VASUDHA FOUNDATION
Green ways for a good earth!

MANAGING
PEAK ELECTRICITY DEMAND
IN THE INDIAN ELECTRICITY SECTOR

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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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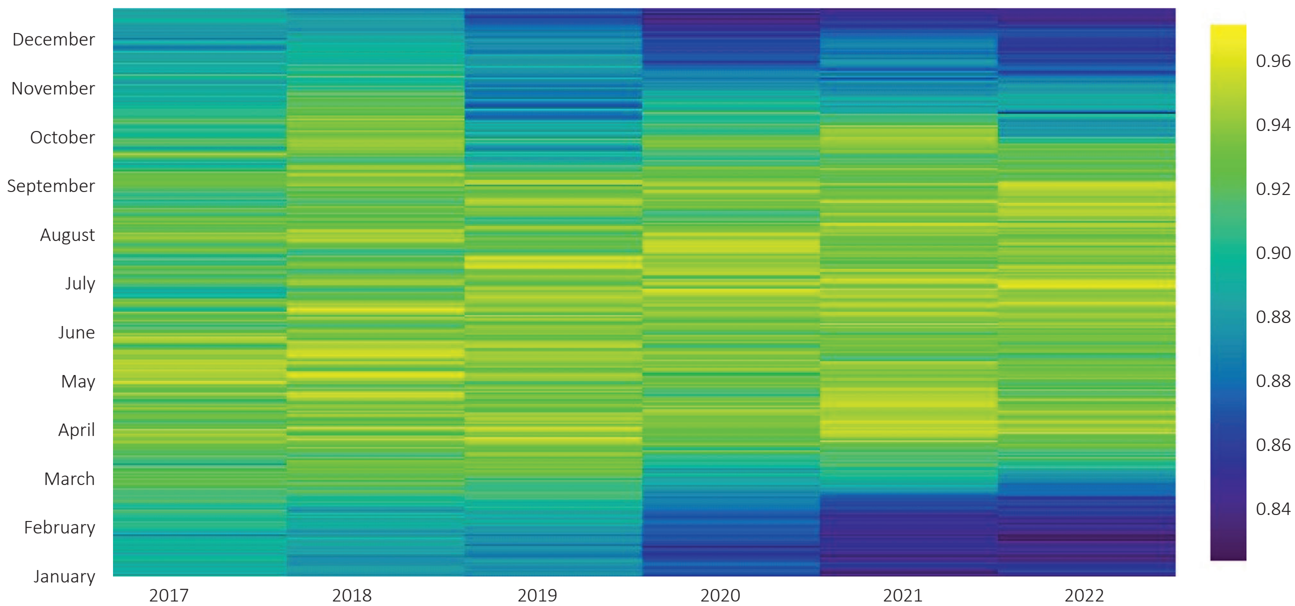
EXECUTIVE SUMMARY

The Peak Electricity Demand in India is Increasing at a Rate Higher than that of the Total Electricity Consumption

In the last 5 years, the growth rate of instantaneous peak demand has been 5.7 percent, surpassing the average electricity demand growth rate of 5.0 percent. This trend has led to a gradual decrease in the load factor over time, indicating a higher concentration of peak demand and an observable seasonal pattern. Over the last five years, in aggregate terms, the load factor has decreased from 83 percent in 2017 to 79 percent in 2022. Figure ES1 illustrates a drop in the load factor between 2017 and 2022, particularly during the winter months spanning from October to March. This decline in the load factor, especially in winter, highlights electricity usage for a specific time of day in activities such as space heating or agricultural practices like sowing Rabi crops. Addressing this trend is crucial to achieving a more balanced consumption pattern and a higher load factor.



ES Figure 1 : Daily Variation in Load Factor in the Last Six Years*
(Authors' analysis based on India Climate and Energy Dashboard [ICED], 2023)

In Recent Years, the Occurrence of Peak Demand has Shown Seasonal and Time-of-day (ToD) Change

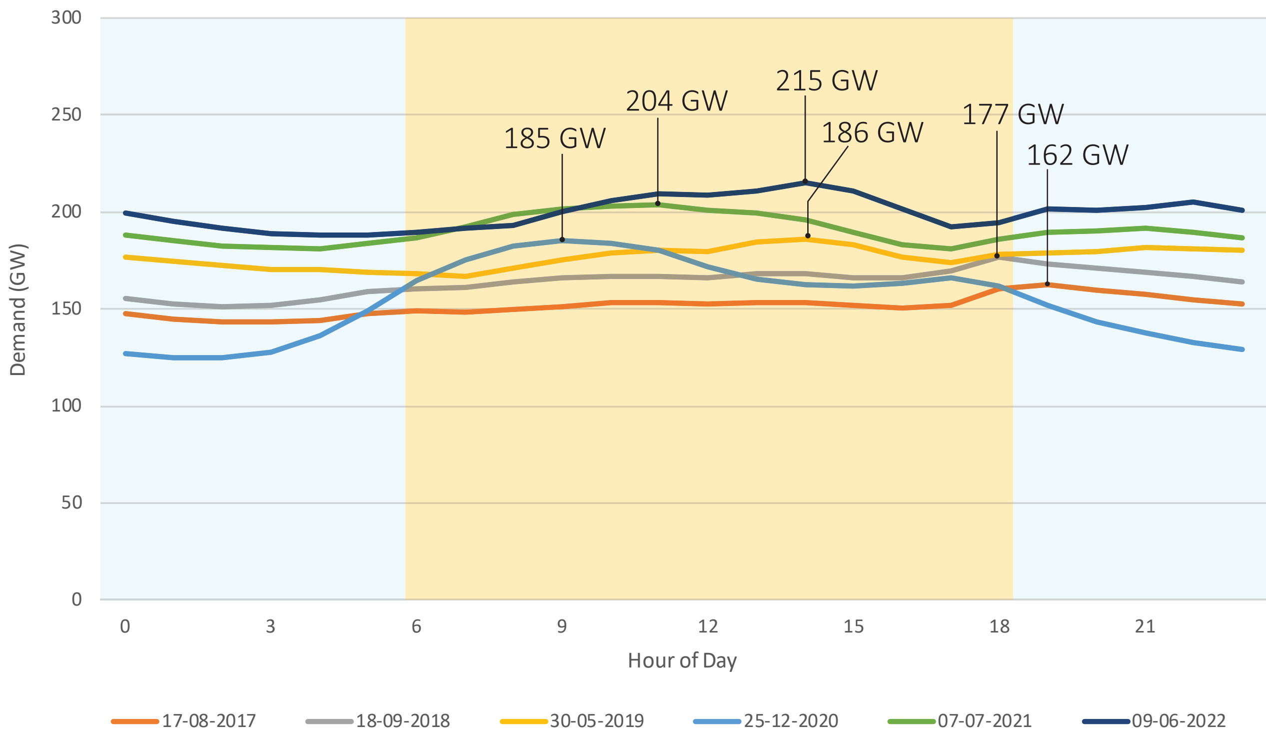
The annual peak electricity demand has increased from 128 GW in 2011 to 216 GW in 2022. The pattern of annual peak demand lacks a precise regularity, though certain observations can be drawn from Figure ES2. Prior to the advent of the COVID-19 pandemic, India's electricity demand typically reached its zenith between August and October, which comprised a substantial portion of the monsoon period. However, in recent years, the annual peak demand has shifted to the summer months (April–July) due to intense heat conditions in the country, compounded by factors such as the widespread adoption of remote work practices, post-pandemic economic resurgence and other influencing elements.

*The load factor signifies the ratio of average demand to peak demand.

	Jan	Feb	Mar	Summer Apr	Summer May	Summer Jun	Monsoon Jul	Monsoon Aug	Monsoon Sep	Oct	Nov	Dec
2011	121	121	122	122	122	122	124	122	128	127	125	126
2012	125	130	128	129	133	135	130	128	132	134	127	129
2013	133	128	132	132	136	133	131	132	135	131	128	131
2014	135	136	136	142	142	148	146	146	146	146	137	142
2015	140	139	143	137	144	142	145	149	153	151	141	138
2016	138	143	145	153	151	149	147	151	160	155	149	145
2017	148	150	155	159	160	156	157	164	162	162	151	153
2018	159	159	162	162	172	172	170	173	177	173	163	164
2019	164	162	169	177	184	184	177	179	175	165	156	172
2020	172	179	171	133	167	167	172	169	177	171	161	184
2021	190	190	186	183	169	194	203	198	181	180	167	184
2022	196	197	203	212	209	215	193	199	203	189	190	206

ES Figure 2: Peak Electricity Demand Requirement (GW) Heat Map (Authors' analysis based on ICED, 2023)

Moreover, not only has the occurrence of peak demand undergone seasonal shifts, but it has also exhibited variations throughout the day (Figure ES3). In 2017, 2018 and 2019, demand peaked during the evening hours, particularly between 7 PM and 10 PM. Conversely, in 2020, 2021 and 2022, the peak demand shifted to the daytime, primarily around midday, from 12 PM to 3 PM. Rather than a complete transition in peaking patterns, the nation's electricity demand now manifests in dual peaks – one during midday, followed by the previously observed evening peak. A notable advantage of this daytime peak is its compatibility with renewable energy generation, particularly solar power; thereby, offering a positive aspect to address the increased demand.

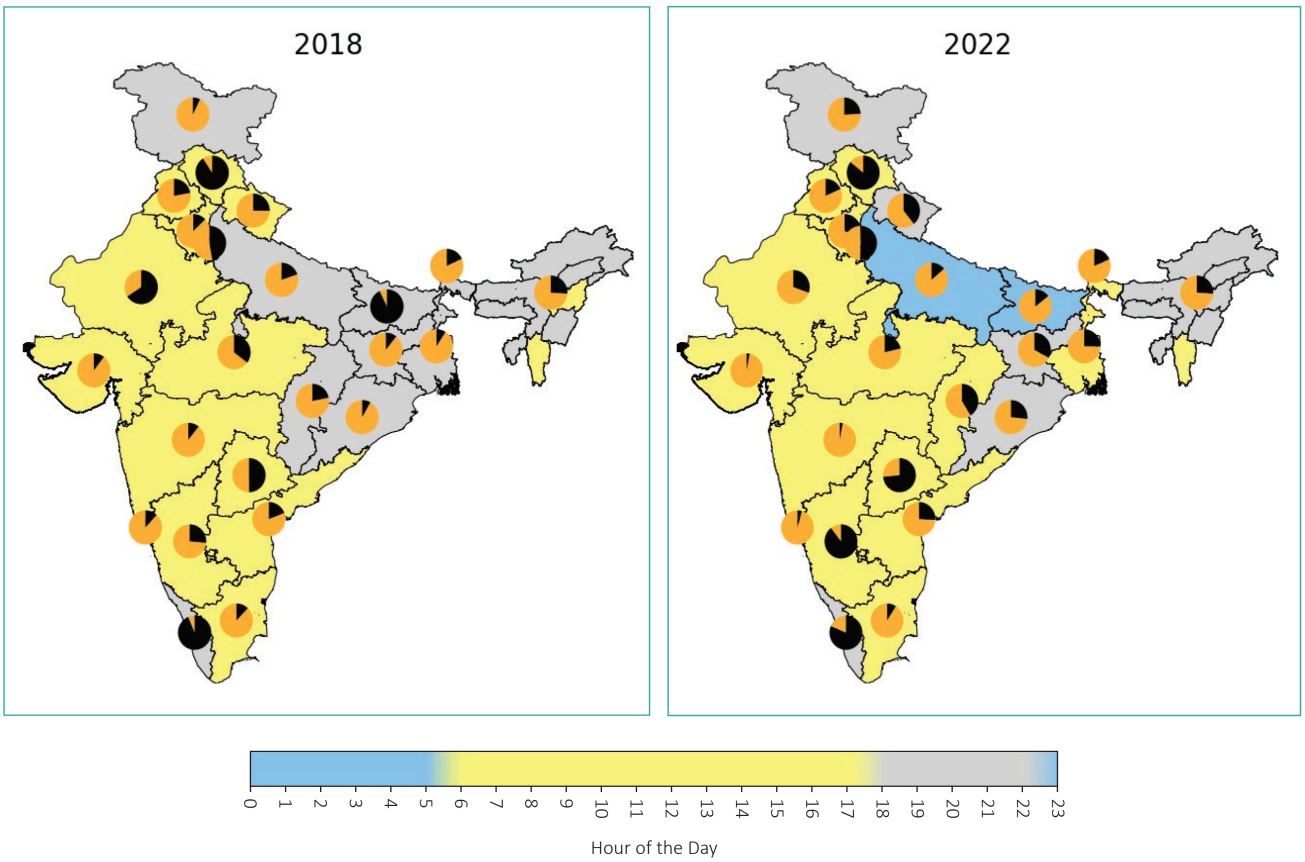


ES Figure 3: Hourly Demand Curve of Peak Demand Day of Last Six Years (ICED, 2023)

Over the Years, More States are Experiencing a Daytime Peak for Most Days in the Year

Our analysis reveals changing trends in peak electricity demand patterns across various Indian states and regions. Daytime peaks are becoming more prominent, impacting both consumption and energy generation strategies. Many states, including Uttar Pradesh, Tamil Nadu, Maharashtra, Gujarat, Rajasthan, Bihar, Kerala and Madhya Pradesh, observed an increased share of daytime peak days in their annual demand profiles (Figure ES4). A rise in the annual occurrences of daytime peak demand days was observed across all regions of India. This shift is particularly significant in the Northern Region (NR), given the extreme summer conditions and substantial contribution to peak demand during the summer months.

In 2018, Bihar and Uttar Pradesh in NR – and several states in the Eastern Region (ER) and North Eastern Region (NER) – witnessed a peak in electricity demand during the evening hours (6 PM to 10 PM). However, there was a slight shift in this trend by 2022. In NR, states primarily characterised by domestic loads experienced a night-time peak demand (between 10 PM and 6 AM), whereas Chhattisgarh and West Bengal experienced a transition from evening peaks to daytime peaks. In the Western Region (WR) and Southern Region (SR), the overall pattern of annual daytime peak occurrences remained consistent, largely due to significant industrial loads during daytime hours.



