



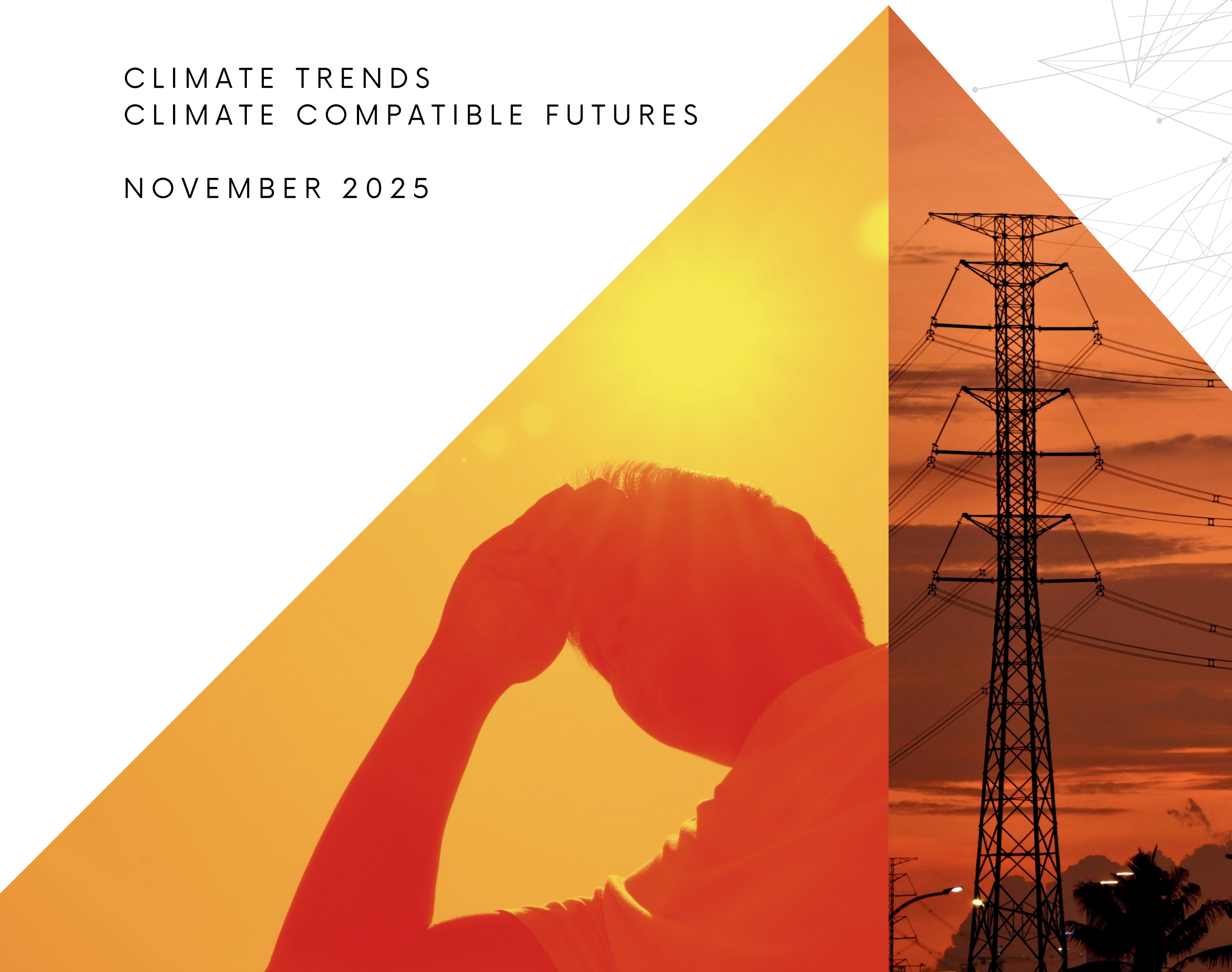
BREAKING THE CYCLE

CAN INDIA ESCAPE THE HEAT-POWER DEMAND TRAP?

A DECADAL ANALYSIS OF
TEMPERATURES AND POWER

CLIMATE TRENDS
CLIMATE COMPATIBLE FUTURES

NOVEMBER 2025



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Executive Summary

India's power sector stands at a critical juncture where the accelerating impacts of climate change, rising electricity demand, and growing emissions are converging towards the need for a comprehensive and well-planned energy transition. This research study further examines the decadal trends across the various states and union territories of the country and brings out key insights on rising temperatures, heatwave occurrences, growing electricity demand, power capacity and generation, an increase in fossil fuels-based emissions, and analyzes heat action plans across the country from an electricity demand perspective.

Over the last decade (2015–2024), the nation's average temperature rose by 0.65°C above the 1991–2020 baseline, marking 2024 as one of the hottest years on record. This persistent warming has directly translated into record-breaking electricity demand, reaching around 250 GW during the summer of 2024, largely due to surging cooling needs across residential, commercial, and industrial sectors.

Despite substantial progress in renewable energy deployment, India's electricity system continues to rely heavily on fossil fuels to meet peak demand during heat-intensive months. Over the decade, installed power capacity increased from 285 GW to 461 GW, a 62% increase - driven primarily by rapid additions in solar (from 5.3 GW to nearly 98 GW) and wind (from 24 GW to 48 GW). However, coal remains the foundational base of India's power system, growing from 170 GW to 219 GW and still accounting for the majority of generation. Fossil-based generation rose from 873 BU to 1,327 BU, sustaining high emissions during summer peaks. In contrast, renewables now represent 46% of installed capacity but contribute only 21% to actual generation, highlighting the need for storage, flexibility, and grid modernization. This imbalance is most visible during the summer months when the demand for cooling peaks as solar generation declines in the evening.

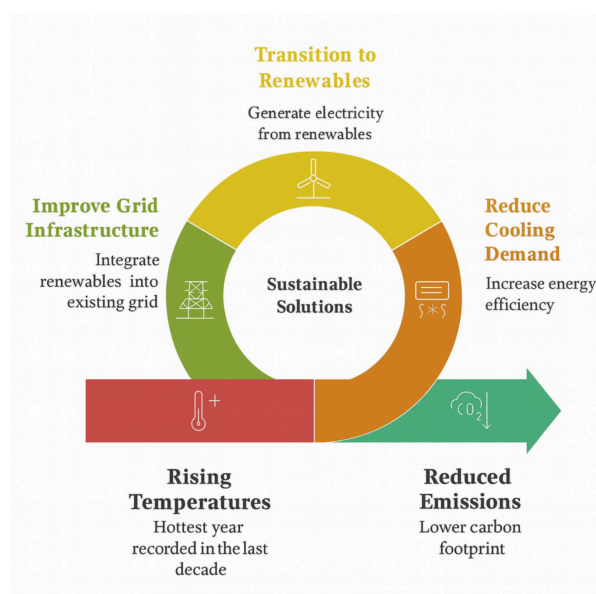


Figure 1: Breaking the climate-energy trap

Heatwaves have also expanded socio-economic vulnerabilities as urban centers suffer from intensified heat stress due to dense infrastructure and rising cooling demand, while rural communities continue to face unreliable electricity and limited access to cooling infrastructure. Failures of transformers, overloads in feeders, and localized outages during heat waves have become more frequent, particularly in rural settlements. These incidents highlight the vulnerability of the

existing grid infrastructure and the disparity in adaptation capabilities among different regions.

A review of Heat Action Plans (HAPs) throughout various states and cities highlights inconsistent progress in incorporating electricity considerations into heat preparedness strategies. Some of the urban and state-level plans feature initiatives like pre-summer maintenance, prioritized power supply for healthcare facilities, and installation of renewable backup systems, while the majority of them concentrate primarily on health and emergency services. A very few HAPs address electricity demand forecasting, load management strategies, or long-term infrastructure development. This lack of attention hampers their ability to effectively mitigate the cascading impacts of extreme heat on both power reliability and public health.

Key Findings

1. **Rising National Temperatures:**
India's annual maximum temperatures increased steadily across most states from 0.1°C to 0.5°C during the last decade, with 2024 emerging as the hottest year on record, averaging +0.65°C above the 1991-2020 baseline and surpassing the 2016 record.
2. **Extreme Heat in the Indo-Gangetic Plain:**
The Indo-Gangetic region witnessed persistent temperature rises, with summer peaks frequently exceeding 45°C and an unprecedented 52.3°C recorded in Mungeshpur (Delhi) in 2024, marking intensified and prolonged heat waves.
3. **High Heatwave Exposure in Central and Eastern States:**
States such as Madhya Pradesh, Jharkhand, and Chhattisgarh faced more than 500 heatwave days during the decade, driving sustained high electricity generation and extended grid stress.
4. **Regional Heat Concentration:**
The northern Indian states, including Delhi, Uttar Pradesh, Punjab, and Haryana, were identified as the most affected regions, exhibiting the sharpest increases in summer temperature surges.
5. **Notable Temperature Escalation in the Himalayan Region and States:**
Traditionally cooler regions such as Uttarakhand (11.2%) and Ladakh (9.1%) registered the highest percentage increases in annual summer temperatures, signaling expanding vulnerability in high-altitude areas.
6. **Expansion and Intensification of Heatwaves:**
The number of days with temperatures $\geq 40^{\circ}\text{C}$ rose sharply in the latter half of the decade, with 14 states recording a $\geq 15\%$ increase in summer heat intensity between 2015 and 2024, highlighting that extreme heat events are becoming both more widespread and more severe across India.

7. **Sharp Surge in Heatwave Days in 2024:**
Several states witnessed a spike in heatwave frequency in 2024, most notably Uttarakhand, where heatwave days jumped from 0 in 2023 to 25 in 2024, reflecting the growing reach of extreme heat into previously moderate regions.
8. **Temperature-Demand Correlation:**
Uttar Pradesh recorded the strongest linkage between temperature and electricity consumption, with peak demand surging from ~14.2 GW (2015) to ~25.5 GW (2024). Similar correlations were observed in Rajasthan and Delhi, where intense pre-monsoon heat consistently drove higher summer demand.
9. **Heat-Driven Electricity Growth:**
India's electricity demand rose by 9% during the peak heatwave months of April–June 2024, as compared to April–June 2023, aligning closely with other reports of an over 10% surge in the same timeframe.
10. **Emissions Analysis:**
Five states- Uttar Pradesh, Chhattisgarh, Madhya Pradesh, Maharashtra, and Gujarat, accounted for the highest fossil-fuel emissions in 2024, with annual emissions reaching 140 MtCO₂, 144 MtCO₂, 128 MtCO₂, 121 MtCO₂, and 63 MtCO₂, respectively, highlighting the concentration of thermal generation in major demand centers.
11. **Limited Renewable Integration in Heat Action Plans:**
Only four states, three cities, and one district currently integrate renewable energy measures such as solar-powered systems or battery backups into their Heat Action Plans (HAPs), exposing critical policy gaps in linking climate adaptation with energy resilience.
12. **Enhancing Rural Resilience:**
Rural India's vulnerability to heat and unreliable power supply highlights the need for solar-powered microgrids and battery-backed community cooling centers to ensure uninterrupted electricity for healthcare, water, and essential services during extreme heat events.
13. **Strengthening Heat Action Plans (HAPs):**
Existing HAPs lack comprehensive integration of energy and electricity planning. Future frameworks must include renewable backup systems, demand forecasting models, and urban cooling strategies to enhance preparedness and energy resilience during heatwaves.

Key Recommendations and Way Forward

To address the growing interlinkages between climate stress, electricity demand, and emissions, the report outlines a set of actionable priorities aimed at building a climate-resilient power system and protecting communities from the dual risks of heat and energy insecurity:

- **Integrate climate projections into energy planning:** Incorporate temperature and heatwave forecasts into energy planning, resource adequacy studies, and grid expansion strategies. Establish carbon-constrained planning aligned with India's net-zero trajectory and include shadow carbon pricing in investment decisions.
- **Develop District-Level Demand and Vulnerability Maps:** Use granular data to identify heat-demand hotspots and guide targeted infrastructure investments in renewable capacity, energy storage, and grid enhancement.
- **Strengthen Rural Energy Access:** Deploy decentralized solar microgrids and community cooling centers to ensure uninterrupted power for health, water, and essential services during heat emergencies.
- **Enhance Urban Heat Preparedness:** Enforce cool roof programs, expand shaded and green spaces, and establish solar-powered cooling shelters to reduce exposure and grid stress in high-density cities.
- **Reform Heat Action Plans (HAPs):** Elevate HAPs from short-term emergency tools to integrated energy-climate resilience frameworks, embedding electricity demand forecasting, renewable energy adoption, and equity-based resource allocation.
- **Accelerate Energy Storage and Demand Flexibility:** Expand large-scale battery storage (100–150 GW by 2030) and incentivize demand response programs for industries and households to shift consumption away from evening peaks.

India's way forward lies in turning the climate-energy challenge into an opportunity for transformation. By embedding climate intelligence into power sector planning, increasing clean and flexible energy generation, and creating inclusive adaptation strategies, India can safeguard its citizens against extreme heat while advancing toward a low-carbon and resilient energy future.

1. Introduction

Climate change has emerged as one of the defining challenges of the 21st century, and India is among the most vulnerable countries due to its geographical, demographic, and socioeconomic characteristics. Human-induced global warming results in both long-lasting alterations to the Earth's system and the occurrence of climate extremes, which affect the intensity and frequency of extreme weather and climate events in every part of the globe¹.

Over the last decade, India's average temperatures from 2015 to 2024 were 0.65°C higher than the 1991-2020 baseline, with 2024 ranking as one of the warmest years on record². Systematic attribution studies of 213 global heatwaves between 2000 and 2023 show that climate change has consistently amplified such events, increasing their intensity and frequency over time. Compared to the pre-industrial baseline (1850-1900), the median increase in global heatwave intensity rose from 1.4°C in 2000-2009 to 2.2°C during 2020-2023¹.

The Climate-Energy Trap

India stands at a critical juncture where climate change impacts and energy system responses have created a potentially catastrophic climate-energy cycle. As global greenhouse gas levels continue to escalate, largely due to fossil fuel combustion for electricity, India is facing increasingly intense heatwaves that lead to a rapidly rising demand for energy-intensive cooling solutions. This surge in demand has been predominantly met through increased fossil fuel-based electricity generation, which releases additional greenhouse gases that contribute to further warming, creating what climate scientists increasingly recognize as a dangerous climate-energy trap.

The phenomenon of rising temperatures has evolved from a seasonal challenge to a persistent climate reality that fundamentally changes the nation's energy landscape. During heat waves, peak demand records are consistently surpassed, India meeting an unprecedented 250 GW of demand in May 2024³, largely driven by cooling needs. These impacts extend far beyond human comfort, directly influencing electricity consumption patterns, grid stability, and energy security.

Global Challenge

The challenge is not limited to India, as the recent attribution research highlighted by NPR⁴ reveals that some of the world's major fossil fuel businesses, particularly those that have historically profited from fossil fuels, are responsible for increasing the frequency of lethal heatwaves and the subsequent demand for energy-intensive cooling. Breaking the cycle of heat-driven demand increase necessitates systemic adjustments that go beyond temporary remedies and address the fundamental links between climate extremes, fossil fuel dependence, and power security.

Why Breaking the Cycle Matters

The urgency of addressing India's temperature-electricity nexus extends far beyond national boundaries. As one of the world's largest economies and most populous nations, India's electricity system choices have global implications for climate change trajectories. The International Energy Agency projects that India will account for the largest increase in energy demand of any country across all of the IEA's scenarios by 2040, with cooling demand representing the fastest-growing segment⁵. Several critical factors highlight the urgency of this analysis:

Climate Security: As global temperatures continue rising, India faces the prospect of increasingly severe heat extremes. India's average temperature has risen by around 0.7°C during 1901-2018. This temperature rise is largely on account of GHG-induced warming, partially offset by forcing due to anthropogenic aerosols and changes in LULC⁵. Understanding current trends provides the foundation for anticipating future challenges and designing appropriate adaptation strategies

Energy Security: A 7% increase in India's electricity demand in 2023 is expected to grow above 6% on average annually until 2026, supported by strong economic activity and expanding ownership of cooling demand⁶. The concentration of these demands during summer months creates seasonal stress on grid infrastructure, potentially compromising supply security during periods when electricity is most critical for public health and economic activity.

Economic Implications: Heat-induced electricity demand affects multiple economic sectors simultaneously. Industrial productivity declines during extreme heat events, agricultural operations require additional energy for irrigation and cooling, and household electricity expenditure increases substantially. The economic costs of power outages during heatwaves disproportionately affect vulnerable populations and small businesses.

Policy Integration: Current sectoral approaches to climate adaptation, energy planning, and urban development often operate in isolation. This analysis demonstrates the need for integrated policy frameworks that simultaneously address climate resilience, energy security, and social equity concerns.

The findings of this study directly inform several critical policy processes, including India's Nationally Determined Contributions (NDC) updates, state electricity regulatory commission planning processes, urban heat island mitigation strategies, and disaster risk reduction frameworks. As India aspires to achieve net-zero emissions by 2070 while maintaining rapid economic growth, understanding and managing the heat-electricity nexus becomes fundamental to sustainable development pathways.

Extreme Temperatures

According to IMD and media reports, the hottest temperature ever recorded in India was 52.9°C in Mungeshpur, Delhi, in 2024. Rajasthan remains the country's most heat-prone region, with Phalodi reaching 51.0°C in 2016 and Churu consistently exceeding 50°C, including 50.8°C in 2019. Trend statistics show repeated peaks above 50°C, with minor falls in 2020 (48.0°C) and 2021 (44.2°C) before rising sharply again in 2024. These

extremes show escalating climate dangers, the urban heat island effect, and increasing vulnerability across northern and northwest India.

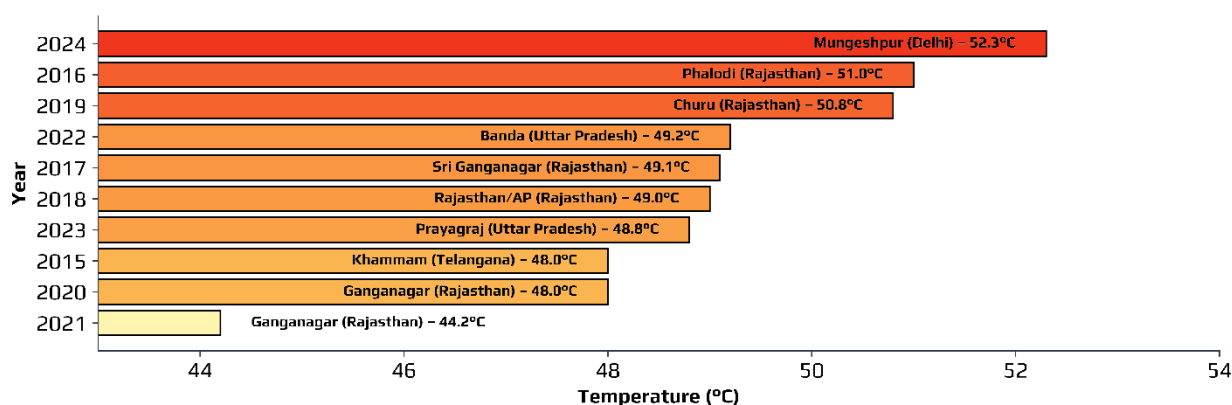


Figure 2: Maximum Temperatures recorded in India at various stations

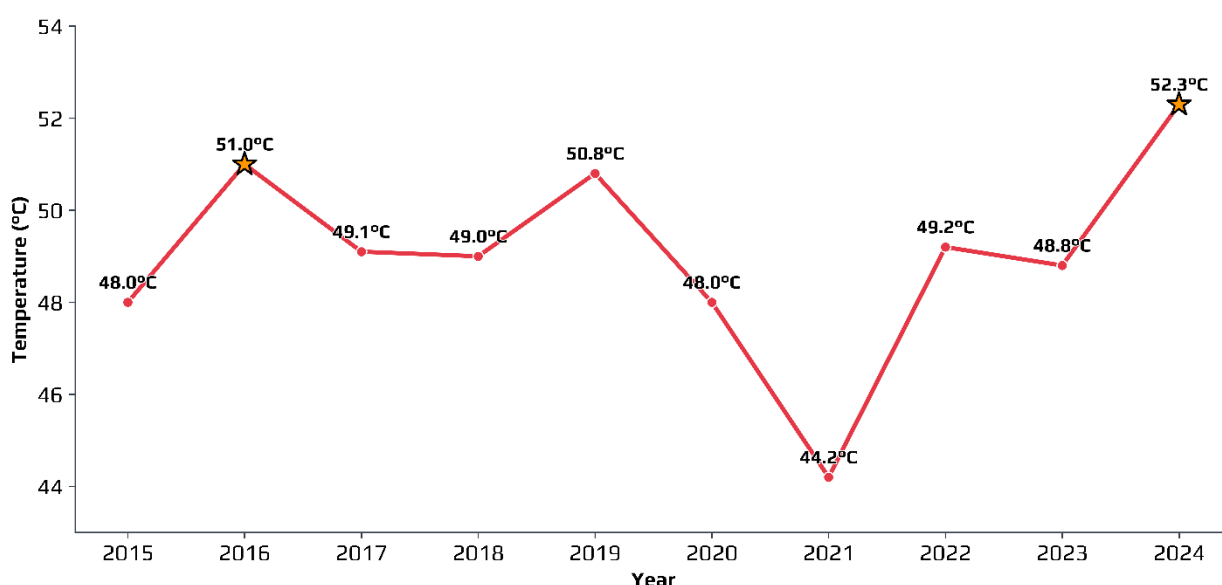


Figure 3: Maximum temperatures recorded over the years

The broader national trend reflects this pattern of increase. Between 2015 and 2024, India's annual average temperature increased from 25.37°C to 25.74°C, making 2024 the warmest year since national records began in 1901. Maximum temperatures followed a similar trend, with 2024 ranking among the greatest in both mean and peak values. Seasonal and monthly breakdowns reinforce the ongoing warming. Maximum temperatures rose by an average of 1.41% across the decade, indicating that India's heat extremes are becoming more severe and systemic.

