Powering through the heat: how 2024 heatwaves reshaped electricity demand

Extreme heatwaves in the world's three largest electricity markets - China, the US and India, had a measurable impact on electricity demand, contributing to a surge in fossil generation.

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About

Many countries across the world sweltered under severe heatwaves in 2024. Extreme heat events drove air conditioner use to a record high, increasing electricity demand and putting pressure on grids. However, the precise impact of heatwaves on power consumption has until now remained unquantified. Ember has developed a methodology to estimate the global impact of high temperature on electricity demand. The present report zooms in on the role of air cooling in the three largest power markets - China, the US and India - though the implications are worldwide.

Highlights

37%

Cooling accounted for an estimated 37% of the increase in US electricity demand during April-September 2024 vs April-September 2023.

2x

Cooling doubled the year-on-year increase of China's electricity demand in August and September and contributed to the entire year-on-year increase of US demand in June.

59%

The share of China's annual coal generation growth that occurred in just August and September, due to extreme cooling demand.

Executive summary

Heatwaves drove a surge in electricity demand in 2024

Cooling demand soared during hot periods in the world's three largest electricity markets in 2024, contributing to sharp increases in fossil fuel generation and exposing the urgent need for cleaner energy systems.

Hotter weather during summer 2024 significantly increased electricity demand across the largest markets in the world, highlighting the growing challenge of extreme weather for power systems worldwide.

Across the world's three largest electricity consumers—China, the United States and India—heatwaves added tens of terawatt-hours to electricity demand during critical summer months. These countries, which accounted for 53% of global electricity demand in 2023, offer insights into how climate change is reshaping energy trends.

01 Hotter weather led to more power consumption in summer 2024

Hotter weather in the three largest electricity markets in the world - China, the US and India - was a key factor in driving increased electricity demand in summer 2024. According to Ember's calculations, 37% of the increase in electricity demand in the US from April to September 2024, compared to the same period in 2023, was due to higher air cooling needs. Air cooling accounted

for 31% of the April to September year-on-year demand increase in China and 19% in India.

02 Heatwaves were the main drivers of demand growth in some months

Air cooling needs driven by heatwaves significantly increased demand in specific months - August and September in China, June in the US and May in India. Cooling doubled the year-on-year demand increase in China during August and September 2024. It also accounted for the entire year-on-year demand increase in the US in June 2024. In India, increased air cooling contributed an estimated 30% of the year-on-year demand increase from April to June 2024 compared to the same period in 2023 and over a third of the demand increase in the month of May alone. With rising AC ownership, the impact of high temperatures is expected to intensify in the future.

03 Coal generation surged to meet heatwave-driven demand

The months most affected by hotter weather saw a significant year-on-year increase in coal generation - and in the US, a year-on-year rise in gas generation - to meet the higher electricity demand. Coal generation in China grew by 4.4% in August 2024 and 10% in September 2024, compared to the same months in 2023. In the US, coal rose by 6.4% year-on-year in June, along with a 4.6% increase in gas generation. In India, coal met 70% of the year-on-year demand increase in May.

These three countries were not the only ones affected by hot weather events. Countries like Japan, Australia, Mexico, Greece and the UK also experienced heatwaves in 2024, highlighting the global scale of this challenge. According to

the Intergovernmental Panel on Climate Change (IPCC), human-induced greenhouse gas emissions are the main driver of more frequent and severe heatwaves, with hot temperature extremes expected to intensify further, even if global warming is stabilised at 1.5°C. As air conditioning ownership grows, particularly in the Global South, cooling demand during heatwaves will increasingly drive up electricity demand.

Relying on fossil fuels to meet rising electricity demand is a losing strategy. It is bound to further accelerate climate change, driving even more severe and frequent heatwaves. Renewable energy sources, especially wind and solar, due to their rapidly falling costs and scalability, offer an opportunity to meet rising electricity demand in the cheapest way, while also avoiding a large rise in emissions.

Extreme heat events, driven by climate change, are becoming more frequent and intense. 2024 was the hottest year on record, with heatwaves causing massive spikes in electricity demand—and the pressure will only grow as the planet warms. The solution is twofold: scale up efficient AC adoption to cut costs and ease peak demand, and invest in clean, flexible power to keep grids resilient as extreme weather intensifies. The crisis is accelerating—our response must, too.

