INDIA's POWER OUTLOOK

Building Power Sector Resilience Under Extreme Weather Conditions

VOLUME 7

VASUDHA FOUNDATION
Green ways for a good earth!

The **Power Outlook Series** developed by Vasudha Foundation provides an overview of the current status of India's power sector with a focus on significant and emerging developments. The outlook series aims to develop a more informed understanding of the power sector and act as a tracking tool for stakeholders. 'Building power sector resilience under extreme weather conditions' is seventh in the series of India Power Outlook Reports.

The **Volume 7** conducts a thorough assessment of the rise in extreme weather events and its possible impacts on the power sector value chain. It further opines possible approaches and adaptation options for making the power sector climate resilient. The series also examines Delhi as a case study to reveal the vulnerability of the power sector of Delhi and its possible responses against one extreme event i.e, heatwave.

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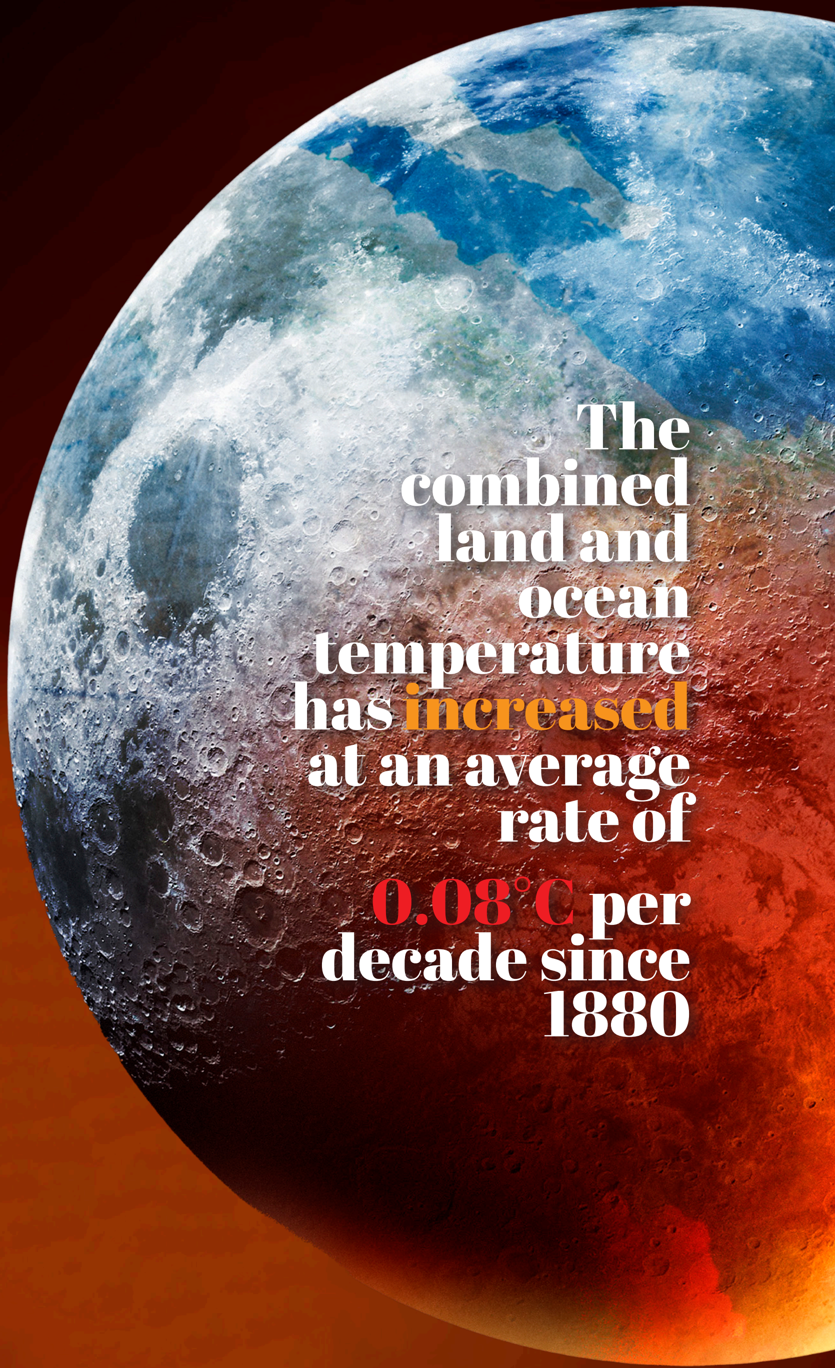
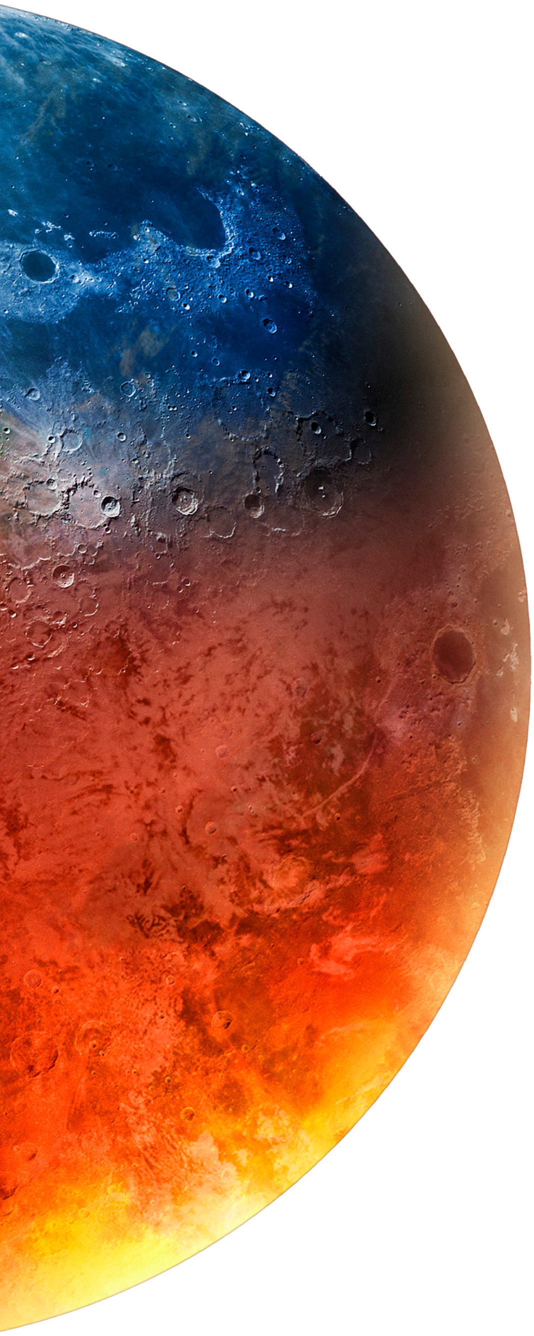
1. Introduction

Climate change is caused by an imbalance between incoming and outgoing solar radiation in the atmosphere. As the amount of heat-trapping greenhouse gases (such as carbon dioxide, methane, and nitrous oxide) in the atmosphere increases, the average surface temperature of the Earth rises. The planet is warming at a quicker rate than at any other time in recorded history. At this point, greenhouse gas concentrations are more significant than they have ever been in the past 800,000 years. The combined land and ocean temperature has increased at an average rate of 0.08 degrees Celsius per decade since 1880. Because of this temperature rise, more water evaporates from the seas and other water sources into the atmosphere, resulting in a feedback loop causing an even more significant increase in temperature. This will have a disastrous impact on the earth resulting in starvation, flooded houses along the coast, more wildfires, storms, droughts, and more. The consequences would be particularly debilitating for developing countries like India, and would further erode the resilience of poor, vulnerable groups, which account for around one-quarter to one-half of the population in most Indian cities.

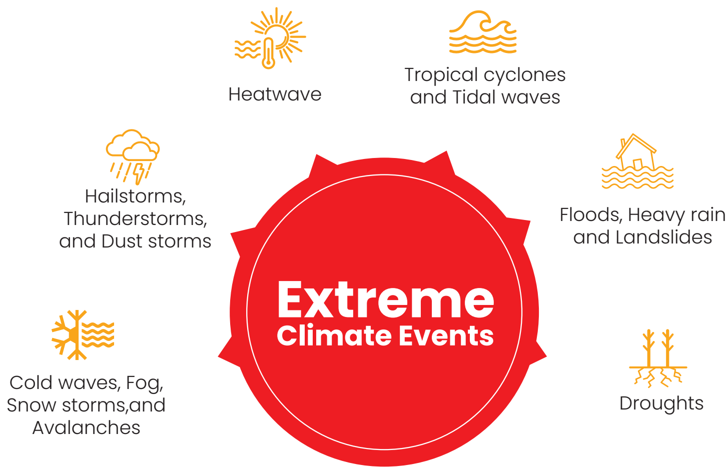




2 India's Changing Weather Conditions due to Climate Change & the Linkages with Power Sector

India's weather encompasses four seasons: i) Winter (January and February) ii) Pre-monsoon or hot weather season (March - May) and (iii) Summer Monsoon Season in the Southwest (June - September) (iv) Post monsoon season (October - December). Climate change is bringing about significant variations in weather and the occurrence of climatic anomalies/extremes in these four seasons. Figure 1 represents the various climate extremes manifested in the last few years in India.