ES Figure 4 : Illustration of Occurrence of Daily Peak Demand in 2018 and 2022 (India Climate and Energy Dashboard, 2023)

Note: *The colour scale (at the bottom) represents the absolute state-wise peak occurrence hour in the represented year. Further, each state includes a pie chart indicating the share of daytime (yellow) and night-time peaks (black) in the represented year. North–Eastern states' daytime/night-time peak distribution is depicted as one region.*

By the Next Decade, the Peak Demand is Likely to be 1.5 Times the year 2022 Peak Demand

The All-India peak demand is expected to grow to 320–334 GW across both the current trajectory (CTS) and high growth rate (HGR) scenarios considered in this study. This is close to the peak demand of 366 GW projected in the 20th Electric Power Survey. The peak demand of various regions follows a very similar trend compared to the base year of 2022, with NR exhibiting the highest peak demand, followed by WR, SR and other regions. Over the years, t here has been a substantial increase in peak demand across all regions, with NR consistently leading in demand. In 2032, under the CTS scenario, NR is expected to reach a peak demand of 120 GW, followed closely by WR at 100 GW and SR at 101 GW. ER's peak demand is projected to be 42 GW, while NER is anticipated to reach 5 GW. Notably, in the CTS scenario, SR's peak demand grew at a compound annual growth rate (CAGR) of 6.1 percent, followed by NR at 5.6 percent, whereas WR grew by a CAGR of 4.8 percent. This growth in SR was largely due to an increase in industrial as well as residential load in the states of Tamil Nadu and Karnataka.

Table 1: Peak Electricity Demand (GW) Projections for 2032

Year	2011	2022	Vasudha's Scenario For Year 2032		CEA 20th EPS (2032)
			CTS	HGR	
All India	128	215	320	334	366
NR	40	77	120	123	127
WR	42	69	100	104	114
SR	38	60	101	101	107
ER	15	27	42	43	50
NER	2	3	5	5	6

Various Factors are Driving Changes in Electricity Demand Patterns; More Granular Data on Sectoral Patterns is Crucial for Peak Management

The findings highlight several key drivers shaping India's peak electricity demand. Economic growth – exemplified by a resilient pre–COVID-19 growth rate – has spurred higher electricity demand, with a post-pandemic recovery contributing to increased economic activity and consumption. Climate change driven by rising temperatures has led to elevated cooling-related electricity demand, notably for air conditioning. Combined with easy financing, urbanisation has propelled appliance penetration and residential cooling demand. Policy mandates, such as electric vehicle adoption, green hydrogen production, railway electrification and support for electric cooking, are amplifying electricity consumption.

India's evolving policy landscape emphasises electrification across sectors, underscoring the importance of monitoring changing electricity consumption patterns amidst sustained economic growth and transformative policies. Access to accurate and up-to-date data, particularly at the sectoral level, is essential for tracking changes in peak demand, identifying trends – such as increased cooling demand and services sector growth – and formulating effective energy policies. Collaborative efforts between central and state agencies would be vital to provide open-source data on various aspects, enabling informed decision-making and shaping successful electricity reforms for a sustainable energy future in India.

1 CHAPTER INTRODUCTION

The Indian power system has operated under a paradigm of electricity shortage since Independence, owing to insufficient energy production in the country. In 1947, per capita electricity consumption was a mere 17 kWh and installed generation capacity was 1.36 GW. From the 1950s to the 1980s, power generation grew by 10–11 percent annually – a rate significantly higher than the real GDP growth during the same period. Further, in recent years, energy and peak deficits have dropped to 0.4 percent and 1.2 percent, respectively, which is a significant improvement from the long-term average of 8 percent and 15 percent, respectively. However, a few states continue to experience deficits due to a lack of supply resources and/or limited grid infrastructure. Since 2018, India has had surplus generation capacity with low-capacity utilisation, resulting primarily from excessive coal capacity addition during the 12th five year plan (2012–17).

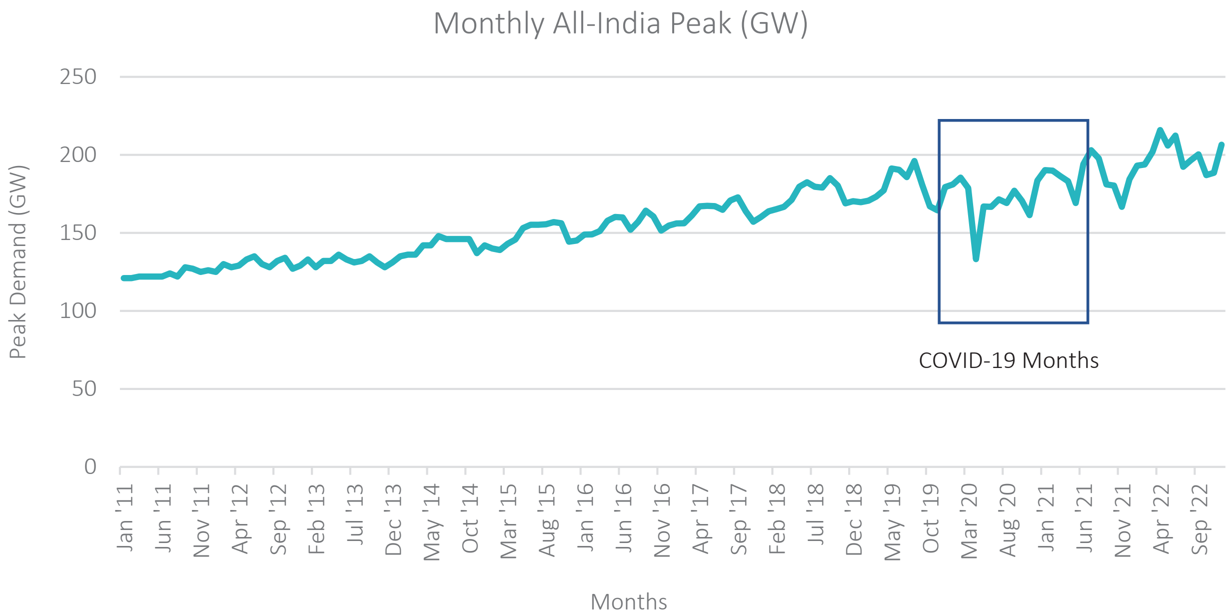


Figure 1: Growth of All-India Peak Demand in the Previous Decade (Central Electricity Authority, 2022)

Figure 1 illustrates the monthly peak demand rise since 2010. Though the Indian power system is well-positioned to meet overall electricity demand, managing the peak power requirement continues to be challenging. For example, during the summer of April 2022, the peak demand requirement reached an all-time high at 216 GW, primarily driven by the weather, in this case, extreme heat. Coupled with coal shortages, this resulted in power outages of six to eight hours for a few days across many states. In some states, the power outages were some of the worst in as many as six to eight years.

Temperature rise impacts the commercial and domestic sectors significantly, increasing electricity requirements for space cooling. Air conditioning units have become increasingly affordable over the years with rising purchasing power and enhanced financing mechanisms. Air conditioning is now considered a necessity rather than a luxury, as reflected in the significant growth in unit sales from three million in 2012 to an anticipated nine million in 2023.

Peak demand has witnessed an unprecedented rise in the last few years, with the rolling back of pandemic restrictions. With peak demand for the summer of 2023 projected to reach 230 GW, the government has started planning to meet this demand at the earliest. A slew of measures includes, but is not limited to:

- Directive to keep thermal units online and postpone any retirement of thermal units before 2030
- Timely supply of gas from GAIL to 5 GW gas-based generating units during the summer
- Floating of fresh tenders for imported coal to supply an additional 1.5 GW of power
- Invoking Section 11 of the Electricity Act 2003, the Government of India (GOI) has asked all imported coal–based companies (ICB) to run at full capacity

Thus far, these measures are enabling short-term peak mitigation. However, in the long run, robust planning will be required. Against this backdrop, this report investigates the peak power position in the country and analyses trends at the national and sub-national levels. This report also includes a projection of peak demand, up to year 2032, as well as long-term recommendations to mitigate peak demand shortage in the country.

2 CHAPTER

CHANGE IN THE NATIONAL AND SUB-NATIONAL PEAK DEMAND OVER THE YEARS

2.1 Peak Demand at the National Level

Over the last decade, India's peak electricity demand has risen from 128 GW in 2011 to 216 GW in 2022, exhibiting an average growth rate of 5 percent (5.4 percent till 2019). Prior to the COVID-19 pandemic, electricity demand in India usually peaked during August and September, which constitutes a significant portion of the monsoon season. This upswing in peak demand was largely due to an increase in domestic and commercial loads, especially lighting and space-cooling loads in highly humid conditions. However, in the past few years, the annual peak demand has been occurring during the summer season (April–July) due to extreme heat conditions coupled with various other factors such as the mass adoption of work-from-home, the economic rebound after the COVID-19 pandemic, etc. High temperatures and severe heat waves were the main reasons for the upsurge in electricity demand, especially in April 2022.

				Summer			Monsoon					
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	121	121	122	122	122	122	124	122	128	127	125	126
2012	125	130	128	129	133	135	130	128	132	134	127	129
2013	133	128	132	132	136	133	131	132	135	131	128	131
2014	135	136	136	142	142	148	146	146	146	146	137	142
2015	140	139	143	137	144	142	145	149	153	151	141	138
2016	138	143	145	153	151	149	147	151	160	155	149	145
2017	148	150	155	159	160	156	157	164	162	162	151	153
2018	159	159	162	162	172	172	170	173	177	173	163	164
2019	164	162	169	177	184	184	177	179	175	165	156	172
2020	172	179	171	133	167	167	172	169	177	171	161	184
2021	190	190	186	183	169	194	203	198	181	180	167	184
2022	196	197	203	212	209	215	193	199	203	189	190	206

Figure 2: Monthly Peak Demand (GW) in the Last Decade. Green to Red Colours Signify the Increasing Intensity of Peak Demand (Central Electricity Authority, 2022)

2.1.1. Decreasing Load Factor Over the Years

Over the years, the instantaneous peak demand is increasing at a faster rate than the average electricity demand. From Figure 3, which represent maximum, minimum, and average demand of last six years (since 2017), we see that the gap between the maximum and minimum demand has increased over the years, which suggests that peak demand is increasing at a higher rate (5.8 percent) than average demand (4.7 percent). The same is further explored in the national load duration curve for the last six years in Figure 4.

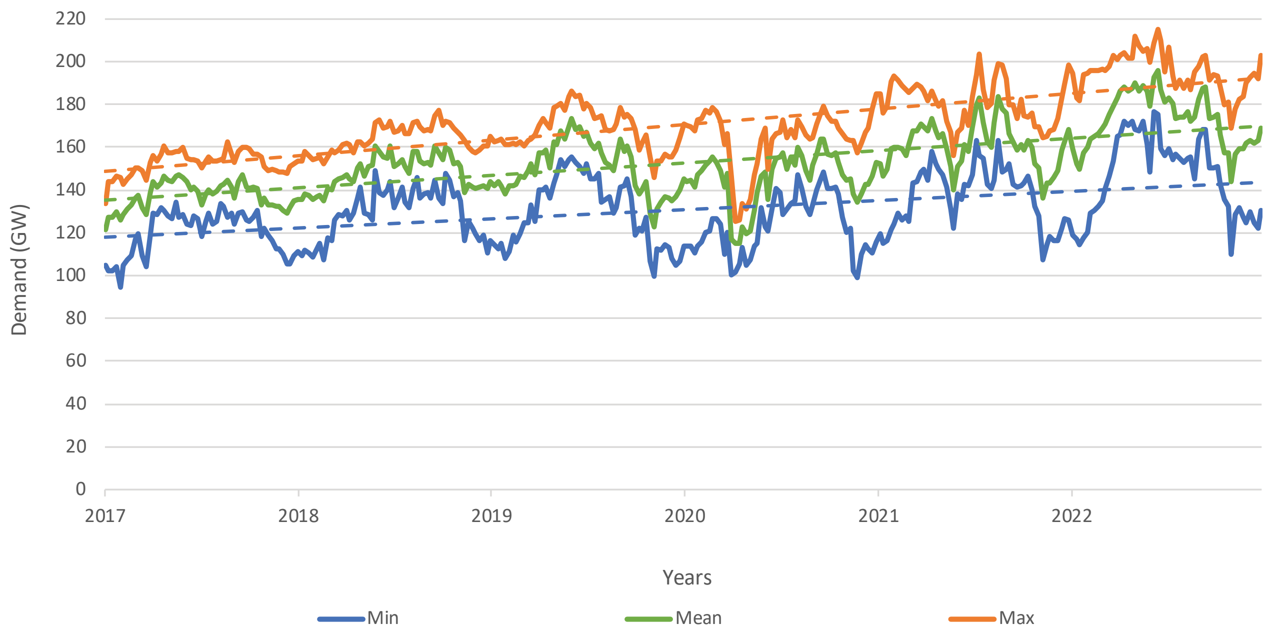


Figure 3: India's Weekly Maximum, Minimum and Average Demand Trends (2017–2022) (Authors' analysis based on Grid-India, 2021)

Figures 4 and 5 show a comparison of the national load duration curve[1] and national load factor from 2017 to 2022. The load duration curve shows a change over the past few years (notably the pandemic years), which has had implications for power procurement by distribution utilities. Firstly, the decreasing trend in the year-on-year load duration curve signifies a drop in the national level load factor over the past five years, owing to incidental peak occurrence. This incidental peak may have occurred due to increased demand in various segments, one of which is possibly the residential segment, predominantly driven by space cooling (especially during day hours) and rapid urbanisation.