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Chapter 1: Heatwaves Raised Electricity Demand in 2024

Heatwaves measurably increased electricity demand in 2024

The largest electricity consumers in the world experienced extreme heatwaves in 2024, leading to sizable increases in electricity demand.

In 2024, record-breaking heatwaves swept the world. In particular, China, the US and India - the world's three largest electricity markets, which together account for over half of the global demand, experienced significantly warmer temperatures. This led to higher air conditioning usage and therefore, higher electricity consumption. After some milder-than-normal summer temperatures in 2023, the year-on-year changes were particularly large.

Heatwaves scorched largest electricity consumers as 2024 becomes warmest year ever

2024 turned out to be the year of heat, with temperatures soaring to record breaking points across the world. There were a few months that saw prolonged and intense heatwaves – August and September in China, June in the US and May

in India. But heatwaves do not automatically drive up electricity demand - for that, they need to happen in populated areas.

To capture this, we calculated population-weighted temperatures - in other words, the temperature experienced by people living in a given locality. We divided each country into small squares, 30 km by 30 km. In each square, we looked at two things—how hot it got and how many people live there. This way, our results reflect the impact of increased air conditioning on electricity demand.

China

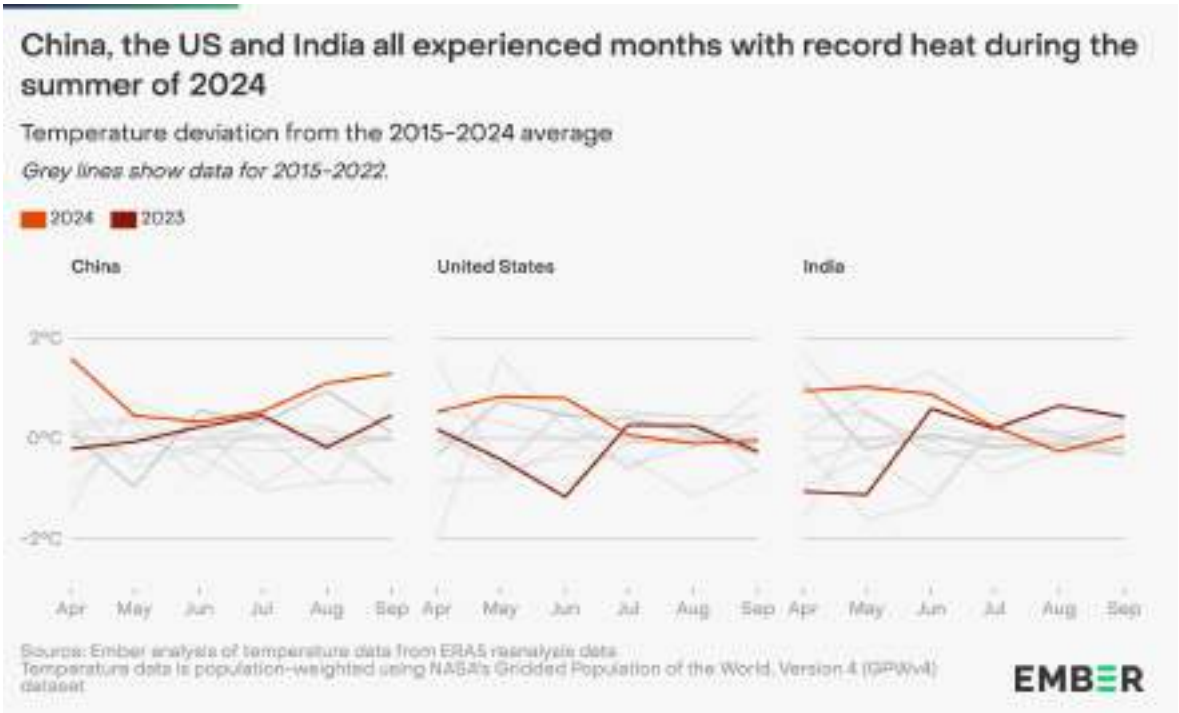
2024 was China's hottest year on record, with densely populated regions in the south and east of the country bearing the brunt of summer heatwaves. The average population-weighted temperatures in August (26.5°C) and September (23.1°C) were higher than any other August and September of the last 10 years, also marking a notable increase from 2023.