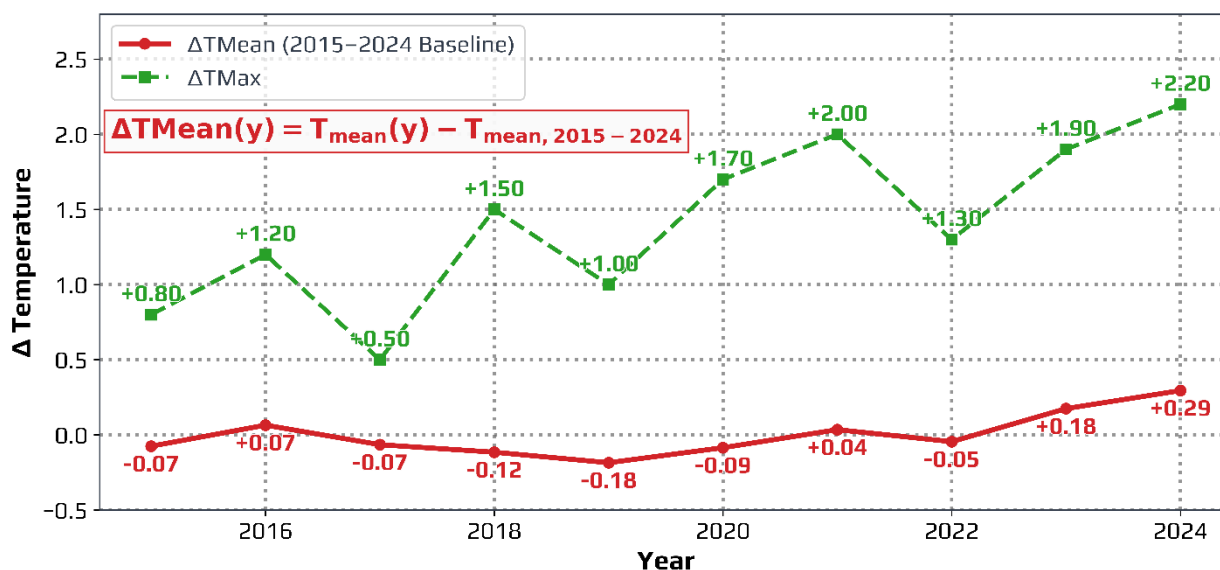


Figure 4: Change in mean and maximum temperatures in India (2015–2024)

Heatwaves and Severe Heatwaves (1951–2016)

Based on the study⁶, between 1951 and 2016, India had a significant increase in the frequency, duration, and distribution of heatwaves, especially from March to July. Since the 1980s, the country has experienced approximately 12 more heatwave incidents per decade compared to previous decades. Regional trends also shifted: West Madhya Pradesh showed the largest increase at 0.80 events per year, while Gangetic West Bengal experienced a reduction of -0.13 events per year. These rising hotspots highlight the increased vulnerability of areas unused to prolonged heat stress.

Severe heatwaves (SHW) have increased in frequency, duration, and spread by ~5 each decade since the 1980s, hitting southern and coastal India. East and West Rajasthan, Gujarat, and West Madhya Pradesh have seen the greatest growth, while SHWs have spread southward into coastal and southern India. The degree of human effect is demonstrated by the substantial statistical link with mortality: 0.62 in Odisha and 0.73 in Andhra Pradesh. Since the 1980s, SHWs have increased by around five incidents every decade, posing an urgent and systemic threat to public health.

Scope

The temporal scope of this analysis encompasses January 2015 to December 2024, providing a complete decadal perspective on evolving trends. This period captures significant policy milestones, including the Paris Agreement implementation, India's National Solar Mission acceleration, and various state-level renewable energy initiatives.

The geographical scope covers all 28 Indian states and 8 Union Territories, with detailed analysis conducted at the state level. The study examines multiple interconnected dimensions:

Climatic Dimensions: Maximum temperature trends during summer and annually, and heatwave frequency analysis based on the India Meteorological Department (IMD) classification systems.

Energy Dimensions: Electricity demand patterns during summer and annually, peak demand characteristics, generation mix patterns, installed electricity capacity additions, and renewable energy additions across states during this decade.

Environmental Dimensions: Emissions from the power sector, fossil fuel dependency aspects, and environmental co-benefits of renewable energy deployment during peak demand periods.

Policy Dimensions: Heat Action Plan analysis across state, district, and city levels, focusing on electricity demand management components and grid resilience measures.

Objectives

This comprehensive analysis aims to systematically examine the interconnected relationships between rising temperatures, heatwave occurrences, electricity demand, generation, and corresponding emissions trends across Indian states during the last decade of 2015-2024.

Primary Objective: To analyze the relationships between rising temperatures, heatwave patterns, electricity demand growth, electricity generation, and resulting emissions that contribute to further warming across Indian states over the last decade.

Secondary Objectives:

- State-wise temperature trends and heatwave patterns, identifying regions where the climate-energy trap is most pronounced
- Analyze electricity demand patterns and their correlation with temperature variables, isolating heat-attributable consumption growth
- Assess the generation mix response to heat-driven demand, quantifying fossil fuel dependence during critical summer months (April – June)
- Estimate emissions implications of heat-induced electricity consumption and their contribution to the climate-energy loop
- Evaluate policy responses through the analyses of Heat Action Plans across the states, districts and cities of the country and further identifying gaps in integrated climate-energy planning
- Develop recommendations for breaking the cycle through coordinated adaptation-mitigation strategies

2. Methodology & Data

This research uses a comprehensive analytical framework to address the relationships between rising temperatures, heatwaves, electricity demand, and emissions in India from 2015 to 2024. The analysis progresses step by step from data collection to estimation and correlation analysis, followed by policy mapping, resulting in a thorough understanding of climate and energy dynamics.

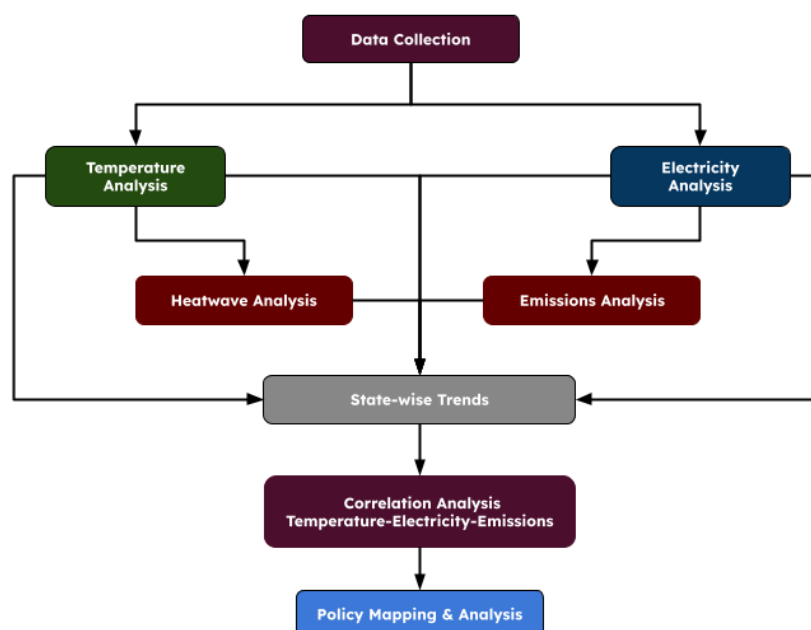


Figure 5: Methodology for decadal analysis of temperatures and electricity demand

Data Collection

Maximum temperature data are obtained from the India Meteorological Department. Electricity capacity and generation data are sourced from the Central Electricity Authority (CEA) and the India Climate and Energy Dashboard (ICED), NITI Aayog. To calculate emissions, fossil fuel use in power generation was transformed into carbon dioxide equivalent emissions using a yearly emission factor.

State-wise Analysis

This section focuses on converting raw data into meaningful indicators of how heat and energy interact at the state level in India. The estimation process not only allows for standardized comparisons across locations, but it also emphasizes the wide range of hazards and difficulties that are arising as India's climate changes.

- **Heatwave Estimation:** Heatwave events were recognized based on a temperature threshold of 37°C, in line with the classification for heatwave conditions set by the

India Meteorological Department (IMD). The analysis assessed the occurrence and severity of such events across states from 2015 to 2024. It is essential to recognize that this estimate relies solely on recorded temperatures, excluding the 'feels like' temperature, which accounts for factors such as humidity, wind, and solar radiation. This difference can greatly influence the perceived effects of heatwaves. Decadal and annual summaries are created, and variances are obtained by finding the maximum monthly peak temperatures for each year (2015-2024) and then calculating the difference between the highest and lowest yearly maxima.

- **Emissions Estimation:** Using fossil fuel-based power generation data and a yearly emission factor, emissions are estimated on an annual and summer-month basis. This enabled a clear comparison of regular annual emissions and peak seasonal contributions during the hottest months.

The state-wise analysis extends across all four domains: Temperature, Heatwaves, Electricity, and Emissions. By disaggregating each dataset to the state level, the study identifies both overlapping stress zones and locations where trends differ. This method identifies not only which states are most vulnerable to growing climatic extremes but also how local energy systems and emission profiles interact with these changes, offering a solid framework for targeted responses.

Correlation Analysis

Temperature, Heatwave, Electricity, and Emissions were all used in a correlation analysis. This step established links between climatic extremes and energy consumption, namely the reinforcing cycle in which rising temperatures drive higher electricity demand, which contributes to increased emissions. These associations were compared across states to identify regional differences in the climate-energy nexus.

Policy Mapping and Analysis

The final stage of the methodology involved mapping existing Heat Action Plans, policies, and initiatives across states. These were evaluated alongside the quantitative findings to identify policy gaps, strengths, and challenges. The combined evidence informs recommendations for targeted interventions to strengthen climate resilience, promote sustainable energy transitions, and safeguard vulnerable populations against escalating heat risks.

3. Results: Analysis & Insights

3.1 Temperature and Heatwave Trends

Heatwaves in India are defined as periods of abnormally high temperatures, most often occurring between March and June, and sometimes stretching into July. These events are particularly intense in the northern and central states, where prolonged heat leads to significant health risks and, in extreme situations, can culminate in fatalities.

The decade from 2015 to 2024 has demonstrated how climate change is no longer a distant risk but an immediate stressor, particularly through rising maximum temperatures and intensifying heatwaves. A heatwave in India is defined as a period of abnormally high temperatures, typically occurring between March and June, and sometimes extending into July, characterized by thresholds set by the India Meteorological Department (IMD). For the plains, heatwaves require maximum temperatures of at least 40°C, and for hilly regions, 30°C, with additional departures from normal needed to classify as moderate or severe. Independently, any maximum above 45°C qualifies as a heatwave⁷.

Our analysis of temperatures from 2015 to 2024 reveals a consistent warming trend in the majority of states. The decade witnessed a steady increase in both average summer maximum temperatures and the number of heatwave days per year. India's annual maximum temperatures rose steadily across most states during the decade, with increases of 0.1°C to 0.5°C. The year 2024 became the hottest on record, with the national average land surface temperature measured at +0.65°C above the 1991-2020 baseline, surpassing the previous record set in 2016⁸.

The increase in temperature is not sporadic or limited; rather, it represents a systematic change, with northern and central states like Rajasthan, Uttar Pradesh, Madhya Pradesh, Delhi, and Haryana being most affected, often recording 60-80 heatwave days annually during peak years such as 2016, 2019, and 2022. Eastern states such as Odisha, Jharkhand, and Bihar experienced multiple April-June periods of 40-43°C, demonstrating the eastward expansion of temperature rise. In coastal and southern states, despite lower absolute temperatures, maximums between 38-41°C often satisfied IMD's heatwave standards, particularly in Andhra Pradesh, Telangana, and Gujarat.

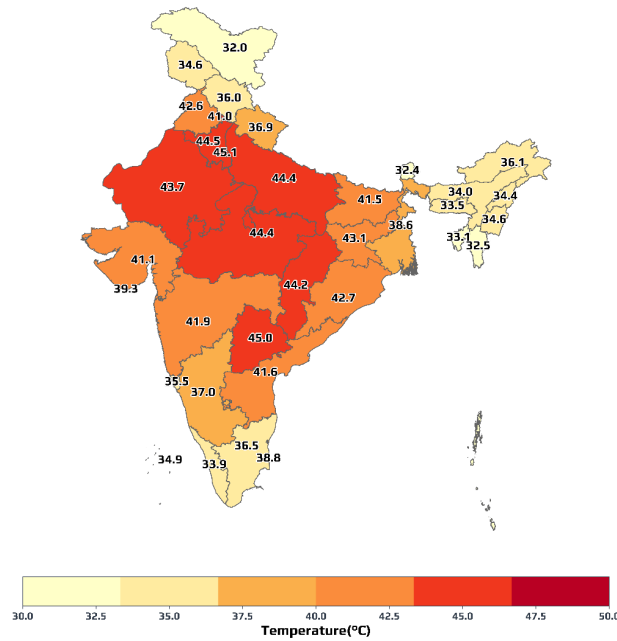


Figure 6: Maximum temperatures during summer in 2015

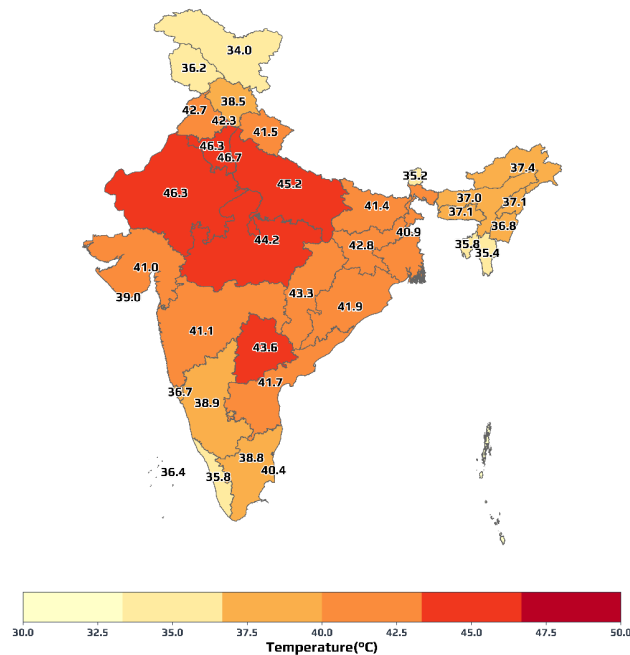


Figure 7: Maximum temperatures during summer in 2024

The densely populated Indo-Gangetic Plain experienced sustained temperature rises throughout the decade, with maximum temperatures frequently exceeding 45°C during summer months and peak temperatures reaching a staggering 52.3°C in Mungeshpur (Delhi) in 2024. This extreme occurred during a prolonged heatwave that triggered an emergency surge in electricity demand, forcing grid operators to implement rotating blackouts precisely when cooling was most critical for human survival. States like

Madhya Pradesh, Jharkhand, and Chhattisgarh experienced more than 500 heatwave days across the decade, necessitating not only temporary spikes in electricity supply but also sustained high generation over extended heat periods.