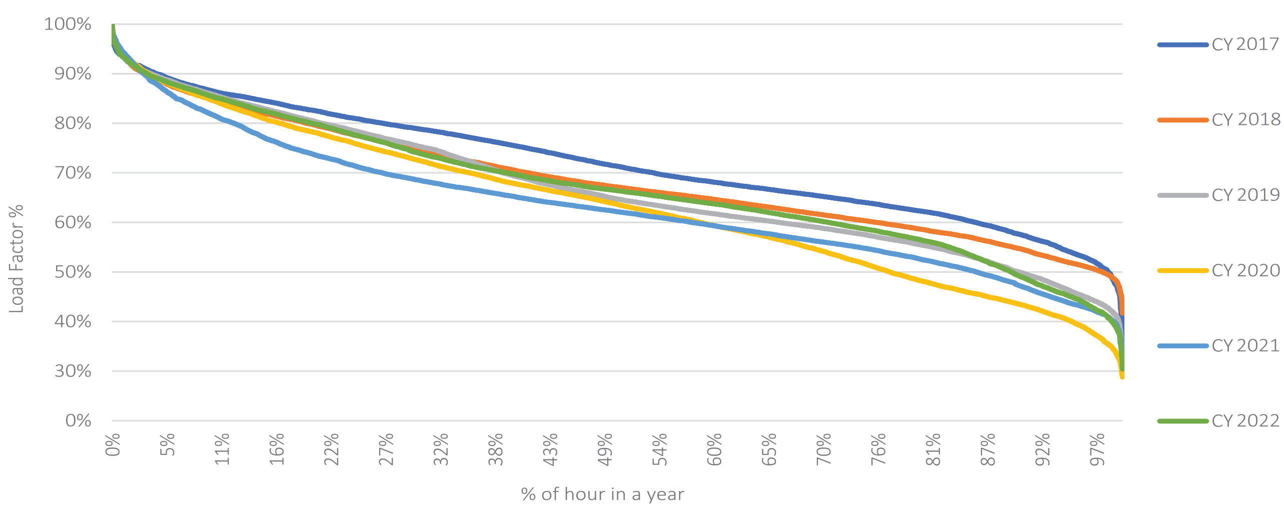


Figure 4: All-India Level Load Duration Curve for the Last Six Years (Source: Authors' analysis based on ICED, 2023)

1 Load duration curve is a graphic representation of the hourly demand, arranged along the X-axis from highest to lowest, for every hour of the year, with electricity demand on the Y-axis.

The growth in uneven load over years and days is further depicted in Figure 5 through a heatmap. In aggregate terms, the load factor has come down from 83 percent in 2017 to 79 percent by 2022. As evident from the figure, between 2017 and 2022, the drop in the load factor can be seen from October through March.

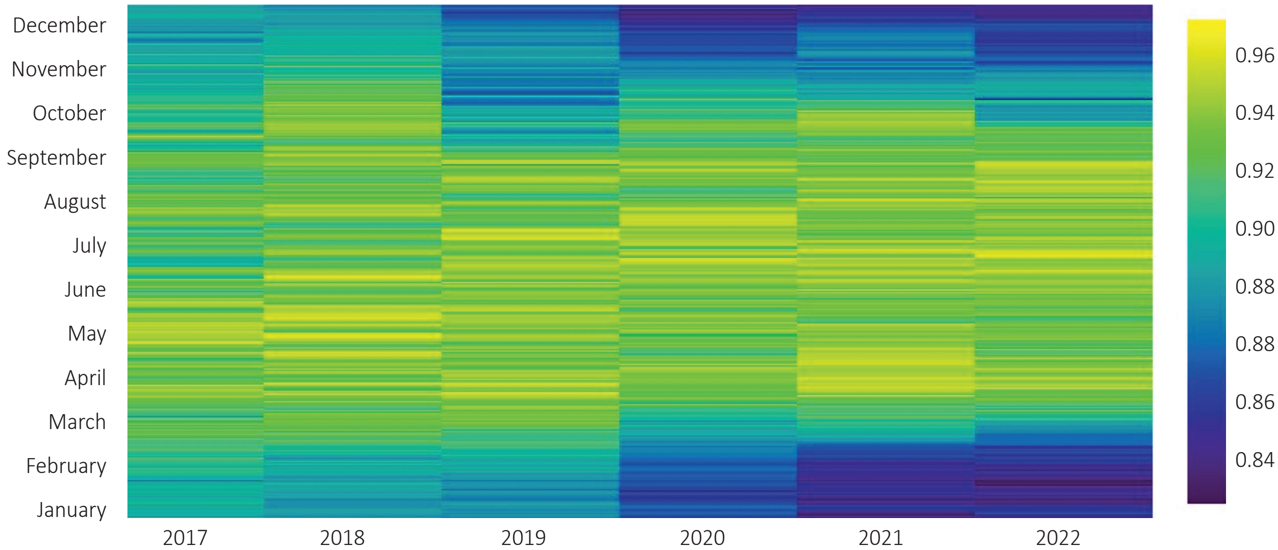


Figure 5: Year-on-year National Load Factor at Day-level Granularity (Authors' analysis based on Central Electricity authority, 2022)

2.1.2. Change in Peak Demand Occurrence from Late Evening to Daytime Peak

Further, the occurrence of peak demand has not only changed yearly but also through the day. Figure 6 shows the hourly demand profile of peak demand days for the past six years, with the plot colours representing different periods of the day. In 2017, 2018 and 2019, the peak demand occurred during the evening hours, especially from 7 PM to 10 PM. Whereas in 2020, 2021 and 2022, the peak demand occurred in the daytime, mostly midday between 12 PM to 3 PM. To be precise, the peak has not completely shifted; rather, we are seeing two peaks – one during midday followed by the previously noted evening peak – which can be attributed to the growing residential load. However, one positive aspect of peak demand occurring during daytime is that it can be better met by renewables generation, especially solar.

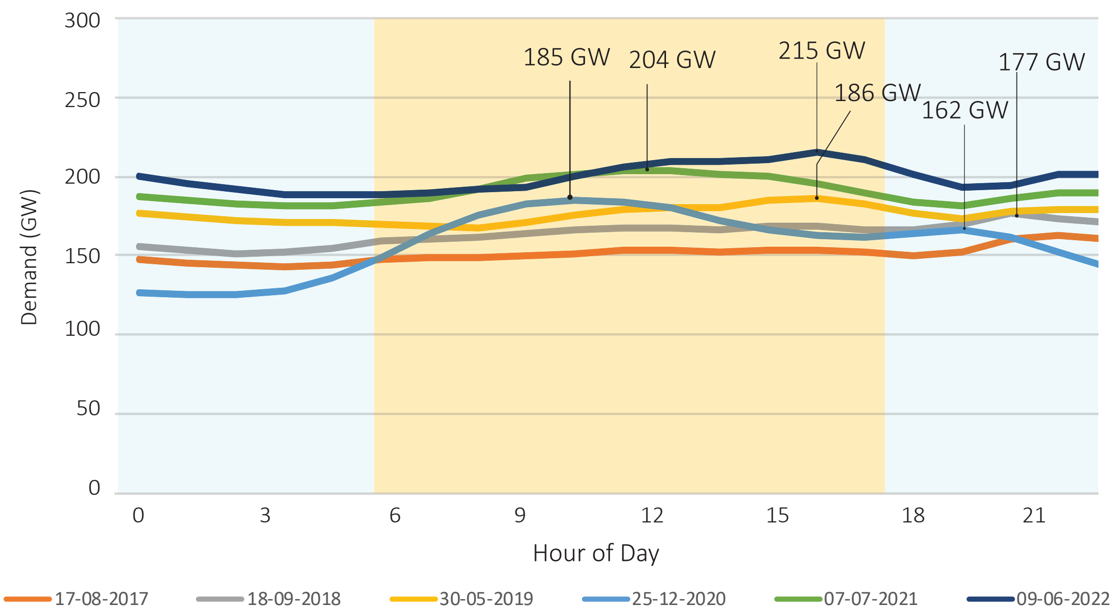


Figure 6: Hourly Demand Profiles of a Peak Demand Day (2017–2022) (Authors' analysis based on ICED, 2023)

Box 1: Resource Adequacy and the Role of Generating Portfolios in Meeting Electricity Peak Demand

Peak demand in the past has been met reliably through coal-based generation. Between 2018–2019 and 2022–2023, the contribution of coal generation in meeting peak demand reduced only marginally from 72 percent to 70 percent, whereas that of renewable energy (RE) generation rose from 6 percent to 15 percent. The increased RE contribution in the peak demand met may be attributed to the occurrence of the electricity peak during daytime in recent years.

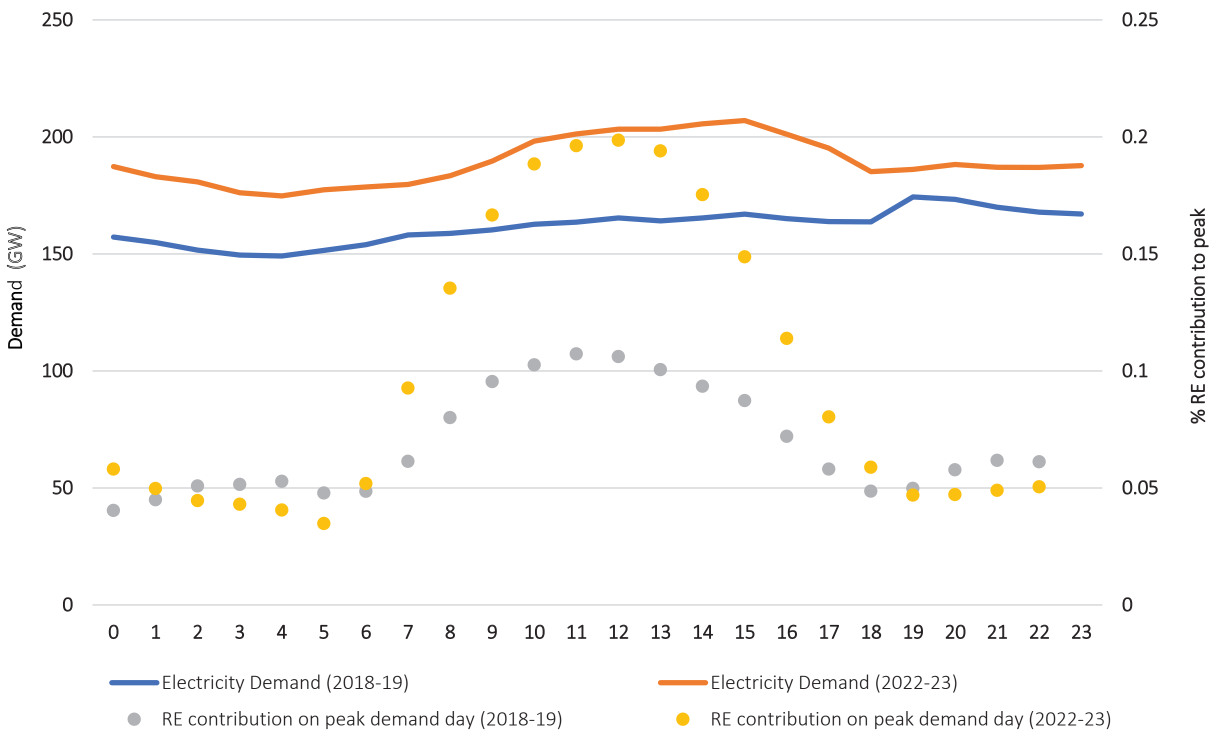


Figure B1: Hourly Demand Curve of Peak Days for 2018 and 2022 with the Share of Renewables to Meet the Peak Demand on the Secondary Y-axis(Grid-India, 2023)

In Figure B1, we analyse the daily demand curve for the peak days of FY 2019 (September) and FY 2022 (June). The share of RE generation in meeting the peak is represented on the secondary Y-axis, while demand is shown on the primary Y-axis. Upon comparing, it becomes apparent that the peak observed from 6 PM to 9 PM in 2019 has shifted to midday in 2022. Although the peak has shifted to midday, a significant portion of the overall daily peak persists late in the evening, the timing of the peak demand. Instead, the peak demand is observed both during the midday and evening, suggesting a bi-daily peak occurrence. This bi-daily peak provides an added advantage in terms of integrating RE generation, especially solar power. This is because RE generation shows a positive correlation with the daytime peak demand. Moreover, solar electricity is among the cheapest electricity-generating sources available.

2.1.3. Seasonal Peak Demand Day Curve

To understand variations in peak demand across the three seasons – summer, monsoon and winter – we analysed the seasonal peak day demand curve for 2022 (Figure 7). Although demand variations across seasons were not very significant – from 203 GW during the monsoons to 215 GW in summer – all the seasonal peaks occurred during the daytime. There has been a considerable increase in daytime demand in the summer months, which could be due to space-cooling needs. During the winter months, there is a marked decrease in demand during the night and early morning when temperatures are low. However, there are considerable ramp-up needs in winter during working hours, which could be due to the heating load, especially in the northern region. Furthermore, demand during the peak demand day of the monsoon season follows a uniform pattern similar to the summer peak profile, but with limited peak periods, although this distribution could vary across regions, which is discussed in the next section.

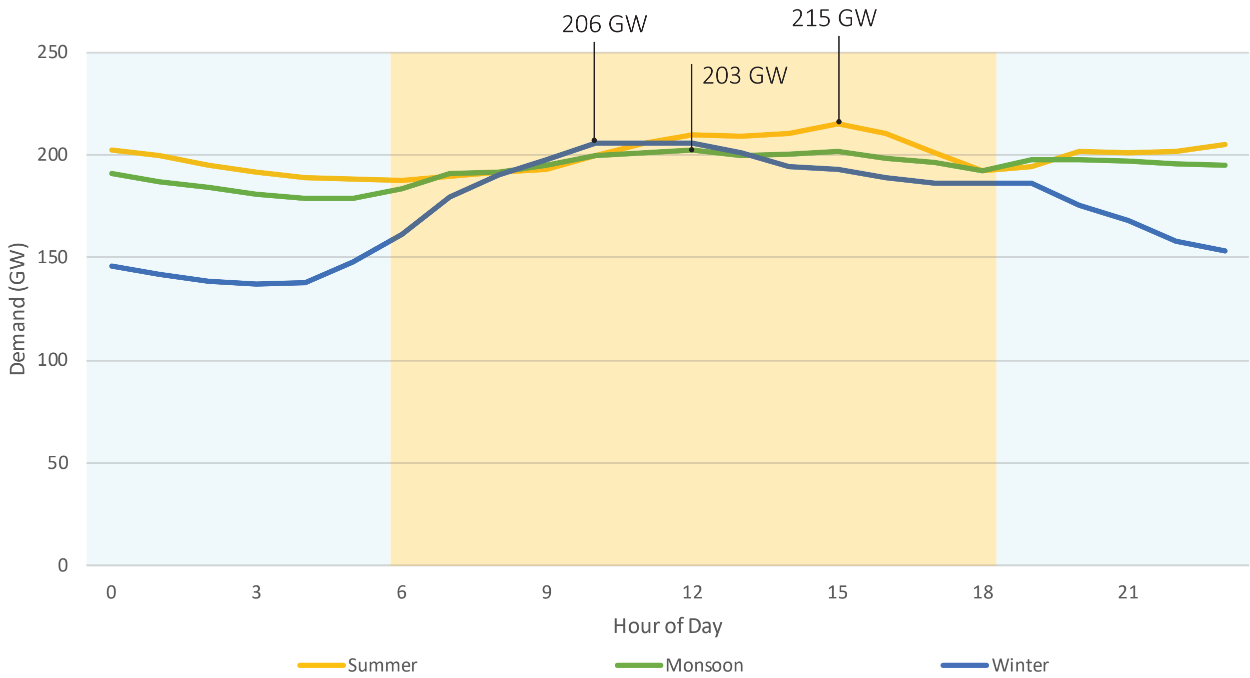


Figure 7: Seasonal Variations in Peak Day Load Curves (2022) (Grid-India, 2023)

2.2. Peak Demand at the Regional Level

In the preceding section, we analysed peak demand patterns on a national scale. To gain a deeper understanding of the reasons for peak occurrences and their shifts, it is necessary to explore demand patterns at a sub-national level. This section provides a comprehensive discussion of regional variations in peak demand.