United States

The US also experienced its hottest year on record in 2024. June 2024 saw population-weighted temperatures rise to 23.8°C, the highest for the month in the past decade. It was also a sharp 2°C increase from June 2023 (21.8°C) which had recorded the lowest average June population-weighted temperatures in the last decade.

India

India endured an extreme heatwave season from April to June 2024, with northern and eastern regions experiencing double the usual number of heatwave days. This period saw some of the highest population-weighted temperatures in a decade, averaging 30.9°C—a sharp 1.5°C increase compared to April-June 2023. May 2024 was the hottest, with temperatures averaging 31.7°C - a 1°C increase from May 2023.



Countries saw a surge in cooling demand

The heatwaves in 2024 led to higher year-on-year growth in electricity demand across all three countries, highlighting the impact of extreme weather events on power systems worldwide. Similar impacts are likely in other countries that faced severe heatwaves last year.

China

From April-September 2024, China's electricity demand rose by 7% compared to April-September 2023, with an estimated 31% of this year-on-year growth driven by hotter temperatures. The impact was especially pronounced during August and September. Ember estimates that demand would have grown by just 4% year-on-year in August but cooling needs added another 5%, pushing monthly demand 9% higher than the previous year - more than doubling it. In September, cooling needs caused the year-on-year demand increase to double, from 4.4% to 9%.

United States

In the US, electricity demand from April-September 2024 was 3.3% higher than the same period in 2023 with an estimated 37% of the increase attributed to hotter temperatures. The impact was especially evident during the June heatwaves. Ember estimates that demand in the country would have fallen by 1.3% in that month but cooling needs resulted in a 9.4% rise instead.

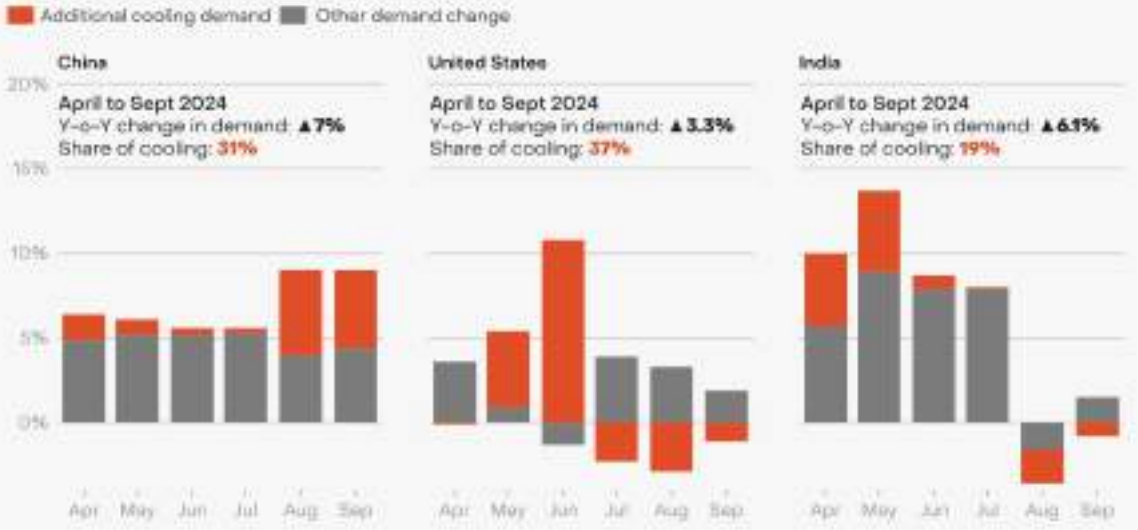
India

In India, electricity demand during April-September 2024 was 6.1% higher than April-September 2023. An estimated 19% of this increase can be attributed to hotter temperatures compared to 2023. From April to June 2024, when heatwaves were particularly severe across the plains, electricity demand in India was 10.8% higher than in the same period last year. This was primarily driven by economic growth, with air conditioning accounting for an estimated 30% of the year-on-year increase. In May, cooling was responsible for more than one-third of the year-on-year demand increase.