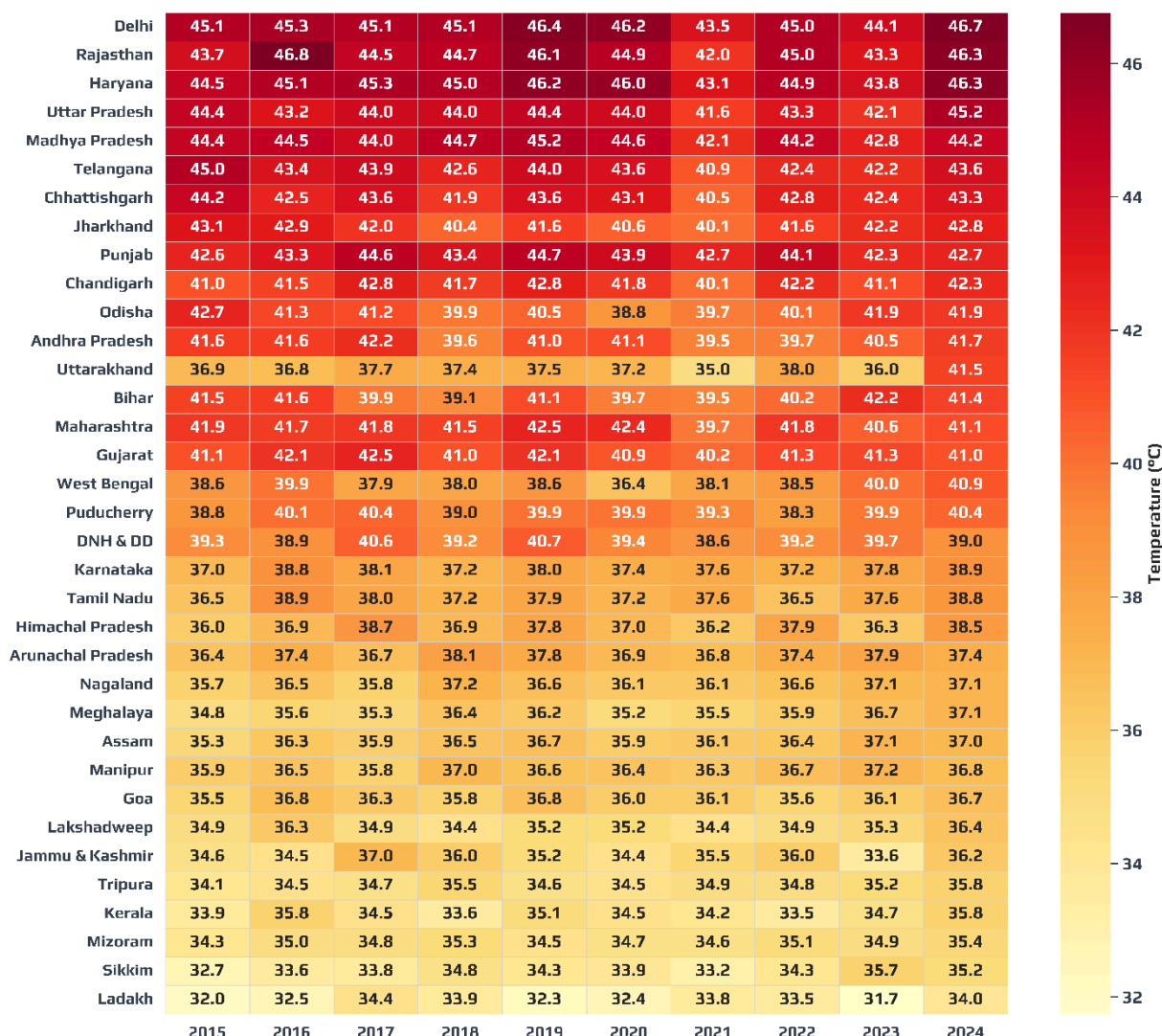


Figure 8: Maximum temperatures across states

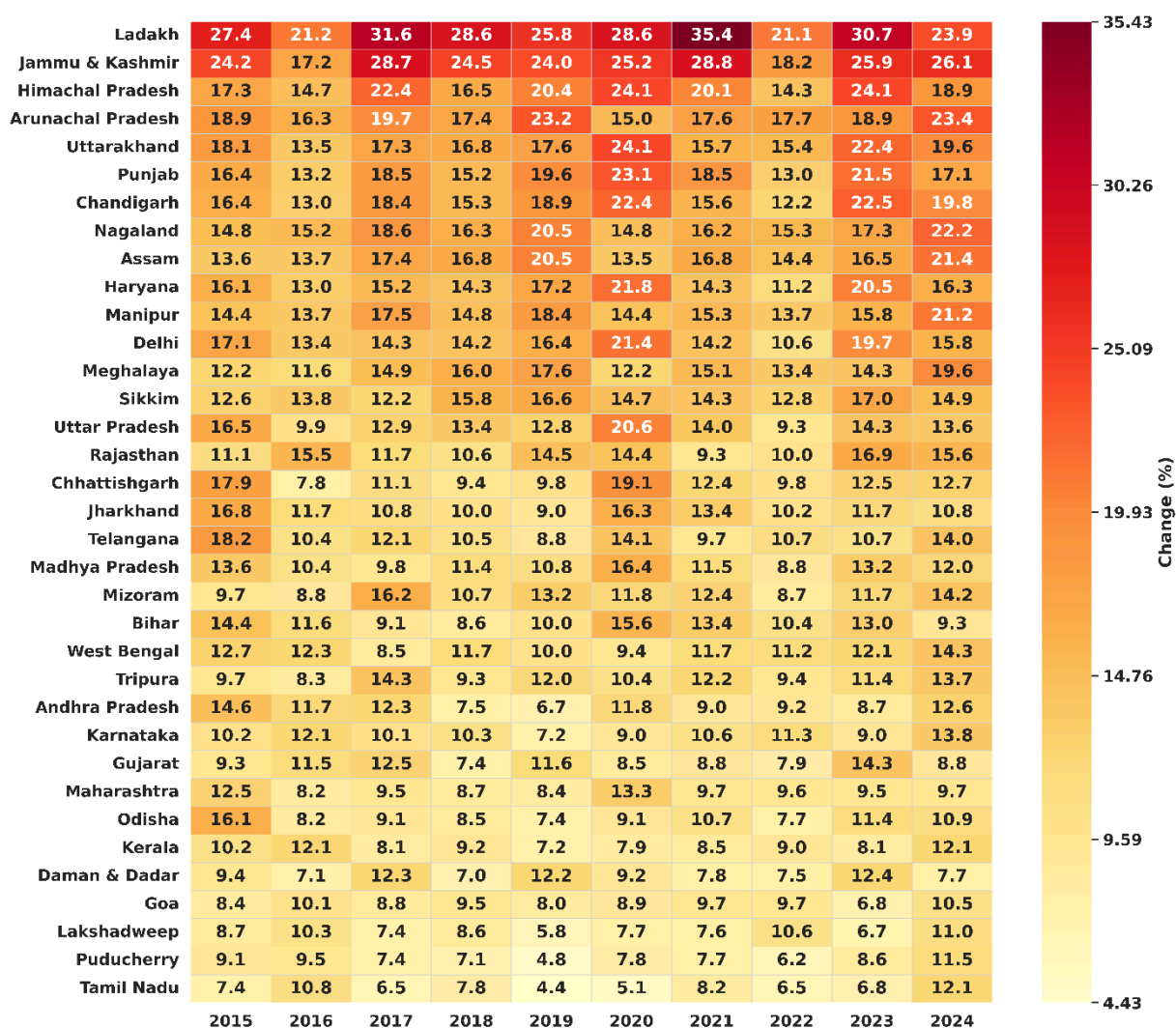


Figure 9: Surge in temperatures during summer

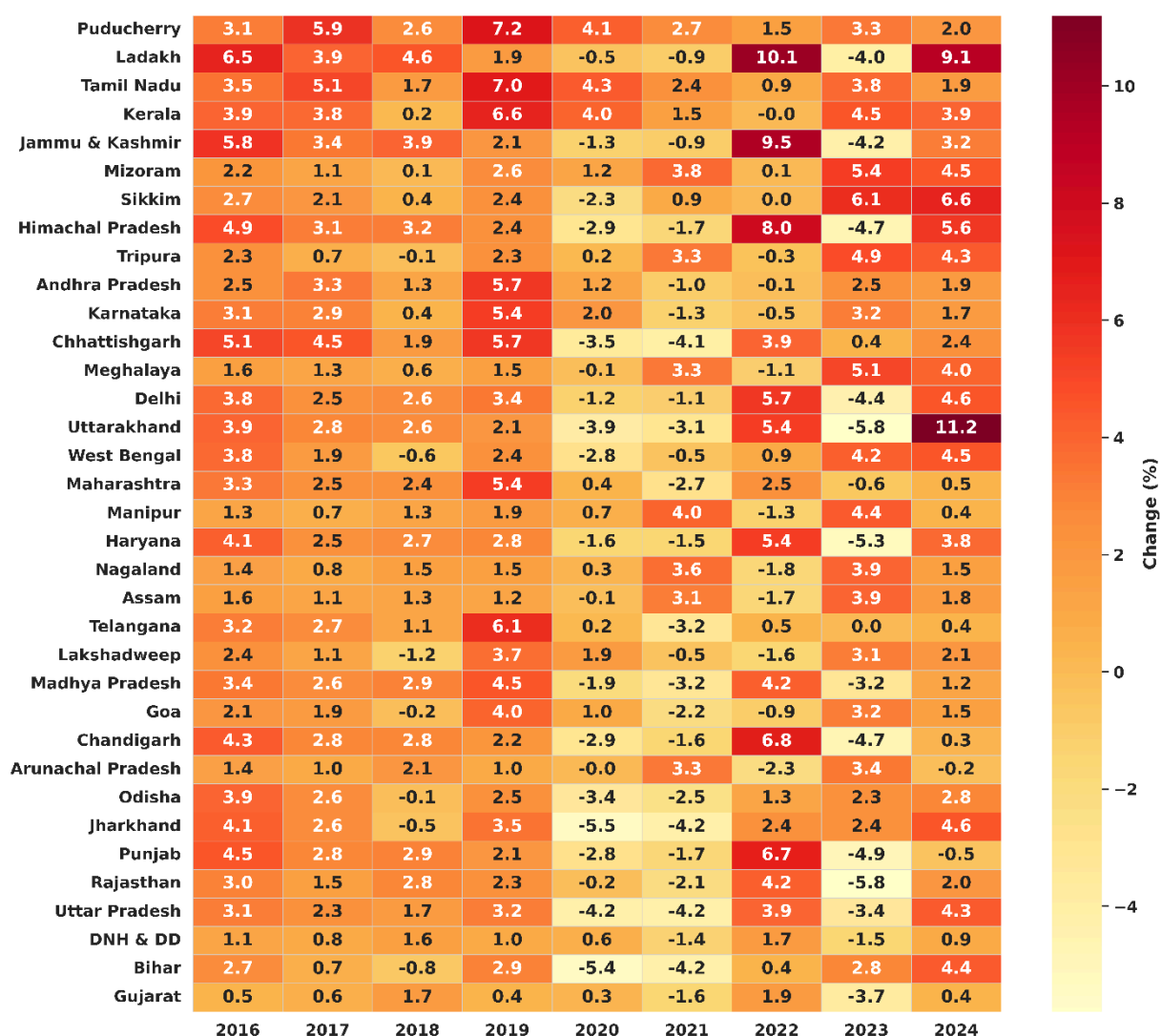


Figure 10: Annual change in temperatures during summer

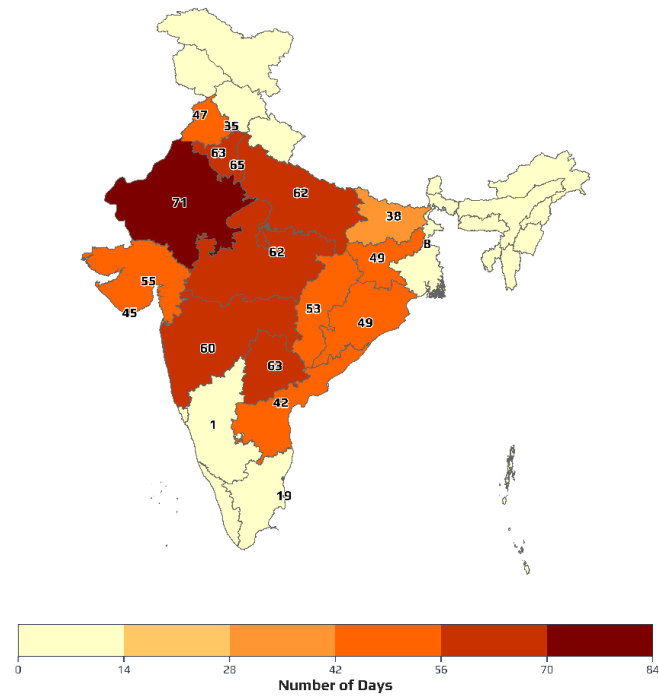


Figure 11: Heatwave days in 2015

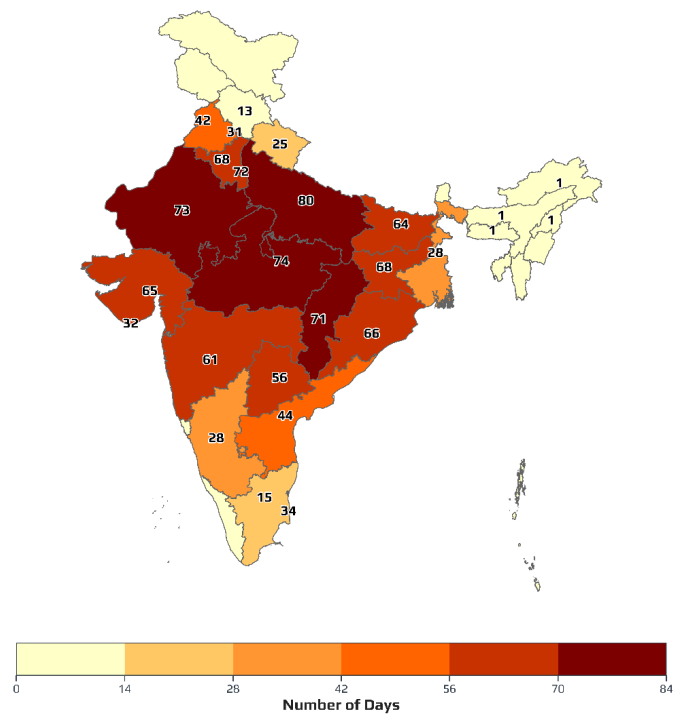


Figure 12: Heatwave days in 2024

Analyzing the temperature rise during the summer months (April-June)

The pre-monsoon period (April-June) exhibits the strongest warming signal over the decade:

- Rajasthan: The median high temperatures in late May increased from approximately 41°C in 2015 to over 43°C in recent years, with a notable number of instances exceeding 45°C, reflecting a seasonal temperature increase of 0.3-0.5°C.
- Uttar Pradesh: Starting in 2019, numerous districts experienced prolonged temperature plateaus between 41- 44°C, particularly severe in the years 2022 and 2024.
- Madhya Pradesh: The occurrence of temperatures hitting 41-44°C during April-June, particularly in 2019, 2022, and 2024, indicates a trend toward higher temperature extremes.
- Telangana and Andhra Pradesh: Inland regions noted an increase in the number of days reaching 40-42°C after 2018, signifying a gradual escalation in temperatures.
- Gujarat and Maharashtra: An increasing number of days with temperatures ranging from 39-41°C suggests a slow yet consistent rise in warming.

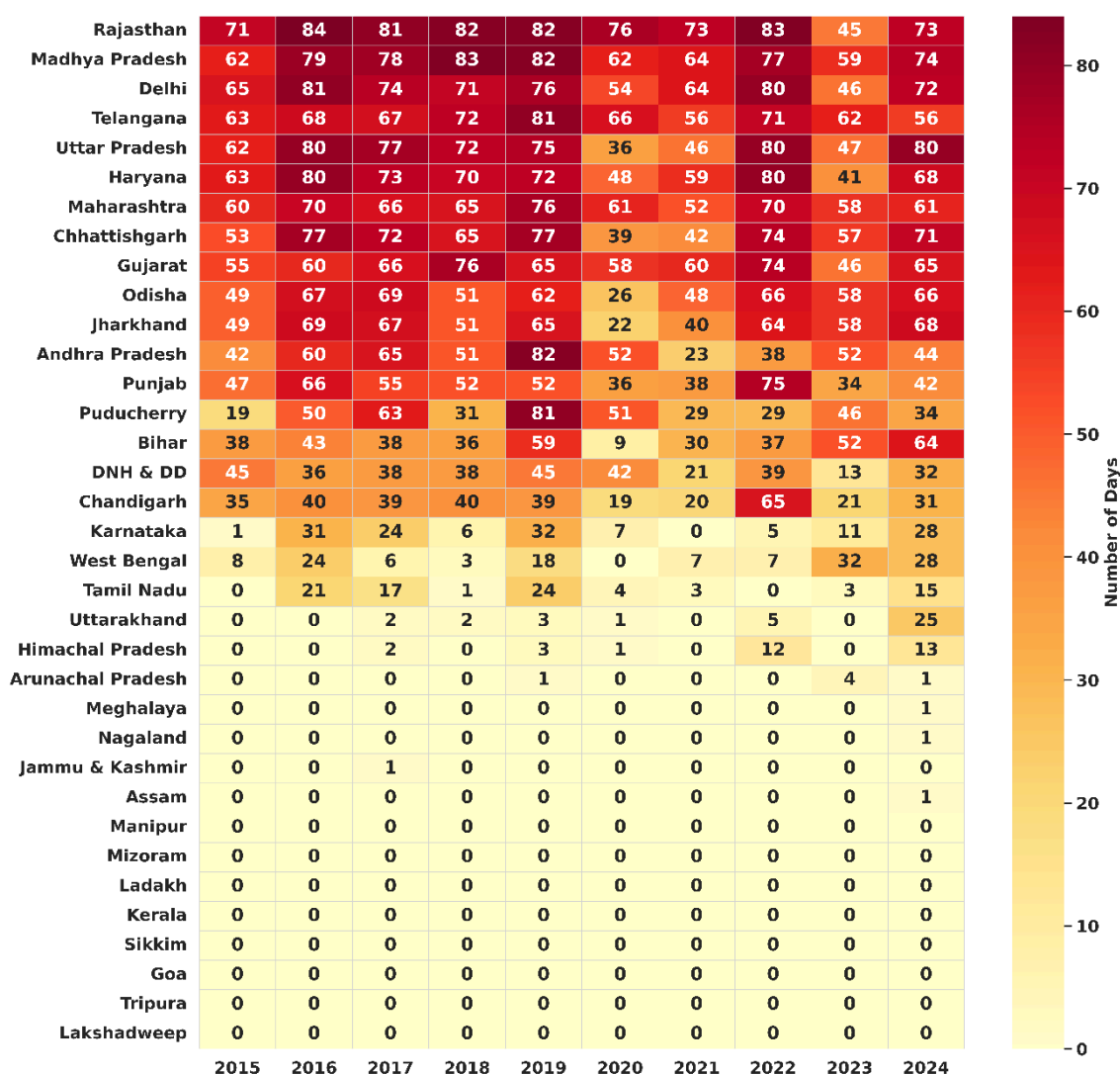


Figure 13: Heatwave days across states

The analysis conducted during the summer months reveals a significant rise in days with temperatures reaching $\geq 40^{\circ}\text{C}$ in the latter part of the decade, with numerous states witnessing an increase of over 15% in summer heat intensity. These findings highlight the growing occurrence of extreme heat events linked to climate change in India. The blend of rising temperatures and more frequent heatwaves requires the immediate integration of IMD alerts with public health preparedness, urban development, and energy management, particularly during the crucial summer season.

3.2 Electricity Demand Trends

Electricity demand growth

Electricity demand has mirrored the climatic intensification as the state-wise annual peaks rose sharply between 2015 and 2024, reflecting both economic growth and temperature rise. By 2024, Maharashtra, Uttar Pradesh, Gujarat, and Tamil Nadu had become the largest demand centers, propelled by their urbanization, industrialization, and rising air-conditioning penetration.

- Maharashtra: Peak demand grew from ~20 GW in 2015 to ~28 GW in 2024, driven by metro expansion, industrialization, urbanization, and cooling needs.
- Uttar Pradesh: A decadal rise in peak demand from ~14 GW in 2015 to 23-25 GW by 2024, driven by population growth, electrification, and an increasing rise in cooling demand in the Indo-Gangetic plains, where summers regularly coincide with IMD heat alerts.
- Gujarat: Climbed the peak demand from ~15 GW in 2015 to ~23 GW by 2024, reflecting both industrial growth and intense summer cooling demand, especially during late summer heatwaves.
- Tamil Nadu: Grew peak demand from ~13-14 GW in 2015 to ~21 GW in 2024, with growth concentrated in residential and commercial cooling loads and industrial demand across southern urban centers.

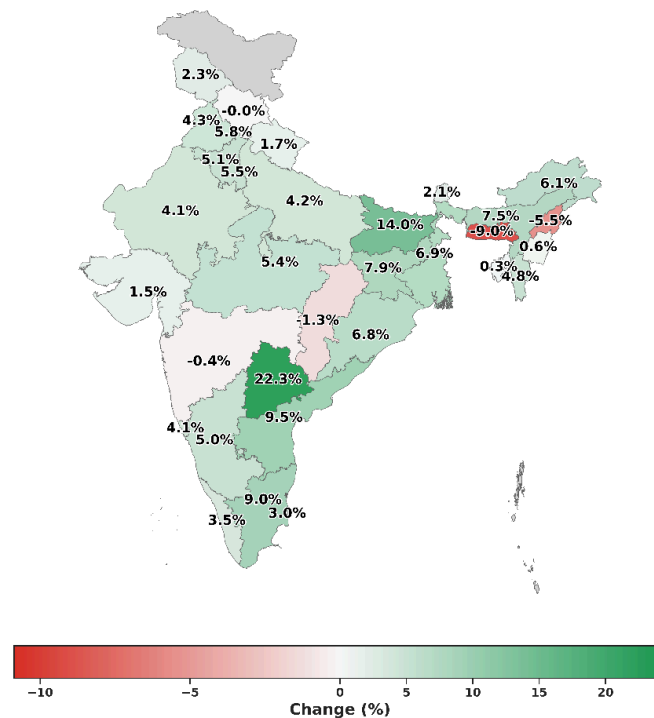


Figure 14: Change in annual peak demand in 2016 compared to 2015

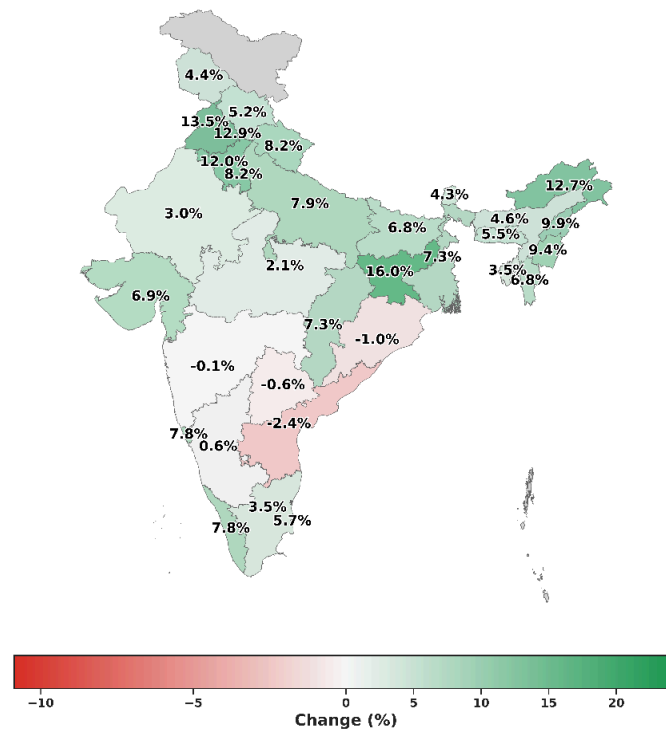


Figure 15: Change in annual peak demand in 2024 as compared to 2023

Our decade-long analysis reveals a clear correlation between rising temperatures and electricity demand across India. The summer months (April-June) consistently emerge as the most electricity-intensive period, with several states experiencing double-digit percentage increases in summer peak demand compared to shoulder months.

States like Rajasthan, Uttar Pradesh, Madhya Pradesh, and Delhi recorded summer peak surges exceeding 10-15% during intense heat years (2019, 2022, 2024). While Gujarat, Maharashtra, Andhra Pradesh, and Telangana showed varied but generally positive summer increments influenced by heat intensity and energy consumption patterns.

Extreme heat events have transformed daily consumption patterns, shifting demand toward afternoons and evenings, with residual heat keeping ACs running well into the night. This effect was most pronounced in northern and central states, but also visible in the south and west.