2.2.1. Regional Contribution to National Peak Demand

The Indian power sector has five regionally interconnected grids: the Northern Region (NR), Western Region (WR), Eastern Region (ER), Southern Region (SR) and North-Eastern Region (NER) grids. Through FY2012 and FY2022, the peak electricity demand shares of regions have been fairly constant except for a percentage point difference in the NR and SR regions. NR contributes a third of the country's total peak demand, whereas WR and SR together contribute half of the national peak demand. It should be noted that the peak demand of all of India and a few regions do not coincide temporally. This is due to a number of reasons, such as different climatic conditions, varying geographical conditions and variations in demand patterns across regions. For example, NR is a residential-dominated region whereas WR and SR are energy-intensive and industry-dominated regions.

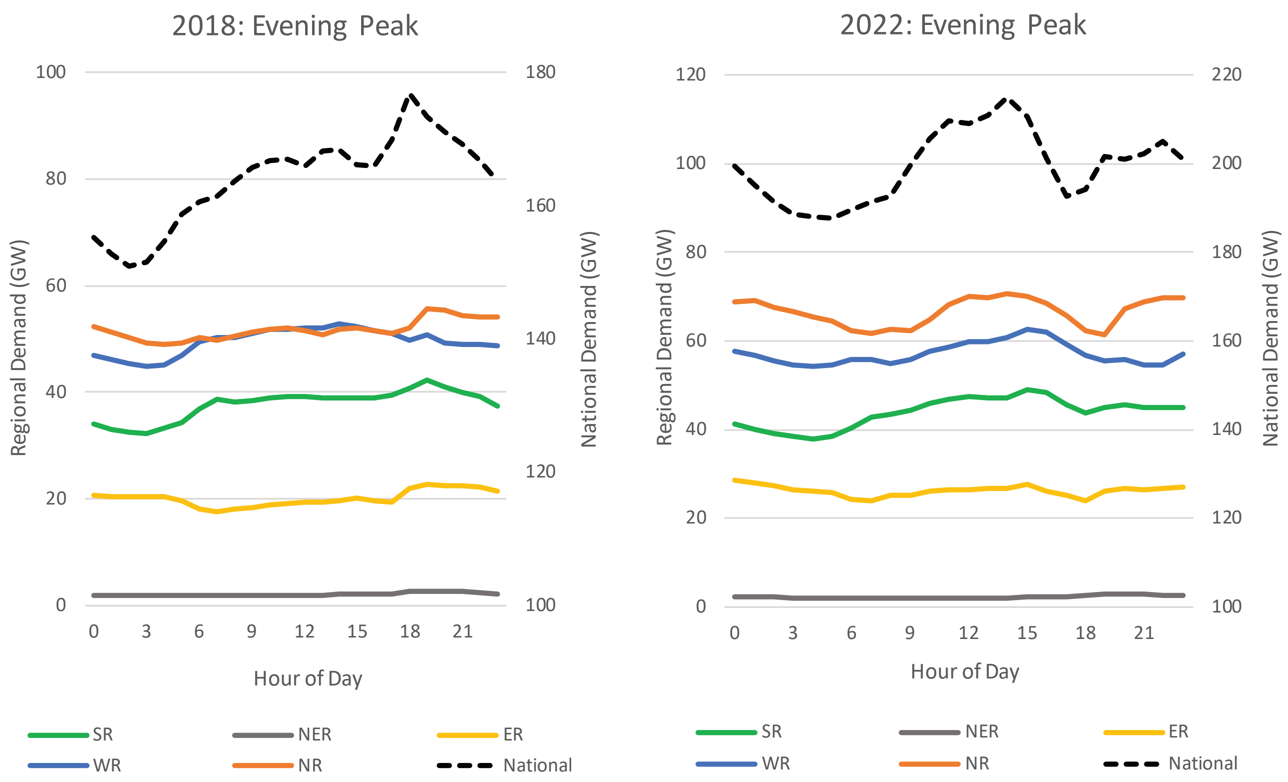


Figure 8: Regional Distribution of Peak Days for 2018 (Evening Peak) and 2022 (Day Peak). The Primary Y-axis Depicts the Regional Demand Whereas the Secondary Y-axis Shows the National Demand (Grid-India, 2023)

The national-level peak demand rose from 177 GW to 215 GW between 2018 and 2022. Figure 8 shows the regional demand distribution on the peak days in 2018 and 2022, with national demand shown on top of the regional load profiles. While the peak demand occurred during the late evening in September 2018, it occurred during the midday in June 2022. Major changes can be seen in the NR, SR and ER demand patterns. The peak demand in NR, which occurred late in the evening in 2018, occurs in both the afternoon and the late evening in 2022. A significant proportion of the electricity demand is from residential consumers in the NR grid and industrial consumers in the WR grid. A similar change in pattern is observed in the demand in SR and ER. The significantly greater variance in peak demand in NR followed by other regional grids can thus be attributed to the impact of the heat wave and the post–COVID-19 growth in residential consumption in FY2022.

Between 2015 and 2021, the residential sector registered the fastest growth in the NR grid – at an annual growth rate of 6.8 percent against the 6.2 percent growth rate of the industrial sector in the WR grid during the same period. With an annual growth of 8.5 percent, the NR grid also registered the highest growth in peak demand over the last 10 years, followed by the NER grid at 6.5 percent, though its marginal contribution to peak demand was less significant. As NR is more of a residential load centre, the change in the demand pattern can be attributed to growing cooling needs in residential and commercial buildings during the daytime.

2.2.2. Change in Regional Demand and Load Duration Curve

Electricity demand within various Indian grid regions is subject to climatic conditions and economic growth. Thus, demand patterns vary across seasons within a low or high intensity.

Figure 9 depicts a heatmap of peak demand for each region across months. Peak demand is intense in summer in NR and moderate in ER; this is because, between June and September, cooling demand increases due to humid weather in these regions. Further, WR has peak demand in November–December, with the onset of the sowing season. SR has peak demand in March–April. Further, NER has a similar peak demand period as ER but with a considerably lower peak. The occurrence of peak demand in different months across regions brings an opportunity for inter-regional power trade. For example, during the monsoon months, WR records high RE generation whereas there is peak demand in NR, creating an opportunity for power trade.

Comparing the load duration curves of all five regions over five years provides insights into the changes in demand before and after the COVID-19 pandemic, as well as the growth in demand segments within each region (see Figure 10). Firstly, the demand factor exhibited significant deviations, ranging from 100 percent to as low as 20 percent, with NER experiencing the highest variation. However, NR and SR displayed more pronounced dips in demand during the post–COVID-19 period. This can be attributed to the slower recovery of industrial output and faster growth of residential consumption, which is characterised by high intraday and seasonal variability. Additionally, WR and ER experienced growth in the higher quartile demand distribution (highest peak demand instances) after the pandemic, with approximately 9 percent of demand instances contributing to the top 10 percent of the peak demand.

The load duration curves indicate a downward trend in load curves over the years. This trend highlights the occurrence of a short period of peak demand each year. The peak demand is predominantly concentrated in specific durations or seasons, emphasising the importance of addressing the factors driving this pattern to enable the flattening of load duration curves.

Northern Region

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	33.087	33.167	31.870	34.242	36.431	40.648	41.790	38.469	37.174	36.518	34.389	34.743
2013	35.516	33.962	34.581	35.764	40.738	41.606	42.523	41.750	42.774	38.385	35.526	36.717
2014	38.227	38.330	35.829	38.555	41.007	47.232	47.367	47.642	43.931	44.618	39.070	42.592
2015	40.774	38.586	38.423	40.003	42.357	49.545	49.028	50.230	50.622	45.940	40.187	41.090
2016	42.109	41.195	40.282	44.934	49.977	52.612	51.658	50.081	51.816	48.514	41.082	44.389
2017	44.447	43.098	45.659	49.643	51.820	54.890	55.865	58.448	54.649	50.289	42.390	45.360
2018	46.252	46.578	43.777	48.367	56.243	60.715	61.726	57.975	55.649	49.635	44.899	44.899
2019	47.210	45.227	47.210	47.210	59.343	64.838	65.865	61.367	62.023	49.615	44.189	51.159
2020	50.780	50.519	45.531	40.680	56.620	64.885	67.578	64.836	67.806	57.975	48.083	55.345
2021	56.513	56.513	52.576	51.852	52.885	70.691	72.935	72.935	63.326	57.491	49.319	55.546
2022	56.213	56.213	53.577	62.217	68.399	76.561	74.143	74.143	75.674	60.710	54.006	59.004

Western Region

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	34.038	35.535	36.509	36.247	35.629	35.259	31.836	32.471	35.781	39.486	37.363	37.246
2013	37.331	36.382	38.263	37.361	37.216	35.077	32.817	33.930	36.818	37.358	40.006	40.304
2014	39.731	40.331	39.768	42.365	41.050	40.731	41.170	38.019	42.757	42.614	42.462	43.035
2015	41.553	42.750	43.145	42.690	43.240	41.884	42.689	41.781	43.325	48.199	44.645	44.902
2016	45.204	45.071	44.225	44.940	44.957	43.998	38.709	39.903	46.010	46.090	46.865	47.463
2017	47.844	47.821	48.313	49.788	49.048	47.034	41.280	45.174	45.710	46.392	49.569	49.635
2018	50.085	48.691	48.924	50.434	52.442	50.922	44.574	49.629	52.895	55.821	54.171	53.292
2019	53.544	54.292	52.965	56.222	57.093	56.768	52.509	47.633	46.261	50.631	54.375	56.739
2020	58.643	59.416	56.851	43.729	51.148	47.627	47.860	46.427	49.368	52.702	57.890	61.199
2021	61.692	61.242	59.885	60.966	56.071	52.294	58.995	58.608	52.195	54.891	60.856	63.140
2022	63.829	64.608	65.205	69.350	68.091	65.826	53.550	56.976	57.709	58.367	66.739	71.677

Southern Region

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	29.358	29.982	32.188	31.085	31.271	31.287	30.048	29.008	29.595	29.281	27.168	29.012
2013	29.743	31.189	31.586	32.507	32.090	31.456	30.885	34.151	33.161	32.968	31.786	33.541
2014	34.129	34.544	36.048	35.698	34.409	34.578	34.541	34.162	35.238	33.209	33.003	34.137
2015	35.446	35.818	37.047	36.786	36.529	35.005	36.464	35.892	35.564	34.778	34.511	34.869
2016	36.745	37.370	39.875	40.472	39.667	36.817	36.172	40.532	41.259	41.610	40.192	38.528
2017	40.744	41.155	42.232	42.535	40.885	38.844	42.404	40.089	40.852	38.905	40.720	42.458
2018	43.115	45.326	47.210	45.684	43.234	42.658	44.719	44.617	45.428	45.226	43.837	45.302
2019	44.615	48.000	49.534	49.103	47.465	44.844	45.250	45.350	44.591	41.492	42.827	48.664
2020	49.165	52.993	53.465	42.767	45.646	43.043	43.176	44.106	44.625	43.710	44.944	49.556
2021	53.839	54.215	58.395	58.430	47.784	51.046	50.121	52.559	53.388	47.729	41.168	48.886
2022	53.070	57.132	59.781	60.876	53.669	50.879	48.810	51.829	52.335	45.413	48.013	54.600

Eastern Region

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	12.366	13.545	13.999	14.545	15.415	14.330	14.256	14.145	14.288	14.324	14.253	13.056
2013	13.385	13.988	14.592	15.052	15.110	15.071	15.528	15.023	15.075	14.870	14.318	13.501
2014	14.082	14.499	15.598	16.309	16.342	16.094	16.086	16.010	16.609	16.566	15.684	14.593
2015	15.373	15.892	16.932	17.304	17.221	17.710	17.642	17.149	17.573	17.972	17.068	16.592
2016	17.043	17.061	18.056	18.345	18.596	18.213	18.075	18.024	18.276	18.571	17.937	16.782
2017	17.438	17.636	18.788	19.191	19.032	18.987	19.141	19.220	20.208	19.836	18.161	17.733
2018	18.256	18.797	20.485	21.275	21.249	21.487	21.790	22.290	22.100	22.733	20.322	18.023
2019	18.702	20.341	21.245	22.378	22.781	22.808	23.154	23.398	23.126	21.706	19.212	18.068
2020	18.705	18.892	18.670	18.093	20.169	21.832	22.643	22.192	23.563	23.374	20.402	19.546
2021	20.496	20.643	24.016	24.405	24.191	23.494	25.145	24.157	25.010	23.675	20.961	20.631
2022	21.204	21.198	24.582	25.690	25.070	26.196	26.609	27.218	26.650	26.220	21.741	20.720