Overall, the impact of higher temperatures in 2024 compared to 2023 on India's electricity demand was less pronounced than for the US and China, likely due to unmet cooling needs. As air conditioning ownership continues to rise, the impact of extreme heat on India's electricity demand is expected to become even more pronounced in the future.

Heatwaves in the US, China and India led to higher year-on-year electricity demand growth in summer 2024

Electricity demand change in 2024 vs 2023 by contributing factor, %



Source: Monthly electricity data, Ember; Ember analysis of temperature effects on electricity demand. January and February data in China are reported together by the CEC. Demand changes are split equally over both months

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Chapter 2: Heatwaves Drove Coal Surge

The heatwaves led to large rise in coal generation

There was a significant rise in coal generation - and also a smaller rise in gas generation - to meet the surge in electricity demand during the 2024 heatwave months.

Countries are investing in renewable energy sources to meet increased electricity demand, but big and unexpected surges can mean more fossil generation at times. The heatwaves of summer 2024 led to a rise in fossil generation in China, India and the US - in particular coal in China and India and gas in the US.

China: heatwave-driven demand fuelled coal surge

In August 2024, electricity demand was 79 TWh (9%) higher than August 2023, with cooling needs contributing 44 TWh of this surge. Clean generation was 54 TWh higher in August 2024 than in August 2023, leaving a 25 TWh shortfall that was primarily met by coal. Coal generation was 4.4% higher year-on-year in August, more than double the 2024 annual average increase (+2%).

In September, electricity demand was 70 TWh (9%) higher than September 2023, with cooling needs accounting for 36 TWh. Clean generation in that month grew

by only 24 TWh, limited by a 19 TWh decline in hydro outputs due to a drought in the country. To meet the demand surge, coal generation jumped even more sharply, increasing by 44 TWh (a 10% year-on-year rise) and covering 63% of the year-on-year demand growth in that month (and more than 100% of the increased demand contribution from cooling).

Across August and September, coal generation increased by a combined 68 TWh, accounting for 59% of the total annual increase in China's coal generation (115 TWh).

United States: heatwaves boosted coal and gas generation

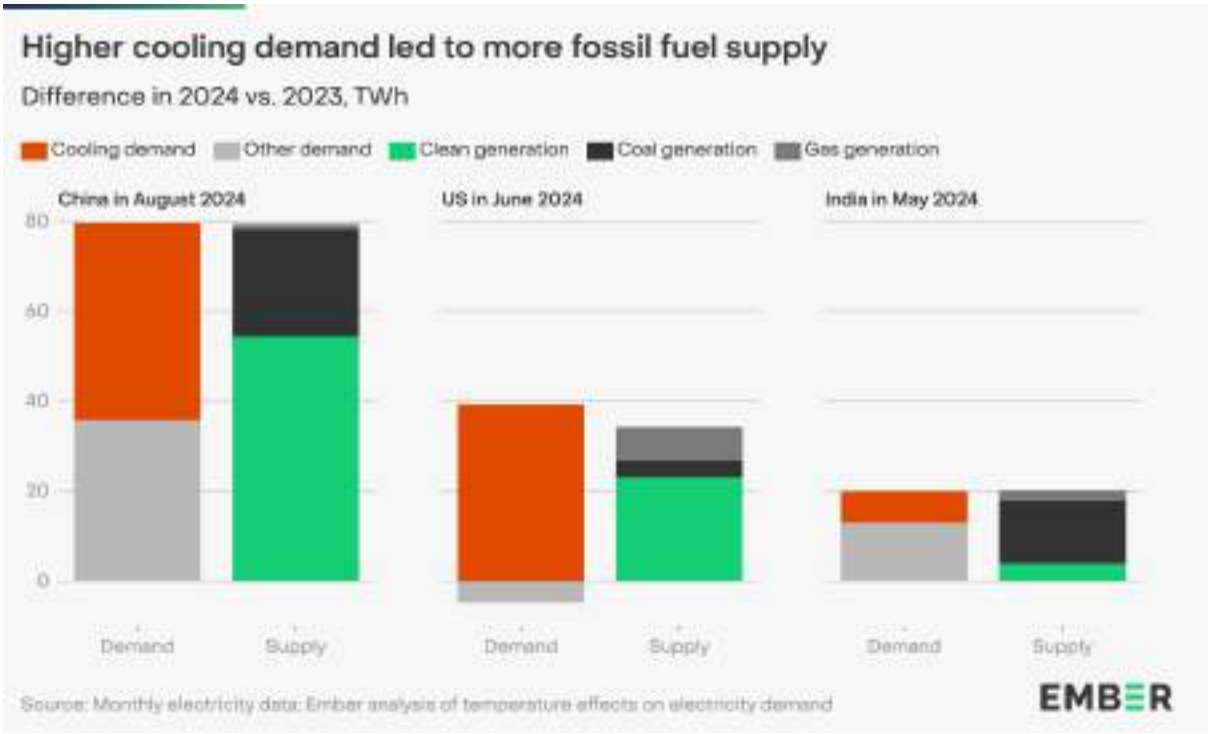
In June 2024, heatwaves hit the United States. The electricity demand this month was 35 TWh (+9.4%) higher than June 2023, with cooling demand adding a substantial 39 TWh, turning a small fall in demand into a substantial rise. Clean generation was 23 TWh higher than the previous year, meeting more than two thirds of the increase (67%), with gas (+7 TWh) and coal (+4 TWh) rising to cover the rest.