Figure 1: Extreme Climate Events in India



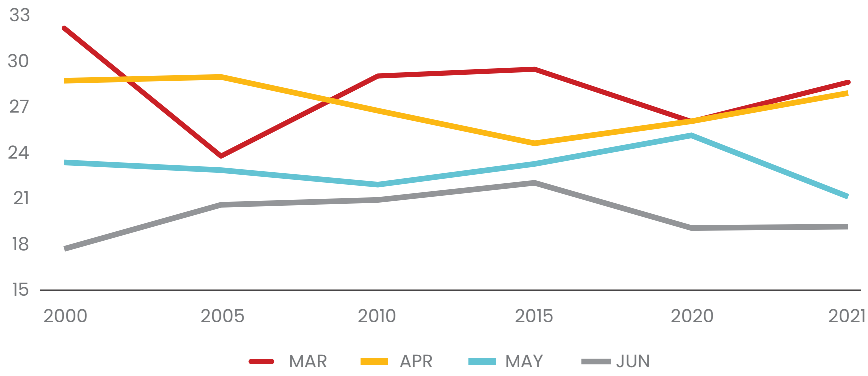
There is an increased frequency and intensity of aforementioned extreme weather events that are expected to have varying spatial and socioeconomic implications on people. Also, more areas/populations are increasingly subject to climate risk as a result of competing goals of economic development leading to rapid urbanization and agricultural expansion.

2.1 Gradual Changes in Normal Weather Parameters

I) MEAN ANNUAL SURFACE TEMPERATURE

Temperature is a key climate variable that has a direct impact on both human and environmental systems. The global mean surface temperature is a significant indicator of climate change because it rises quasi-linearly with cumulative greenhouse gas emissions, as shown in successive IPCC assessment reports. The estimates produced from the POWER Data Access Viewer v2.0.0 gridded monthly were used to assess India's averaged annual mean surface air temperature for the long-term period 2000–2021[1]. The trend in Figure 2 shows the early onset of summers in recent years (i.e., March and April), leading to an elongated period of high-temperature days in the country.

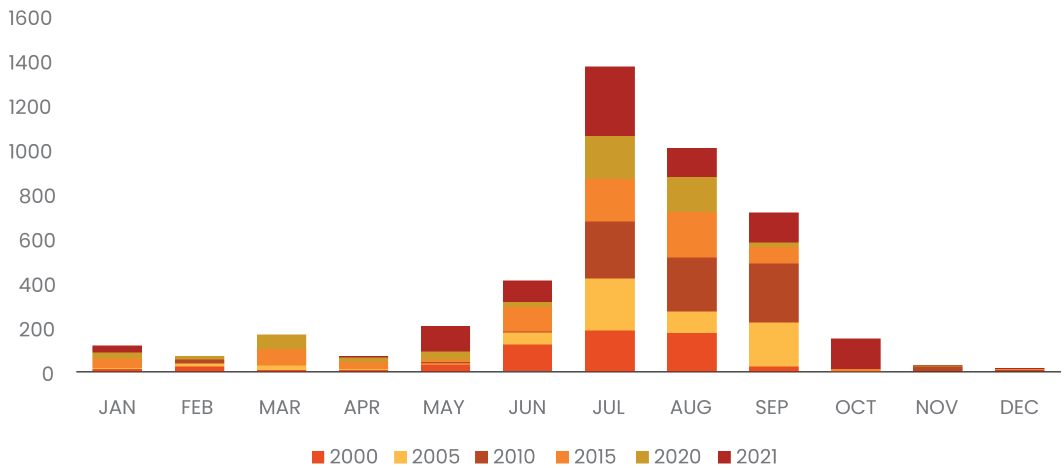
Figure 2: Mean Annual Surface Temperature for India (2000-2021)



II) PRECIPITATION

Precipitation is another critical component of the global water cycle, and the effects of anthropogenic climate change on precipitation have major implications for several sectors. We have analyzed the data on precipitation from 2000 to 2021 and found a significant change in the rainfall pattern as shown in Figure 3. It can be seen that the spread of the rainy season has widened across months and the intensity of precipitation has increased in May and October.

Figure 3: Precipitation in India (2000-2021)



India ranks 7th globally in the Climate Risk Index

2.2 Occurrences of Extreme Weather Events

As per Germanwatch Global Climate Risk Index (CRI) that reveals a country's level of exposure and vulnerability to extreme events, India is ranked 7th globally[2]. These extreme events are occurrences of unusually severe weather or climate conditions that can have catastrophic consequences for communities, agriculture, and natural ecosystems. The Emergency Events Database (EM-DAT)[3] from the Centre for Research on the Epidemiology of Disasters (CRED) contains crucial core data on the occurrence and effects of over 22,000 global mass disasters.

We have furnished the data from 2000 to 2022 (Present) for the analysis of extreme weather events. Also, we have considered 4 extreme weather events for our analysis.

- **Cyclone**- A tropical storm originates over tropical or subtropical waters. It is characterized by a warm-core, non-frontal synoptic-scale cyclone with a low-pressure center, spiral rain bands, and strong winds[4].
- **Flood** - A general term for the overflow of water from a stream channel onto normally dry land in the floodplain (riverine flooding), higher-than-normal levels along the coast and in lakes or reservoirs (coastal flooding) as well as ponding of water at or near the point where the rain fell (flash floods)[4].
- **Heatwave** - A period of abnormally hot and/or unusually humid weather. Typically, a heat wave lasts two or more days. The exact temperature criteria for what constitutes a heat wave vary by location[4].
- **Cold wave** - A period of abnormally cold weather. Typically, a cold wave lasts two or more days and may be aggravated by high winds. The exact temperature criteria for what constitutes a cold wave vary by location[4].

Figure 4: Extreme Weather Events for India (2000-2021)

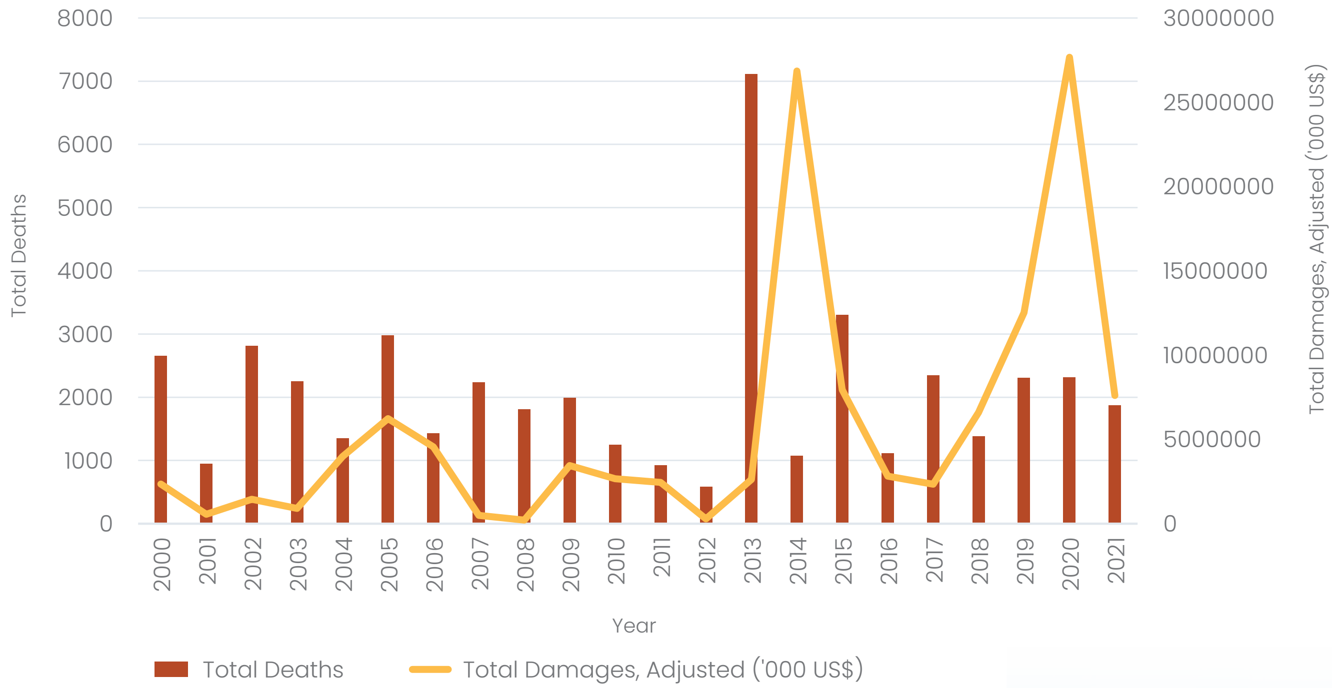
As seen in Figure 4, a significant change in the occurrence of extreme weather events is observed. In the last decade, there has been a dominance of events like floods, and cyclones. There were 46 cyclones & storms and 71 floods in the entire country from 2011 to 2020. Moreover, in the last 5 years, the occurrence of heatwaves and cyclones is significantly high.

There were 46 cyclones & storms and 71 floods in the entire country from 2011 to 2020

2.3 Total Losses due to extreme weather events

India has experienced significant monetary losses due to extreme weather events. Figure 5 captures the progression of financial losses in the last 10 years[3]. These losses result from the destruction of assets including machinery, buildings, and automobiles.

Figure 5: Total Annual Losses due to Extreme Weather Events



2.4 Impact on the Power Sector

Changes in weather patterns and the frequent occurrences of extreme weather events will have serious consequences for the country. Going forward, the most pronounced feature of climate change will be the increase in mean temperatures and the greater intensity of rainfall. These events will, directly and indirectly, impact the entire value chain of the power sector. For instance, the conjunction of soaring ambient temperatures and the shift of high-temperature days to typical non-summer months leads to significant cooling demand. This in turn hampers the demand-supply planning for the power sector. Second, the higher ambient temperatures lead to warming ambient water bodies that reduce the effectiveness of cooling needed by nuclear and fossil fuel-based thermal power plants. Third, evaporation rates in hydropower reservoirs increase when ambient temperatures rise, limiting the resource base

available for power generation. Similarly, the increased precipitation and subsequent flooding events cause major setbacks in electricity generation & distribution, fuel movement, and continuous power supply.

This brings forth the need for a detailed assessment of the possible impacts of these events on the power sector value chain, to identify the possible adaptation options for making the sector climate resilient.

The next section aims to thoroughly analyze the vulnerability of the Power Sector of Delhi against one extreme weather event, i.e., a Heat Wave.