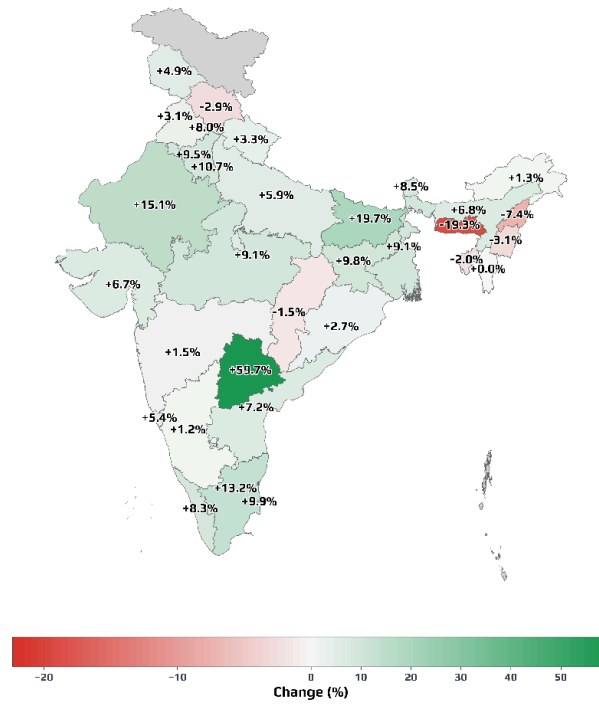


Figure 16: Change in annual summer peak demand in 2016 as compared to 2015

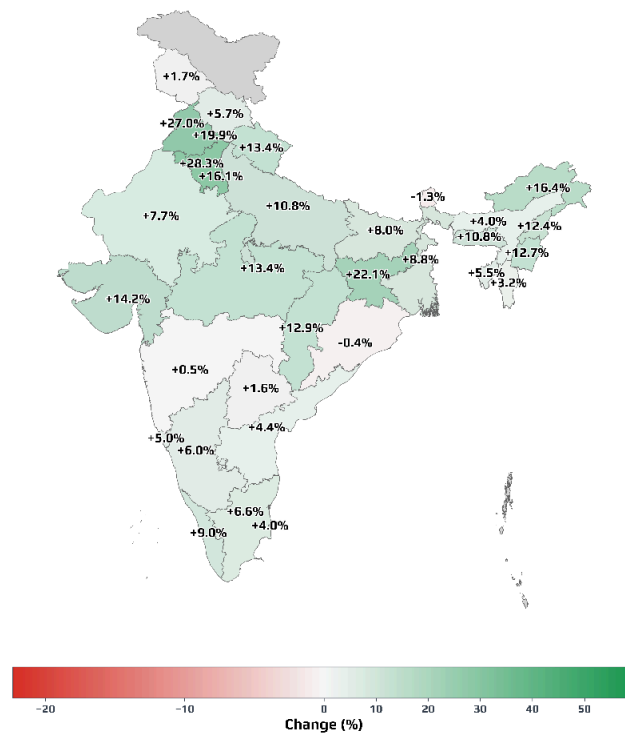


Figure 17: Change in annual summer peak demand in 2024 as compared to 2023

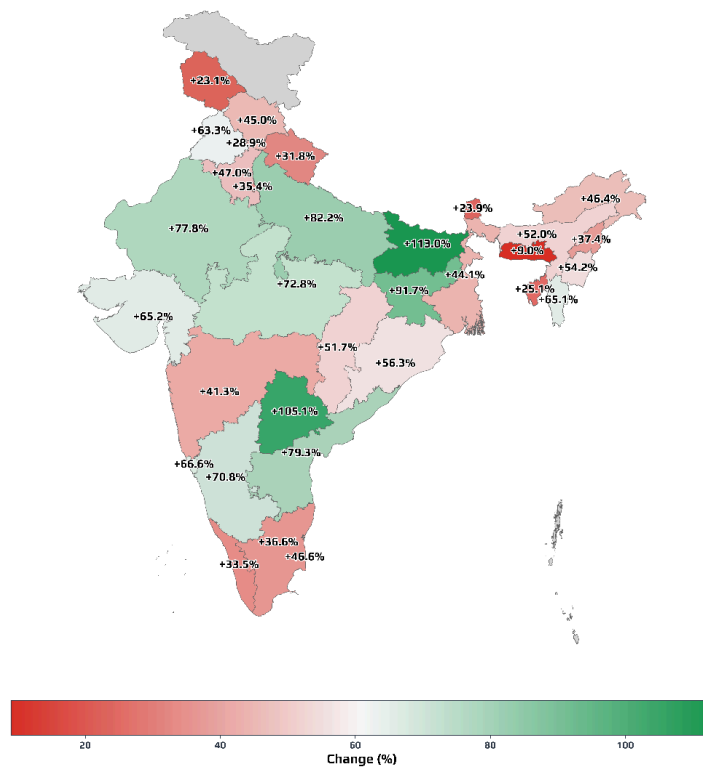


Figure 18: Decadal change in annual peak demand

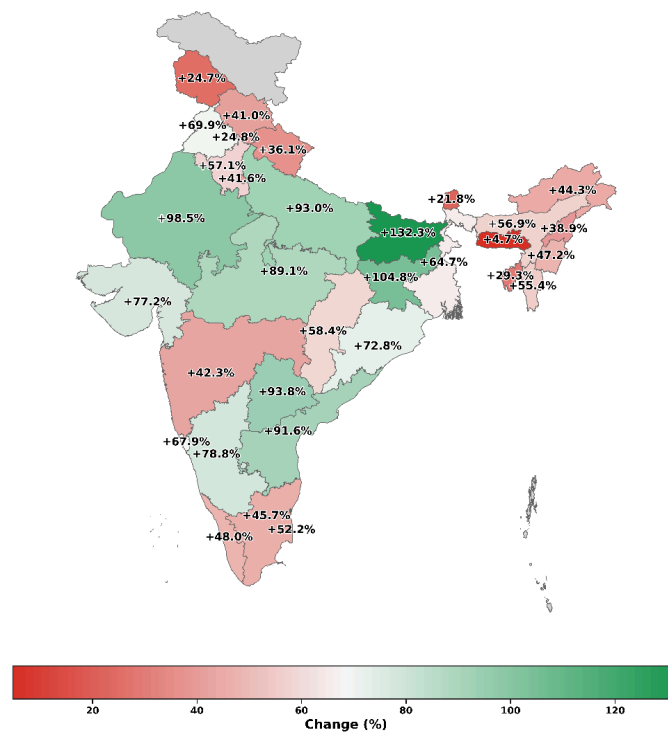


Figure 19: Decadal change in summer peak demand

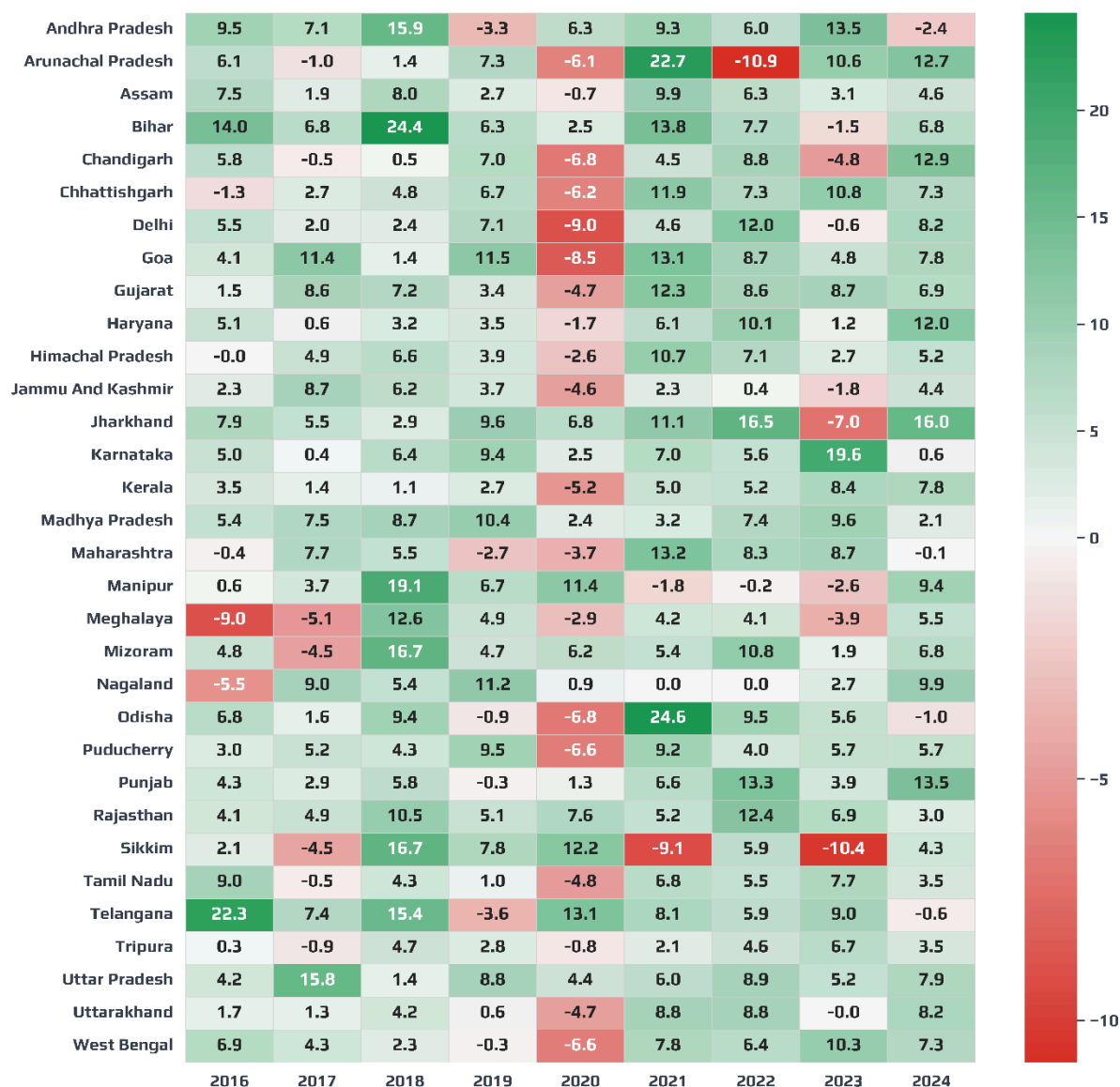


Figure 20: Change in annual peak demand

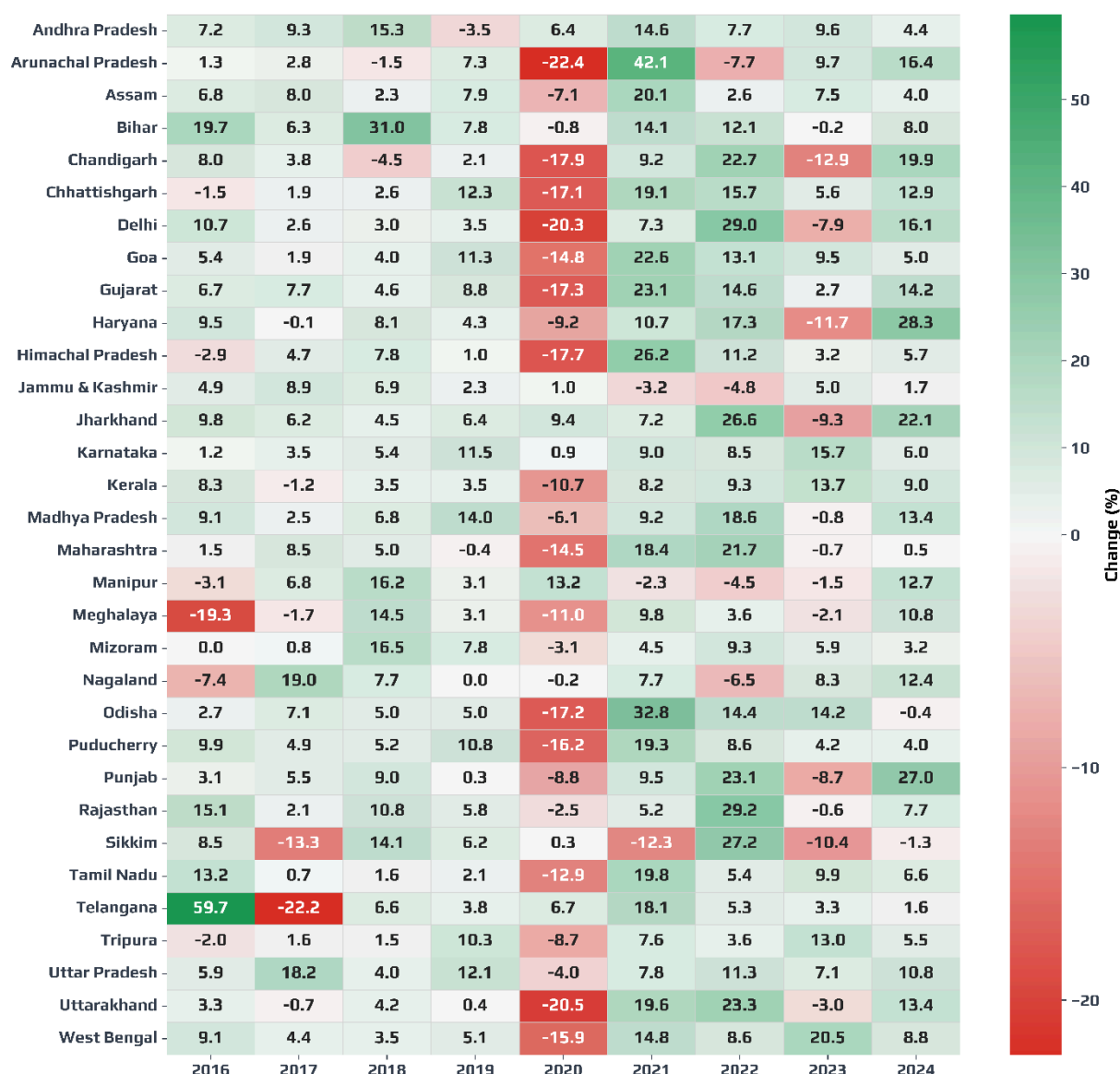


Figure 21: Change in summer peak demand

The increase in state-wise peak demand highlights dual drivers: economic growth and climate change. Heatwaves have become a structural driver of demand growth rather than seasonal anomalies. Evening ramps during hot periods present the most critical reliability challenge, requiring accelerated deployment of battery storage, flexible hydro, and targeted demand response for urban cooling loads. State-specific strategies should focus on urban-industrial corridors and high-growth states where summer increments are sharpest and heatwave clustering is most pronounced.

Power Capacity & Generation Trends across India

India's power sector underwent a period of rapid expansion and structural transformation between 2015 and 2024, marked by both strong capacity growth and a gradual diversification of the generation mix. Total installed power capacity rose by nearly 62%, increasing from approximately 285 GW in 2015 to 461 GW in 2024. This decade-long progress reflects India's simultaneous efforts to meet growing electricity demand while advancing its clean energy transition.

Installed Capacity Trends

Coal-based power continues to dominate India's electricity system, maintaining its position as the single largest contributor to installed capacity. Coal-based power plant capacity increased from 170 GW to 219 GW, a 29% rise, though the pace of new installations has slowed considerably since 2020, reflecting a structural shift toward renewables. Oil and gas-based generation remained largely stable at around 25 GW, accounting for less than 6% of total installed capacity.

Among non-fossil sources, hydropower capacity grew modestly from 47 GW to 52 GW (~11% increase), while bioenergy expanded from 8.1 GW to 11.4 GW (+41%), though it still represents a relatively small share of the total mix.

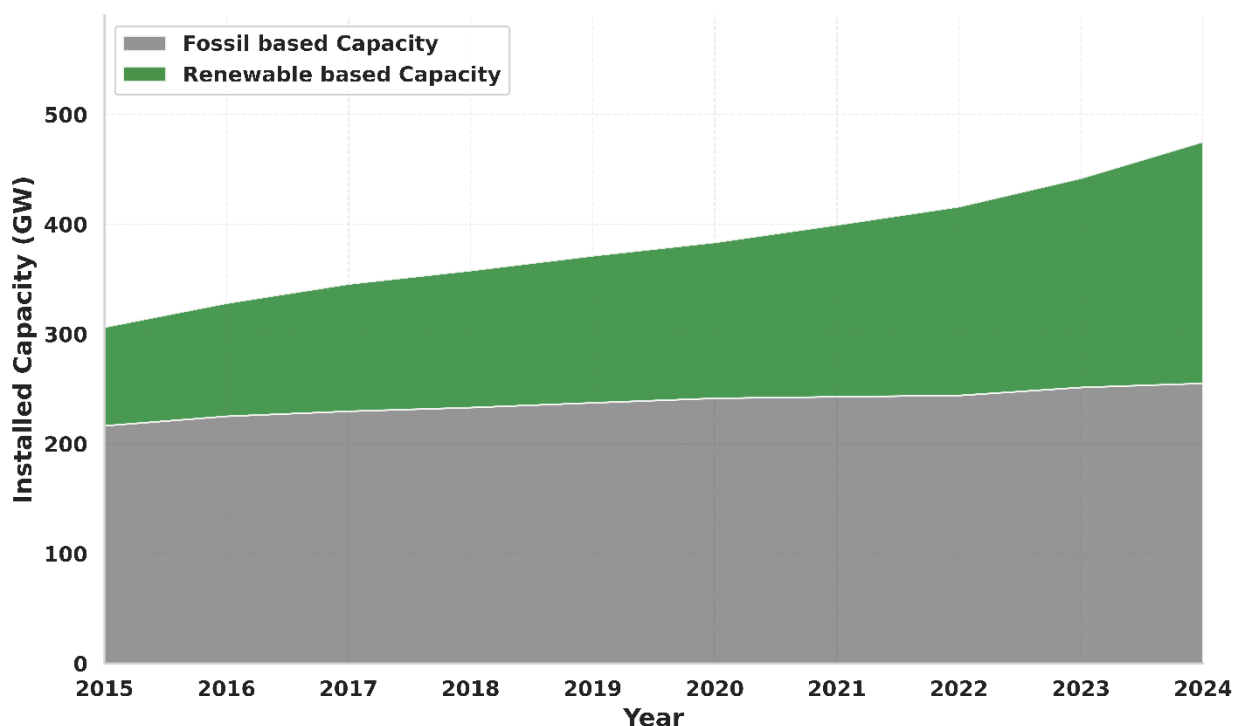


Figure 22: Installed capacity growth in India from 2015 to 2024

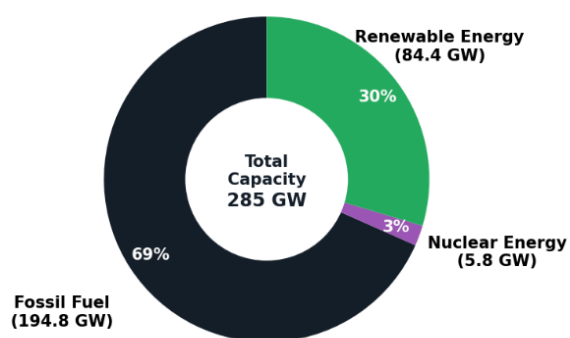


Figure 23: Installed Capacity in India as of 2015

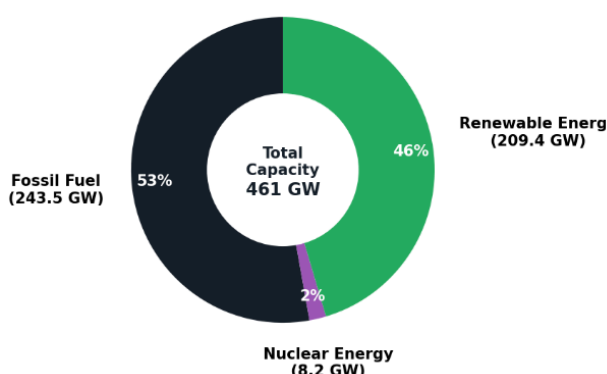


Figure 24: Installed Capacity in India as of 2024

The most remarkable transformation occurred in renewable energy, particularly solar and wind. Solar capacity surged from 5.3 GW to 97.9 GW, achieving an eighteenfold increase and emerging as India's second-largest power source after coal. Wind power nearly doubled, rising from 24.3 GW to 48.1 GW (+98%). Collectively, renewables now account for 46% of total installed capacity, up from 30% in 2015, while fossil fuel capacity declined from 69% to 53%. This transition highlights India's accelerating momentum toward its Nationally Determined Contribution (NDC) and long-term net-zero 2070 targets.

