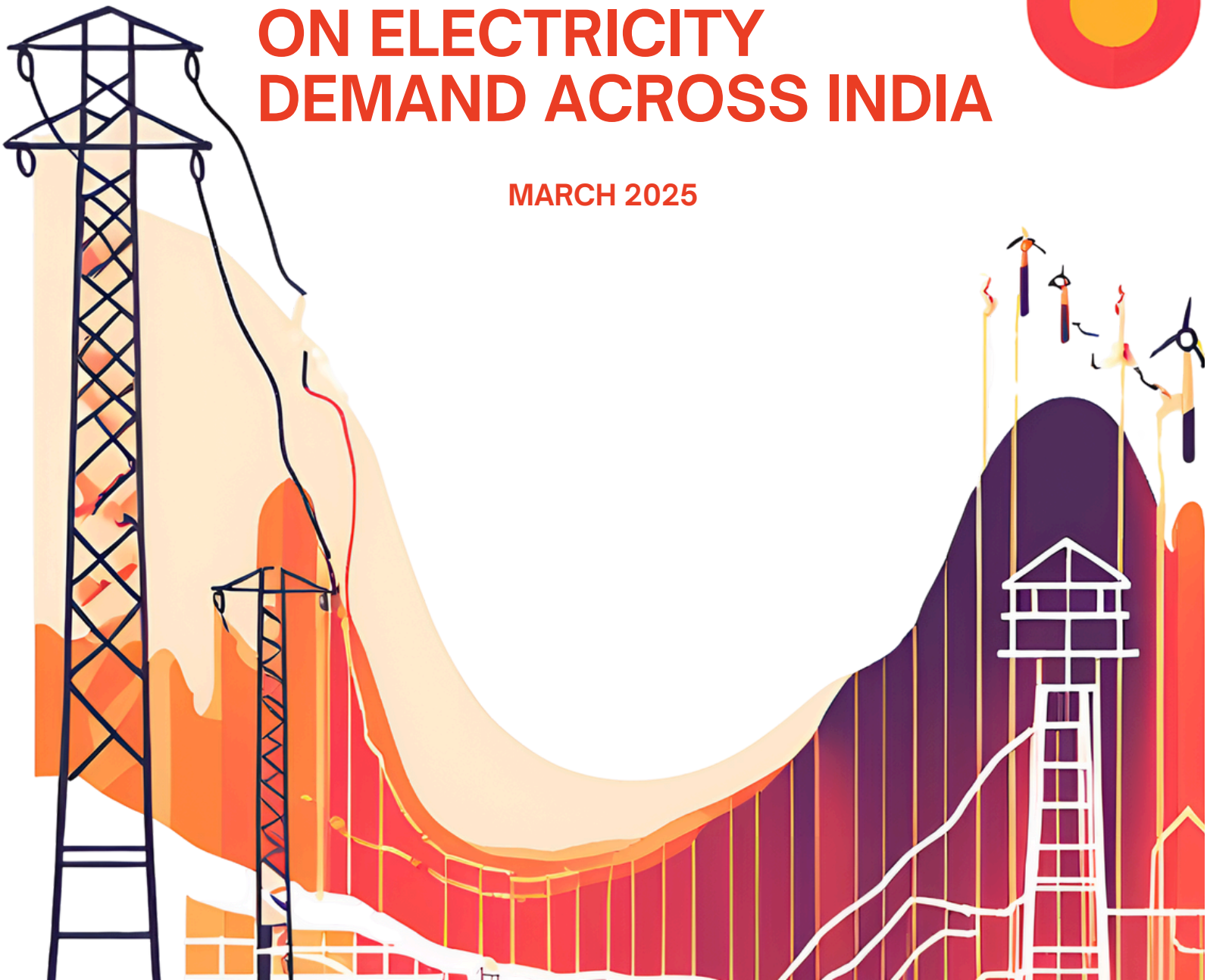
CLIMATE TRENDS

IMPACT OF INCREASING TEMPERATURES ON ELECTRICITY DEMAND ACROSS INDIA

MARCH 2025



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Contents

Key Findings

Aspects	Key Findings (2023)
Temperature Trends	The average maximum temperature across all States & UTs reached **44°C** in the summer months. However, in some places the maximum temperatures breached 50°C across the country.
	73 heatwaves (≥37°C) and **50** heatwaves (≥40°C) recorded across the country.
	The average temperature increase during summer (April-June) was **22%**.
	Central and eastern regions saw the highest summer temperature increases, with peaks of **24%**.
Electricity Demand	Average electricity demand increased by **41%** during the summer months across India.
	Peak summer demand reached **220 GW** across India. The annual average demand is **181 GW**, while the summer average demand rises to **185 GW**.
	State-level increases in electricity demand during summer months ranged between **16%** to **110%**.
Electricity Generation	Fossil fuel-based electricity generation rose by **2,853 MU (3%)**, contributing additional **2 million tons of CO_2 emissions** in 2023.
	Renewable energy-based electricity generation increased by **1,351 MU (4%).**
	On an annual basis, fossil fuels contributed **76%** of total electricity generation; renewables accounted for **21%**.
Urban-Rural Division	Urban areas experienced higher demand growth due to reliable electricity access.
	Rural demand remained constrained by limited infrastructure and availability.
Policy Recommendations	Promote energy-efficient cooling technologies and building designs.
	Expand renewable energy adoption and invest in energy storage solutions.
	Modernize grids for flexibility and resilience.
	Ensure equitable energy access for rural and urban areas across India.
	Accelerate efforts to meet summer peak demand from clean and renewable energy sources

1. Introduction

India's electricity demand has grown significantly over recent years due to urbanization, economic growth, and industrial activity. In addition, peak demand for electricity has been increasing rapidly due to the growing reliance on air conditioning to meet cooling needs during summer months and beyond. In the summer of 2023, this trend became especially apparent as India faced an exceptionally hot season with frequent heatwaves. Rising temperatures drive higher electricity demand, especially for cooling, and this brief note presents the impacts of temperature increases on electricity demand across the states of the country.