North Eastern Region

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	1.620	1.622	1.625	1.704	1.698	1.770	1.762	1.789	1.805	1.864	1.815	1.853
2013	1.815	1.845	1.752	1.718	1.810	1.900	1.973	1.920	1.987	2.048	1.966	1.890
2014	1.925	1.929	1.995	2.045	1.986	1.998	1.996	2.053	2.112	2.141	2.125	2.170
2015	2.202	2.155	2.131	2.114	2.185	2.190	2.356	2.283	2.255	2.301	2.352	2.320
2016	2.332	2.328	2.367	2.358	2.401	2.475	2.391	2.387	2.373	2.439	2.314	2.223
2017	2.320	2.234	2.200	2.209	2.391	2.387	2.429	2.442	2.520	2.499	2.380	2.314
2018	2.317	2.333	2.250	2.552	2.611	2.564	2.798	2.795	2.850	2.700	2.620	2.511
2019	2.552	2.480	2.535	2.780	2.674	2.861	2.861	2.861	2.861	2.878	2.639	2.530
2020	2.588	2.592	2.509	2.433	2.676	2.884	2.828	3.069	3.104	3.107	2.832	2.690
2021	2.660	2.664	2.841	2.938	2.987	3.053	3.053	3.115	3.231	3.360	2.751	2.707
2022	2.795	2.794	3.079	2.908	3.212	3.193	3.371	3.603	3.497	3.405	2.905	2.911

Figure 9: Monthly Peak Demand (GW) of the Regions in the Last Decade. Green to Red Colours Signify the Increasing Intensity of Peak Demand (Authors' analysis based on ICED, 2023)

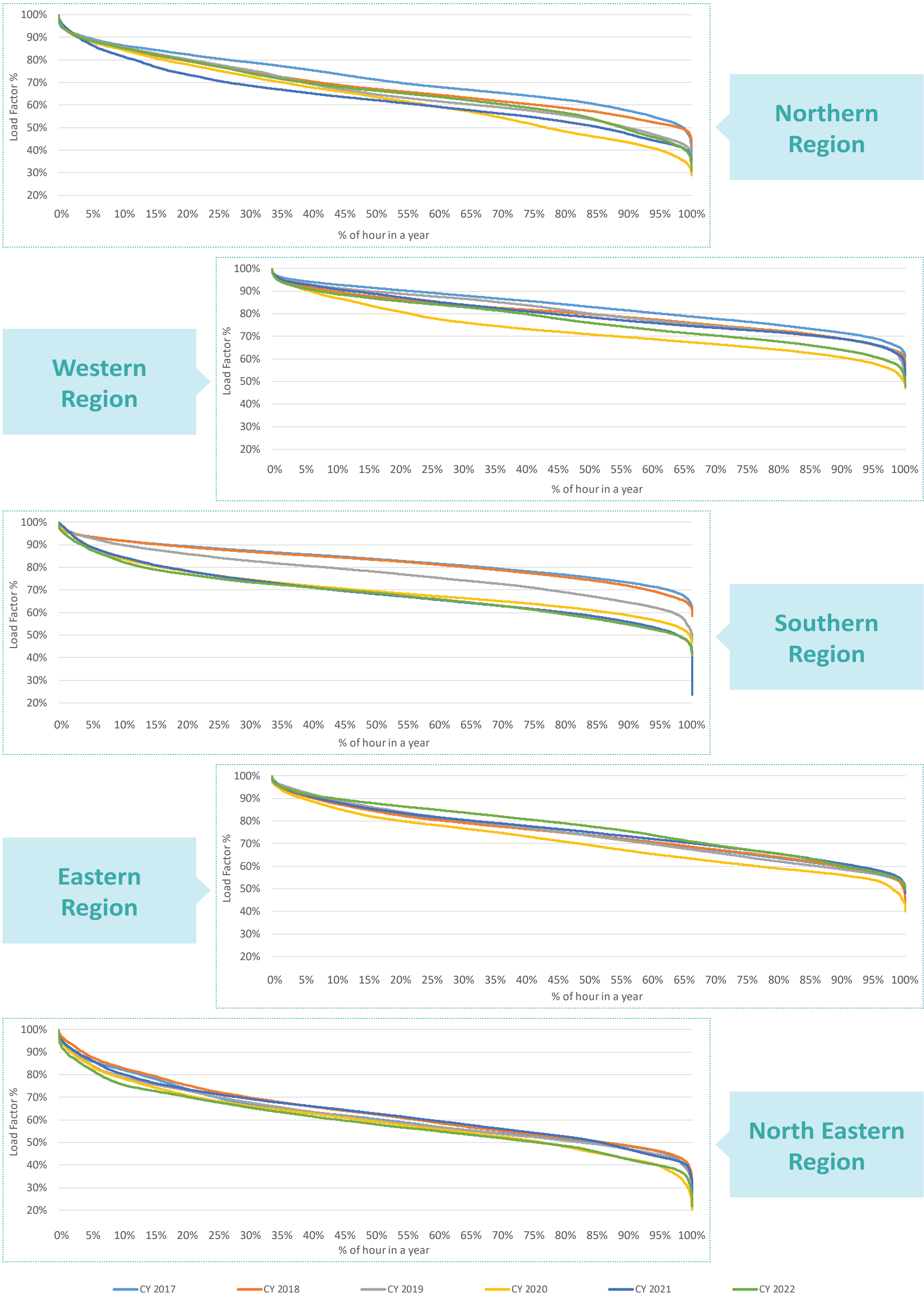


Figure 10: Load Duration Curve Across the Regions in 2018 and 2022 (Authors' analysis based on ICED, 2023)

2.2.3. Seasonal Variation in the Demand

Figure 11 shows the descriptive statistics of electricity demand across 2022, which will help us understand the intensity of peak electricity demand in various regions and months. Further, these graphs show variations across quartiles, signifying the intensity of peak demand through various periods of the month. Two significant insights emerge from the figures:

- Demand variations within regions: To get an overview of variations in demand, we need to observe demand distribution in the first and third quartiles in all the regions. We see that WR, ER and NER have minimum demand variations beyond the median demand and with a limited extent of extreme periods. On the other hand, NR and SR have larger variations within the quartiles as well as the extreme periods, suggesting peaks and troughs in demand.
- Inter-seasonal variation: The graphs also illustrate an interesting trend within regions in terms of seasonality. Barring NER (minimum deviation between seasons), seasonal change in electricity demand is observed in all regions. Where high temperatures prevail during summer to late monsoon in NR, WR has a lean demand period complemented by a high wind-generating season. During winters (November–February) the demand falls in all the regions except WR due to the moderately higher agricultural activity in these months due to the sowing of Rabi crops in Rajasthan, Madhya Pradesh and Maharashtra.

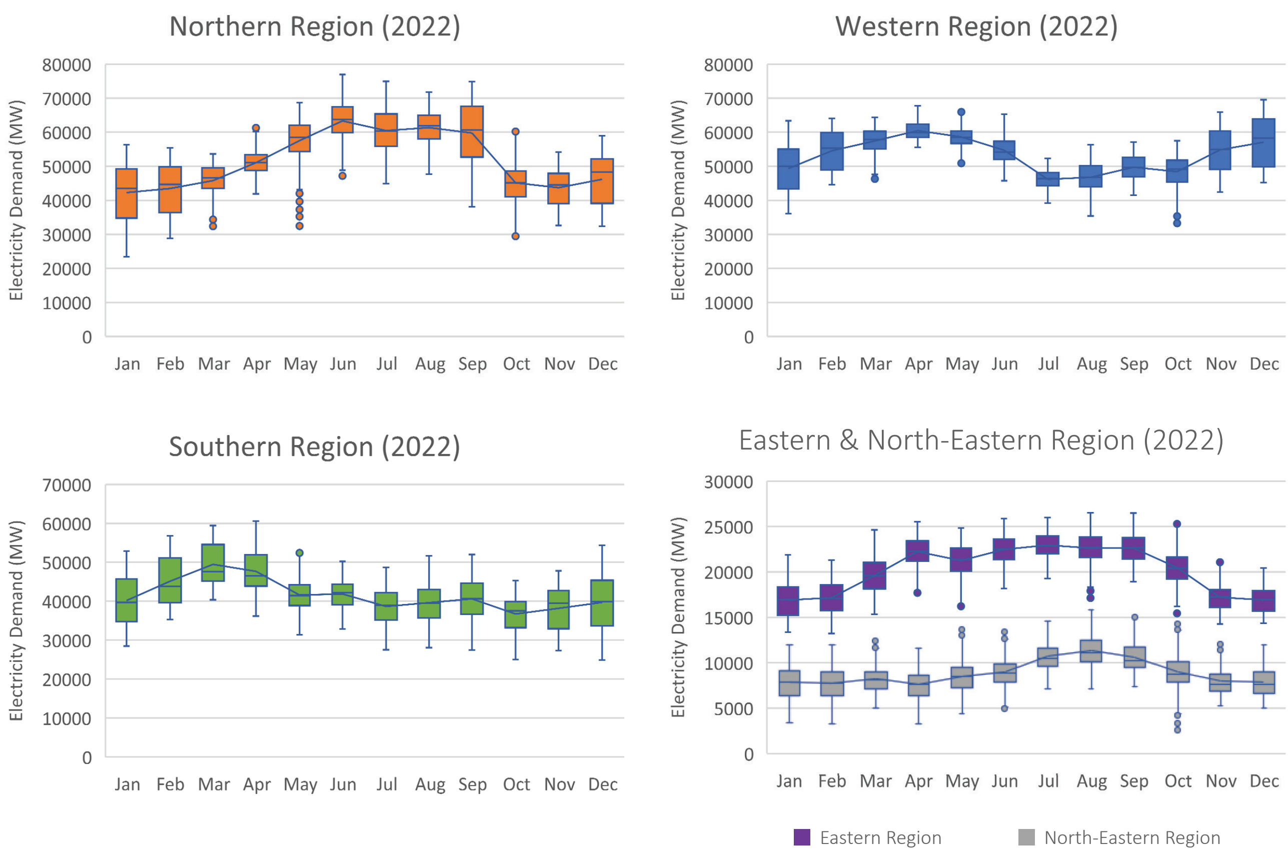


Figure 11: Monthly Regional Variation of Electricity Demand (2022)

2.3. Peak Demand at the State Level

We now delve deeper into the analysis of peak demand by examining it at the state level. Table 2 provides a summary of electricity demand in 10 states, with two states selected from each region.

The selection of states is based on the magnitude of peak demand in the region. Moreover, the states covered in the analyses, such as Maharashtra, Uttar Pradesh (UP), Gujarat, Tamil Nadu and Rajasthan, are the top five states in terms of peak demand requirements in the country.

Among these 10 states, Bihar, UP, Rajasthan and Assam have demonstrated peak demand growth rates exceeding 7 percent. Further, when considering electricity sales within each state, Bihar and UP exhibit yearly growth rates above 7 percent. A common trend that emerges from the table is that peak demand growth in these states is comparatively higher than the growth in electricity consumption, suggesting a decreasing load factor over the years. On the contrary, Gujarat and West Bengal have higher electricity consumption growth than peak demand growth, indicating an increasing system-level load factor.

Another noteworthy observation is that in the majority of states, peak electricity demand occurs during the summer seasons. This is evident in states such as UP, Gujarat, Maharashtra, Tamil Nadu and Karnataka. However, Rajasthan experiences its peak demand during winter, which can be attributed to the sowing of Rabi crop. Similarly, Meghalaya's peak demand in winter may be influenced by residential heating requirements along with agricultural demand.

Table 2: Electricity Consumption and Peak Demand Requirements in 10 States

State	Region	Peak Demand in 2012		Peak Demand in 2022		Peak Demand Season	Peak Demand Growth Rate	Electri-city Consu-mption Growth Rate	Sector Contributing Most to Total Electricity Use	Share of the dominating Sector in Total Electricity Use (percent)
		GW	Month	GW	Month		2012–2022 (percent)	2012–2022 (percent)		
Uttar Pradesh	NR	12.00	Jun	26.60	Sept	May–Sep	8.24	7.01	domestic	49
Rajasthan	NR	8.26	Dec	16.60	Dec	Nov–Jan	7.24	6.29	agri-culture	40
Gujarat	WR	11.96	Oct	21.38	Apr	Apr–Jun	5.98	6.76	industrial	57
Maha-rashtra	WR	16.76	Apr	28.85	Apr	Apr–Jun	5.58	4.58	industrial	35
Tamil Nadu	SR	11.05	Jun	17.25	Apr	Mar–Jun	4.55	4.44	domestic	38
Karnataka	SR	8.50	Mar	14.82	Mar	Feb–Apr	5.65	3.21	agri-culture	36
West Bengal	ER	7.25	May	9.90	Apr	Apr–Sep	3.17	4.11	domestic	40
Bihar	ER	1.78	Jun	6.65	Aug	Jun–Oct	14.07	14.07	domestic	68
Assam	NER	1.15	Dec	2.38	Aug	Jul–Oct	7.55	6.92	domestic	54
Meghalaya	NER	0.30	Dec	0.41	Jan	Dec–Feb	3.09	2.21	other sector	46

Source: Authors' analysis based on (India Climate and Energy Dashboard, 2023), (Central Electricity authority, 2022); ARR documents of various state utilities

To illustrate the nature of peak demand at the state level, the peak demand occurrence in individual states for 2018 and 2022 has been compared in Figure 12. The colour scale depicts the hour of the day when the annual peak occurred, while the pie chart represents the distribution of daytime peak days (between 6 AM and 6 PM) versus night-time peak days (between 6 PM and 6 AM). In 2018, Bihar and Uttar Pradesh in NR, as well as most of the states in the ER and NER, observed an evening peak (between 6 PM and 10 PM). The trend changed slightly in 2022, where NR states – which are domestic load–dominated – experienced peak demand during night-time hours (between 10 PM and 6 AM), whereas Chhattisgarh and West Bengal observed a shift in the peak from evening hours to daytime. The overall trend in annual daytime peak occurrences remained the same in WR and SR, mainly due to predominant industrial loads in the region during the daytime.

Looking at the data overall, the annual share of daytime peak days has increased in many states such as UP, Tamil Nadu, Maharashtra, Gujarat, Rajasthan, Madhya Pradesh, etc. Overall, the number of daytime peak occurrences annually has increased across all of India's regions. But especially, substantial change is observed in states in NR, where an increased annual number of daytime peak days has been observed (Worringham, 2023). This is quite important as NR experiences harsh summers and contributes a major share to the peak during the summer months of the year.