BOX 1: CYCLONE HUDHUD (2014)

On October 12, 2014, the VSCS "HUDHUD" made a disastrous landfall close to Vishakhapatnam (Vizag) on India's east coast. According to a report by P.L.C.'s Aon Benfield Group, insured losses were $650 million compared to an anticipated economic loss of $11 billion[23].

Numerous significant industrial facilities were affected by the cyclone, including RINL, Hinduja Power, NTPC, and other organizations. Losses of roughly over Rs 500 crore had been reported by Hinduja Power[24]. The Jawaharlal Nehru Pharma City estimated opportunity losses of around INR 1 billion per day as a result of the power outage, which lasted roughly 18 days[25].

Summary of all the affected elements of the power sector due too HUDHUD[26]

Name of component	Total number affected
Generating Units of Simhadri	4
400 KV Substations	3
220 KV Substations	12
400 KV Lines	20
220 KV Lines	30
400/220 KV ICTs	5
132 KV Elements	86
Traction Substation	12

3 Delhi- A case study

Rise in electricity consumption and peak demand is an ultimate response towards the worsening weather conditions due to climate change. Delhi, the capital city of India, located in the northern part of the country, provides a perfect testimony to this statement. Delhi has a semi-arid climate, with hot summers, average rainfall and moderate winters. The variation of temperature is high with minimum of 3.5 degree Celsius in January 2022 to maximum of 47.7 degree Celsius in May 2022.

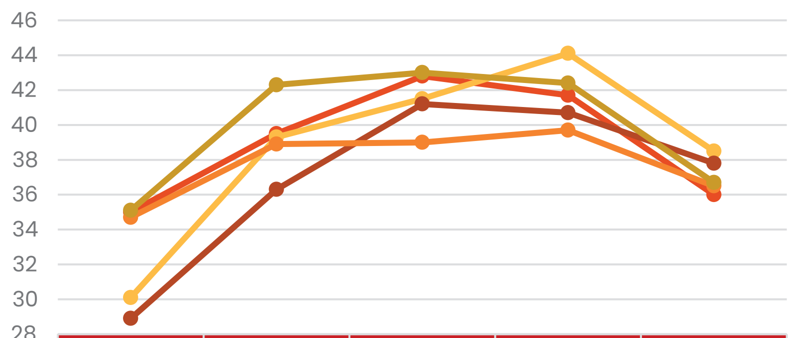
Rise in extreme weather events, shrinking of seasons, higher maximum and lower minimum temperatures are all the various impacts of climate change. Together, this affects the power system planning and its operations. In the next section, we discuss the impact of temperature and changing weather patterns across the power sector value chain for Delhi.
Electricity & State Growth Statistics for Delhi (2011-2022) [4]

The variation of temperature is high with minimum of 3.5 degree Celsius in January 2022 to maximum of 47.7 degree Celsius in May 2022

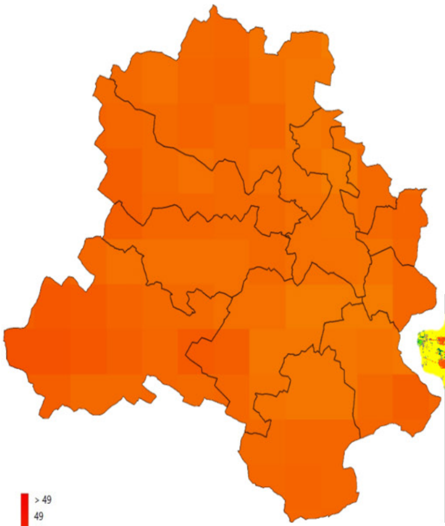
Parameters	Unit	2010-11	2021-22	Growth Rate
Population	No.	1,67,88,000	2,09,65,000	25%
Urbanisation Rate	%	97.5%	99.5%	2%
Peak demand	MW	4,810	7,323	52%
Electricity Consumption	MU	25,581	30,944	21%
Per Capita Energy Consumption	kWh	1,524	1,476	-3%
GSDP (at current prices)	₹ Crore	2,61,470	9,23,967	253%

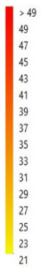
3.1 Temperature change

We examine the monthly average maximum temperature for five summer months (March – July) for Delhi. We observe that there is a gradual increase in the mean maximum temperatures. The trend is much apparent for the months of March and April, where the mean maximum averages have warmed to 35.1 degree Celsius and 42.3 degree Celsius over the last 5 years. This further alludes to the expansion of the summer months, leading to an elongated period of high-temperature days in the country and a resultant need for increased demand for cooling.

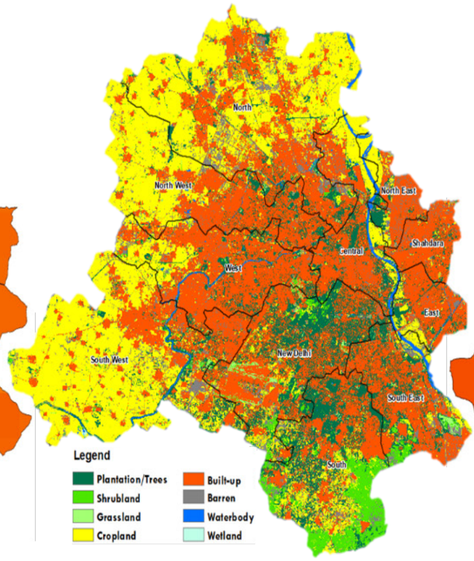


	March	April	May	June	July
2018	35	39.5	42.8	41.7	36
2019	30.1	39.3	41.5	44.1	38.5
2020	28.9	36.3	41.2	40.7	37.8
2021	34.7	38.9	39	39.7	36.5
2022	35.1	42.3	43	42.4	36.7

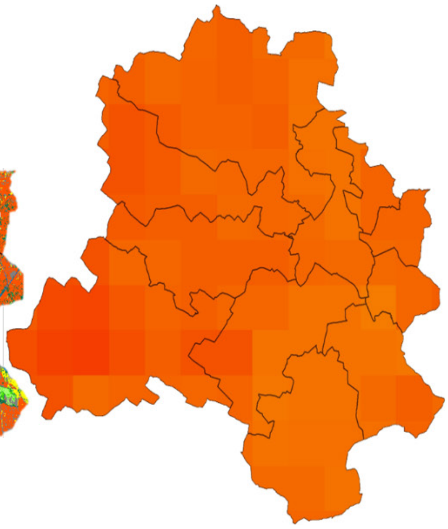




Mean temperature 2021
(March-July)



Land-use/cover Map of Delhi
Year 2020-21



Mean temperature 2022
(March-July)

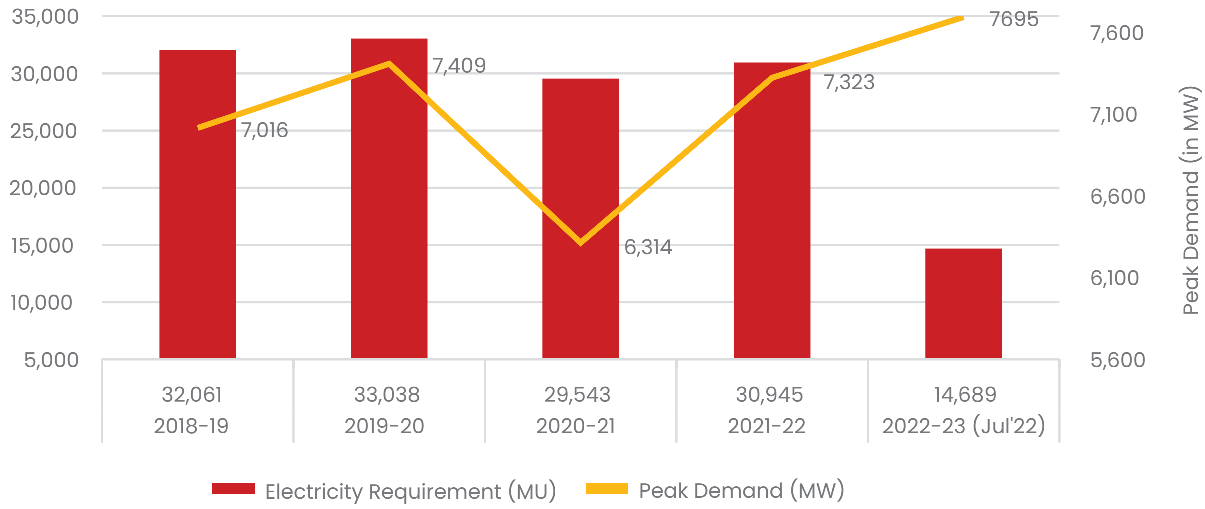
The electricity peak demand in Delhi increased by almost 2% CAGR between 2018 - 19 and 2022 - 23

We plotted the daily mean maximum surface temperatures from March-July in 2021 and 2022 and further mapped the land use/cover map for Delhi. It is observed that the north and west parts of Delhi experience higher mean temperatures as compared to central and southern parts of Delhi. When superimposed with the land use/cover map of Delhi, it is deciphered that the south and central Delhi have higher share of green cover in the form of plantations/trees and shrubland. However, the north and west Delhi is highly concretised resulting in a higher population density and associated anthropogenic emissions. This creates an urban heat island effect that increases the temperatures by a few degrees compared to the neighbouring areas.