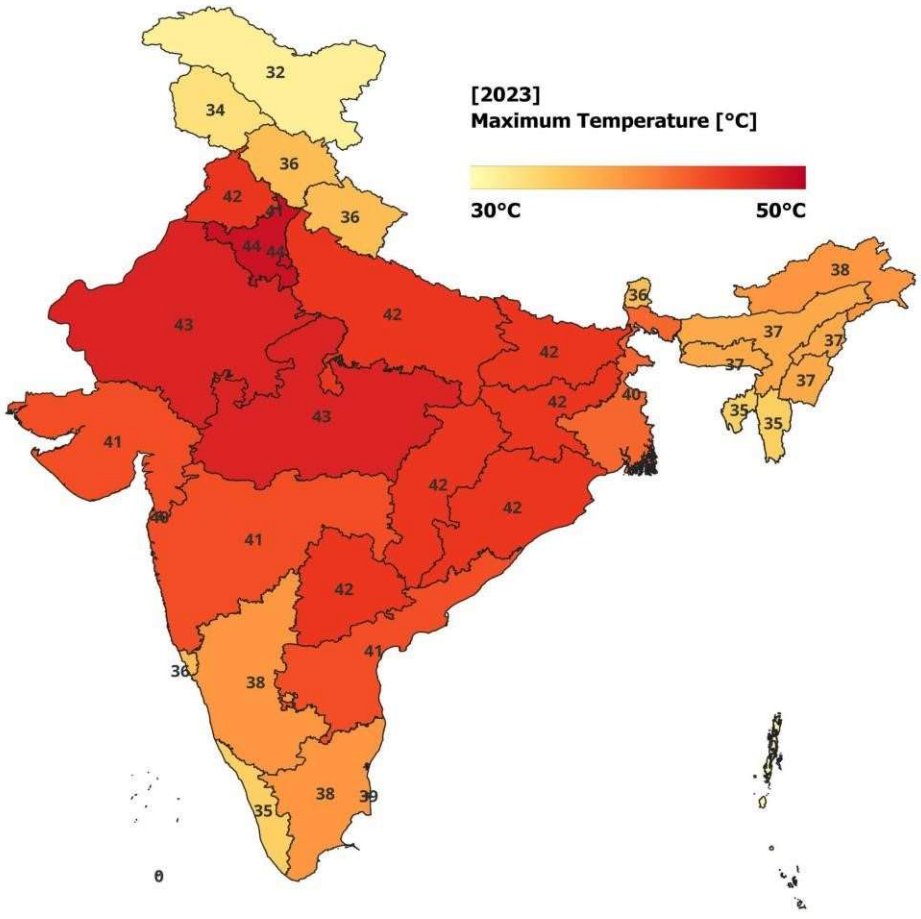

Figure 1: *Maximum temperatures across states and union territories*
Source: IMD

India's energy landscape is increasingly being influenced by rising temperatures, driven by the effects of global climate change. Electricity for cooling improves health, and quality of life and is an important mode of adapting to extreme weather conditions and climate change [1].

Heatwaves and prolonged periods of high temperatures have led to a surge in the use of cooling appliances, such as air conditioners, which are the primary drivers of peak electricity demand during the summer months. The requirement for electricity in India has been consistently increasing, driven by fast economic growth, urban development, and the rising use of energy-consuming devices. In 2023-24, the country's electricity demand surged by 7.8%, reaching 1,622 billion units (BU). This research examines the increase in temperature and corresponding effects on electricity demand, particularly during the summer months of April to June in 2023, across India's states and union territories.

2. Methodology

This research employed a systematic and data-driven approach to examine the relationship between increasing temperatures and electricity demand across India. Each step was designed to ensure a comprehensive understanding of the dynamics between temperature variations, electricity demand, and electricity generation in 2023.