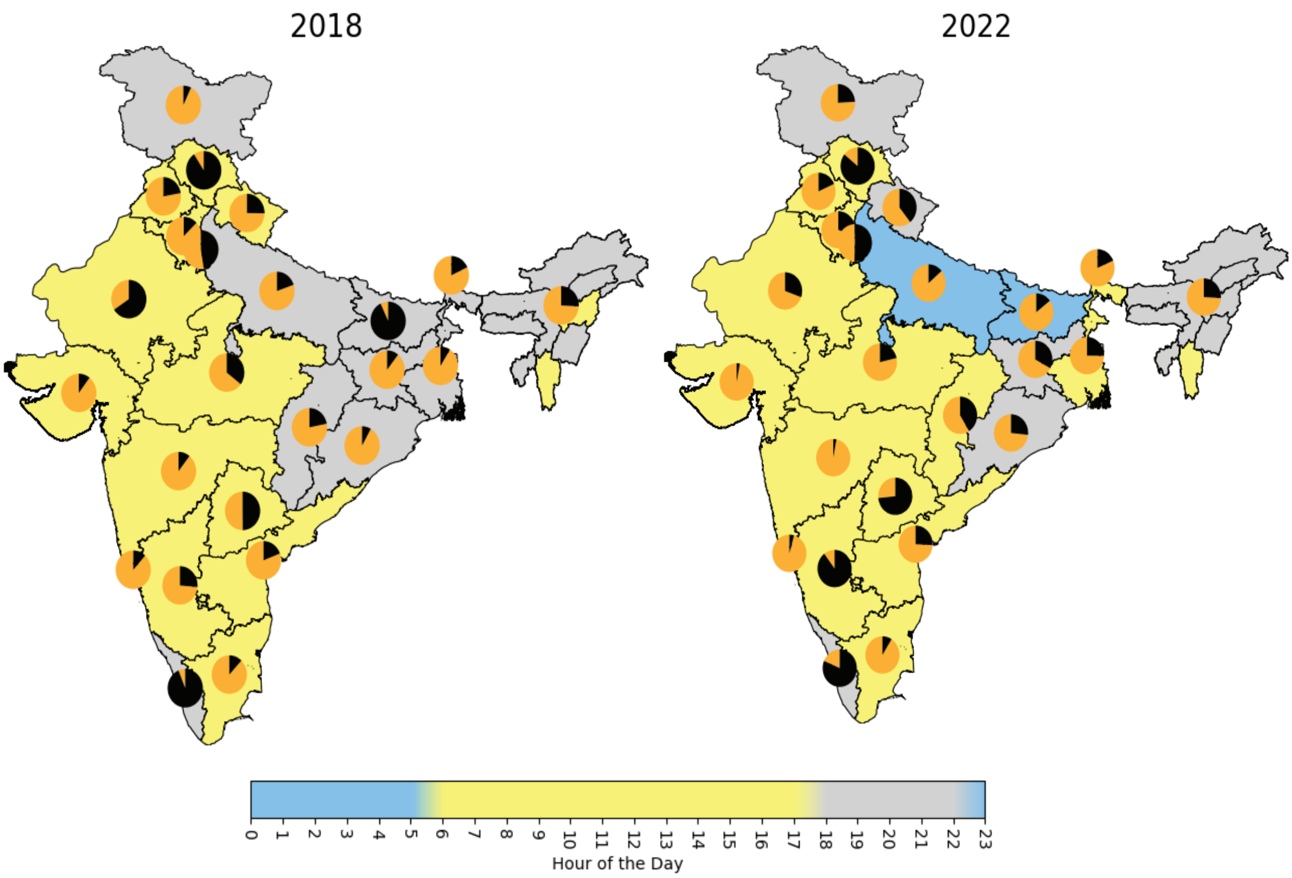


Figure 12: A Comparison of Peak Demand Occurrence in Individual States for 2018 and 2022 (Authors' analysis based on (India Climate and Energy Dashboard, 2023)

Note: *The colour scale (at the bottom) represents the absolute state-wise peak occurrence hour in the represented year. Further, each state includes a pie chart indicating the share of daytime (yellow) and night-time peaks (black) in the represented year. North–Eastern states' daytime/night-time peak distribution is depicted as one region.*

We have explored the occurrence of peak demand at both the national and sub-national levels. However, the underlying reasons for these changes – or 'why the is change happening' – have not yet been analysed. The upcoming chapters will delve into a detailed discussion of these factors and provide an understanding of the drivers behind the observed changes in peak demand.

It is crucial to recognise the significance of having hourly electricity data at the end-use consumption level when analysing power systems. Nevertheless, it is important to acknowledge the limitations associated with accessing such data. One major constraint is the absence of comprehensive and detailed data that captures the hourly electricity consumption patterns of individual consumers. Although the aggregate data for the regional or national levels – which we have also examined in the preceding sections – is frequently accessible, it does not offer the required level of granularity for conducting thorough analyses. However, in the absence of such end-sector consumption data, we will discuss current issues that could be possible drivers for the changes in demand patterns. State-wise deep dive into electricity peak demand is listed in detail in the state primer.[2]

2 http://www.vasudha-foundation.org/state-peak-demand/

3 CHAPTER

WHAT IS DRIVING THIS CHANGE IN DEMAND PATTERNS AND WILL IT ESCALATE FURTHER?

Peak demand has evolved over the years and multiple reasons have contributed to this change. In this chapter, we discuss the major drivers and their significance in terms of explaining the rise in peak demand in particular segments.

3.1. Economic Growth Resulting in Higher Electricity Demand

The Indian economy had grown at a robust growth rate of 6.1 percent pre–COVID-19 for the past decade. The electricity sector grew with the achievement of 100 percent electricity access, increased indigenous manufacturing and strong growth in the residential as well as services sectors. Electricity demand grew 6.7 percent during this period. During the pandemic years, the COVID-19–induced economic contraction stood at −5.8 percent during the first wave of the pandemic in 2020–2021. However, the Indian economy experienced the anticipated V-shaped recovery with 9.1 percent and 7.2 percent growth in 2021–2022 and 2022–2023, respectively. This has two major reasons. First, the real private final consumption expenditure share of India's GDP was increasing prior to the pandemic, growing by 3 percentage points to 58 percent between 2012–2023. Second, post–COVID-19 recovery fuelled economic activity, resulting in infrastructural growth. Strong growth was witnessed in the services, commodity trade, construction, tourism and mining sectors. Thus, as economic activity resumed, disposable income increased, directly impacting consumer purchases of appliances and household construction. For instance, there was approximately a 13 percent increase in construction post-pandemic. Electricity consumption growth in the residential and services segment grew at 6.9 percent and 14 percent post-pandemic, respectively, although a higher growth in services was visible due to a lower base effect. Thus, the electricity consumption pattern has witnessed change due to economic rebound as well as climate-induced factors. With economic growth anticipated to grow at 6.3 percent by 2030, it is worthwhile to notice further changes in the end-use electricity consumption pattern.

3.2. Climate Change and Its Possible Impact

The increasing global temperature due to global warming is a key factor driving the change in electricity use patterns. Rising temperatures due to climate change are leading to an increased demand for electricity, as people are beginning to rely more on air conditioning and cooling systems to cope with heat waves. To test this hypothesis for the past years, we plotted the daily maximum and minimum temperature along with the daily peak demand for eight states in India.

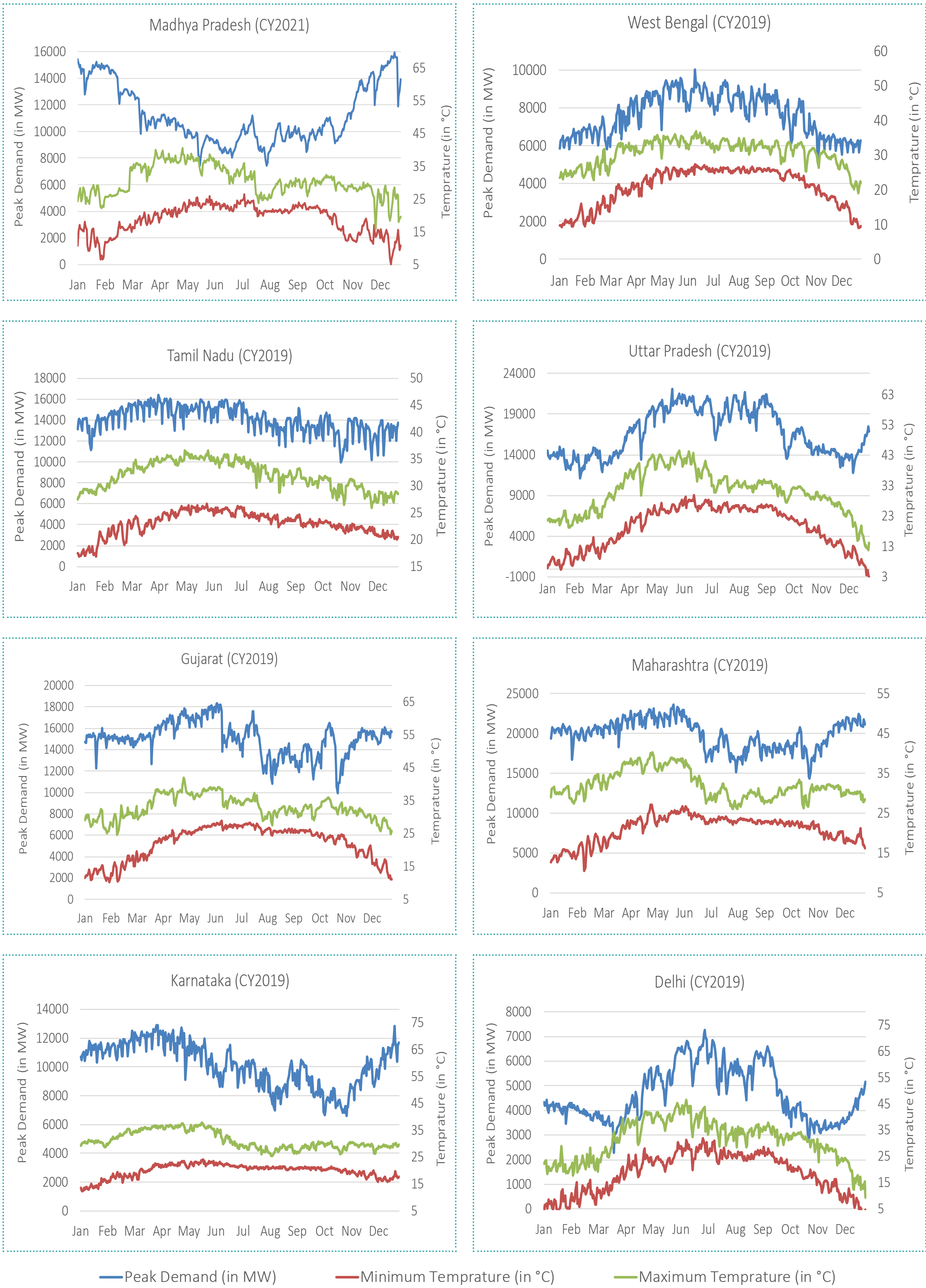


Figure 13: Change in Demand with Variation in Maximum and Minimum Temperatures (ICED, 2023).

The correlation between peak demand and temperature variation is depicted in Figure 13. As per Figure 13, a spike in demand is observed whenever there is a significant change in the maximum temperature. It is interesting to note that the shape of the demand curve follows a similar pattern as that of the maximum temperature curve, clearly depicting the significant contribution of residential cooling in the growth of peak demand. Among these states, we have been witnessing a varying trend of peak demand correlation with maximum temperature. The states having higher correlation are Delhi, West Bengal, UP and Maharashtra. Some states registered peak demand with a weaker correlation to temperature, including Madhya Pradesh and Karnataka. This is because the sowing season coincides with the peak. Overall, it can be said that temperature alone is not the major driver, but it is one of the major determinants of peak demand in the majority of Indian states.

Box 2: Cooling Degree Days of Four Metro Cities in India

Cooling degree days (CDD) hold significant importance in analysing cooling requirements and their implications. CDD serves as a standardised measure to assess the demand for cooling and air conditioning systems, enabling analysis of energy consumption patterns and estimation of cooling-related energy needs. Furthermore, CDD data is also valuable for evaluating the impact of climate change on cooling demand and can inform adaptation strategies.

Here, we analysed the CDD patterns of four major Indian cities: Delhi, Mumbai, Kolkata and Chennai. The increasing number of CDD over the last seven decades indicates a greater demand for space cooling, resulting in increased energy consumption. Among these four cities, Chennai exhibits the highest slope, indicating the most significant change in average CDD over the years. It could be because Chennai is comparatively closer to the equator, hence more vulnerable to climate change. Although lower diurnal variations are prevalent in tropical climatic regions, climate-induced extreme heat events and intensifying summers are increasing CDD in the coastal towns in India as well.

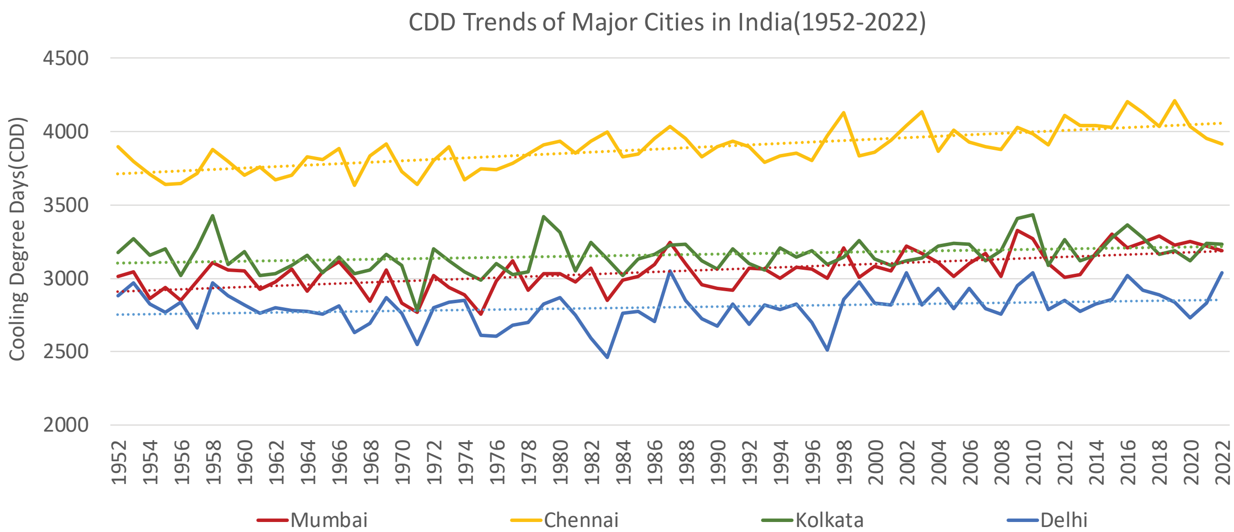


Figure B2: Yearly Cooling Degree Days Trend of Four Indian Metro Cities (Indian Meteorological Department, 2023)

3.3. Urbanisation, Residential Cooling Demand, Affordability and easy access to Finances

A services-dominated economy is expected to spur faster urbanisation over the next decade – it is expected that 45–50 percent of the population will live in urban areas by mid-century (International Energy Agency [IEA], 2021). With this, per capita energy consumption at the domestic level is bound to increase given the possibility of higher penetration of appliances that will be required to meet the needs of the growing urban working class. Figure 14 shows the household appliance penetration projections for the next decade. Till the current fiscal year, only TVs, refrigerators and air coolers were major energy-consuming devices. However, new utilities will emerge in the next decade, with air conditioning being one of the largest electricity-intensive appliances.