3.2 Overview of the Power sector in Delhi

3.2.1 ELECTRICITY DEMAND[5]

The electricity requirement in Delhi for the year 2021-22 presents a negative growth rate of 1.2% CAGR since 2018-19 which could be largely due to the Covid-19 pandemic. However, the peak demand increased by almost

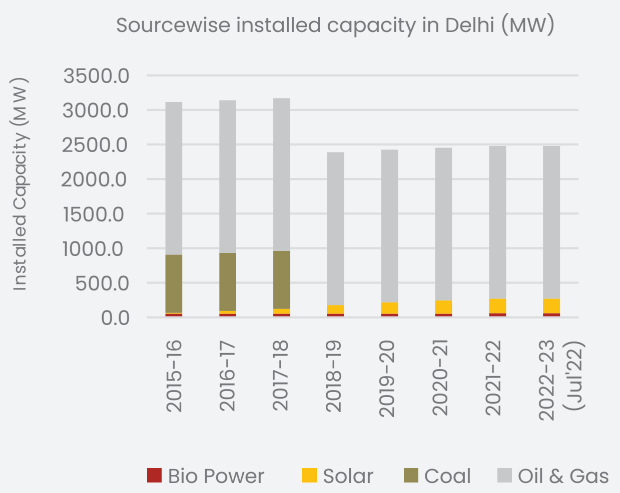


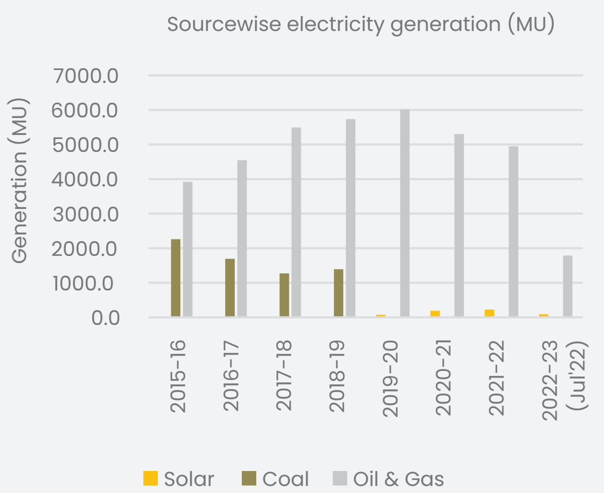
2% CAGR between 2018-19 and 2022-23, we further observe a rise in higher mean monthly temperatures over the years (depicted above).

3.2.2 ELECTRICITY GENERATION

Owing to its geographical location and limited land resources, Delhi has a total installed power capacity of only 2478.5 MW. This primarily includes the two gas-based generation plants - Indraprastha Power Generation Company Limited (IPGCL) and Pragati Power Corporation Limited (PPCL), 211 MW of rooftop solar capacity and 59 MW of bio power. The two coal-based plants -Badarpur Thermal power plant and Raj Ghat thermal power plant were shut down due to environmental and inefficiency concerns and stopped generating since 2019-20.

There is an increase in the solar generation particularly due to the surge in rooftop solar installations by commercial and industrial segment.[6]

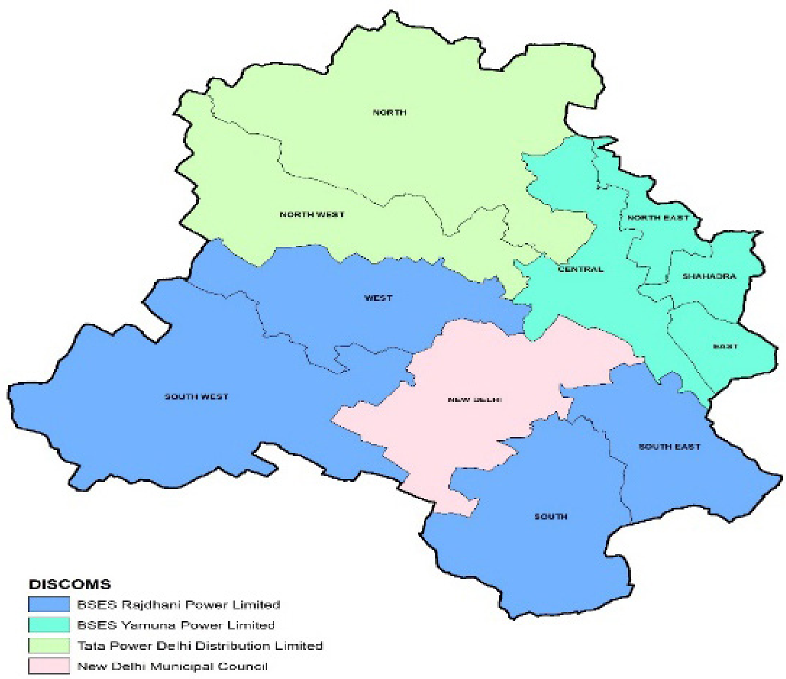




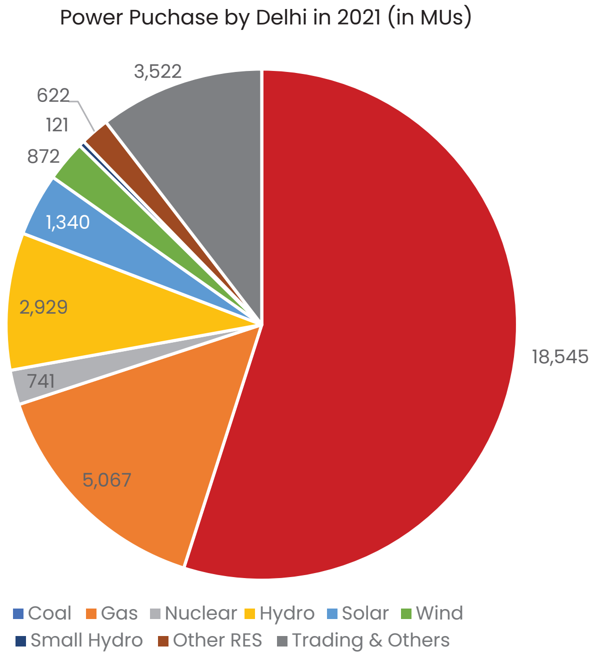
3.2.3 ELECTRICITY DISTRIBUTION

The electricity distribution in Delhi is largely catered by three private DISCOMs and one public DISCOM. These are as described below:

- BSES Rajdhani Power Limited (BRPL) - South and West Delhi.
- BSES Yamuna Power Limited (BYPL) - East and Central Delhi
- Tata Power Delhi Distribution Limited (TPDDL) - North and North West Delhi
- New Delhi Municipal Council – New Delhi aka 'Lutyen's Delhi'

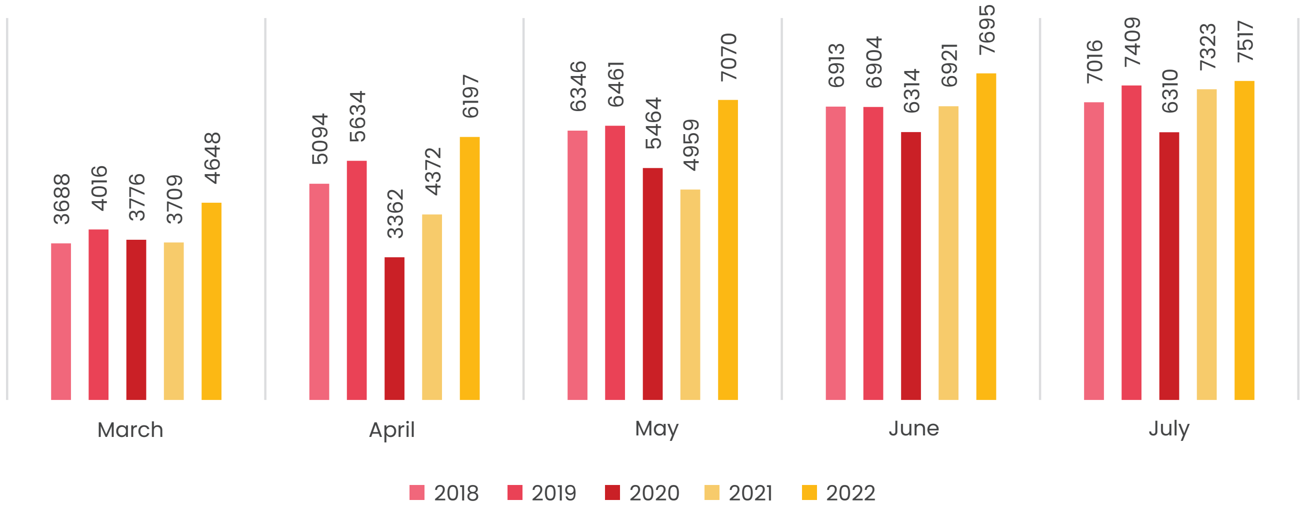


Delhi procures more than 80% of power from either Central Government or other generation sources