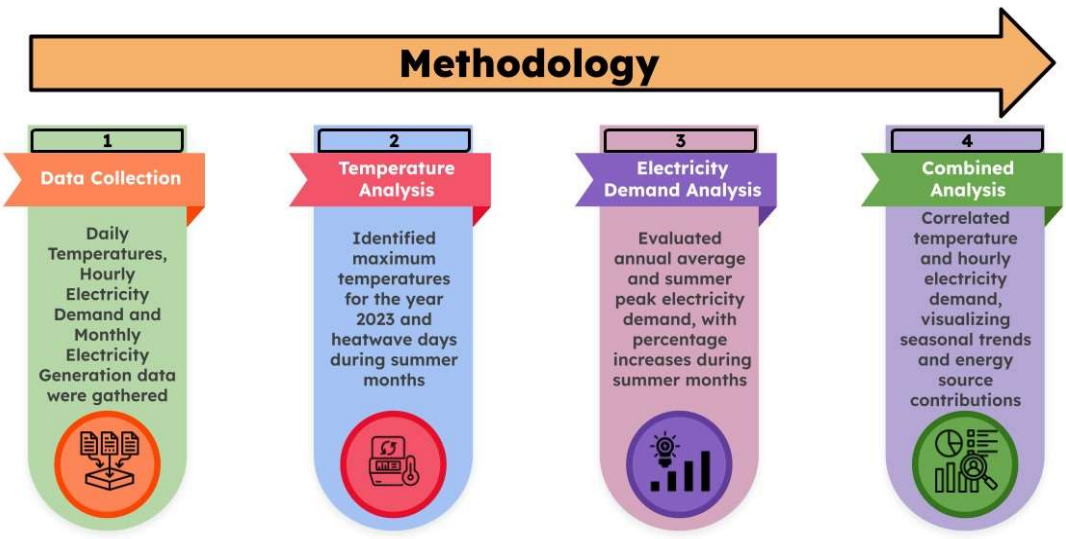

Figure 2: *Schematic diagram of adopted methodology for analysis*

Our approach to applying this methodology is as follows:

- **Temperature Trends**

To analyze the impact of rising temperatures, we examined temperature data from all states and Union Territories (UTs) across India. The average temperatures for states and union territories were used in this analysis. As a result, maximum temperatures in some regions of the country may exceed the average temperatures considered here.

The following approaches were used:

- **Maximum Temperature Calculation:** The highest recorded temperature across all states and UTs was identified to determine peak summer temperatures.
- **Heatwave Estimation:** Two criteria were used to assess the frequency of heatwaves:
  i. The number of days with temperatures exceeding **37°C** during summer months (April-June).
  ii. The number of days with temperatures exceeding **40°C** in the same period.
- **Average Temperature Increase:** The overall temperature rise during summer months was calculated as the average of temperature increases across all states and UTs.
- **State-wise Temperature Increase Calculation:** The increase in temperature for each state was derived using the formula:

$$\textit{Increase in Temperature}\ [\%] = \frac{\textit{Max}_{\cdot(Avg.)} - \textit{Avg}_{\cdot(Avg.)}}{\textit{Avg}_{\cdot(Avg.)}}$$

This calculation was applied for the period of April to June to determine the relative temperature increase.

- **Electricity Demand**

To understand the correlation between temperature rise and electricity demand, the following parameters were analyzed:

- **Increase in Electricity Demand:** The demand surge in each state was calculated using:

$$\textit{Increase in Electricity Demand}\ [\%] = \frac{\textit{Daily Average Demand}_{\cdot(Avg.)} - \textit{Monthly Peak Demand}_{\cdot(Avg.)}}{\textit{Average of Daily Average Demand}_{\cdot(Avg.)}}$$

This calculation was applied from April to June.

- **National Average Electricity Demand:** The countrywide electricity demand increase was estimated as the average of demand surges across all states and UTs.

- **Electricity Generation**

To assess the impact of rising demand on electricity generation, we calculated:

- **Increase in Electricity Generation:**

$$Increase\ in\ Electricity\ Gen. = Average\ Electricity\ Gen.\ (April - June) - Annual\ Average\ Electricity\ Gen$$

This helped quantify the additional electricity required to meet summer demand compared to the yearly average.

3. Temperature Trends and Heatwaves across India

The World Bank projects that India's mean summer temperature will increase by 5 degrees Celsius by the end of the 21st Century under the RCP 8.5 emission scenario [2]. India's climate is diverse, ranging from tropical in the south to temperate and alpine in the north. Over the past few decades, India has experienced a significant rise in average temperatures. According to the India Meteorological Department (IMD), the annual mean temperature has been increasing at a rate of approximately 0.6°C per century [3].

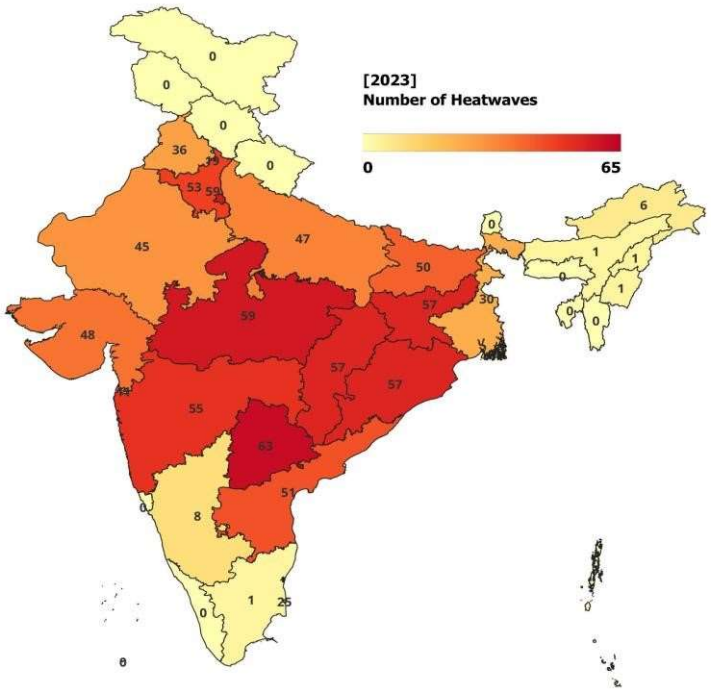

Figure 3: *Number of heatwaves across states and union territories*
Source: IMD

- ***The increase in maximum temperatures ranges from about 17% to 36% across the states in 2023.***
- ***The central and eastern states that witnessed the most heat waves indicate an increase of about 20% to 24% in 2023.***
- ***India recorded 73 heatwaves (max temp ≥ 37°C) and 50 heatwaves (max temp ≥ 40°C) from April to June 2023.***

The frequency and intensity of heatwaves have also risen, affecting both urban and rural areas. Heatwaves will persist in India, and those lacking cooling options will suffer the most. Electricity-driven access to cooling boosts demand, necessitating various measures to maintain that demand at a manageable level. In addition to the rapid acceleration of solar generation and expansion of inter-regional transmission capacity, there is a need for widespread adoption of the Energy Conservation Building Codes to reduce the need for cooling and make it more efficient when used [4].