Gas generation rose by 4.6% year-on-year in June, noticeably higher than the 2024 annual average increase (+3.7%). Coal generation increased by 6.4% year-on-year in June marking the third largest rise of the year, following January (+23%) and December (+11%). Without the additional 4 TWh year-on-year increase of coal generation in June, US coal generation would have declined by 4% in 2024. Instead, the demand surge during the heatwave limited the decline to 3.5%.

India: coal met majority of demand increase

India experienced a prolonged heat spell in summer last year. In May 2024, India's electricity demand was 20 TWh higher than May 2023 - the largest year-on-year increase in a single month in all of 2024. Ember estimates that hotter temperatures contributed 7 TWh out of this 20 TWh increase. Unlike in China and the US, where heatwaves led to sharper spikes in electricity use, the contribution of cooling to year-on-year demand growth in India was less pronounced — but still significant.

Clean generation met 19% of the extremely high year-on-year demand increase in May 2024, while coal continued to be the primary source, meeting 70% and gas, the rest. As heatwaves become more frequent and AC ownership rises, ensuring sufficient electricity supply to meet cooling needs is a major challenge in India.



Conclusion

The growing impact of heatwaves

Relying on fossil fuels to meet growing power demand exacerbates climate change and fuels even more frequent and intense heatwaves.

In 2024, the world experienced its hottest year ever recorded, with global temperatures surpassing pre-industrial levels by more than 1.5°C (1.55°C) for the first time. Behind the calculated rise in average temperatures, however, lies a reality of more frequent and intense hot extremes, including prolonged and life-threatening heatwaves worldwide. Climate change, driven by human-induced greenhouse gas emissions, has made these extreme heat events more likely, frequent and severe. Going forward, hot temperature extremes will continue to intensify and become more recurrent as global temperatures rise. Their severity is projected to double at 2°C of warming and quadruple at 3°C—with an intensification virtually certain even if warming stabilizes at 1.5°C.

The rise in heatwaves is driving sharp spikes in electricity demand, particularly due to the widespread use of air conditioning. This trend is found in OECD countries and is also becoming more pronounced in the Global South, where rapid urbanization and unrelenting heat are leading to a surge in AC ownership.

To address the growing challenge, three policy responses could help mitigate future risks:

- Energy-efficient air conditioners: Encouraging the sale of more efficient air conditioners is crucial. Current models often operate at half the efficiency of the best available technology, but cost barriers prevent many from

upgrading. Incentivizing energy-efficient units can help reduce the strain on the grid.