The household penetration of room air conditioners is less than 7–9 percent in the residential segment, but owing to rapid urbanisation, the decreasing prices of air conditioners, access to easy financing, rising heat events and the increasing purchasing power of the growing middle class, it is expected to grow significantly in the next decade (Ministry of Environment, Forest & Climate Change, 2020) to 21 percent and 40 percent in 2027–2028 and 2037–2038, respectively. The increased demand is fuelled by the number of households purchasing their first air conditioners as well as existing households purchasing subsequent units.

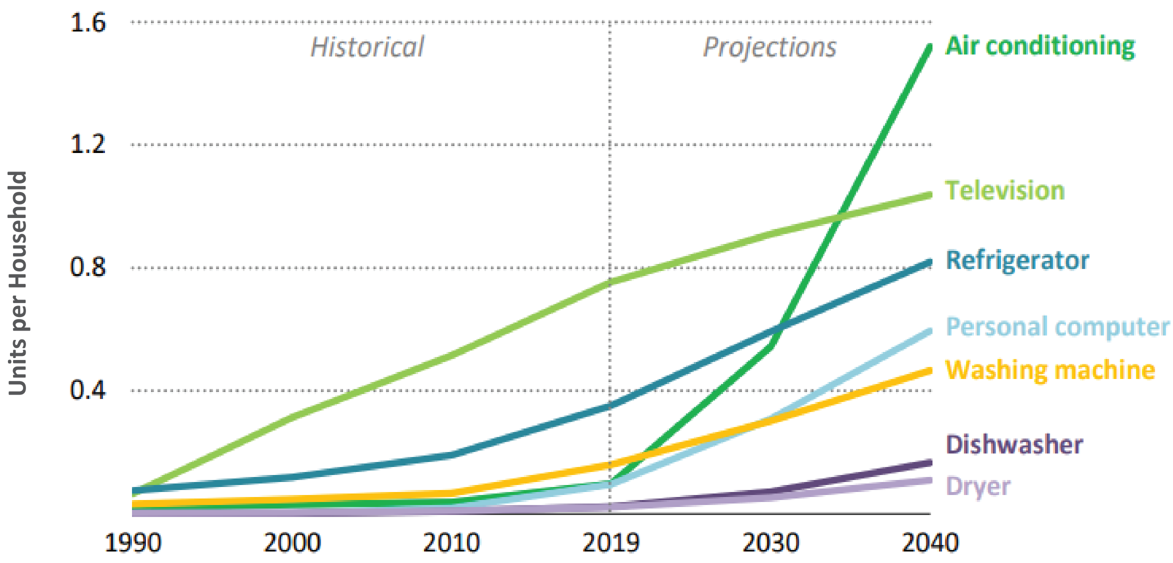


Figure 14: Projection for Appliance Penetration in India (IEA, 2021)

Box 3: Easy Financing Options Provide the Required Boost to the Indian Appliance Market

Easy access to debt financing has increased the penetration of capital-intensive appliances in moderate-income Indian households and will fulfil the aspiring needs of the Indian middle class in the next decade. With the advent of microfinancing schemes, such as no-cost EMI, buy-now-pay-later schemes and 100 percent financing, households in rural areas have easy access to finance and can now afford appliances such as air conditioners and refrigerators. Estimates have shown that 50–60 percent of TV and appliance sales in India are on finance (Mukherjee, 2022). Overall, the availability of easy financing options is a major driver of appliance sales in India, particularly in areas where affordability is a key concern for consumers.

A strong support for this argument is the case of Home Credit, a European consumer finance company that entered the Indian market in 2019 (Mint, 2020). Over the years, with its hassle-free financing options available through a strong network of around 31,500 points-of-sale (PoS), the company is serving millions who wish to purchase a new appliance for their homes. Samsung India, in collaboration with DMI India, introduced a digital consumer lending programme for appliances in 2022 (News18, 2022) to facilitate easy access to finance. This programme, available in over 1,000 cities, provides quick credit access to individuals residing in urban and semi-urban areas. With a remarkably fast processing time of just 20 minutes, it enables customers to conveniently avail credit for purchasing appliances, thereby boosting appliance sales.

3.4. Policy Mandates Driving New Demand

Higher Penetration of Electric Vehicles: One of the key policy mandates driving new demand for electricity in India is the increasing penetration of electric vehicles (EVs) in the country. This ranges from private to public electric transportation – from last-mile delivery fleets to city buses. Further, new registrations of private electric two- and four-wheelers are steadily increasing. The Indian government has set a target of achieving 30 percent EV penetration by 2030, which will require significant infrastructural development, including charging infrastructure. The charging behaviour associated with EV charging – as most individual owners charge their vehicles at night or at their convenience – could pose a significant challenge to grid operations.

- In addition to the EV sector, there are several other factors contributing to the growing electricity demand in India. The rise of quick commerce websites and services, such as home delivery and fast delivery businesses, has led to an increased need for energy-intensive warehousing and logistics operations, especially in Tier A and Tier B cities of India. The quick commerce industry is expected to grow 15 times by 2025 and will rely on EV fleets for guaranteed last-mile delivery (within 10–20 minutes) (Khan, 2022). With these last-mile delivery fleets expanding year-on-year, a higher share of electricity in transportation would be needed to power these vehicles.

Rising Electricity Demand in Industry, Railways and Cooking: With the introduction of the National Green Hydrogen Mission, the mandate to produce five million tonnes per annum (MTPA) of green hydrogen demand by 2030 – especially targeted towards heavy industries such as fertilizers, petrochemicals, and steel – is estimated to consume 250 terawatt hours (TWh), i.e., 8–10 percent of the electricity requirement. Thus, a huge portion of electricity demand is expected to arise from green hydrogen production itself. The ongoing electrification of railways is another significant driver of new electricity demand. Given the target of fully electrifying the railways by 2025, there will be a substantial increase in electricity consumption by the rail network. As part of a broader vision to enhance the country's energy security, the government has been actively promoting electric cooking as a clean and efficient alternative to traditional cooking methods (Palit, 2021). With electrical loads typically ranging from 700 W to 2 kW, the increased adoption of electric cooking appliances by households will result in additional electricity demand, particularly during evening cooking hours. This growing demand for electricity during peak cooking times will contribute to the overall national peak demand.

- The policy landscape in India is increasingly embracing and promoting the electrification of key sectors through a host of schemes, policies and other such initiatives. The concept of deep electrification, which involves electrifying various sectors beyond transportation and cooking, is gaining attention. Electrifying various sectors yields a range of advantages that extend beyond the reduction of greenhouse gas (GHG) emissions. Further, policy support for various sectors, such as the production-linked incentive scheme (PLI) for manufacturing industries, the Make in India initiative and smart cities, will contribute to an increase in overall electricity demand and add to peak demand challenges.

4

CHAPTER

POSSIBLE SOLUTIONS TO ADDRESS THE PEAK DEMAND CHALLENGE

So far, the report has analysed and discussed the implications of peak demand occurrence across the national, regional and state levels. To address these issues, various supply and demand side interventions are possible. Furthermore, these interventions may be enacted through policy support and market-based mechanisms. A few of them are discussed in this chapter.

4.1. Planning for Resource Adequacy

To meet peak demand reliably, adequate resources are needed to meet the last portion of the demand curve. In its latest guideline (Ministry of Power, 2023b) published a framework for such a resource adequacy planning mechanism, which is a positive step in this direction. This means that the central agency needs to consider the uncertainty associated with load probability and unserved energy thus maintaining planning reserves and projecting future peak demand. Furthermore, load dispatch centres and utilities are directed to undertake resource adequacy studies in the short to medium term (ranging from one to 10 years). Thus, the need for a dedicated planning exercise similar to the optimal generation mix study conducted by CEA is the need of the hour. This will ensure that state-level planning cells actively forecast demand in addition to a national-level planning exercise through the use of reliable and dedicated planning tools. Scenario planning given a large number of load and supply patterns, outage conditions, RE variability, etc., must be performed and integrated into the resource adequacy planning framework. Though the levelised cost of electricity (LCOE) of various technologies is an important parameter for the selection of technologies, the impact of technologies on the overall system cost – including grid integration and reliability costs – should be considered in developing the framework for the resource adequacy exercises.

It is also important to understand the current supply and demand balancing situation in India and revamp it if needed to ensure resource adequacy. Currently, the supply-side resource portfolio consists of 422 GW, of which 205 GW consists of coal-based capacity, whereas renewables constitute 176 GW (including large hydro). Around 90 percent of the power is tied up in bilateral power purchase agreements (PPA), and load dispatch centres distribute the power within their jurisdiction in each region or state. However limited foresight in terms of scheduling power hinders cost optimisation of generating resources, thus leading to an un-requisitioned surplus. However, recently, the emphasis has shifted to enabling market operations in balancing power demand to ensure regional power trade. Security-constrained economic dispatch (SCED) and market-based economic dispatch (MBED) are a few mechanisms that can reliably meet demand in the system. The former is currently in practice and the latter is proposed to increase the power market in the country.

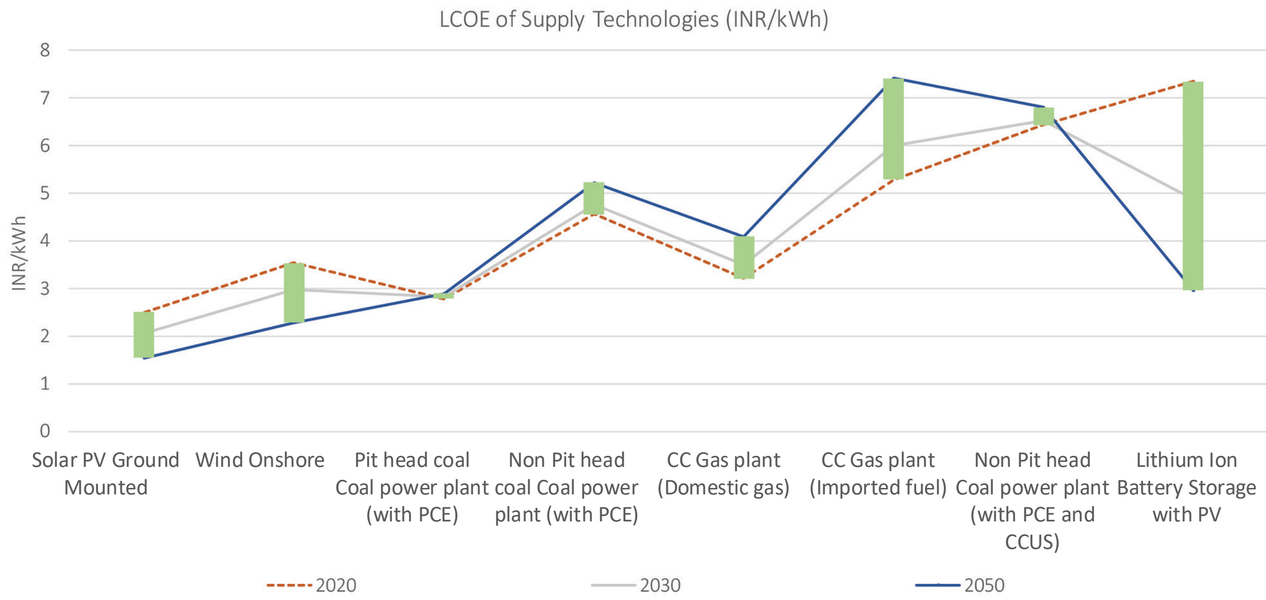


Figure 15: LCOE of Supply-side Technologies From 2020 to 2050 (Author's analysis)

4.2. Demand Shifting and Behavioural Changes

Implementing demand-side management holds significant potential for effectively reducing peak demand. The measures range from shifting load from peak to off-peak hours, implementing utility-level demand response programmes and behavioural changes, especially in utilities with a high share of domestic sales. The GoI has already released mandates for agricultural load shifting through solarisation of the grid under the Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan Yojana (PM-KUSUM). This is envisaged to shift a considerable portion of agricultural pumping demand from late evening to midday. Further, utility-level programmes to implement smart grid facilities have huge potential wherein commercial and industrial consumers could avail monetary incentives to shift their operations and production.

As EV penetration increases, a rationalised time-of-use tariff is anticipated for private and public vehicles to encourage charging from distributed solar during the daytime. Given India's target of installing close to 250 million smart meters within the next five years, utilising the technology optimally would be integral. This includes, but is not limited to, delivering nudges and notifications to customers to lower appliance usage or modify air conditioner set points, which will eventually provide incentives for consumers. Further, discoms should periodically undertake load research studies to estimate the evolving consumer mix, thus shaping peak demand. The same could be approached with a provision for dynamic tariff realisation to the regulatory commission.