4. Electricity Demand and Temperature Correlation

Electricity consumption in the form of cooling demand provides thermal comfort to people that can reduce heat-induced mortality at a large scale [5]. As temperatures increased, there was a significant rise in electricity demand, reaching its highest point during the hottest summer months. Data indicates a sharp increase in demand as temperatures surpass a comfort level of approximately 24°C, resembling a hockey stick curve, largely due to the use of cooling appliances. This pattern is shown in the temperature-demand graphs, where the hourly and daily electricity demand lines demonstrate a direct relationship with temperature (see Annexure).

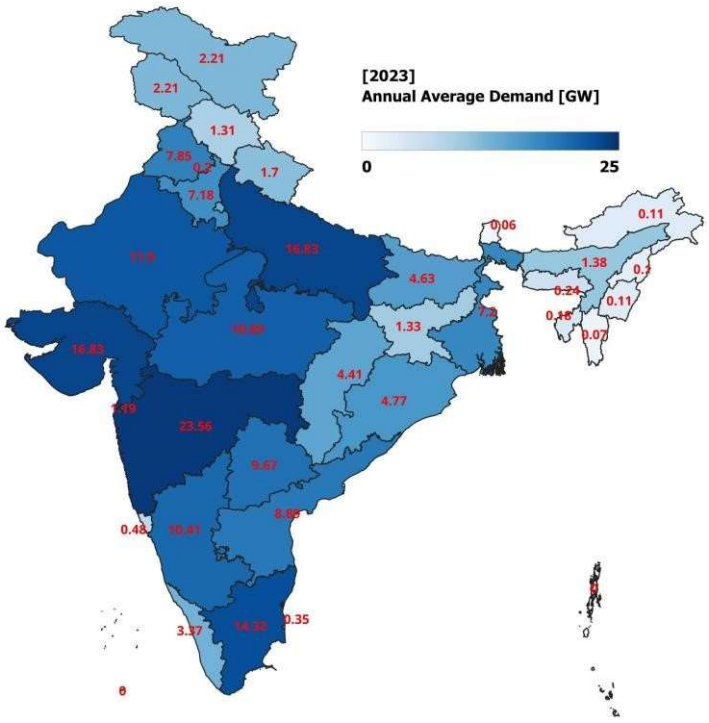

Figure 4: *Annual average electricity demand across states and union territories*
Source: ICED

- ***Annual average electricity demand significantly ranges from about 60 MW to 24 GW across the states in 2023.***
- ***The summer peak electricity demand varies significantly from about 100 MW to 29 GW across the states in 2023.***
- ***India's annual average electricity demand is 181 GW in 2023.***

Hourly Fluctuations: The data shows substantial fluctuations in hourly demand, especially during peak summer hours. Urban areas with reliable power and cooling devices see sharper demand increases compared to rural areas, where electricity supply is less consistent.

Seasonal Demand Variations:

Winter (December-February): Electricity demand is generally low due to mild or cold temperatures but in urban areas electricity demand increases also for heating needs.

Spring (March): Electricity demand increases slightly as there is the beginning of temperature rise. **Summer (April-June):** Electricity peak demand aligns with maximum temperatures, driven heavily by air conditioning and fan usage. Most of the heatwaves occur during these periods across the country. **Rainy Season (July-September):** Lower temperatures decrease the need for cooling due to rainfall across many states and union territories in India.
Autumn (October-November): Cooler temperatures reduce demand for cooling.

Impact on different Sectors:

Residential Sector: Households are the largest consumers of electricity for cooling purposes. The adoption of air conditioners and coolers spikes during the summer months, leading to a substantial rise in electricity consumption.
Commercial Sector: Offices, malls, and commercial establishments see a surge in electricity usage to maintain comfortable indoor environments for employees and customers.
Industrial Sector: Industries, especially those involved in manufacturing and production, require consistent cooling to maintain equipment efficiency and worker safety, further driving up electricity demand.