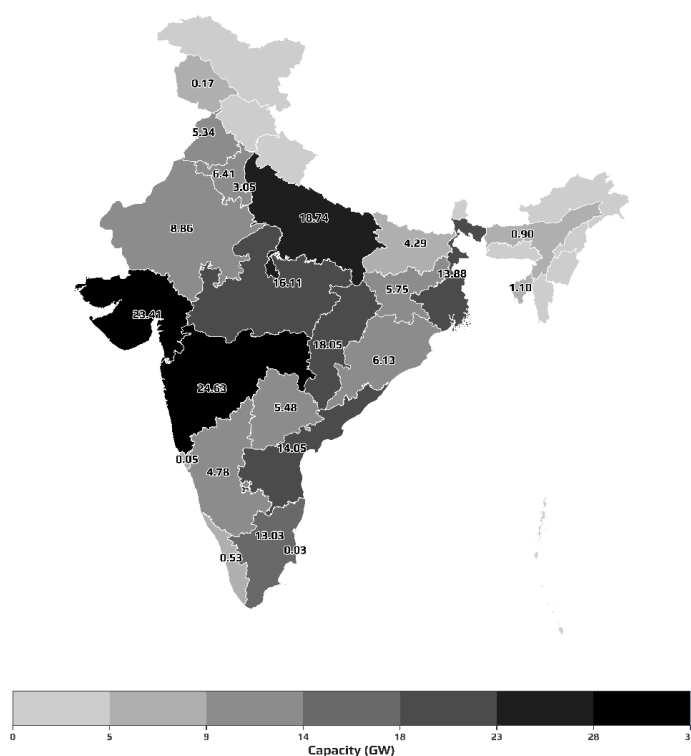


Figure 25: Installed capacity of fossil fuel-based power plants as of 2015

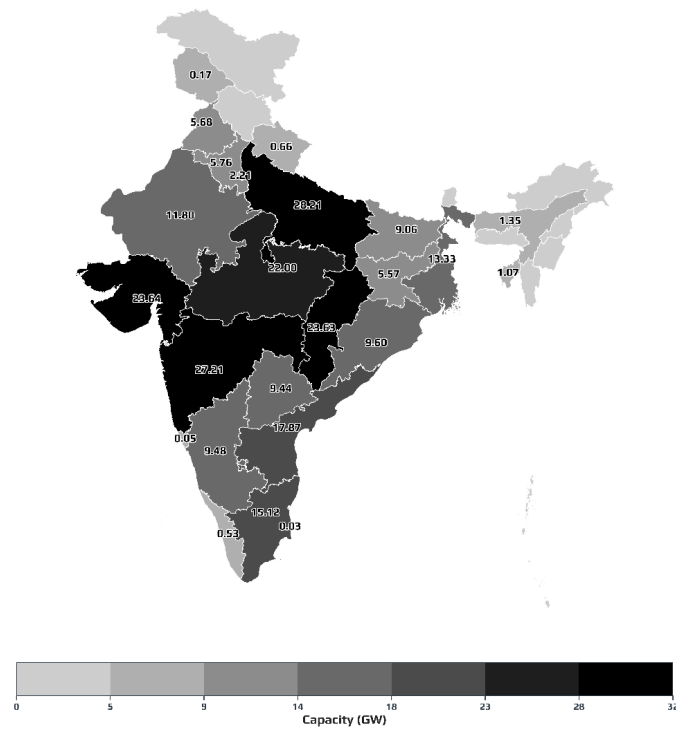


Figure 26: Installed capacity of fossil fuel-based power plants as of 2024

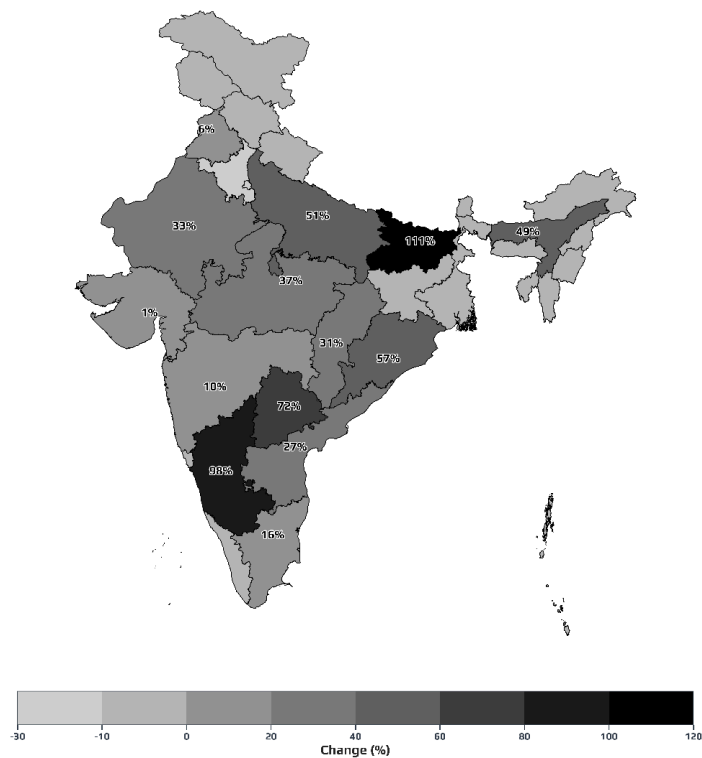


Figure 27: Decadal change in fossil-based installed capacity

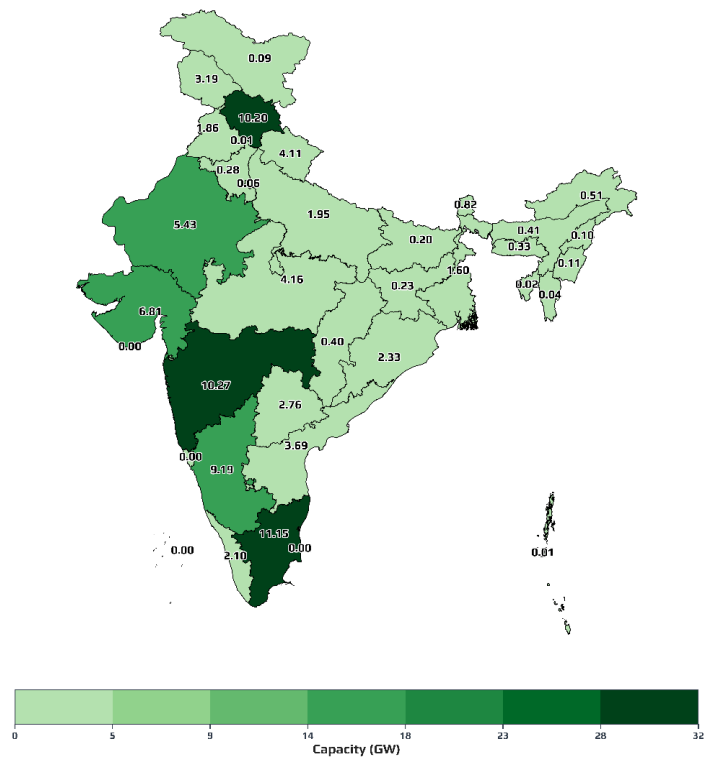


Figure 28: Installed capacity of renewables as of 2015

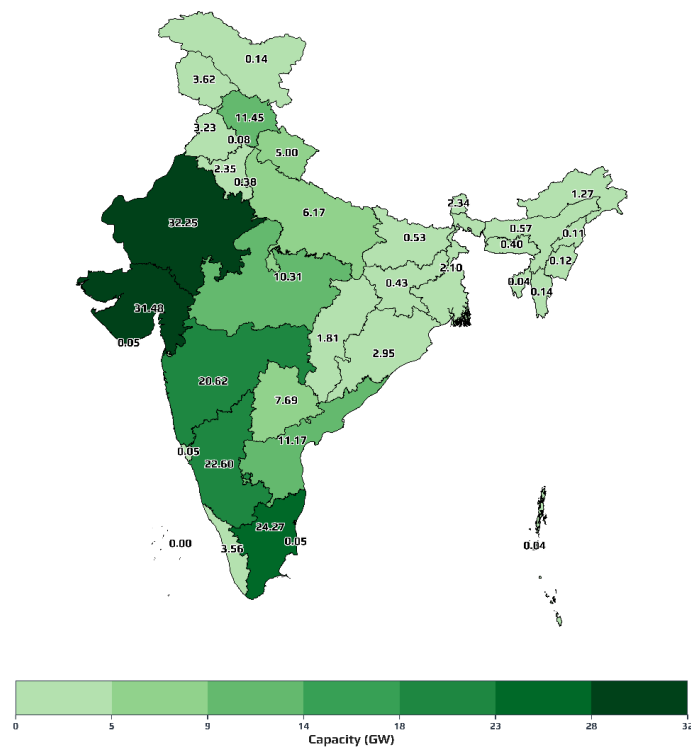


Figure 29: Installed capacity of renewables as of 2024

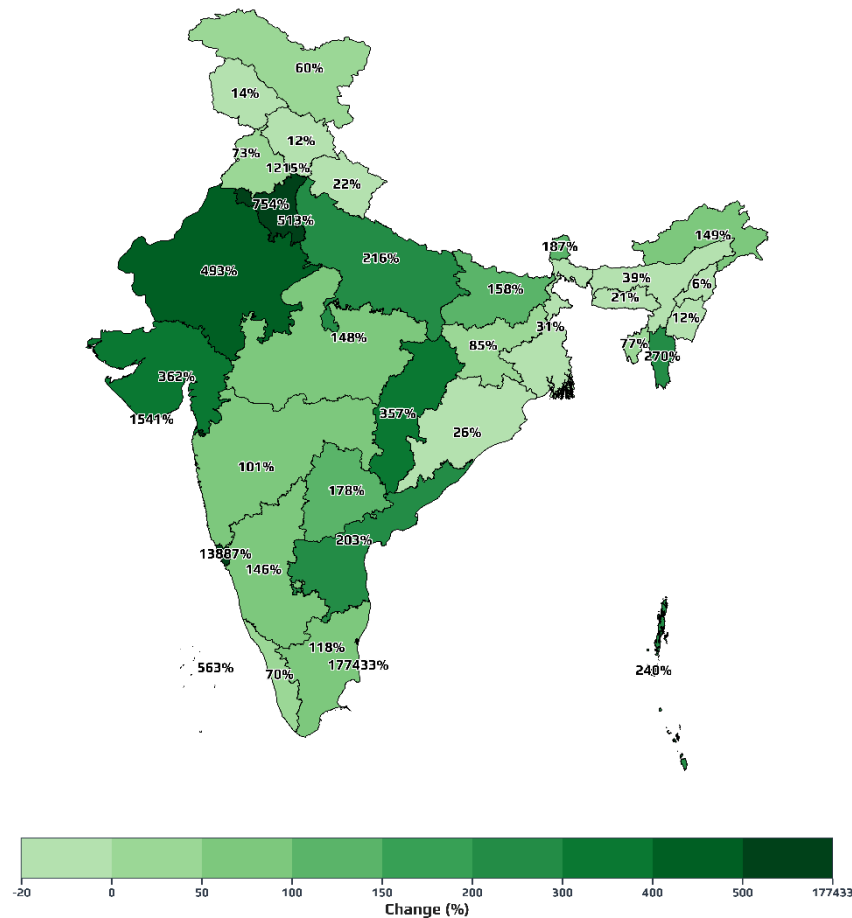


Figure 30: Decadal change in renewables capacity

Electricity Generation Trends

Generation trends closely mirror capacity changes but also reveal the continued centrality of fossil fuels in meeting base and peak electricity demand. Coal-based generation increased from 873 billion units (BU) in 2015 to 1,327 BU in 2024, a 52% rise, reinforcing its role as the foundation of India's power supply. In contrast, oil and gas generation remained nearly flat at 34-35 BU, contributing under 2% of total generation.

Among renewables, hydropower generation rose modestly from 131 BU to 156 BU (+19%), and bioenergy generation increased from 10.5 BU to 16.3 BU (+55%), together accounting for under 2% of total generation. The most striking gains came from solar and wind: solar generation expanded exponentially from 5 BU to 134 BU, a 26-fold increase, while wind generation grew from 28 BU to 82 BU (+192%).

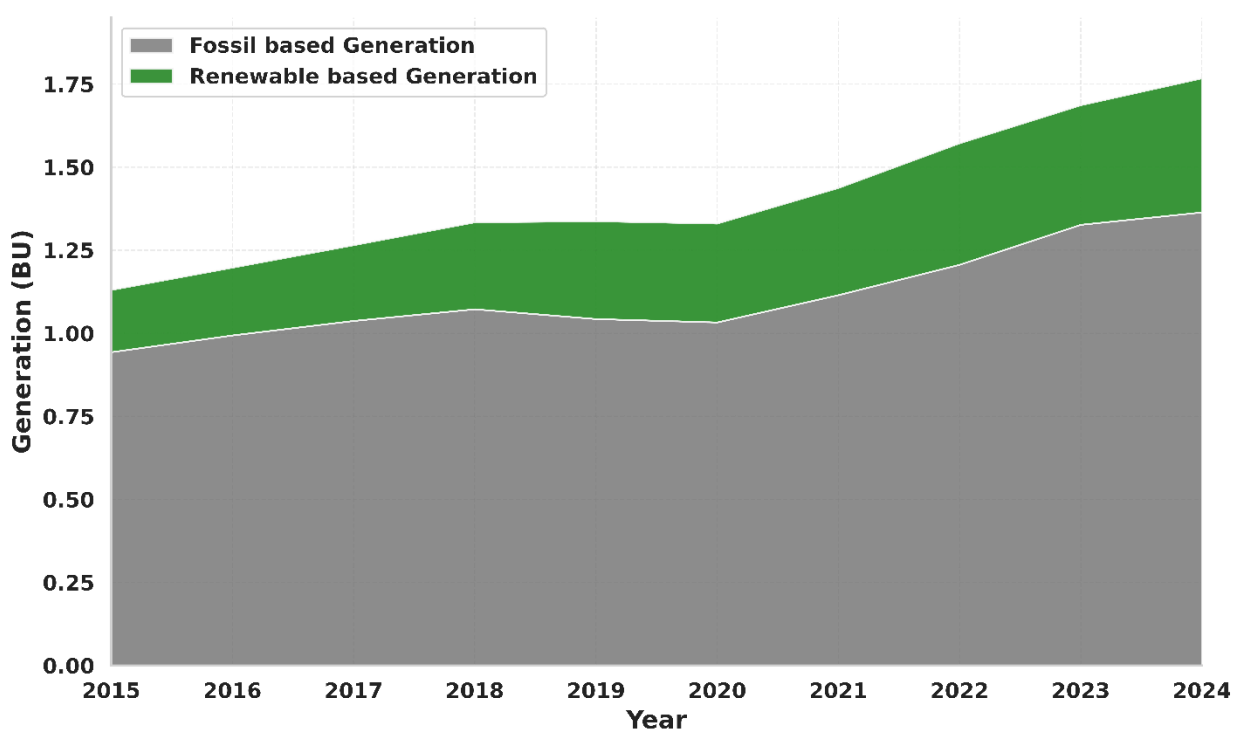
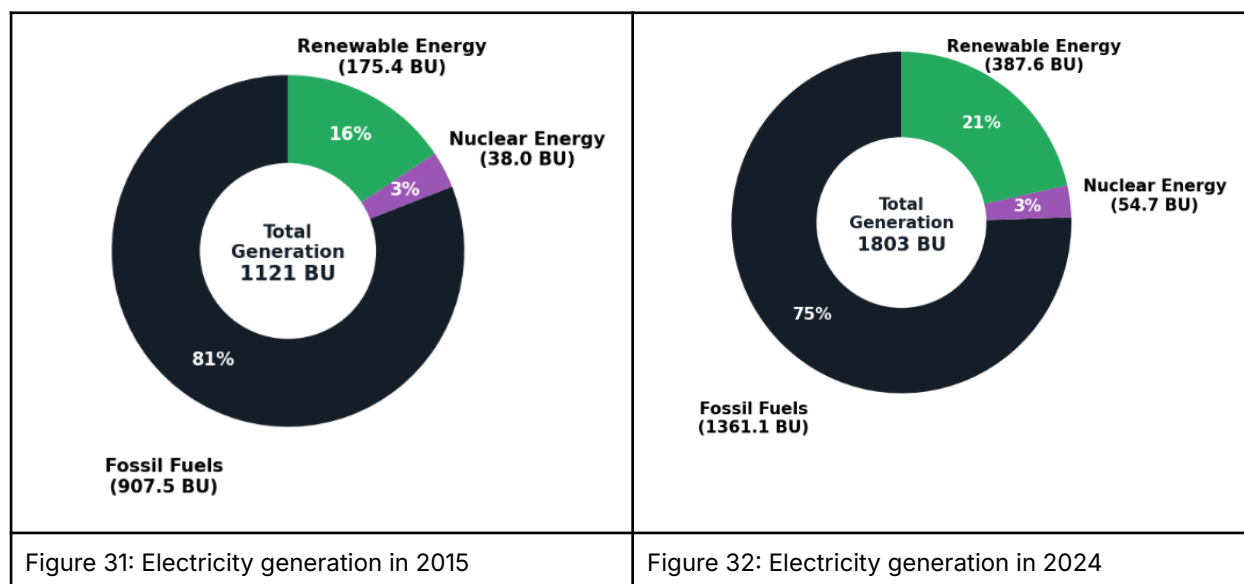


Figure 33: Electricity generation growth over the decade

By 2024, renewables contributed approximately 21% of total generation, up from 16% in 2015, while fossil fuels' share declined from 81% to 75%. This indicates a measurable

though gradual rebalancing of India's generation mix, with renewables increasingly complementing rather than displacing fossil-based power.

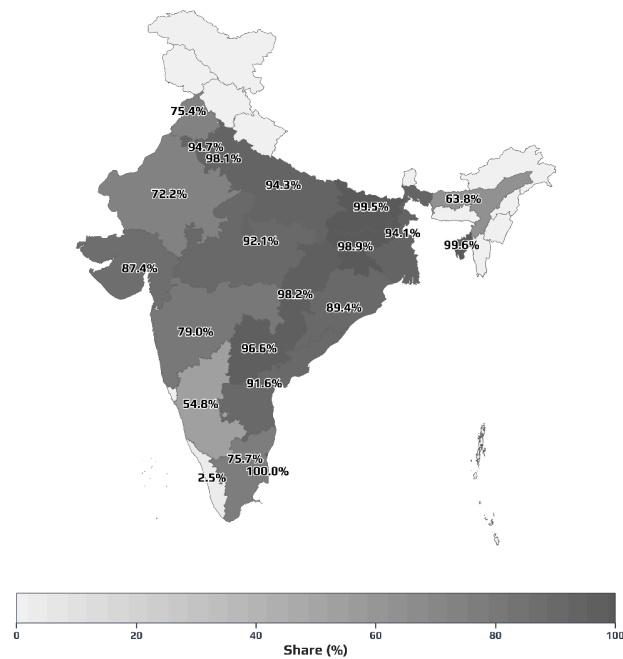


Figure 34: Share of fossil fuels in electricity generation in 2015

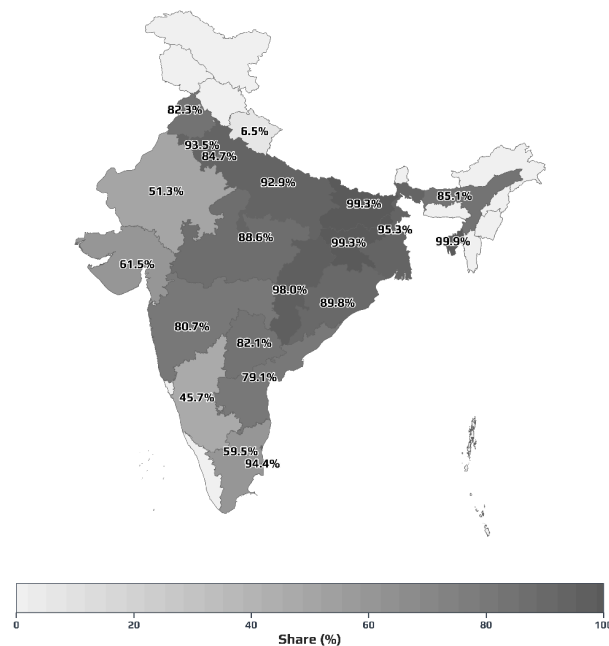


Figure 35: Share of fossil fuels in electricity generation in 2024

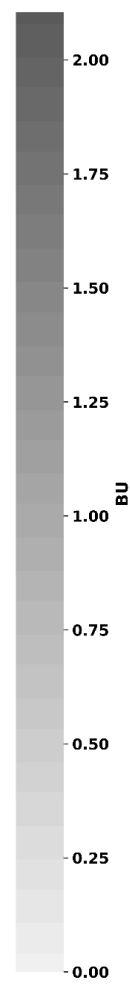


Figure 36: Excess fossil fuel-based power generation during summer

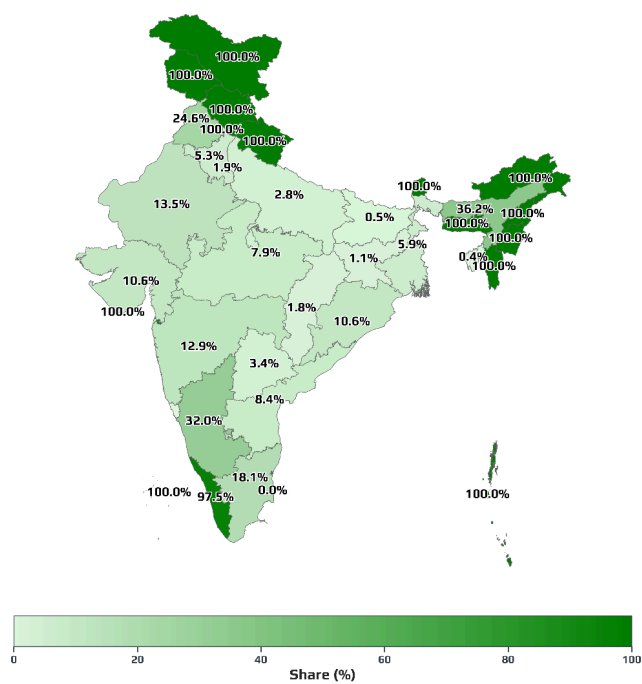


Figure 37: Share of renewables in electricity generation in 2015

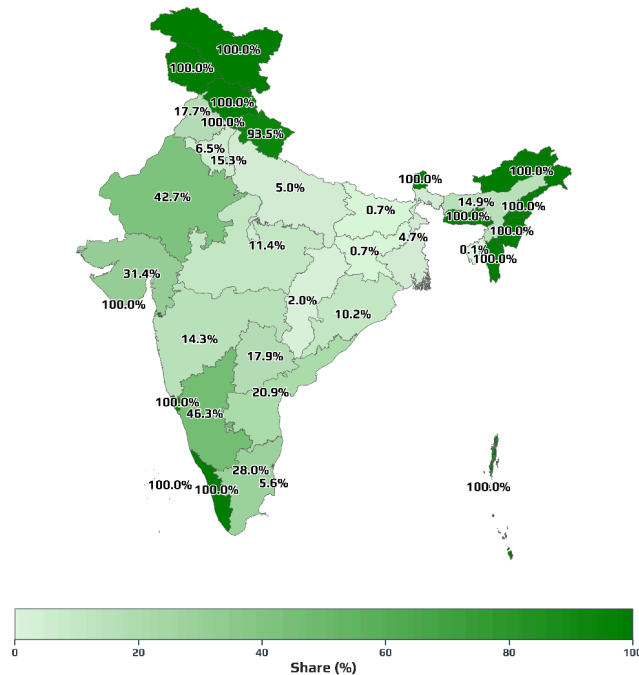


Figure 38: Share of renewables in electricity generation in 2024

3.3 Correlation between Rising Temperatures, Heatwaves, and Electricity Demand

Our analysis of temperature and electricity demand data from 2015 to 2024 reveals a clear correlation between heat events and power consumption patterns across India. Uttar Pradesh demonstrates the strongest correlation, with peak demand surging from ~14.2 GW in 2015 to ~25.5 GW by 2024, directly paralleling the frequency of April-June heatwaves. Similarly, Rajasthan and Delhi consistently registered significant summer demand increases during years with intense pre-monsoon heat, confirming that temperature extremes amplify consumption beyond baseline growth.

The temperature demand analysis reveals distinct regional patterns in how electricity demand responds to heat across India. The Northern and Central Plains exhibit the highest levels of sensitivity, featuring double-digit increases in summer demand and sustained evening usage caused by heat retention at night. In the Western states, the challenges are magnified by a combination of hot, dry conditions and humidity. While Southern states have been known for more moderate temperatures, they are quickly becoming more susceptible to demand fluctuations due to the rising prevalence of air conditioning. The Eastern regions are emerging as new vulnerability hotspots with consistent demand surges during heat events. In the hilly regions and the Northeast face significant pressure during temperature rises due to their limited reserve capacities. These regional disparities highlight the necessity for customized strategies in grid management as climate patterns become more severe.

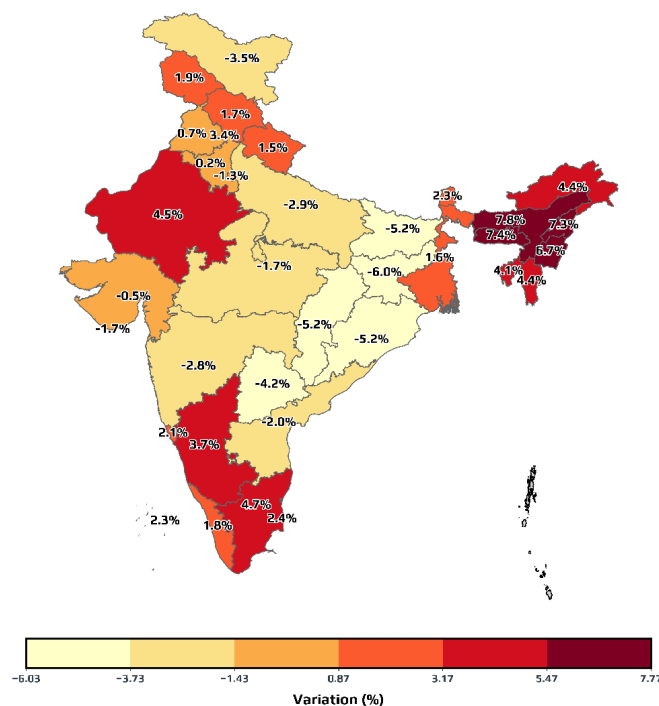


Figure 39: Decadal variation in maximum temperatures

These changes are evident in generation trends as well, with installed capacity increasing from approximately 285 GW in 2015 to around 461 GW in 2024, primarily driven by renewable energy growth in Rajasthan, Gujarat, Karnataka, Tamil Nadu, and Maharashtra. However, despite the increase in the share of renewables, their impact during the summer months has been limited, as solar energy diminishes at the same time that cooling demand reaches its peak.