4.3. Utilisation of Old Thermal (Coal and Gas) Assets

In a recent notification by CEA, it has directed power utilities to halt the retirement of thermal-based units until year 2030 on account of increasing demand, especially in the peak demand, which occurs late in the evening during the monsoon season. Coal and gas plants thus play an important role in ensuring resource adequacy in the Indian grid. Presently, India has 25 GW of gas-based units that are currently stranded, running at a plant load factor (PLF) of 24 percent due to the unavailability of domestic gas in the power sector. However, Govt. of India, approved a machanism for operationalization of 5 GW gas-based capacity to support peak demand by increasing gas allocation to the power sector. Furthermore, GAIL and Petronet have also promised an increased gas supply to meet peak demand during the summer of 2023 (Financial Express, 2023).

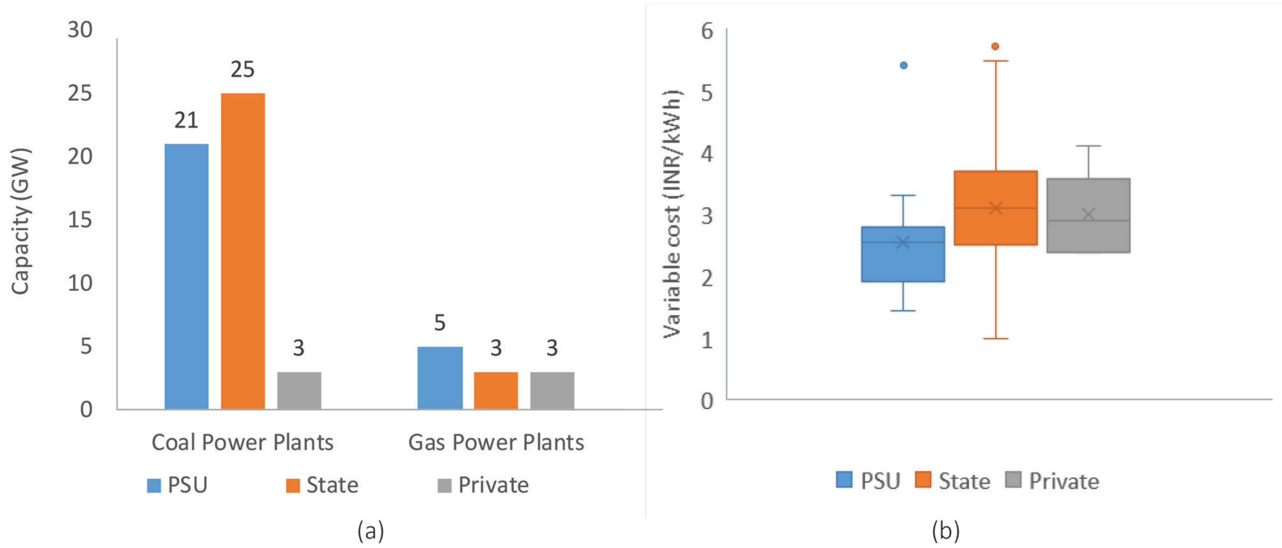


Figure 16: a) Coal- and Gas-based Power Plant Capacity Over 25 Years of Age in 2030;
b) Sector-wise Variable Costs of the Coal Power Plants Presented in (a) (Author's analysis)

As per our analysis, by 2030, around 60 GW of India's coal and gas capacity will be above 25 years of age, most of which is owned by public sector undertakings (PSU) and states. After the completion of their economic lifetime, the plants could undergo a life extension programme and be retrofitted to provide a higher degree of flexibility (lower technical minimum and higher ramp-up/down rates). Thus, these plants could be used to meet regional/state peak demand that occurs at different times irrespective of location and previous PPA arrangements through the central pool scheme.

These thermal plants, which are regulated centrally under a pool scheme, will run seasonally/monthly during the peak demand periods of the year (with more frequent starts and stops) and be entitled to support only during this period. These plants will thus pave the way for the transformation of coal power from all-season operations to seasonal operations to meet peak demand. Similarly, state plants, which have legacy PPAs with state-owned utilities, could exit and join the same arrangement to increase the ambit of such a mechanism. Thus, plants beyond 25 years, irrespective of the holding company, have a substantial role to play as envisaged in the recently released norms on tariff pooling for coal units retired beyond economic lifetime (Ministry of Power, 2023c).

Further, with high RE penetration in the grid, two-shifting operational requirements from thermal assets for several months of the year – including March, April, May and June (The Energy and Resources Institute, 2021) – will become paramount. It would thus be beneficial to utilise old thermal units for meeting seasonal and daily peak demand.

4.4. Market Strengthening

Market strengthening is a crucial aspect in effectively managing peak electricity demand, especially in light of the proposed changes outlined by the Union Ministry of Power. These measures aim to create an efficient and reliable market framework that can accommodate the increasing penetration of RE sources and address the challenges associated with peak demand. To enhance market operations, it is essential to address the dominance of inflexible long-term contracts that may hinder the integration of RE. By facilitating the market participation of renewables, the electricity market can provide a platform for RE generators to sell their power, thereby increasing the share of renewables in the overall energy mix.

Resource adequacy planning at the central and state levels is crucial to meet the growing electricity demand. Monitoring mechanisms should be in place to ensure that state utilities maintain an adequate supply of electricity. This would involve assessing capacity and reserve margins to ensure a reliable power supply, particularly during periods of heightened demand.

Measures such as real-time pricing and ToD tariffs can incentivise consumers to participate in demand response activities, reducing stress on the grid during peak hours. The ToD pricing regime (Ministry of Power, 2023a)to be introduced in the commercial and industrial segment is a welcome move from MoP towards a dynamic retail pricing regime. This could be extended to various segments such as vehicle charging, high-residential-load areas, etc.

Additionally, implementing a regional-level balancing framework for deviation management can reduce deviation penalties for states at the interstate transmission system (ISTS) level. This reduction in penalties would lower reserve requirements, leading to more efficient utilisation of resources and improved market performance.

5 CHAPTER

FUTURE TRAJECTORY FOR INDIA'S ELECTRICITY PEAK DEMAND

Accurate projection of peak electricity demand is crucial for efficient planning and management of electrical systems. Anticipating the highest level of electricity consumption allows for the optimisation of power generation, transmission and distribution, ensuring a reliable and stable electricity supply to meet the needs of consumers. Ultimately, accurate projection of peak electricity demand is essential for ensuring the reliability, resilience and cost-effectiveness of electricity systems, while also facilitating the transition to cleaner and more sustainable energy sources. In this chapter, we discuss the methodology employed in this study, the scenarios considered and the projections of the future peak demand at both national and sub-national levels.

5.1. Methodology

To forecast the national peak demand in 2032,[3] a bottom-up approach was used by estimating state peak demand individually for all states across the country. The annual state electricity requirement at the consumption level (excluding transmission and distribution losses, or T&D losses) was forecast by multi-linear regression over and above the historic demand. From the state-wise electricity requirement data and peak electricity demand, we estimated the compound annual growth rate (CAGR) of peak demand over the period. Further, based on the CAGR of peak demand, we project the state-wise peak demand for 2032. With the computed state-wise peak demand and the base year (2022) time series data of state-wise consumption, we computed the ex-bus electricity load profiles for 2032. The load curves at the state periphery were derived after considering the T&D losses for 2032 as per the 20th Electric Power Survey (EPS) of state-level consumption. The load curves were further aggregated at the national level. We consider two scenario categories: the current trajectory scenario (CTS) and the high growth rate scenario (HGR).

3 Since the hourly demand curves on the ICED are available in the form of the calendar year, we consider the calendar year approach in our analysis.

5.2. Results

The All-India peak demand is expected to grow to 320–334 GW across both scenarios considered in this study. This is quite close to the peak demand of 366 GW projected in the 20th EPS. The peak demand of various regions follows a very similar trend compared to the base year of 2022, with NR exhibiti ng the highest peak demand, followed by WR, SR and other regions. Notably, in the CTS scenario, SR's peak demand grew at a CAGR of 6.1 percent, followed by NR at 5.6 percent, whereas WR grew by a CAGR of 4.8 percent. This growth in SR was largely due to an increase in industrial as well as residenti al load in the states of Tamil Nadu and Karnataka. State-wise peak electricity demand projecti ons are presented in the annexure.

Table 3: Historical and Projected, All-India and Regional Peak Demands (GW) Across Various Scenarios

Region	Year 2011	Year 2022	Vasudha's Scenario For Year 2032		CEA 20th EPS (2032)
			CTS	HGR	
All India	128	215	320	334	366
NR	40	77	120	123	127
WR	42	69	100	104	114
SR	38	60	101	101	107
ER	15	27	42	43	50
NER	2	3	5	5	6

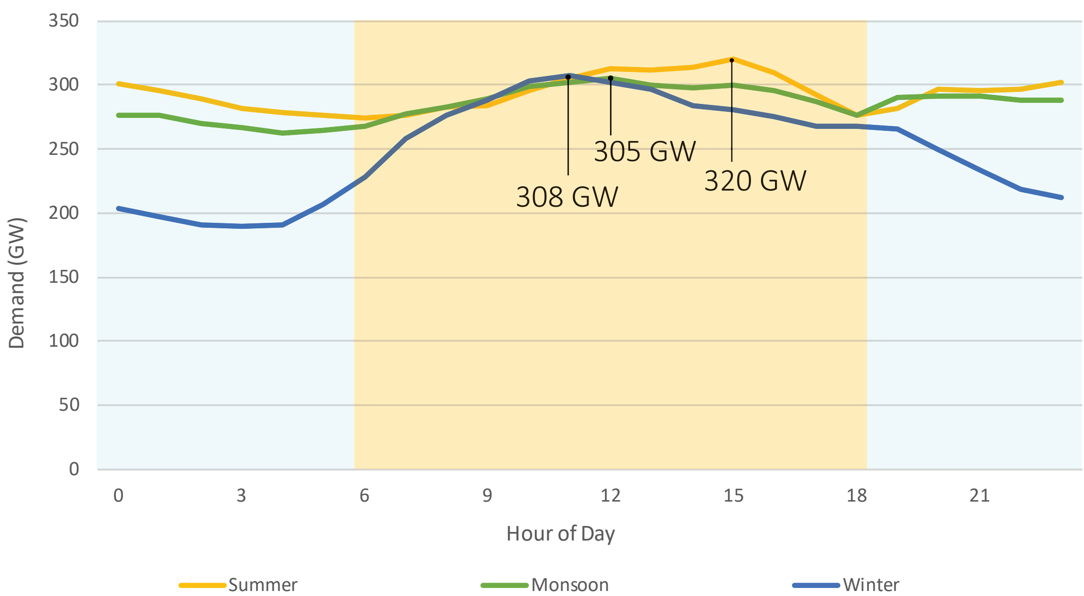


Figure 17: Peak Day Demand Curve at the National Level, CTS Scenario (2032) (Authors' analysis)

6 CHAPTER CONCLUSION AND WAY FORWARD

This report extensively analyses changes in peak demand at both the national and sub-national levels. By examining various evidence and data, we have gained valuable insights into the patterns, trends and factors that influence peak demand. Our analysis sheds light on the importance of understanding peak demand variations, as they have significant implications for the reliability, efficiency and planning of power systems. Further, this report provides projections for peak electricity demand requirements in the next decade by state. The national-level demand would likely be in the order of 320–334 GW in the year 2032.

Though this report relies on a comprehensive analysis to explain the rise in India's peak electricity demand at the national and sub-national levels, at the sectoral level, there are underlying causal relations – such as macroeconomic indicators – as well as socioeconomic factors that explain the rise of peak demand. However, the lack of availability of time-varying data on electricity demand at the sectoral level hinders research in this area. Thus, to observe a change in peak demand, demand across sectors has to be verified through empirical evidence. For example, a rise in cooling demand and services sector growth. Thus, robust data availability would help in understanding the rise in peak demand and drafting a shape-effective energy policy. It should be the collective responsibility of central as well as state agencies to furnish open-source, end-use sectoral data at a regular frequency on feeder profiles, appliance stock, housing, agricultural mechanisation, industrial production, etc. This will eventually aid decision-makers and shape India's electricity reforms.

ANNEXURE

Table 3: Summary of Peak Demand Projection of States and 20th Electric Power Survey (EPS) Projections for 2032

State	Actual Demand for 2022 (MW)	VF's Projections for 2032 (MW)	20th EPS (2032) (MW)
Andhra Pradesh	12075	20381	24387
Assam	2354	3715	4128
Bihar	6698	10671	15159
Chhattisgarh	5338	8169	9713
Delhi	7800	12654	12222
Goa	606	943	1128
Gujarat	21506	30284	36287
Haryana	12605	21465	21644
Himachal Pradesh	2032	3689	3190
Jammu and Kashmir	3159	5070	4633
Jharkhand	5389	8253	4997
Karnataka	14859	25783	21613
Kerala	4465	6202	6967
Madhya Pradesh	16926	27020	27386
Maharashtra	29845	43690	44622
Manipur	257	428	448
Meghalaya	434	549	575
Mizoram	163	288	331
Nagaland	171	235	235
Odisha	6611	11482	9782
Punjab	14113	20632	20587
Rajasthan	16518	26980	27032
Tamil Nadu	17511	27903	28291
Telangana	14089	24863	27059
Tripura	344	460	731
Uttar Pradesh	26379	44254	44066
Uttarakhand	2413	3628	4159
West Bengal	9628	13814	16824
DVC	4014	6212	5649

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LIST OF ABBREVIATIONS

GW	Gigawatt
CAGR	Compound Annual Growth Rate
CDD	Cooling Degree Days
CTS	Current Trajectory Scenario
EMI	Easy Monthly Instalments
EPS	Electric Power Survey
ER	Eastern Region
EV	Electric Vehicle
GAIL	Gas Authority of India Limited
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GOI	Government of India
HGR	High Growth Rate Scenario
ICB	Imported Coal–Based Companies
ICED	India Climate and Energy Dashboard
IEA	International Energy Agency
ISTS	Interstate Transmission System
kWh	Kilo Watt Hour
LCOE	Levelised Cost of Electricity
MBED	Market-Based Economic Dispatch
MTPA	Million Tonnes Per Annum
NER	Northeastern Region
NR	Northern Region
PLF	Plant Load Factor
PLI	Production-Linked Incentive
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan Yojana
PoS	Point of Sale
PPA	Power Purchase Agreements
PSU	Public Sector Undertakings
RE	Renewable Energy
SCED	Security-Constrained Economic Dispatch
SR	Southern Region
T&D	Transmission And Distribution Losses
ToD	Time of Day
WR	Western Region

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