5. Key Drivers of Electricity Demand with Rising Temperatures

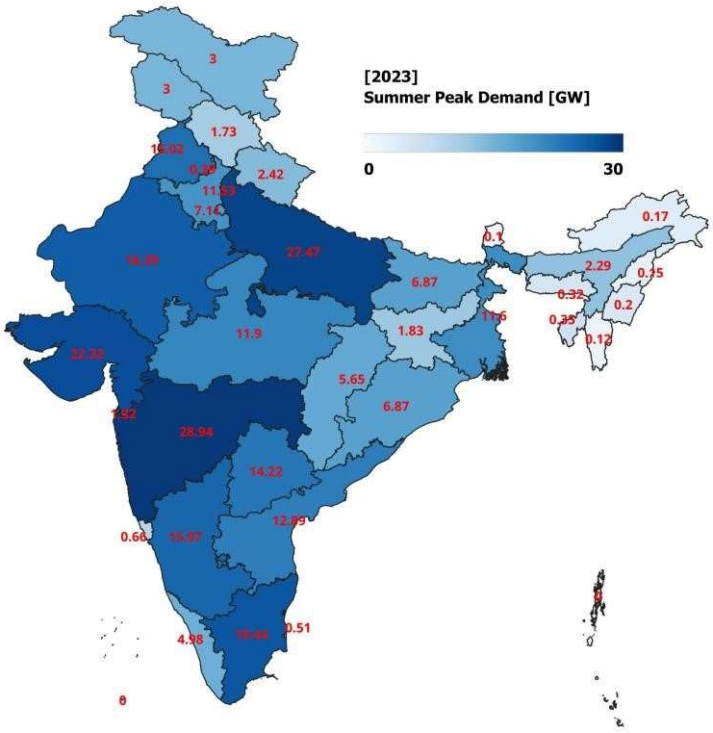

Figure 5: *Summer peak electricity demand across states and union territories*
Source: ICED

- ***India's peak summer electricity demand reached 220 GW during the summer months of 2023.***
- ***The percentage increase in electricity demand varies from about 16% to 110% across the states in the year 2023.***
- ***The average increase in electricity demand across India is approximately 41% during the summer months.***

Cooling Needs: As income grows and with an increase in access to reliable electricity, the demand for air conditioners and electricity for residential cooling is expected to increase. India's residential electricity consumption has increased 50 times since 1971 and is expected to grow a further [6].

The surge in electricity demand aligns with increased cooling needs. Air conditioning has become the primary driver, but other appliances like fans also contribute significantly. The cooling demand's increase is especially pronounced in urbanized regions with more households using air conditioners, fans, and other appliances during heatwaves.

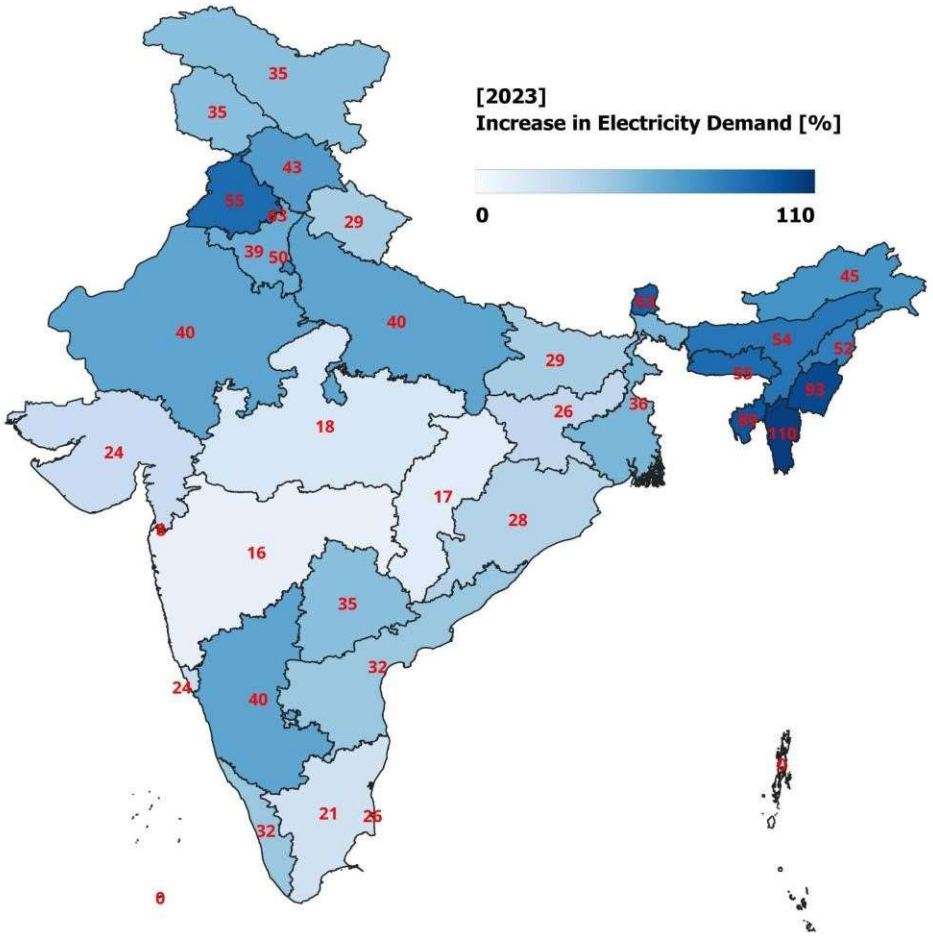

Figure 6: *Increase in electricity demand during summer across states and union territories*
Source: ICED

During the summer months, fossil fuel-based electricity generation increased significantly to meet the surging demand. An additional 2853 million units (MU) were generated from fossil fuels, marking a 3% rise compared to the annual average during the summer months. While fossil fuels played a pivotal role in stabilizing the grid during peak demand. Furthermore, a 3% rise in fossil fuel usage is estimated to have caused an additional 2 million tons of CO_2 emissions[7], worsening climate challenges. Such reliance highlights the urgent need for cleaner and more sustainable alternatives.
The states with the highest percentage increase in electricity demand, compared to their annual average demand are **Mizoram (110%), Manipur (93%), Tripura (89%), Chandigarh (63%) and Sikkim (63%).**