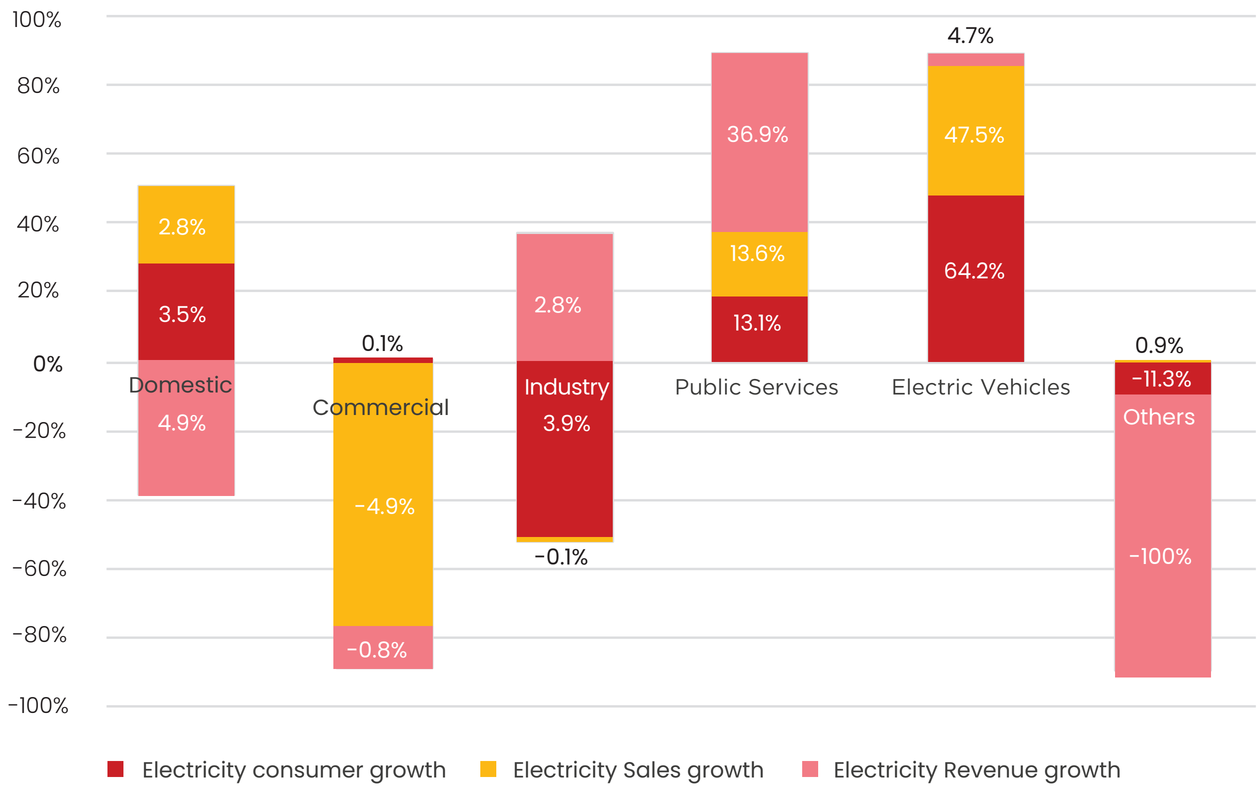


The total power purchase in Delhi for the 2021-22 was 33,759 MUs. Out of this, Delhi procures more than 80% of the power from either Central Government or other generation sources. While the share of coal has declined over the years, it still dominates the power purchase mix. Interestingly, the 10% share of power purchase from power exchanges is the third highest after coal (55%) and gas (15%) based power[7]. This illustrates the gradual transition from centralised and long-term power purchase to shorter and flexible power purchase mechanisms to better manage the demand volatility. Another objective is to replace costly generation with cheaper resources available in other States during system peak hours.

3.3 Understanding Delhi's peak power and its impacts[8]



Due to extreme temperatures, Delhi experiences a high variation in its peak demand. With maximum temperature rising to 44.5 degree Celsius, Delhi recorded a peak of 7,695 MW on 29th June 2022. The peak demand for Delhi generally occurs between late June to early July. In the figure above, the annual peak demand increased by 2.3% CAGR between 2018-2022. However, over the years the city has witnessed higher mean monthly temperatures in the months of March and April. Subsequently, the peak demand for the month of March and April has increased by 6% and 5% respectively during the same period.[9]



The capital city caters to 65.5 million consumers with the total electricity sale of 29,152 MU and a revenue realisation of 12,499 crores for the year 2021-22.

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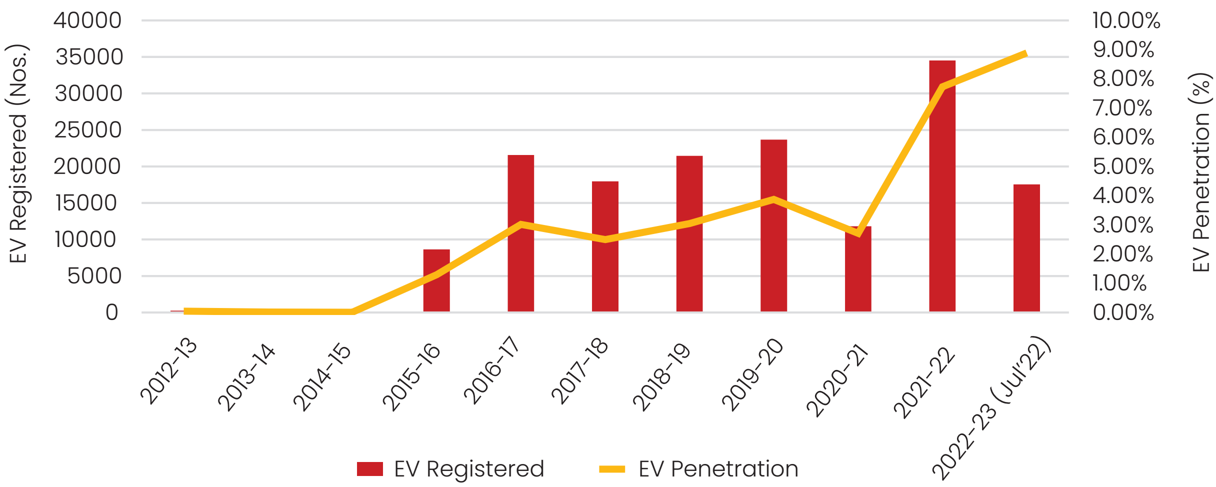
When we compare the consumer, sales and revenue together, it is observed that the power demand from the commercial consumer has declined at an average rate of 5% per annum. This has slightly impacted the revenues from this segment. One major reason could be increased deployment of rooftop solar that is meeting the demand for some of the commercial consumers. During the same period (2018-19 to 2021-22) the solar generation in the state has risen from 10.8 MU to 225.8 MU annually. It could be inferred that owing to higher peak power demand and resultant tariffs for the commercial category, there is an increasing preference for self-generation via rooftop solar.

On the contrary, increased electricity demand growth is prevalent from the domestic sector. However, the revenues from the residential sector have declined. This could be attributed to announcement of residential subsidies and no tariff rise for the segment over the past many years.[10]

Electric Vehicle registered w.r.t. total registered vehicle



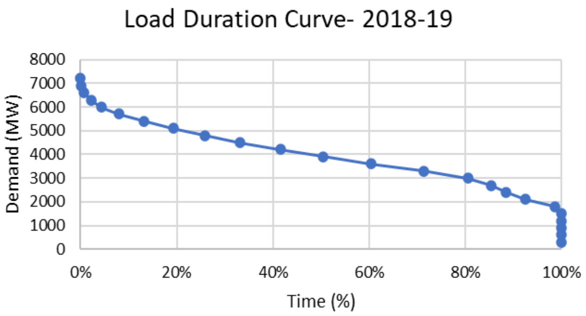
Another interesting observation is the increased penetration of electric vehicles in the city. As per the VAHAN dashboard, there are almost 15,7571 EVs registered in the city (as on Jul'22). The electricity demand from EVs have almost risen by three times from 30MU to 97MU between 2018-19 and 2021-22[11]. Going forward, the vehicle to grid (V2G) technologies (still in progress) would become the most preferred option to flatten the load curve by introducing flexibility into the system. V2G allows the EVs to act as both generation and demand resource. They can be charged during the off-peak hours or during generation peaks of solar energy. On the flip side, they can be discharged during peak hours or when the grid requires voltage or frequency support.

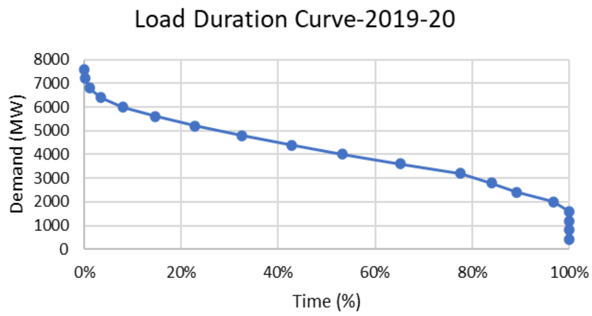
4

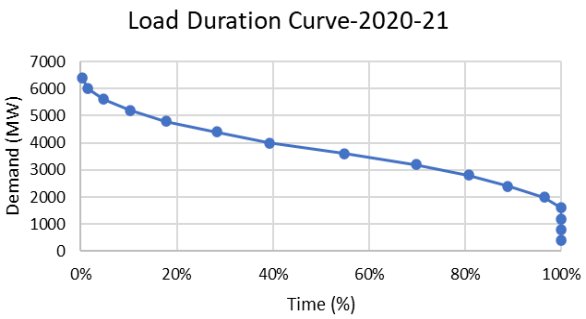
Strategies to reduce peak power load

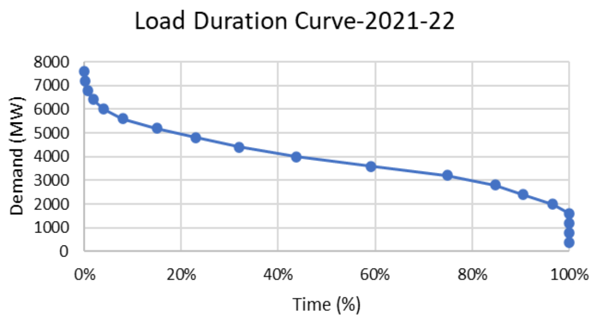
4.1 Understanding the load curve and peak demand occurrences