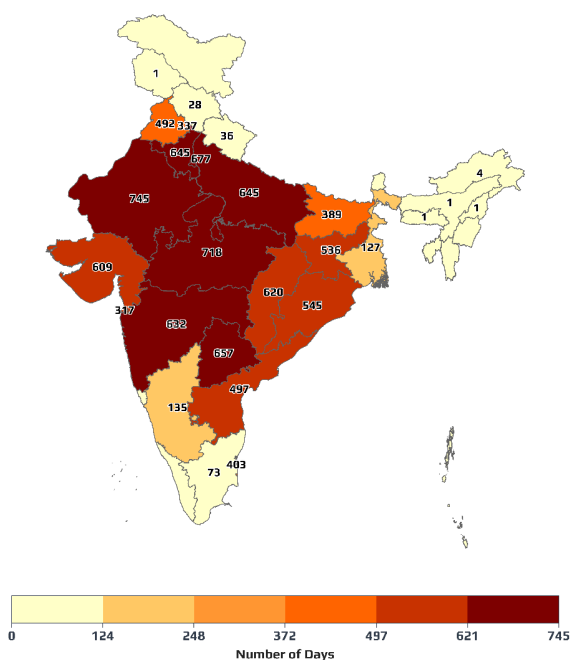


Figure 40: Total heatwave days in the decade

Table 1: Total heatwave days and heatwave years during the decade (2015-2024)

State	Heatwave Days	Heatwave Years
Rajasthan	745	2.04
Madhya Pradesh	718	1.97
Delhi	677	1.85
Telangana	657	1.80
Haryana	645	1.77
Uttar Pradesh	645	1.77
Maharashtra	632	1.73
Chhattisgarh	620	1.70
Gujarat	609	1.67
Odisha	545	1.49
Jharkhand	536	1.47
Andhra Pradesh	497	1.36
Punjab	492	1.35
Puducherry	403	1.10
Bihar	389	1.07
Chandigarh	337	0.92
Daman & Diu & Dadra & Nagar Haveli	317	0.87
Karnataka	135	0.37
West Bengal	127	0.35
Tamil Nadu	73	0.20
Uttarakhand	36	0.10
Himachal Pradesh	28	0.08
Arunachal Pradesh	4	0.01
Assam	1	0.00
Jammu And Kashmir	1	0.00
Meghalaya	1	0.00
Nagaland	1	0.00

Between 2015 and 2024, India experienced a clear escalation in heatwave frequency, with several states facing recurring and prolonged heat events nearly every year. Rajasthan and Madhya Pradesh led with an average of around two heatwave years annually (2.04 and 1.97, respectively), reflecting near-annual extreme temperature conditions. Delhi, Telangana, and Haryana followed closely, each recording over 1.7 heatwave years in the decade, highlighting how heatwaves have transitioned from sporadic to seasonal occurrences across much of northern and central India. This persistent pattern signals a structural climatic shift, where intense summer heat is no longer exceptional but expected, posing growing challenges for electricity demand management, public health, and climate adaptation planning.

To meet the rising electricity demand due to prolonged heatwaves, fossil fuel-based power plants were repeatedly forced to ramp up, particularly in regions where maximum

temperatures rise frequently and for longer durations to meet the cooling demands. As a result, coal-based electricity generation increased from ~873 BU in 2015 to ~1327 BU in 2024 (+52%), while solar jumped from ~5 BU to ~134 BU. Despite this progress, fossil fuel-based generation intensified during heatwaves, driving seasonal surges in emissions.

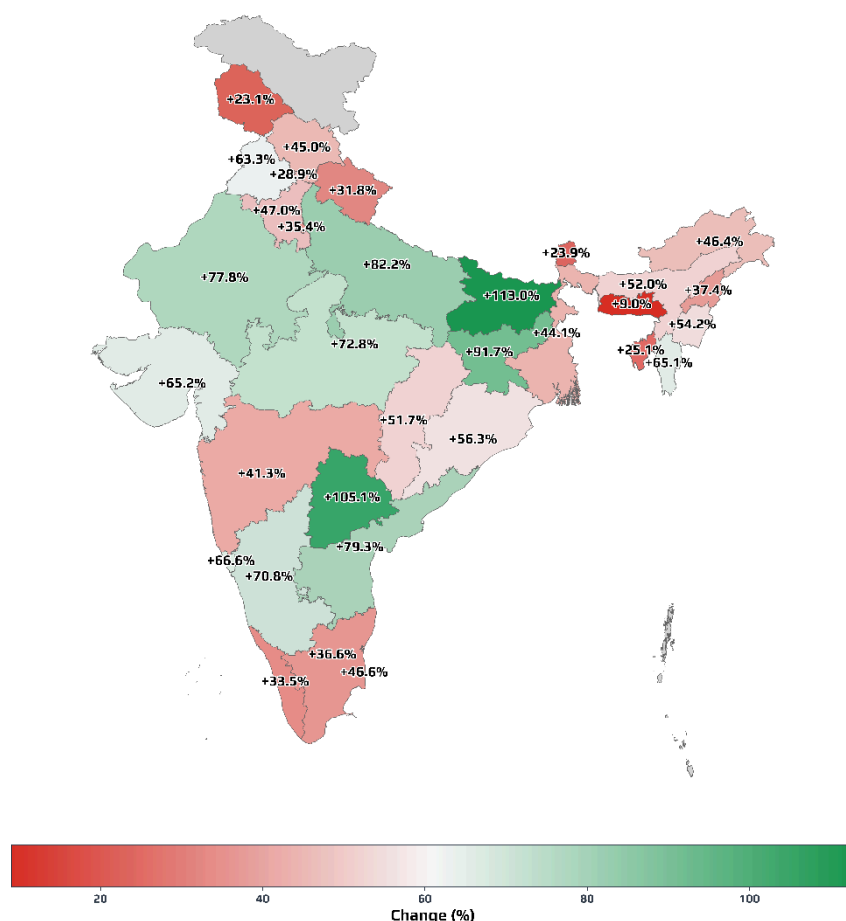


Figure 41: Decadal change in annual peak demand

The decade's evidence shows that rising temperatures, clustered heatwaves, and growing electricity demand are tightly interlinked. By embedding IMD's heat alerts directly into our grid operations, dispatch decisions, and demand response programs, we can anticipate and proactively manage these challenges.

3.4 Emissions Trends

The severe impact of heatwaves on India's energy system is reflected in significant emissions surges throughout the past decade (2015-2024), demonstrating a clear environmental consequence of managing peak demand in extreme heat. Our decadal analysis reveals a direct correlation between heatwaves and measurable CO₂ emission surges across India's power sector.

Annual emissions from fossil-fuel-powered electricity generation show a persistent rise across several major states over the decade, reflecting the cumulative strain of rising

demand and intensified cooling needs. Uttar Pradesh consistently remained the highest annual emitter, increasing from 93 MtCO₂ in 2015 to nearly 140 MtCO₂ in 2024. Similar upward trajectories were visible in Chhattisgarh, which moved from 74 MtCO₂ to 144 MtCO₂, and Madhya Pradesh, which climbed from 77 MtCO₂ to 128 MtCO₂ over the same period. Industrial states such as Maharashtra (rising from 89 MtCO₂ to 121 MtCO₂) also demonstrated sustained dependence on thermal generation.

Gujarat is one of the few major states to record a decline in annual emissions, falling from 88 MtCO₂ in 2015 to 83 MtCO₂ in 2024. This reduction is closely linked to the state's steady adoption of renewable energy and diversification of its power mix. Even states with moderate demand, such as Odisha, Rajasthan, and Tamil Nadu, showed steady annual increases. These long-term emission trends highlight how India's growing electricity demand remains tightly coupled with coal-based generation, especially in states where renewable generation has not yet scaled sufficiently to offset fossil-based baseload requirements.

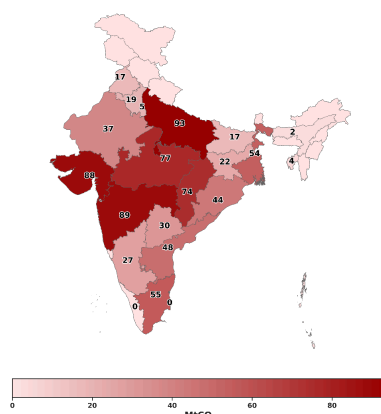


Figure 42: Annual emissions from fossil fuel-based power generation in 2015

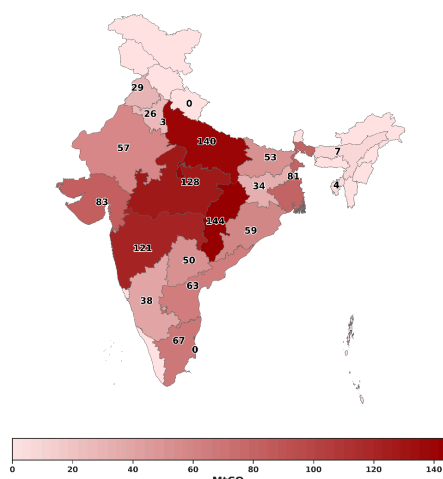


Figure 43: Annual emissions from fossil fuel-based power generation in 2024

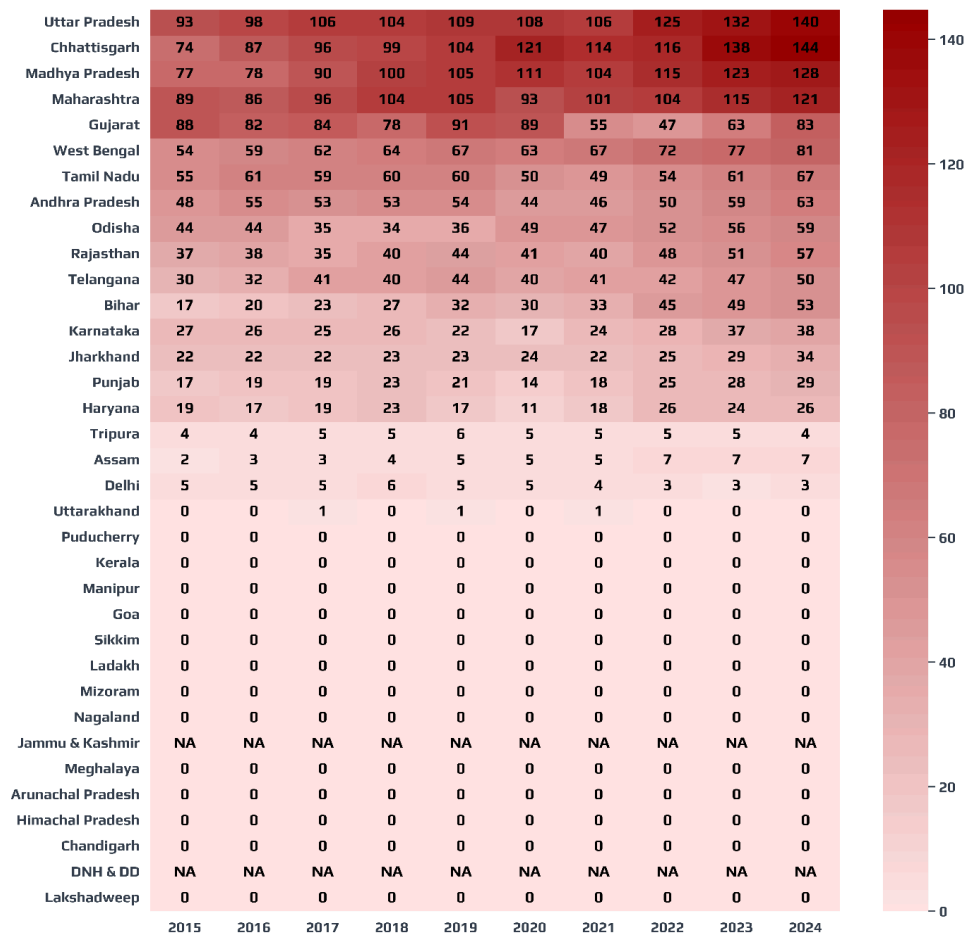


Figure 44: Annual emissions from fossil fuel-based power generation

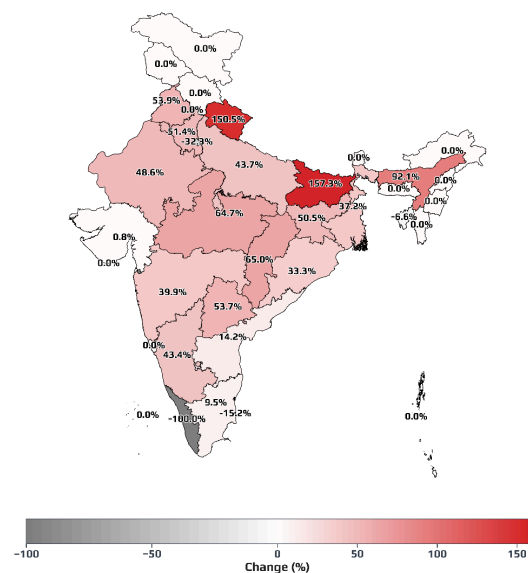


Figure 45: Decadal change in annual emissions

The emission spikes become more pronounced during the summer season, particularly between April and June, when heatwaves drive rapid surges in cooling demand. Uttar Pradesh saw its summer emissions rise from 23 MtCO₂ in 2015 to nearly 39 MtCO₂ in 2024, marking one of the sharpest increases among all states. Chhattisgarh exhibited a similar pattern, climbing from 16 MtCO₂ to approximately 38 MtCO₂ over the same period. Maharashtra's summer emissions consistently remained high, ranging between 21–32 MtCO₂, while Gujarat rose from 22 MtCO₂ in 2015 to 26 MtCO₂ in 2024. Other states, including Odisha, Tamil Nadu, Bihar, and Rajasthan, also recorded seasonal emission increases aligned with intensified summer demand. The emission surges during summer, mostly concentrated in the northern, central, and western states, where heatwaves persist longer and electricity systems rely heavily on coal-fired generation to manage short-term peak loads.

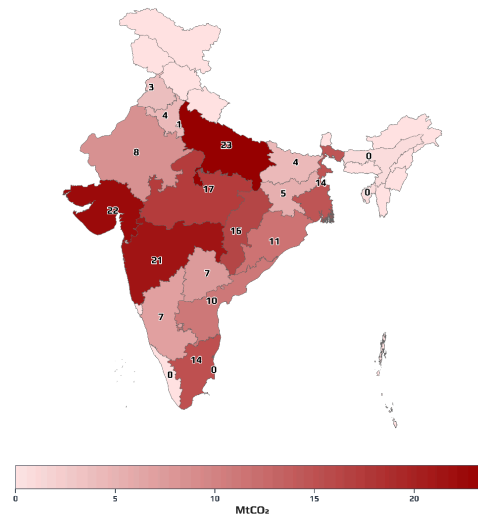


Figure 46: Emissions from fossil fuel-based power generation during the summer in 2015

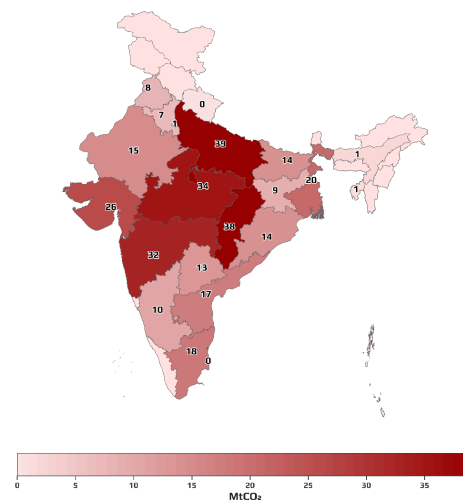


Figure 47: Emissions from fossil fuel-based generation during the summer in 2024

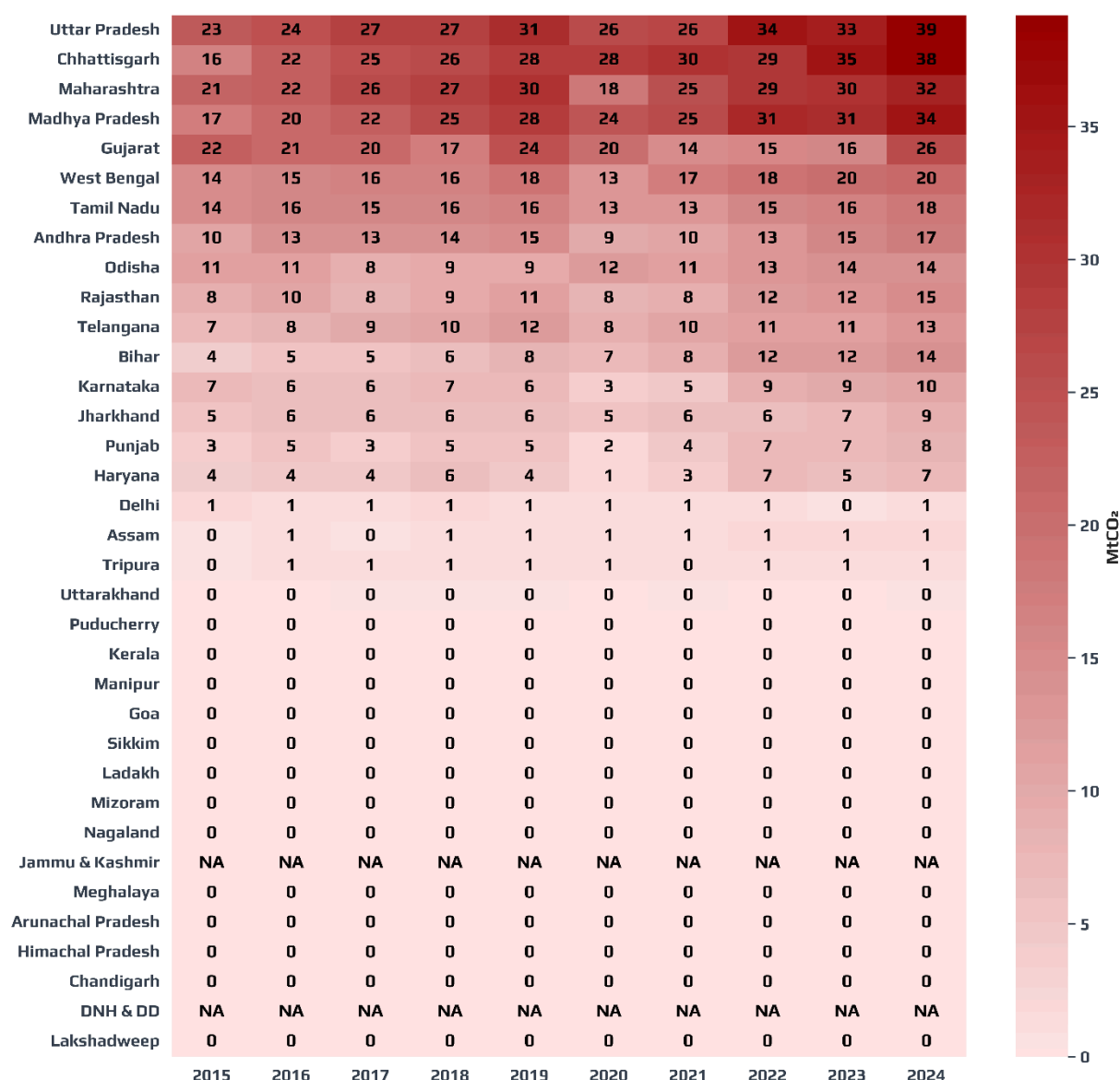


Figure 48: Emissions from fossil fuel generation during summer

Our decadal analysis confirms the ongoing reliance on fossil fuels in states such as Uttar Pradesh, West Bengal, Chhattisgarh, Jharkhand, and Bihar, all of which had fossil fuel shares exceeding 80% in 2024, despite the growth in renewable capacity. Although the integration of renewable energy penetration is gradually increasing in several large consumption states but they still rely heavily on fossil fuels during peak demand hours. The result is a recurring summer cycle: heatwaves amplify demand, fossil fuel-based electricity generation meets the peak demand, and due to this generation, emissions spike, reinforcing the very warming that drives future heatwaves.

3.5 Correlation between Emissions and Heatwaves

The relationship between climate change, extreme heat events, electricity consumption, and carbon emissions is now evident. This report reveals a clear feedback mechanism in which rising temperatures drive increased cooling demand, particularly in urban areas, resulting in peak loads during late afternoons and evenings. With solar generation

declining after sunset and limited storage capacity available, the system continues to rely heavily on fossil fuels to meet these peaks, generating additional emissions that further contribute to warming trends.

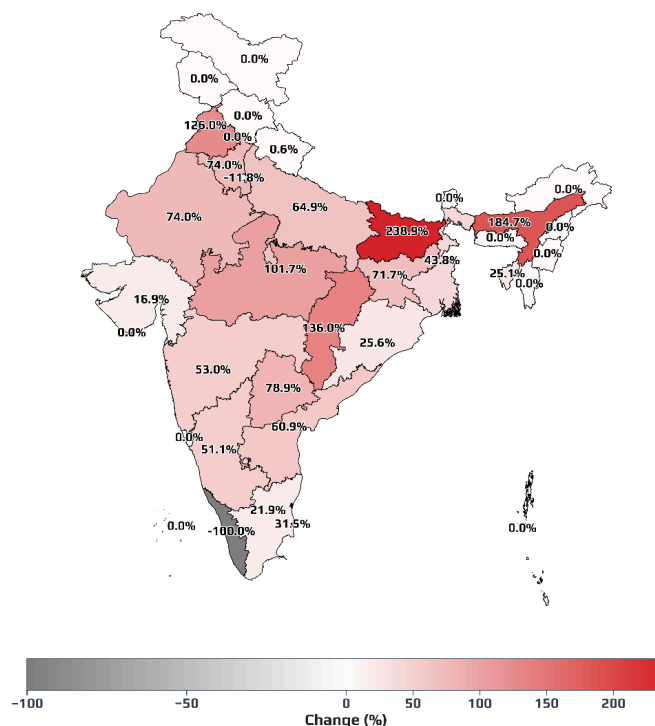


Figure 49: Decadal change in emissions during summer

Between 2015 and 2024, this cycle became clearer when mapped against state-level emissions.