To address the significant rise in CO_2 emissions from fossil fuel-based electricity generation during the summer months, renewable energy emerges as a critical solution. Renewable energy sources, including solar, wind, and hydropower, also saw a notable

increase during the summer months. An additional 1351 MU of electricity was generated from renewables, representing a 4 % rise compared to their annual average generation. This increase highlights the growing role of renewables in addressing peak demand. However, despite their contributions, the intermittency of renewable energy generation particularly from solar and wind technologies continues to challenge their capacity to meet demand without additional energy storage or grid enhancements. Among the states, Rajasthan leads in renewable energy generation, followed by **Gujarat, Karnataka, Himachal Pradesh, and Tamil Nadu.**

Urban-Rural Electricity Consumption Pattern: As urban areas expand due to population growth and economic opportunities, electricity consumption in these areas increases disproportionately compared to rural regions. This growth is strongly linked to enhanced appliance ownership, particularly cooling appliances such as air conditioners and fans, reflecting higher income levels and improved quality of life in urban areas[8].

Urban areas typically exhibit higher levels of economic activity, with tertiary sectors such as information technology, banking, and retail being dominant. These activities not only drive daytime electricity usage but also contribute significantly to nighttime lighting.

While urban areas dominate in terms of electricity consumption growth, rural regions lag behind, as reflected in the subdued night-light intensity. However, rural electrification efforts and the gradual migration of industries into semi-urban areas are beginning to bridge this gap. Initiatives aimed at improving electricity access in rural regions are poised to further increase demand, especially for basic appliances like fans and lighting.

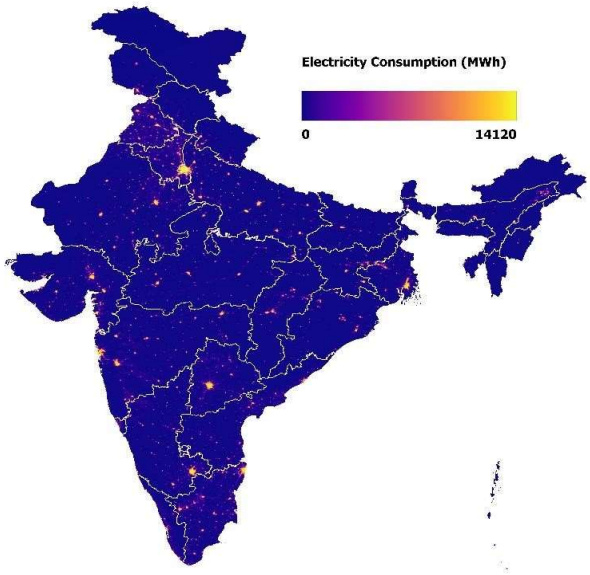

Figure 7: Electricity consumption across states and union territories
Source: Chen,et.al.,(2022)

6. Electricity Generation and Challenges in Meeting Demand

Reliance on Fossil Fuels: The study found that fossil fuels are still the main source for meeting peak electricity demand, especially in the northern and central regions. This reliance can lead to an increase in greenhouse gas emissions, raising environmental concerns.

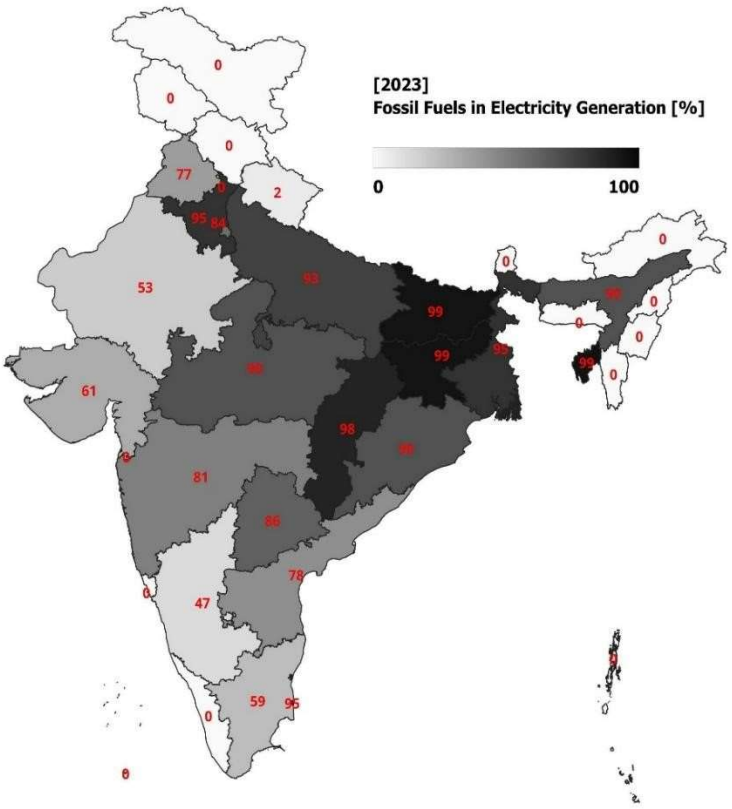

Figure 8: *Electricity generation from fossil fuels across states and union territories*
Source: ICED

- ***Fossil fuels contributed 1294 BU in 2023, accounting for 76% of electricity generation, with state shares ranging from 0 to 99%.***
- ***The change in fossil fuel-based electricity generation ranges from a decrease of 24% in Delhi to an increase of 89% in Uttarakhand.***
- ***Nuclear power generated 48204 MU in 2023, representing 3% of the total***

Renewable Energy Contributions: Southern and western states have been able to partially offset the summer demand spikes with renewable sources, especially solar and wind. However, grid limitations and the intermittency of renewable sources mean that fossil fuel sources continue to play a dominant role in handling peak loads.