1. Delhi's Load Duration Curve for the last four financial years[12]





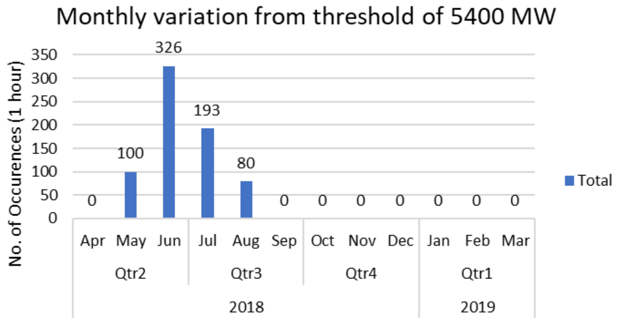


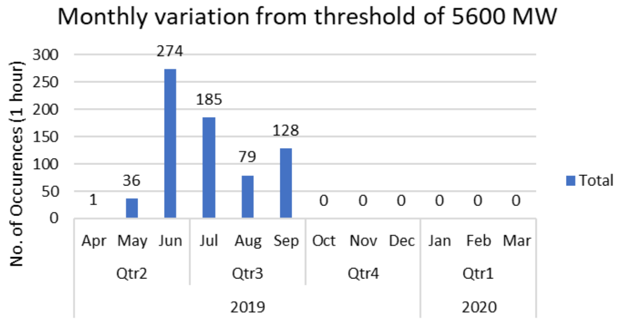


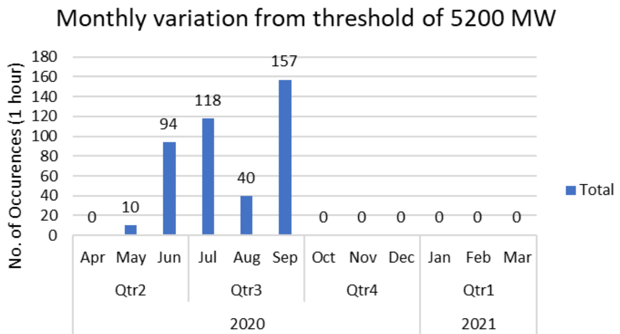
- In order to gauge the impact of soaring daily temperatures and the early onset of the summer season seen in the last four years, we developed the load duration curve for the last four years. This allowed us to visualize how consistently Delhi is using the energy.
- From the curve, it was observed that the base load for Delhi hovered around 1600 MW for all these years.
- However, the peak demand is increasing at a CAGR of 1.92% from 6900 MW in 2018-19 to around 7770 MW on June 29, 2022. This is due to the increased cooling load necessary to relieve the rising mercury in the summer months.
- Another intriguing aspect is the duration of peak demand. In 2021-22, power demand greater than 5600 MW was observed only 8% (700 hours) of the time throughout the year (8760 hours). However, it is the peculiarity of the electricity system that the grid infrastructure planning must be carried out to meet the peak demand even though the infrastructure will remain idle for the remaining time period.
- These plots underscore the presence of opportunity in Delhi to implement peak demand management strategies.

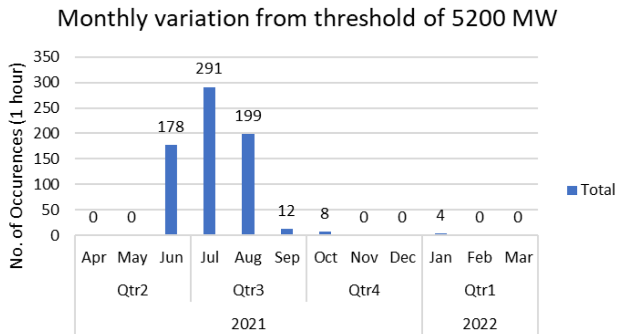
Peak demand is increasing at a CAGR of 1.92% from 6900 MW in 2018-19 to around 7770 MW on June 29, 2022

2. Monthly load variation for the last four financial years[13]



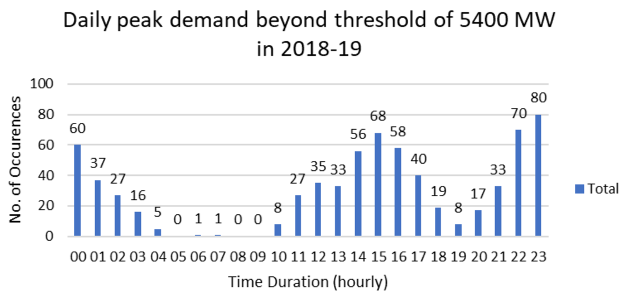


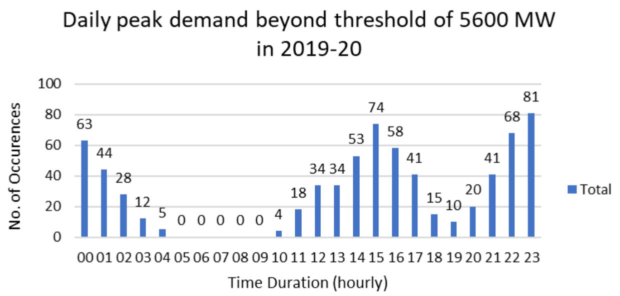


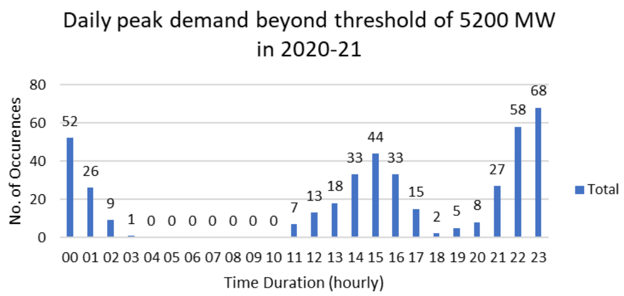


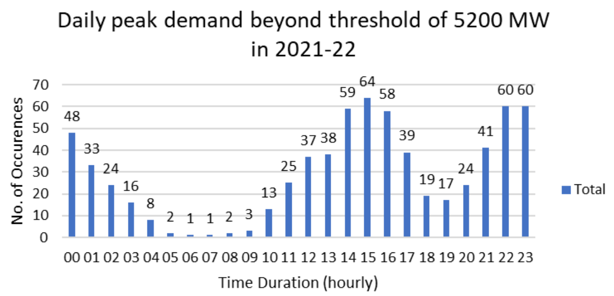
- To further examine the monthly variation of peak load, we plotted a month-wise variation of demand greater than the threshold value on an hourly basis. The selection of threshold value is based on the thumb rule that states the power demand value should be more than 15% of the total time duration in a year.
- It can be observed that the occurrences of power demand greater than the threshold value is spreading out across the months. This includes the occurrence of these instances in September and October.

3. Identify the occurrence of Peak periods for the last four financial years[14]







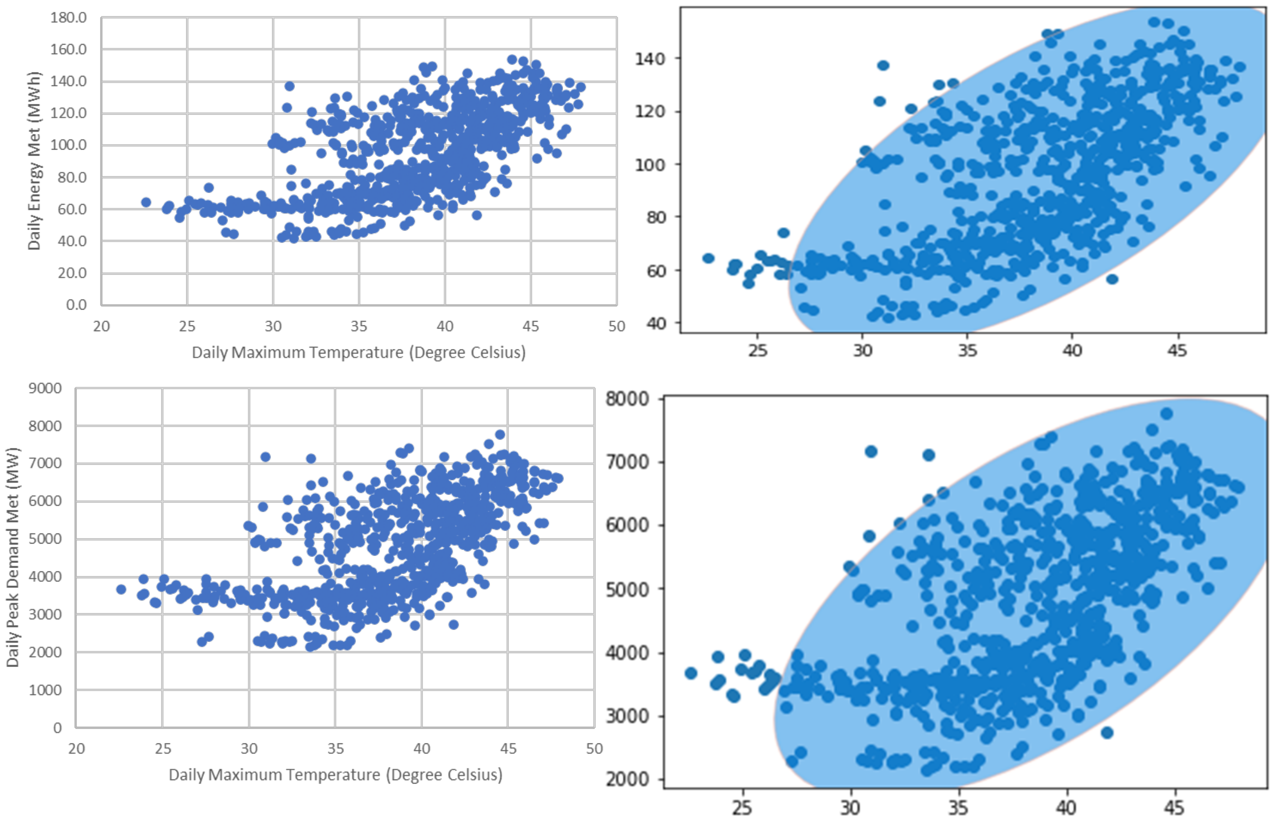


- Another facet of perusal is the spread of occurrence of power demand greater than the threshold throughout the day.
- As seen from these visualizations, Delhi experiences two instances of peak power demand. One occurs during the afternoon (3pm) and one during late night (11pm). However, the peak during the day was comparatively less frequent in the early years. This trend has changed with time and in 2021-22 the frequency of both peak periods was at par.
- Here, it can be safely inferred that the rising temperatures are leading to increased cooling demand during the daytime.

Delhi experiences two instances of peak power demand. One occurs during the afternoon (3pm) and one during late night (11pm).