- Rooftop solar: Promoting rooftop solar offers households and businesses the potential to generate cheaper, cleaner electricity. During peak demand hours, when cooling needs are highest, solar power can help reduce reliance on the grid and provide a sustainable solution for powering air conditioners. Since peak demand often extends into the evening, batteries can help store solar energy for later use, ensuring a smoother, more efficient power supply.

- Improved retail pricing: With the advent of cheap solar, retail electricity should be priced more cheaply in the day to give access to cheaper cooling. There should also be incentives to reduce use during rare crunch moments of supply-demand tightness and therefore avoid blackouts and reduce the need for costly backup generation. This could be through an alert system; for example, in India, consumers can sign up for text alerts to cut demand at critical times, earning rewards while reducing reliance on spare coal power plants.

It is a global imperative to improve access to cooling and to make cooling affordable. Relying on fossil fuels to meet increasing cooling demand is a losing strategy. It exacerbates climate change, fuelling more frequent and intense heatwaves. The best way to do this is with a combination of efficient air-conditioners, solar and improved retail pricing.

Supporting Materials

Methodology

Overview

This methodology outlines the approach used to quantify the impact of temperature on monthly electricity demand, focusing on population-weighted temperature data and the specific effects of heatwaves in the United States, China and India. By using regression analysis with temperature data and electricity demand, this analysis isolates temperature-driven variations from structural changes in electricity consumption.

Data Sources

Meteorological Data: Temperature data was sourced from the ERA5 reanalysis via Open-Meteo, providing hourly temperature readings.

Electricity Demand Data: Monthly electricity demand data was obtained from Ember's monthly electricity data.

Population Data: Population figures were derived from NASA's Gridded Population of the World dataset, with a resolution of 0.25 degrees (30 km).

Time Period: The analysis of temperature effects covers the period from 2015 to 2024, depending on the availability of data for each country.

Calculation of temperature impacts

Normalising Monthly Electricity Demand

Monthly electricity demand was normalised by dividing observed demand by its 12-month trailing average. This process helps to minimize the influence of long-term structural factors such as economic growth or increased electrification, isolating seasonal and temperature-related changes.

Temperature Data

A 1-degree resolution grid was created for each country. Population data was assigned to each grid cell and hourly temperature data was extracted for the centre of each cell.

Population Weighting for temperature and CDD/HDD values

Population weighted temperatures were calculated by weighting temperature for each grid cell by the corresponding population.
Similarly, cooling degree days (CDD) and heating degree days (HDD) values were calculated and weighted using the same approach. This ensures that temperature metrics reflect conditions in populated areas, where electricity demand is concentrated. It also accounts for the non-linear relationship between temperature and energy use. Cooling degree days and Heating degree days were defined as follows:

- Cooling degree days (CDD): The sum of degrees by which daily temperatures exceed
  22°C, reflecting cooling demand.
- Heating degree days (HDD): The sum of degrees by which daily temperatures fall
  below 18°C, reflecting heating demand.

Regression Analysis

To understand the relationship between temperature and electricity demand, we used regression analysis to identify how changes in temperature, measured through Cooling degree days and heating degree days, influence electricity demand per country. The analysis helps quantify the extent to which higher or lower temperatures drive changes in monthly electricity use.

Calculating Temperature Deviations

Monthly deviations in temperature that are most relevant to electricity demand were calculated using Cooling degree days (CDD) and heating degree days (HDD). Deviations were calculated as the difference between observed CDD/HDD and the 10-year monthly averages (2015–2024), establishing a baseline for identifying anomalies.

Calculating Absolute Impact

The actual impact of temperature variations was derived by applying the identified relationship of CDD and HDD data and monthly electricity demand to the deviations in CDD and HDD values from the 10-year averages. These impacts were then translated into absolute figures (TWh), by scaling using the normalised demand. This report focuses on the impact of hotter temperatures and cooling degree days in summer months.

Acknowledgements

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Cover image

Electricity Transmission towers with High Tension wires in India, for distribution of electric power and supply, and a background of rural countryside during golden hours of sunset. These towers are used to transmit electricity for long distances.

Credit: wassup6730 / Alamy Stock Photo