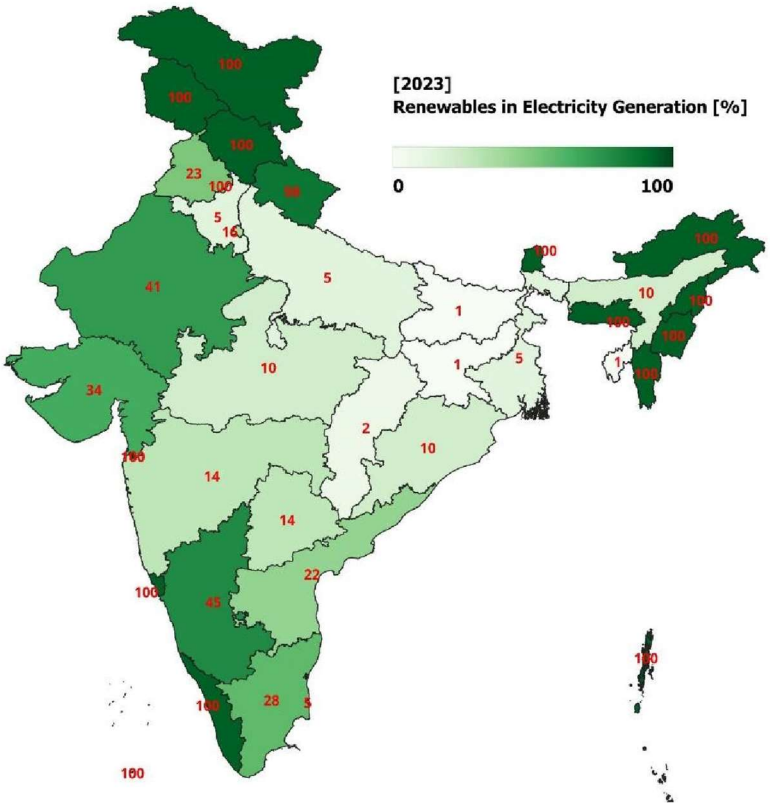

Figure 9: *Electricity generation from renewable sources across states and union territories*
Source: ICED

- ***Renewables generated 362 BU in 2023, representing 21% of total generation, with state shares from 0 to 100%.***
- ***Renewable generation change (April–June) ranged from -73% to +45% across the states in 2023.***

Challenges with Grid Stability: The sharp demand increases during heatwaves can strain the grid, especially in states heavily reliant on fossil fuels, which lack the flexibility of renewables or energy storage solutions. This necessitates a focus on enhancing grid resilience through grid-scale batteries and improved infrastructure.

Figure 10 illustrates the electricity generation in 2023 categorized by different sources, including fossil fuels, renewable energy, and nuclear power. Meanwhile, Figure 11 highlights the seasonal variation in electricity generation during the summer months (April to June). As shown in Figure 11, electricity generation from fossil fuels increased by 3%, and renewables saw a 4% rise to meet the growing summer demand. However, despite the higher electricity demand, nuclear generation declined by 15% during this period.

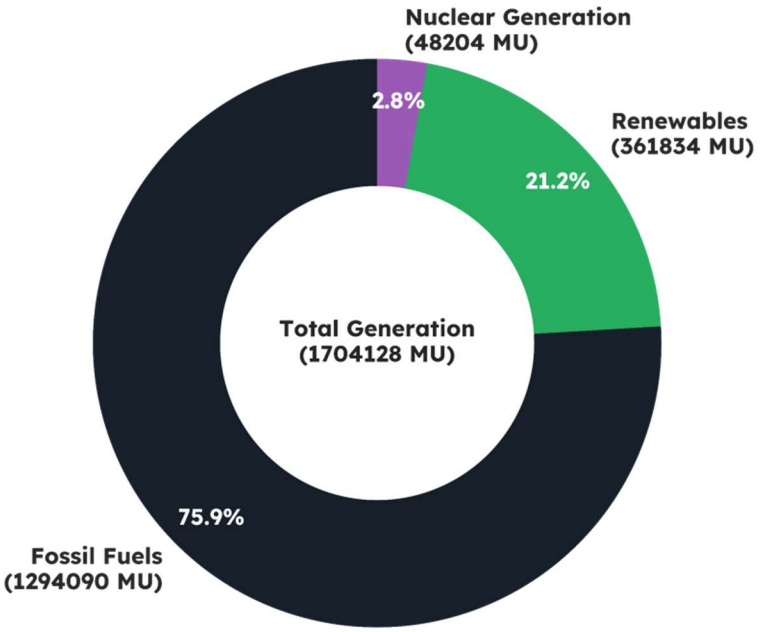

Figure 10: *Annual electricity generation from various sources in India in the year 2023*
Source: ICED