4.2 Accurate understanding of the weather patterns

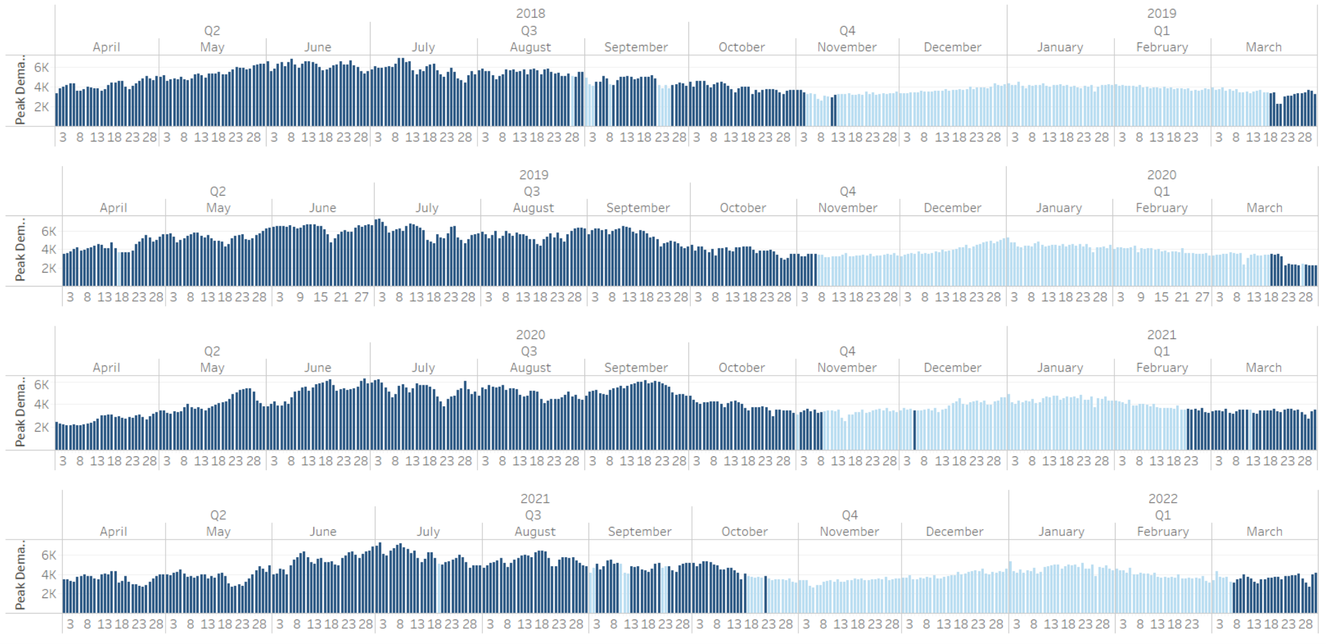
1. Temperature effect on demand and energy met for last four financial years[15]



- We have analysed the variation of daily energy met and peak demand met against the daily maximum temperature for Delhi for the months March-July. And the years considered for this analysis are 2018-2022.
- The correlation between daily energy met and daily maximum temperature is 0.64 and the correlation between daily peak demand met and daily maximum temperature is around 0.6. On carrying out hypothesis testing on these correlation coefficient values, it was inferred that the null hypothesis (Correlation coefficient is zero) is rejected. This underscores that there is a significant correlation between the parameters.

- Moreover, we have also carried out the bivariate outlier detection on these parameters. The ellipse in the above figures represents the area that wraps non-outlier values according to Mahalanobis Distance (MD)[16].
- The majority of outliers lie below 27 degrees Celsius. This is because the daily energy met and daily peak demand met are fairly constant below this temperature point. The daily energy met hovers around 60 MWh and the daily peak demand met is around 3500 MW. Beyond 27 degrees Celsius, the increase in daily energy met and daily peak demand is linear against daily maximum temperature implying that the cooling demand is surging.

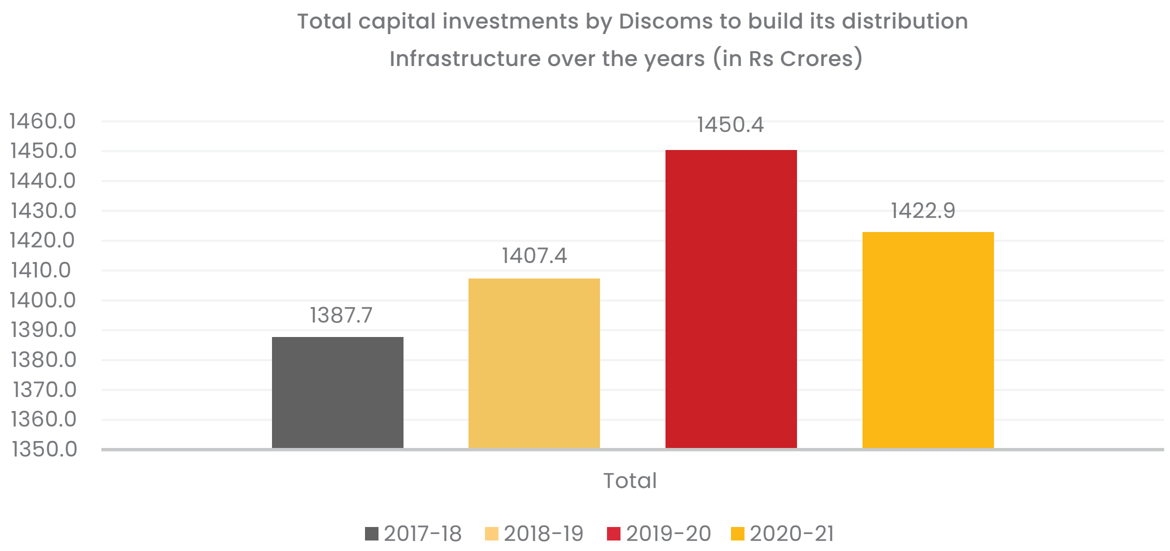
2. Cooling Degree Days - 30 v/s Power Demand:[17]



- Here, we plotted the daily peak demand met for the last four financial years. The dark blue-colored bars represent that the maximum temperature on that day has breached the 30-degree Celsius mark. On average this happens close to 233 days in a year in India.
- It can be observed that there is a slight shift in the daily maximum temperatures. The temperatures rarely cross the 30-degree Celsius mark in the last week of October or the first week of November.
- On the flip side, there is an early onset of summer. From the first and second week of March, the mercury crosses the 30-degree Celsius mark and rarely goes down until October.

4.3 Embracing Demand Side Management options

It is well established that the rising demand needs to be adequately complemented with timely and smart distribution infrastructure upgradation. The three DISCOMs in Delhi (BRPL, BYPL ns TPDDL) have invested a total of INR 5668.4 crores[18] over the last four years for building its distribution and sub-transmission infrastructure (transformers, EHV cables, 11kV feeders, etc). Nevertheless, implementing demand side management measures to reduce/alter/shift demand is paramount. DERC released its DSM regulations in 2014 that elaborated on the guidelines that need to be followed by DISCOMs for implementing DSM measures. At a Pan-India level, the status of DSM measures has only limited itself to appliance replacement/home retrofit-based utility DSM program. Delhi has been embracing few innovative DSM program to tap large energy savings. This ranges from super energy efficient AC replacement schemes to automated demand response pilots and further implementing a behavioural energy efficiency program.



Behavioral Energy Efficiency Program

BRPL partnered with US based Oracle Utilities OPower to implement a pilot program on behavioural energy efficiency project for two lakh customers mostly identified in regions with overloaded distribution capacity. The objective is to generate verifiable energy savings, peak power shaving and increase customer engagement through Home Energy Reports (HERs). HERs use a mix of data analytics and behavioural science help customers understand their energy usage better and further empower them to take steps to adopt more efficient behaviours. The M&V of the program results have affirmed the value of home energy reports for building its customer relationships and almost 38% of the recipients stating that usage has decreased in the last 6 months.

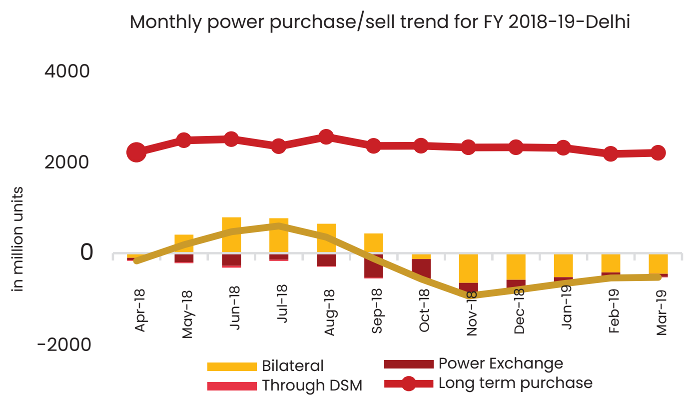
4.4 Installation of Smart Metering Infrastructure

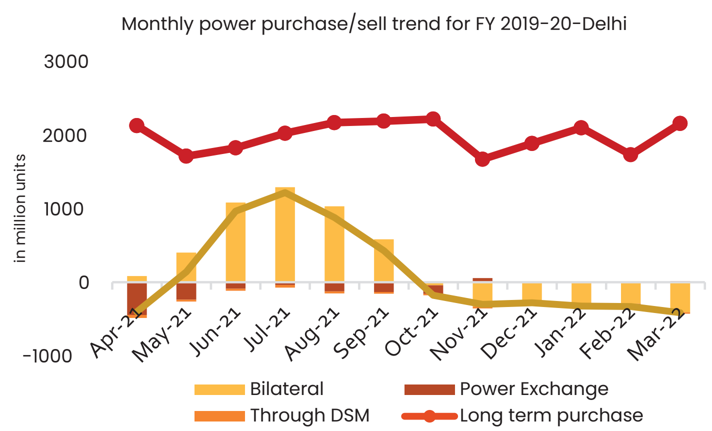
Dynamic Tariffs such as Time of Day (TOD), Critical Peak Pricing (CPP), etc., are some of the tariff based DSM programs that use time of day to incentivise changes in demand patterns. TOD tariff is also applicable in Delhi for all consumers (other than domestic use) whose sanctioned load/ MDI (whichever is higher) is 10kW/11KVA and above.[19]

Delhi has installed only 2.58 lakh smart meter against its total of 65 lakh connections

Dynamic pricing programs, enabled by advanced metering and a smart grid, can reduce the DISCOMs power purchase costs and help manage peak loads. The benefits of smart meter technologies have been established globally. A key application is to provide granular energy consumption data to consumers that would further enable energy efficiency and demand response programs. The Smart Meter National Program aims to replace 250 million conventional meters in India. As on September 2022, Delhi has installed only 2.58 lakh smart meter against its total of 65 lakh connections.