- Uttar Pradesh emerged as the highest emitter, with annual emissions rising from 93 MtCO₂ (2015) to 140 MtCO₂ (2024), while summer emissions increased from 23 MtCO₂ to 39 MtCO₂, reflecting strong temperature-driven demand growth.
- Chhattisgarh showed one of the fastest emission escalations, with annual values doubling from 74 MtCO₂ to 144 MtCO₂ and summer emissions increasing from 16 MtCO₂ to 38 MtCO₂, indicating a heavy dependence on coal during peak heat periods.
- Madhya Pradesh recorded a steady climb in emissions, with annual levels increasing from 77 MtCO₂ to 128 MtCO₂, and summer emissions rising from 17 MtCO₂ to 34 MtCO₂ in response to recurring April–June heatwaves.
- Maharashtra and Gujarat remained major contributors, with Maharashtra reaching 121 MtCO₂ in annual emissions and Gujarat maintaining 55–88 MtCO₂, while both states showed persistent summer-season spikes between 20–32 MtCO₂, driven by industrial load and repeated 40°C+ periods.
- States such as West Bengal, Tamil Nadu, Andhra Pradesh, Odisha, Rajasthan, and Telangana consistently recorded seasonal emissions in the 10–20 MtCO₂ range,

showing that heat-linked fossil-fuel ramping is now widespread across diverse climatic regions.

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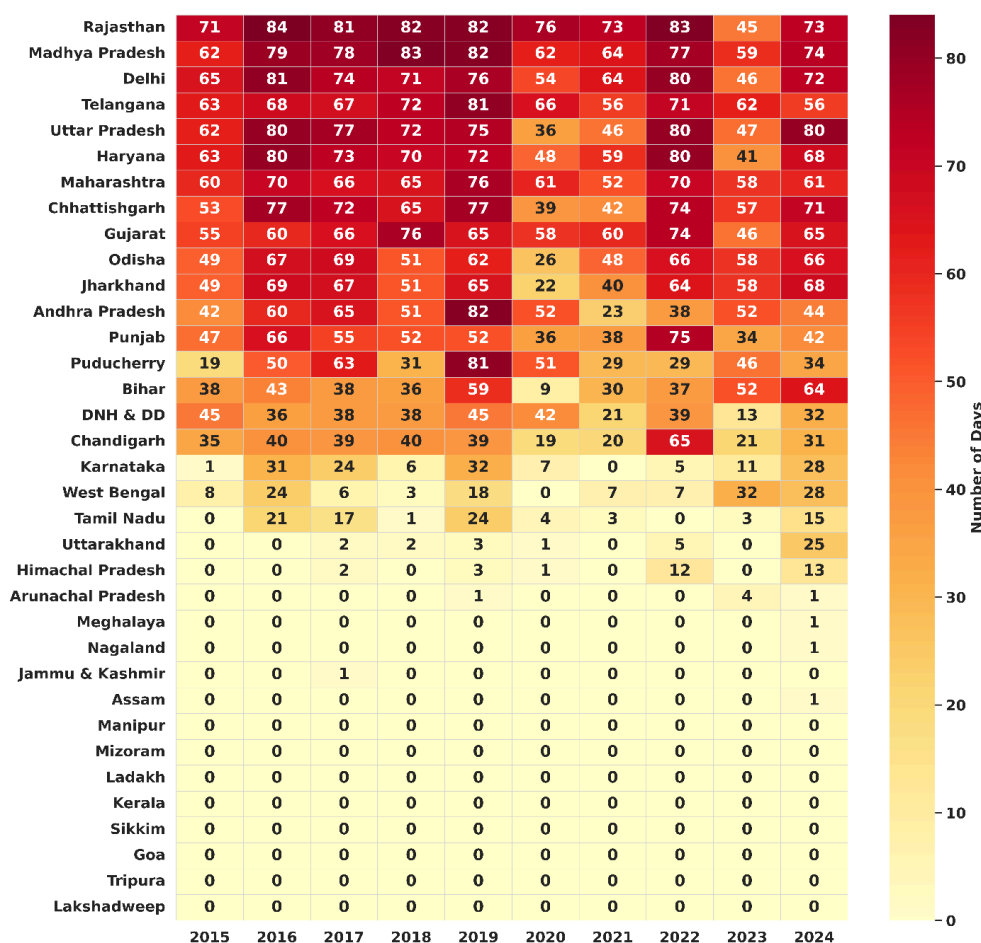


Figure 50: Heatwave days by states in the decade

At the national level, fossil fuel-based generation output rose from ~873 BU in 2015 to ~1327 BU in 2024, and this increase is mirrored almost one-for-one in fossil emissions. This fossil reliance led to emission spikes during heatwave months, locking India into a cycle where higher emissions contribute to further warming and intensified heatwaves.

4. Socio-Economic Impacts

4.1 Vulnerable Populations & Energy Access

Urban vs. rural disparity in coping with heatwaves

The significant difference in coping with heatwaves between urban and rural populations is most visible across the northern and central plains, where April-June hot spells frequently push temperatures beyond 40-45°C. Urban centers suffer more intense stress due to dense built environments, low ventilation, and heat-retaining materials, making them significantly hotter than rural areas. This amplification is directly linked to rising state-wise peak electricity demand, with urban cooling loads driving summer surges.

India's electricity demand rose by 9% during the peak heatwave months of April-June 2024, as compared to April-June 2023, aligning closely with other reports of an over 10% surge in the same timeframe⁹. Air conditioning emerged as a critical factor, accounting for roughly 30% of this additional demand, peaking at over one-third of the incremental consumption in May alone⁹. With summer peak demands consistently exceeding annual averages since 2021, particularly in highly urbanized states, targeted interventions have become essential. There is an urgent need for city-focused resilience measures, such as scaling demand response programs, advancing pre-cooling strategies, and prioritizing critical feeder protection to safeguard essential services during extreme heat events¹⁰.

Overloading and outages in lower-income areas

During the periods of extreme heat, the power sector faces significant stress due to repeated, pronounced spikes in peak electricity demand, driven largely by the rising adoption of cooling appliances like air conditioners¹¹. These demand surges imply higher transformer loading and feeder stress in the distribution networks, particularly those serving low-income urban and semi-urban settlements, which are often characterized by inefficient building envelopes and poorer housing quality¹¹.

While summer-specific "excess fossil generation" often secures an adequate supply of peak demand, it becomes a critical bottleneck during heatwaves, consequently increasing the probability of localized voltage drops and outages. These disruptions impact lower-income communities more severely, as their infrastructure is fragile and non-technical losses diminish reliability even further.

This vulnerability of low-income populations to heat and energy access disruptions is explored further in studies analyzing heatwave impact on mortality, which highlight existing socioeconomic disparities, and scoping reports detailing the stress on India's power sector infrastructure^{10,11}.

Disparity in electricity access across the country

Electricity access across the country exhibits significant disparities, which are particularly evident in the resilience of regional power systems during periods of intense heat. Across India's energy landscape, numerous states continue to rely heavily on fossil fuels, creating a persistent imbalance in the power mix. Despite national progress toward cleaner alternatives, renewable adoption remains strikingly uneven, with several major states still operating at a low renewable share, leaving these regions with limited clean energy capacity and insufficient storage infrastructure to manage peak demand hours effectively.

State peak-demand further highlights structural consumption inequalities, with hilly and Northeastern states showing significantly lower absolute peaks compared to the massive northern and western states. These gaps represent real access limitations that become dangerous during heatwaves, when inadequate cooling capacity leaves vulnerable communities exposed to extreme temperatures. This limited resilience leaves low-access districts especially vulnerable to public health risks during periods of extreme heat, reinforcing the urgent need to bridge regional disparities in energy access and infrastructure resilience⁹.

4.2 Grid Stress and Resilience

India's power grid faces region-specific challenges during heatwaves, with north-central states experiencing the most severe stress. Rajasthan, Uttar Pradesh, Madhya Pradesh, and Delhi show the highest temperature-demand relationship, regularly experiencing double-digit summer demand increases during hot periods. Western states like Gujarat and Maharashtra record high absolute peaks with consistent summer increases, as coastal humidity and urban cooling needs intensify transformer loads and evening demand spikes. Southern systems, including Tamil Nadu and Telangana, show growing heat sensitivity, highlighting the need for heat-alert protocols, demand response programs, and strategic maintenance planning.

Beyond demand challenges, high temperatures directly affect the power systems' infrastructure performance and increase the line sag, consequently elevating the risk of equipment failure during hot days. To address these vulnerabilities and preserve reliability during the heat season, India-focused resilience assessments strongly emphasize key adaptations, including conductor upgrades, improved reactive support, and enhanced operational measures¹².

The increasing frequency of extreme heat events has forced power systems across India to operate in high-alert conditions, with grid operators deliberately deploying excess fossil generation during high-temperature periods to prevent brownouts when cooling-driven demand remains elevated. This thermal generation uplift correlates directly with rising summer emissions and highlights a critical vulnerability, as renewable energy generation alone cannot yet meet the peak demands during summer months, necessitating specific operational measures during summer.

Depending on the location, power outage minutes in India can increase by 15-60% during heatwaves (temperature greater than 40°C), with urban feeders particularly affected by cooling-driven overloads in May-July, reinforcing the need for targeted demand response and feeder prioritization during alerts¹³. The complexity of mitigating these heat-related challenges, including the need to incorporate flexible power sources and improved consumer pricing, is a key area of focus for strategic planning in the Indian power sector⁹.

5. Renewable Readiness Assessment

India's shift to renewable energy is a reflection of unique regional dynamics influenced by infrastructure development, governmental support, and geography. The rate of integration and resilience to climate stress, especially heatwaves, differs greatly amongst zones, despite the fact that renewable capacity has grown quickly in a few zones.

Renewable Penetration as of 2024

The landscape of renewable penetration in India is very varied as of 2024. Supported primarily by hydroelectric resources, the Northern Zone is led by a group of high-performing states, including Jammu & Kashmir (95.4%), Ladakh (100%), Himachal Pradesh (100%), and Uttarakhand (88.3%). Rajasthan (73.2%) strengthens the region's renewable strength by adding a significant amount of solar capacity. However, grid limitations and a lack of available renewable land cause populous and urbanized states like Delhi (14.6%) and Uttar Pradesh (17.9%) to lag.

Madhya Pradesh (31.9%), Maharashtra (43.1%), and Gujarat (57.1%) make up the Western Zone's robust renewable base. Although Chhattisgarh (7.1%) and DNH & DD (100%) draw attention to the differences between large industrial states and smaller regions, both states show a balanced solar-wind mix.

Renewables are deeply and steadily integrated in the Southern Zone. India's renewable foundation is still anchored by Karnataka (70.5%), Tamil Nadu (61.6%), and Andhra Pradesh (38.5%), thanks to advantageous legislation and diverse resource bases. On a smaller scale, island regions like Andaman & Nicobar and Lakshadweep (both 100%) and smaller territories like Puducherry (62.1%) have nearly complete renewable dependency.

The Eastern Zone exhibits unequal development, with Bihar (5.5%) and Jharkhand (7.2%) being in the early stages of development and Odisha (23.5%) and West Bengal (13.6%) showing moderate growth. All of the major states-Arunachal Pradesh, Mizoram, Meghalaya, Manipur, and Sikkim-report near-universal renewable penetration, in contrast to the North-Eastern Zone, which is dominated by hydro.

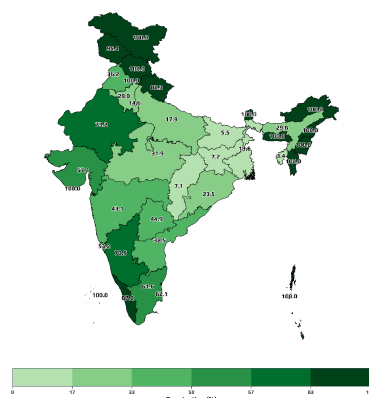


Figure 51: Renewable penetration across Indian states as of 2024

Key Insights: Renewable Capacity and Climate Exposure

A zone-wise comparison of renewable penetration as of 2024 and heatwave exposure in 2024 reveals a clear divergence between renewable readiness and climate vulnerability:

- **Northern Zone:** This region exhibits the highest renewable penetration overall, driven by hydro-rich states and Rajasthan's vast solar resources. However, it also faces severe heatwave exposure, particularly in Uttar Pradesh (80 days and Rajasthan (73 days). The coexistence of high renewable capacity and high heat stress underscores the need for heat-resilient grid planning and cooling demand management.
- **Western Zone:** The zone maintains moderate-to-high renewable penetration but also experiences elevated heatwave risk, especially in Madhya Pradesh (74 days) and Chhattisgarh (71 days). While Gujarat (65 days) has achieved strong renewable growth, sustained heat conditions pose operational challenges for grid reliability and cooling demand.
- **Southern Zone:** This region stands out for its high renewable penetration and low heatwave exposure, offering a stable and resilient energy landscape. States like Karnataka (70.5% RE, 28 days) and Tamil Nadu (61.6% RE, 15 days) showcase strong renewable integration with minimal heat stress, highlighting their advantage in maintaining reliability as renewable shares rise.
- **Eastern Zone:** The Eastern region reflects low renewable penetration with moderate heatwave exposure, a combination that points to both vulnerability and opportunity. Odisha (23.5% RE, 66 days) and Bihar (5.5% RE, 64 days) exemplify states that would benefit most from accelerated renewable adoption aligned with climate resilience strategies.
- **North-Eastern Zone:** The zone presents a unique profile with widespread reports of near-100% renewable penetration, primarily from small hydro and decentralized solar systems. However, the actual renewable contribution to total demand remains modest, reflecting limited industrial and grid-connected capacity. The region's very low heatwave exposure (~1 day annually) offers a climatic advantage, but scaling up robust, grid-integrated renewable systems will be essential to strengthen energy security and reliability.

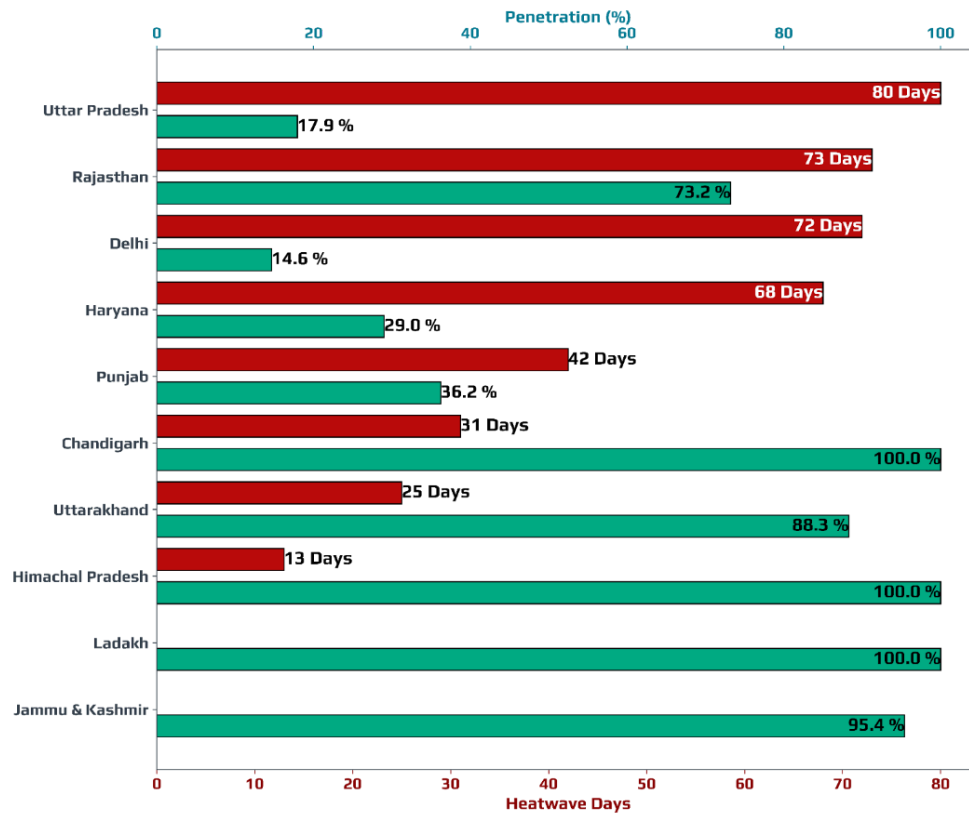


Figure 52: Renewable penetration as of 2024 and heatwave days in 2024 for the northern zone

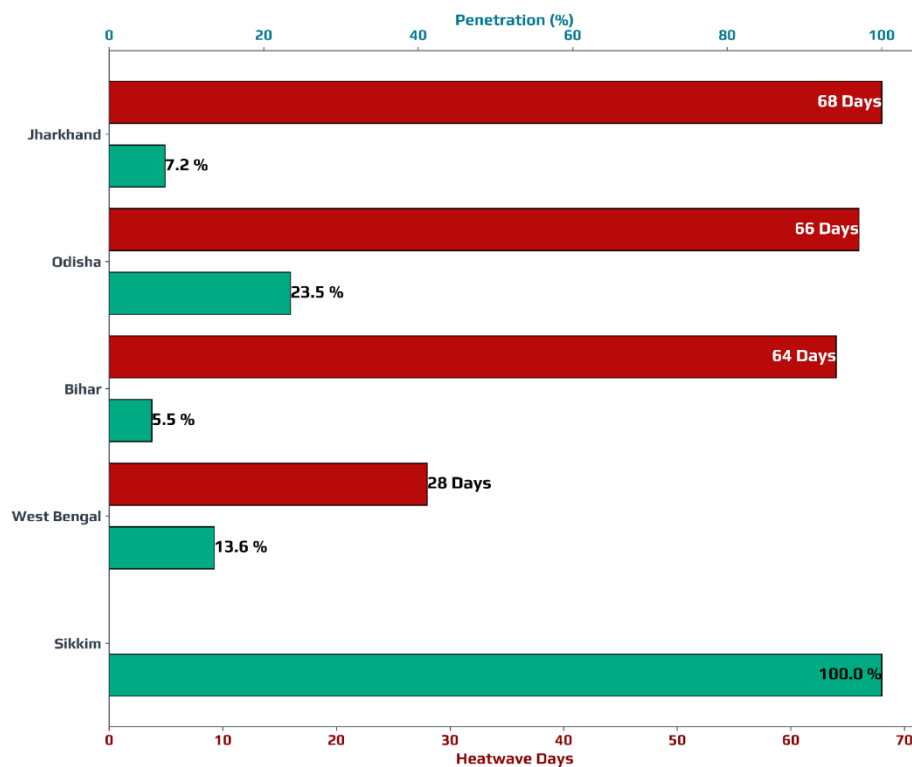


Figure 53: Renewable penetration as of 2024 and heatwave days in 2024 for the eastern zone

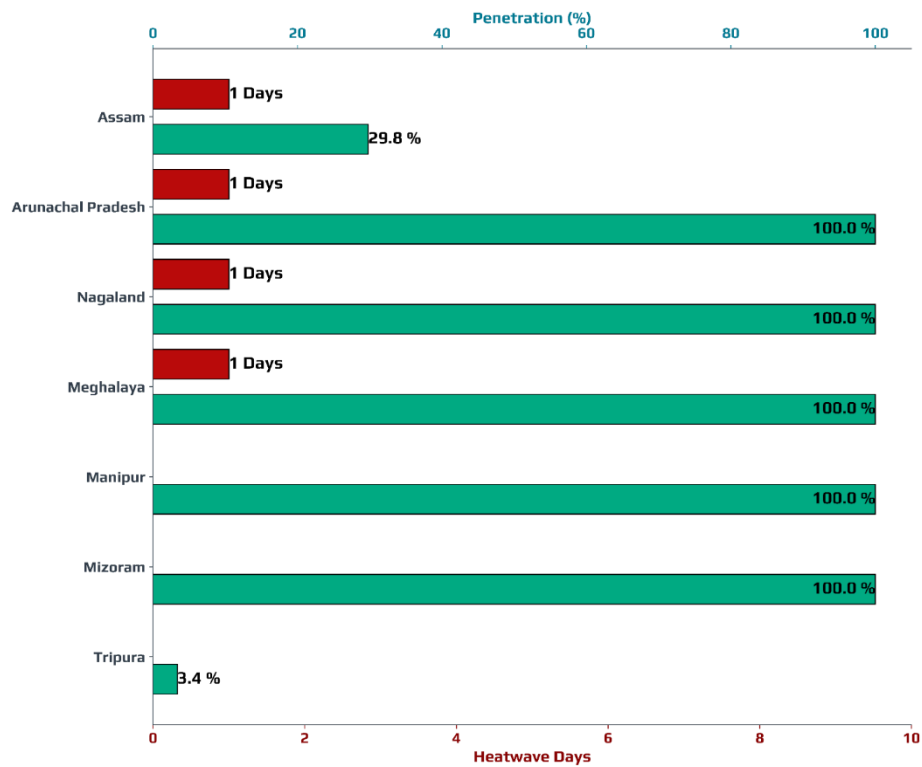


Figure 54: Renewable penetration as of 2024 and heatwave days in 2024 for the north-eastern zone

