	357	299	330	382
Railways	2,641	3,024	3,366	2,720	3,114	3,467
Total	**63,590**	**69,779**	**79,937**	**65,561**	**73,510**	**86,970**

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ABBREVIATIONS

BEE	:	Bureau of Energy Efficiency
CAGR	:	Compound Annual Growth Rate
CC	:	Correlation coefficient
CDD	:	Cooling Degree Day
CEA	:	Central Electricity Authority
CFL	:	Compact Fluorescent Lamps
CO_2	:	Carbon Dioxide
CTS	:	Current Trajectory Scenario
DA & FW	:	Department of Agriculture and Farmers Welfare
DoWR, RD & GR	:	Department of Water Resources, River Development and Ganga Rejuvenation
DRI	:	Direct Reduced Iron
ECBC	:	Energy Conservation Building Code
EMDE	:	Emerging market and developing economies
EPI	:	Energy Performance Index
EPS	:	Electric Power Survey
ER	:	Econometric Regression
ESCerts	:	Energy Saving Certificates
EV	:	Electric Vehicle
FAME	:	Faster Adoption and Manufacturing of Electric and Hybrid Vehicles
GDP	:	Gross Domestic Product
GSDP	:	Gross State Domestic Product
GVA	:	Gross Value Added
GW	:	Gigawatt
HAVC	:	Heating, ventilation, and air conditioning
HGR	:	High Growth Rate
HP	:	Horse Power
IMF	:	International Monetary Fund
KUSUM	:	Kisan Urja Suraksha evam Utthaan Mahabhiyan
LED	:	Light Emitting Diode
MMSCMD	:	Million Metric Standard Cubic Meters per Day (Natural Gas)
MNRE	:	Ministry of New and Renewable Energy
MoEFCC	:	Ministry of Environment, Forest, and Climate Change
MoRTH	:	Ministry of Road Transport and Highways
MORTH	:	Ministry of Road Transport and Highways
MoSPI	:	Ministry of Statistics and Programme Implementation
MP	:	Madhya Pradesh
MSME	:	Ministry of Micro, Small, and Medium Enterprises
MT	:	Million tonnes
MTPA	:	Million Tonnes Per Annum
MU	:	Million units
NFHS	:	National Family Health Survey
NSSO	:	National Sample Survey Office
PAT	:	Perform, Achieve, and Trade
PEUM	:	Partial End-Use Method
RBI	:	Reserve Bank of India
RKM	:	Route Kilometer
SEC	:	Specific Energy Consumption
Sqm	:	square meter
T&D	:	Transmission and Distribution
TERI	:	The Energy and Resources Institute
TR	:	Ton of Refrigeration
TWh	:	Tera Watt-hour
UJALA	:	Unnat Jyoti by Affordable LEDs for All
VA	:	Value Added

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