Additionally, the BSES DISCOMs have issued tenders to replace 50 Lakh existing electricity meters in Delhi with smart meters at a capital outlay of up to Rs. 4000 Crore. The total number of consumer connections for BSES in 2021-22 was around 46 lakhs. Hence, it is safe to assume that the DISCOMs are targeting to replace all its conventional meters with smart meters[20] and as well cater to additional new connections. The project is being coined as one of the fastest and the largest private sector smart meter installation in the country that will be rolled out in the next 2-3 years.





4.5 Optimising power purchase portfolio

Traditionally, most of the DISCOMs in the country had tied themselves into long term and expensive power purchase agreements. However, in the recent years such trends are slowly changing. DISCOMs are preferring to do a greater number of short-term bilateral contracts or procuring cheaper power from the exchanges to meet their seasonal peak load requirements against the long-term power purchase options.

To further strengthen the market and ensure its continuous growth, power exchanges in India have launched many products such as the real-time electricity market (RTM), green term ahead market (GTAM) etc in addition to the Day-Ahead Market (DAM), Term-Ahead Market (TAM) and Renewable Energy Certificates (REC)

A similar trend is visible for Delhi as we unpack the long term and short-term power purchase.

The short-term power purchase for Delhi is more of a mirror image when put across for the months of May to September and October to March where the DISCOMs are buying power via bilateral contracts and power exchanges in the summer months and selling the power in the winter months.

Between FY19 and FY 22, we observed that the long-term power purchase has declined from 28,080 MU to 23,795 MU[21]. On the contrary, there is considerable increase in terms of the purchase/sell from and to the power exchanges. This is much prominent for the peak demand months of June and July where the short-term purchase more than doubled from 1,065 MU in 2018 to 2184 MU in 2022[22]. This further alludes that DISCOMs are progressing towards better optimisation of their power portfolio to manage their dynamic demand requirements and not entering into unnecessary long and expensive PPA arrangements.

It was observed that the long-term power purchase has declined from 28,080 MU to 23,795 MU

5

Conclusion & Recommendations

The analysis in the previous sections clearly presents the need to recognize that climate change poses a significant challenge to the smooth operation of the power sector. Going forward, it will become imperative for the power sector to draft appropriate responses after careful risk assessment of all the extreme weather events. This table aims to identify the impacts and the possible approaches to managing these extreme events better.

Climate Variable	Parameters	Power Sector Value Chain		
		Generation	Transmission & Distribution	End-Use
Heat Wave	Impact	• Lowered generation efficiency • Increased water required for cooling • Self Ignition of coal stock piles	• Can reduce the electricity carrying capacity of T&D lines • Can increase losses within substations & transformers	• Increased electricity demand due to increase usage of cooling appliances
	Adaptation Options	• Ensure availability of water from other sources • Increase the system's ability to return to normal operations rapidly if outages do occur. • Increase decentralized energy generation (with less T&D grid requirements). • Protect fuel storage including coal stockpiles	• Create a crisis plan as a response to extreme events • Ensure effective cooling for substations and transformers. • Ensure the usage of higher temperature-rated switchgear for the upcoming projects • Develop and use "smart transformers" and "smart grids."	• Promote utility-wide energy efficiency programs for cooling appliances like ACs. • Develop S&L programs for all cooling equipment • Promote evaporative cooling and district cooling plants • Implement various demand-side measures to reduce peak demand • Ensure deployment of advanced metering infrastructure

Climate Variable	Parameters	Power Sector Value Chain		
		Generation	Transmission & Distribution	End-Use
Flooding	Impact	• Increased siltation in reservoirs • Damage to Infrastructure • Reduced efficiency or complete shutdown of plants • Deluge coal stockpiles and oil & gas storage tanks	• Can compromise tower structures through erosion. • Can damage underground cables and infrastructure in general. • Can damage the IT infrastructure housed inside the substation	• Increase in maintenance requirements/calls due to damaged power infrastructure in and around the house • Increased demand for electric switchgear spares
	Adaptation Options	• Increase the system's ability to return to normal operations rapidly if outages do occur. • Increase decentralized energy generation (with less T&D grid requirements). • Protect fuel storage including coal stockpiles	• Create a crisis plan as a response to extreme events • Design improved flood protection measures for equipment mounted at ground level in substations. • Reinforce existing T&D structures and build underground distribution systems. • Design redundancy into IT systems. • Develop and use "smart transformers" and "smart grids."	• Ensure installation of the meter, circuit breakers, etc. at an appropriate height and of apt IP rating
Cyclones	Impact	• Disrupt connection to grid • Damage to Infrastructure • Reduced efficiency or complete shutdown of plants	• Can damage T&D lines.	• Increase in maintenance requirements/calls due to damaged power infrastructure in and around the house • Increased demand for electric switchgear spares
	Adaptation Options	• Increase the system's ability to return to normal operations rapidly if outages do occur. • Increase decentralized energy generation (with less T&D grid requirements). • Protect fuel storage including coal stockpiles • Incorporate higher structural standards for all the installations	• Develop a comprehensive framework to reduce the damage caused to power systems • Require higher design standards for distribution poles. • Amend routes of overhead lines along roads away from trees and other tall-weak structures • Develop and use "smart transformers" and "smart grids."	• Ensure installation of the meter, circuit breakers, etc. at an appropriate height and fully covered

References

1 NASA, 2022. ***Power | Data Access Viewer.*** [Online] Available at: https://go.nasa.gov/2HOkeXn

2 David Eckstein, V. K. L. S., 2021. ***Global Climate Risk Index,*** s.l.: Germanwatch. Available at: https://bit.ly/3wHPX8P

3 Centre for research on the Epidemiology of Disasters, 2022. ***EM-DAT.*** [Online] Available at: https://www.emdat.be/

4 National Commission on Population, July, 2022. ***Report of the Technical Group on Population Projections,*** New Delhi: Ministry of Health & Family Welfare. Available at: https://bit.ly/3QanBLw

Vasudha Foundation, 2022. ***Vasudha Power Info Hub.*** [Online] Available at: https://vasudhapower.in/

Planning Department, 2021-22. ***Economic Survey of Delhi,*** Delhi: Govt. of Delhi. Available at: https://bit.ly/3R9AWVv

5 POSOCO, 2022. ***Monthly report,*** New Delhi: POSOCO. Available at: https://bit.ly/3BhoBtf

6 Vasudha Foundation, 2022. ***Vasudha Power Info Hub.*** [Online] Available at: https://vasudhapower.in/

7 DISCOMs, 2021-22. ***Tariff Orders,*** New Delhi: Delhi Electricity Regulatory Commission. Available at: https://bit.ly/3RxYoMf

8 Vasudha Foundation, 2022. ***Vasudha Power Info Hub.*** [Online] Available at: https://vasudhapower.in/

9 DISCOMs Multi Years Tariff Orders & Author's analysis

10 Ministry of Road Transport & Highways, 2022. VAHAN dashboard. [Online] Available at: https://bit.ly/3RzVgzr

11 DISCOMs, 2020-21 and 2021-22. ***Tariff Orders,*** New Delhi: Delhi Electricity Regulatory Commission. Available at: https://bit.ly/3RxYoMf

12 POSOCO, 2022. ***State-wise Hourly Demand.*** New Delhi: POSOCO. Available at: https://bit.ly/2H8j8cM and Author's analysis

13 Author's analysis

14 Author's analysis

15 Vasudha Foundation, 2022. ***Vasudha Power Info Hub.*** [Online] Available at: https://vasudhapower.in/

NASA, 2022. ***Power | Data Access Viewer.*** [Online] Available at: https://go.nasa.gov/2HOkeXn

16 Mahalanobis Distance is a measure of the distance between a point P and a distribution D, introduced by P.C. Mahalanobis in 1936. It is an extremely useful metric having immense application in multivariate anomaly detection.

17 NASA, 2022. ***Power | Data Access Viewer.*** [Online] Available at: https://go.nasa.gov/2HOkeXn and Author's analysis

18 Planning Department, 2021-22. ***Economic Survey of Delhi,*** Delhi: Govt. of Delhi. Available at: https://bit.ly/3Q8Hanh

19 Delhi Electricity Regulatory Commission, 2021-22. ***Electricity Tariff Schedule,*** Delhi: DERC. Available at: https://bit.ly/3AA9SrC

20 The Hindu, 2022. ***BSES to install 50 Lakh smart meters in Delhi.*** [Online] Available at: https://bit.ly/3TwPFM9

21 POSOCO, 2022. ***Scheduling Reports.*** [Online] Available at: https://bit.ly/3CNYRFJ

22 Central Electricity Regulatory Commission, 2022. ***Monthly Report on Short-term transactions of Electricity,*** New Delhi: CERC. Available at: https://bit.ly/3TCfeuZz

23 Business Insurance , 2014. ***Cyclone Hudhud caused $650M of insured losses in India.*** [Online] Available at: https://bit.ly/3ei2mKE

24 G Naga Sridhar, 2021. ***Nearly 90% hudhud cyclone claims of Rs. 2700 Cr settled: IRDA member.*** [Online] Available at: https://bit.ly/3RvPyi5

25 https://bit.ly/3clWiu3

26 S.K. Soonee, S. N. N. H. K. R. G. Y., 2015. Impact of Very Severe Cyclone 'HudHud' on Power System Operation. IEEE. Available at: https://bit.ly/3x9BMdh

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