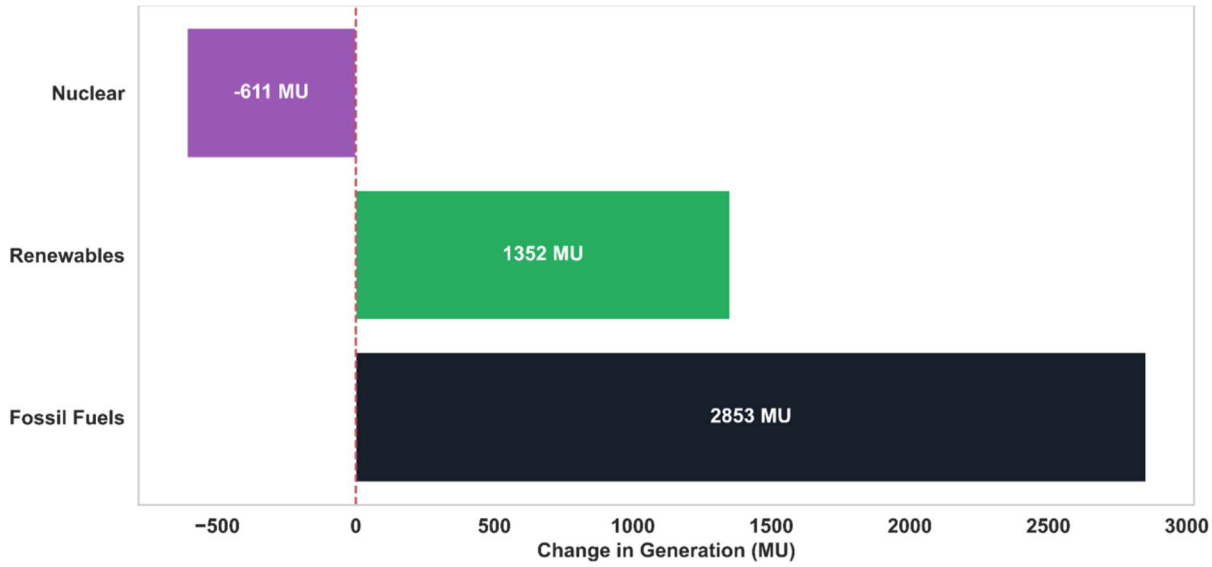

Figure 11: *Net change in electricity generation during summer months (April-June)*
Source: ICED

7. Implications and Limitations of Current Cooling Patterns

Urban vs. Rural Demand Gap: Demand increases are most noticeable in urban centers where air conditioning usage is higher and where demand peaks align with heat waves. Conversely, rural areas with limited electricity access or affordability show a much lower temperature response, indicating a significant gap in adaptive capacity.

Socioeconomic Constraints on Cooling: Lower-income households lack access to cooling, limiting their ability to adapt to rising temperatures due to affordability constraints and inadequate electricity supply. This disparity in adaptive capacity between income groups underscores the need for targeted policies that ensure access to cooling solutions for vulnerable populations.

8. Mitigation Strategies

To address the dual challenges of rising temperatures and electricity demand, several mitigation strategies can be implemented:

Energy Efficiency: Promoting energy-efficient appliances and building designs can significantly reduce electricity consumption. Implementing strict energy efficiency standards for appliances and buildings is crucial.

Renewable Energy: Expanding the use of renewable energy sources, such as solar and wind power, can help meet the increased demand sustainably. Government policies and incentives can play a vital role in accelerating renewable energy adoption.

Demand Response Programs: Implementing demand response programs can help manage peak loads by incentivizing consumers to reduce their electricity usage during high-demand periods. These programs can include time-of-use pricing and direct load control.

Public Awareness: Raising awareness about energy conservation and sustainable practices among the population can lead to more responsible energy usage. Educational campaigns and community engagement initiatives can be effective tools.

9. Conclusion and Way Forward

The impact of increasing temperatures on electricity demand in India presents a complex challenge that requires a multifaceted approach. Rising temperatures are driving higher electricity consumption, especially during the summer months, leading to peak demand spikes. This challenge necessitates sustainable and resilient energy solutions involving technological innovation, policy interventions, and active public participation.

- **Expand Renewable Energy Sources**: Both renewable energy sources and fossil fuels are currently involved in fulfilling the rising electricity demand. However, central and eastern states remain heavily dependent on fossil fuels. Increasing the share of solar, wind, and other renewable energy sources will help to reduce reliance on fossil fuels, particularly in regions with high peak demand. Electricity planners need to account for the increase in power demand due to high temperatures and heatwaves when setting renewable energy capacity targets. Increased power demand resulting from heatwaves and high temperatures should be met with clean and renewable energy sources.

- **Adopt Energy-Efficient Technologies**: Promoting the use of energy-efficient cooling systems, appliances, and building designs can significantly reduce electricity consumption during peak hours.
- **Invest in Storage and Grid Infrastructure**: Advanced energy storage systems and grid modernization are key to integrating renewable energy and ensuring grid reliability during peak demand hours.
- **Implement Demand Management Strategies**: Policies such as time-of-use tariffs, demand response programs, and public awareness campaigns can help manage electricity consumption during peak hours.
- **Strengthen Urban and Rural Energy Access**: The rise in demand is predominantly an urban phenomenon, as rural areas face limited access to reliable electricity, restricting the adoption of cooling technologies. Bridging the urban-rural division through improved electricity infrastructure and access can enhance cooling options in rural areas, promoting equity in energy consumption.
- **Enhance Data and Research**: Conducting detailed research with higher geospatial and temporal resolutions will provide better insights into regional demand patterns and enable policymakers to develop targeted infrastructure advancements and implement more effective energy strategies.

By integrating these strategies, India can address the dual challenges of rising electricity demand and climate change. This approach will ensure a reliable and sustainable energy supply while advancing the country's broader climate goals.

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