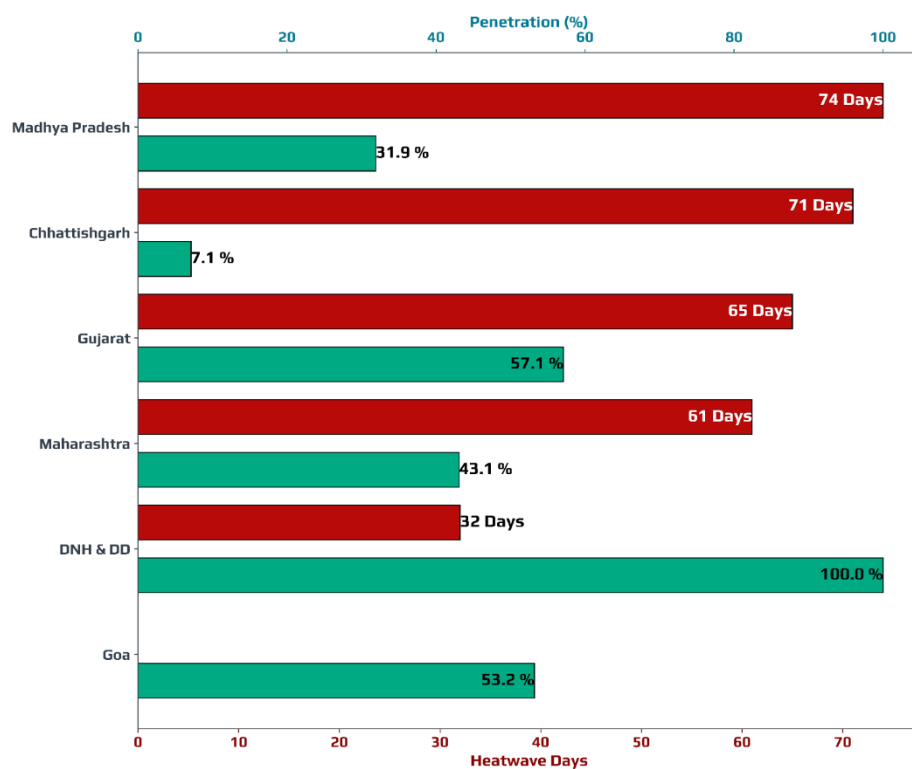


Figure 55: Renewable penetration as of 2024 and heatwave days in 2024 for the western zone

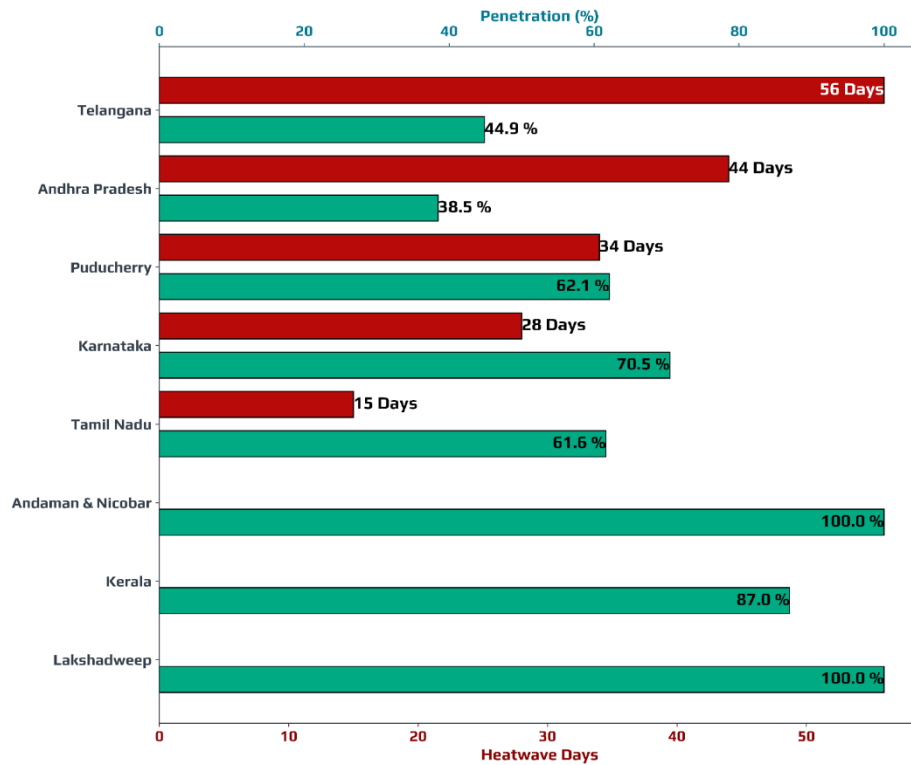


Figure 56: Renewable penetration as of 2024 and heatwave days in 2024 for the southern zone

Overall, the assessment indicates that resilience planning is crucial because Northern and Western India, which have the most renewable potential, also experience the highest levels of climate stress. Replicable examples for integrated, low-risk renewable expansion across India are provided by the Southern and Northeastern regions, which stand out as hotspots for both climate stability and renewable advancement.

6. Policy Analysis: Heatwaves and Electricity in Heat Action Plans (HAPs)

Heatwaves have become increasingly frequent and severe across India, creating multifaceted challenges that cut across public health, energy infrastructure, and climate resilience. This policy analysis examines how Heat Action Plans (HAPs) at the state, district, and city levels address the intersection between heatwave preparedness and electricity demand management. It identifies gaps, best practices, and opportunities for strengthening electricity resilience within the broader climate adaptation framework.

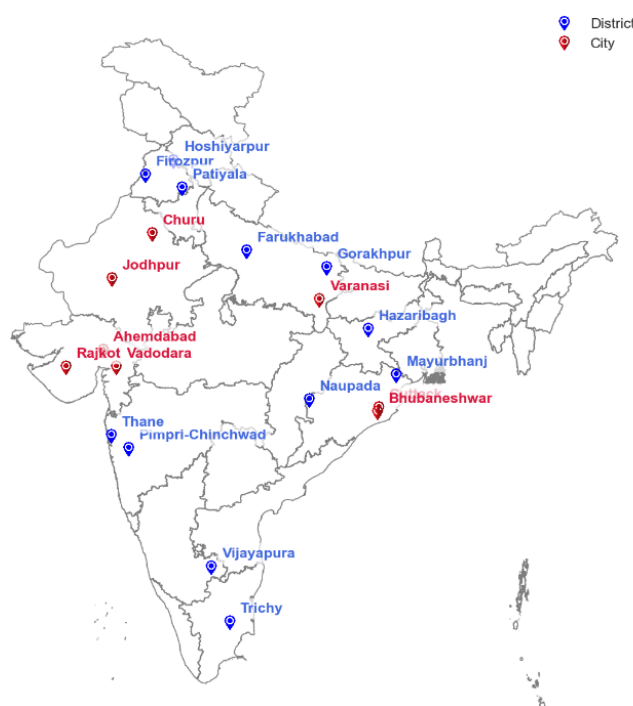


Figure 57: HAP locations

Analytical Framework and Approach

The analysis of Heat Action Plans (HAPs) at the state, district, and city levels focused on understanding how electricity demand is addressed during heatwaves, particularly in terms of preparedness for peak load conditions. Using these HAPs as primary sources, the study employed a structured keyword-based review of terms related to electricity, load planning, and backup systems. Data were organized and analyzed through comparative scoring, categorizing each plan from Level 0 to Level 4 based on the depth of electricity planning. This approach enabled a comprehensive comparison across regions, highlighting variations in how effectively electricity resilience is integrated into heatwave preparedness strategies.

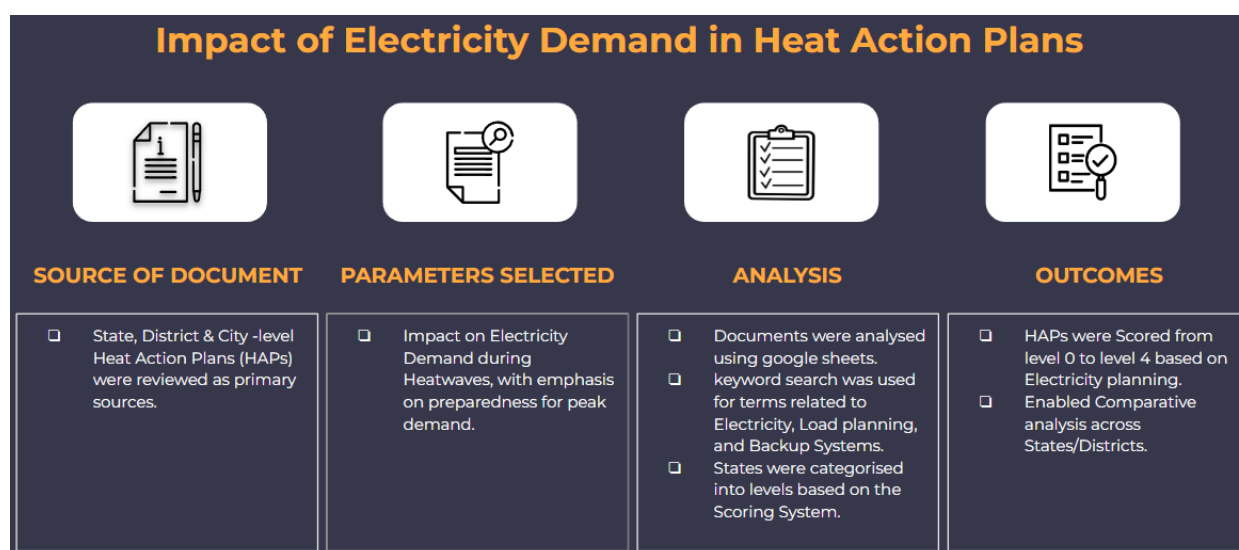


Figure 58: Impact of electricity demand in HAP

The assessment focused on three parameters:

1. Power Demand Surge Recognition – acknowledgment of rising electricity demand and grid stress during heatwaves.
2. Operational Preparedness and Continuity – mechanisms ensuring uninterrupted electricity supply during extreme heat events.
3. Integrated Electricity Planning and Strategic Management – long-term measures promoting sustainable, resilient power systems.

Figure 48 categorizes the extent of electricity-related planning in Heat Action Plans (HAPs) across different administrative levels-State, District, and City-under three major themes: Power Demand Surge Recognition, Operational Preparedness and Continuity, and Integrated Electricity Planning and Management [47-60].

Categories	State	District	City
	Gujarat, Odisha, Telangana, Rajasthan, Delhi, Karnataka, Bihar, Kerala	Nuapada , Vijayapura, Trichy, Vellore, Firozpur	Vadodara, Rajkot, Ahmedabad, Surat, Cuttack, Jodhpur, Churu, Varanasi, Thane
	Gujarat, Odisha, Telangana, Rajasthan, Delhi, Karnataka, Tamil Nadu, Bihar, Goa, Himachal Pradesh, Kerala, Haryana, Uttar Pradesh	Mayurbhanj	Ahmedabad, Surat, Cuttack, Bhubaneshwar, Jodhpur, Churu, Varanasi, Thane
	Odisha, Telangana, Rajasthan, Delhi	Mayurbhanj, Vijayapura, Trichy, Vellore, Firozpur, Patiyala	Rajkot, Ahmedabad, Surat, Cuttack, Bhubaneshwar, Jodhpur, Churu, Varanasi, Thane

Figure 59: HAPs that acknowledge rising electricity demand and potential stress during heatwaves

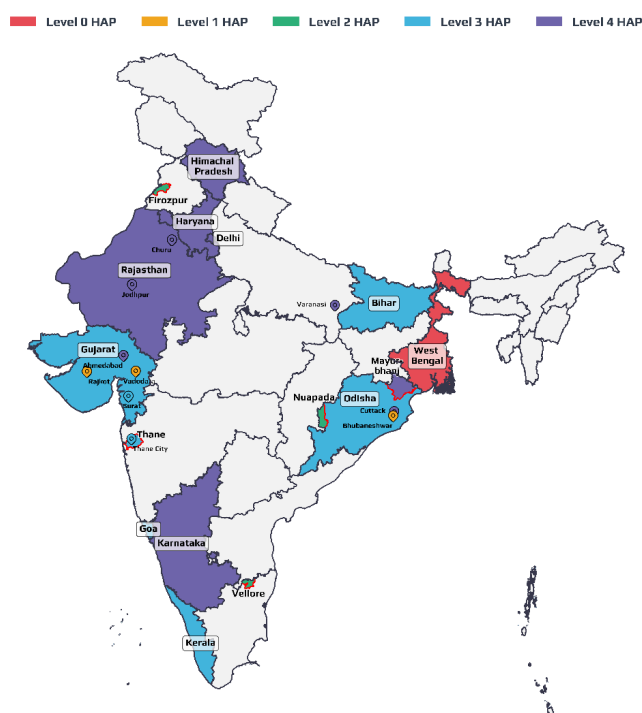


Figure 60: Geo-Location for HAPs

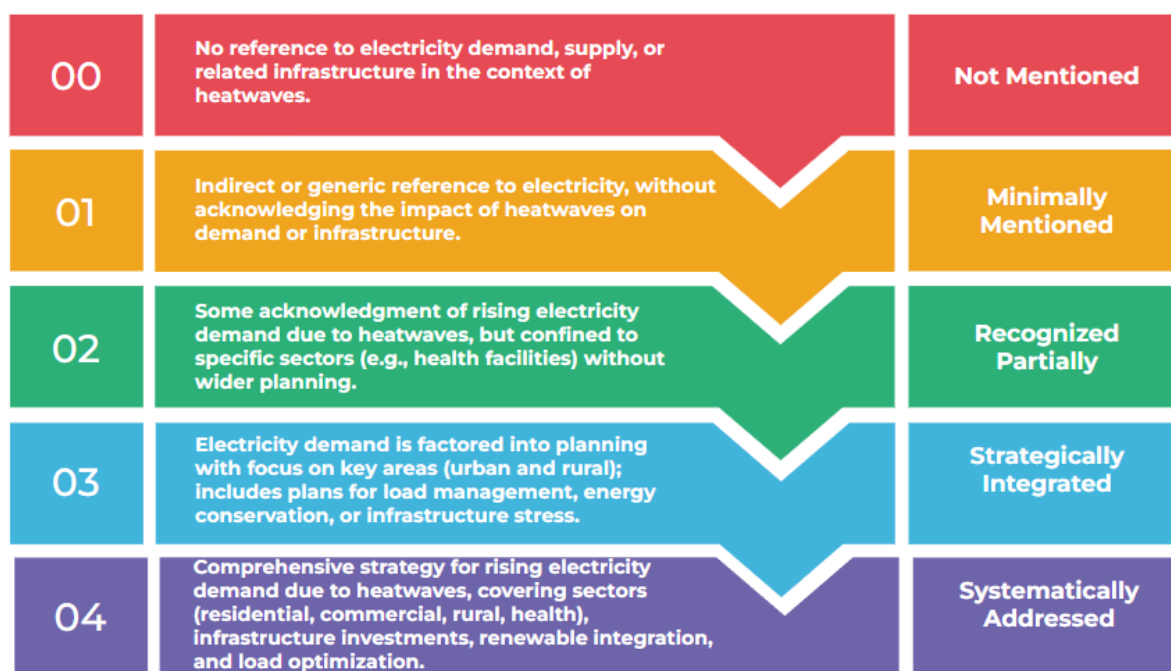


Figure 61: Categorizes Classification for HAPs Study

The comparative analysis revealed great diversity: some states and cities systematically acknowledged rising demand and instituted operational protocols, while others showed gaps, especially where electricity issues were confined to hospitals or omitted entirely.

Key Insights:

Heat Action Plans (HAPs) across India have started incorporating electricity management to address the growing risks posed by frequent and intense heatwaves. These plans recognize increased power demand during heat events, especially in critical sectors like health, water, and cooling.

While some HAPs include specific projections and operational strategies, such as maintenance, load management, and backup power, others reveal gaps due to limited or short-term approaches. Notably, leading HAPs are advancing with renewable energy integration and multi-sectoral coordination, though long-term planning and equity remain areas needing further attention.

- Most HAPs note increases in electricity demand during heatwaves, but some states, such as West Bengal, lack specific strategies for demand recognition.
- City-level HAPs link power needs to water scarcity and other local factors, offering more targeted planning.
- Strategies include pre-summer repairs, transformer maintenance, load-shedding, and ensuring priority supply for hospitals and critical infrastructure.
- Backup solutions focus on temporary generators, emergency centers, and shelters, though rapid solutions tend to dominate over strategic strengthening.

- Coordination among local authorities, electricity boards, and municipal bodies is seen, but it often varies in effectiveness.
- Some HAPs demonstrate innovative operational continuity through renewable energy adoption and efficiency measures, yet multi-level coordination and long-term strategies are less consistent across plans.

7. Key Recommendations

The analysis highlights the urgent need for integrated planning and systemic action to address the rising interlinkages between climate change, heatwaves, electricity demand, and emissions. The following recommendations outline practical and policy-level measures to enhance energy resilience, reduce emissions, and strengthen adaptive capacity across sectors and regions.

Localized Demand Mapping:

- India's heat vulnerability and electricity demand vary significantly across states and districts. To enable effective planning, state governments and utilities should develop district-level electricity demand maps for heatwave months. These maps must integrate temperature forecasts, demographic data, and cooling load profiles to identify high-risk "demand hotspots."
- This granular mapping will help policymakers anticipate peak loads, guide targeted infrastructure development, and prioritize investments in renewable generation, distributed energy systems, and storage solutions in areas where heat exposure and grid stress intersect. Incorporating these insights into state-level power planning will allow for more proactive and adaptive management during extreme heat months.

Strengthen Rural Resilience

- Rural areas, where nearly half of India's workforce is engaged in agriculture, face risks from heat exposure and limited electricity access. Strengthening resilience requires deployment of decentralized renewable microgrids powered by solar energy and supported with battery storage to ensure continuous supply for essential services, particularly cooling centers, water systems, and healthcare facilities, during grid outages.
- Establishing community cooling centers equipped with solar power, water supply, and basic healthcare will help prevent heat-related health crises. Additionally, installing solar backup systems for schools, clinics, and water pumps in heat-prone districts can maintain essential services during high-demand periods, ensuring that rural populations are not left behind in the national adaptation strategy.

Urban Heat Preparedness

- Rapid urbanization and rising heat island effects require immediate attention to urban design and energy planning. All urban development plans in heat-prone states should mandate cool roof programs, promoting reflective and energy-efficient roofing materials to lower indoor temperatures and reduce cooling energy use.
- Cities should also expand green and shaded public spaces, tree-lined streets, and pedestrian corridors that reduce ambient heat levels and provide safe zones during extreme temperatures.
- Additionally, it is essential to create solar-powered cooling shelters in densely populated residential areas, especially in low-income and informal

communities, to provide shelter, water, and medical assistance during extended heatwaves. These actions both alleviate strain on the grid and protect city residents from heat-related stress.

DISCOM Capacity Building

- Distribution companies (DISCOMs) function at the forefront of heat resilience and must be equipped with both technical and financial capabilities to manage escalating summer peaks. Targeted capacity-building programs should focus on anticipatory load management, enabling utilities to forecast heat-driven surges and adjust operations in advance.
- Investments are also needed for the upgradation of the transformer, deployment of predictive monitoring systems (such as thermal and load sensors), and training of emergency response teams for rapid repairs during high-demand periods.
- Establishing dedicated funding channels, through climate finance, central grants, or regulatory mechanisms, will ensure that DISCOMs can modernize infrastructure without burdening consumers. Strengthening grid reliability during heatwaves is crucial for preventing widespread outages and maintaining public safety.

Cross-Sector Planning and Integration

- Electricity resilience cannot be planned in isolation as heatwaves simultaneously stress water supply, agriculture, and public health systems, making integrated cross-sector coordination essential. Collaborative planning frameworks between the energy, water, and agriculture departments should promote time-of-use irrigation schedules aligned with solar generation peaks and encourage solar-powered water pumping to reduce grid demand during peak hours.
- The health sector must also be integrated into electricity planning since all healthcare facilities, particularly hospitals and primary health centers, should be prioritized for uninterrupted power supply and equipped with renewable backup systems. State and district disaster management authorities must establish unified response frameworks that link power restoration, healthcare delivery, and community outreach during heat emergencies.

Strengthening Heat Action Plans (HAPs)

- The analysis of existing Heat Action Plans reveals significant gaps in integrating energy planning with heatwave preparedness. To address these, the following policy measures are recommended:
- Strengthen Demand Forecasting and Surge Identification: Heat Action Plans (HAPs) should integrate quantitative models to predict peak electricity demand during heatwaves, backed by the analyses of temperature demand data and spatial mapping of vulnerabilities. Identifying electricity-stressed wards and communities dependent on heat-sensitive services (e.g., healthcare, water supply) will enable targeted preparedness measures. Linking these forecasts

with health and water sector planning can ensure that interdependent systems operate reliably under extreme conditions.

Integrate Strategic and Long-Term Energy Planning

- Achieving heat resilience necessitates a forward-looking approach that is integrated into the sustainable energy transition. HAPs should encourage the use of renewable energy sources in cooling applications, including solar-powered air conditioning and decentralized storage for public infrastructure. The implementation of Energy Conservation Building Codes (ECBC) and the incorporation of energy efficiency criteria in urban planning are crucial to diminish long-term cooling demands. Effective electricity management must be fully incorporated into multi-sectoral resilience strategies, ensuring alignment with health initiatives.

These recommendations provide a practical framework for transforming India's power sector into a robust and climate-aligned system. The execution of these actions will necessitate strong collaboration among central and state authorities, utilities, urban and rural planners, and local communities. By aligning energy policy with climate adaptation, India has the opportunity to enhance resilience against heatwaves, lower emissions, and build a more equitable and sustainable energy future.

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BREAKING THE CYCLE

CAN INDIA ESCAPE THE HEAT-POWER DEMAND TRAP?

A DECADAL ANALYSIS OF
TEMPERATURES AND POWER

CLIMATE TRENDS
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NOVEMBER 2025