Safeguarding data centers in an era of climate risk

RAMBOLL

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Sustainable change.

Introduction

Data centers are fundamental to the digital economy. However, climate risk significantly threatens their reliability. Increasingly frequent and severe heatwaves, floods, increasing energy costs, and other climate hazards jeopardize not only the operations of these centers but also the regional resources upon which they depend. Climate change influences both the fixed and operational costs associated with developing and managing data centers. Consequently, it is crucial to incorporate future climate conditions and associated risks into the site selection and design processes of data centers to maintain their reliability and manage costs effectively. This briefing first discusses physical risks relevant to data centers, followed by transition risks.

Climate change and data centers power needs

As we swiftly embrace AI and other computationally intensive technologies, the demand for data processing, storage, and the associated energy requirements has surged. Goldman Sachs estimated that by 2030, the power demand of data centers will be 160% of current rates[1], with energy demand of data centers relative to global energy demand growing from the current 1-2% to 3-4%[2]. In addition, increased computational demand leads to greater heat generation by data center servers. Compensating for this added heat is a challenging task for data infrastructure companies, especially with the intensifying and more frequent heatwaves caused by climate change.

As temperatures climb in the decades ahead,
data centers in cities worldwide will require more cooling.

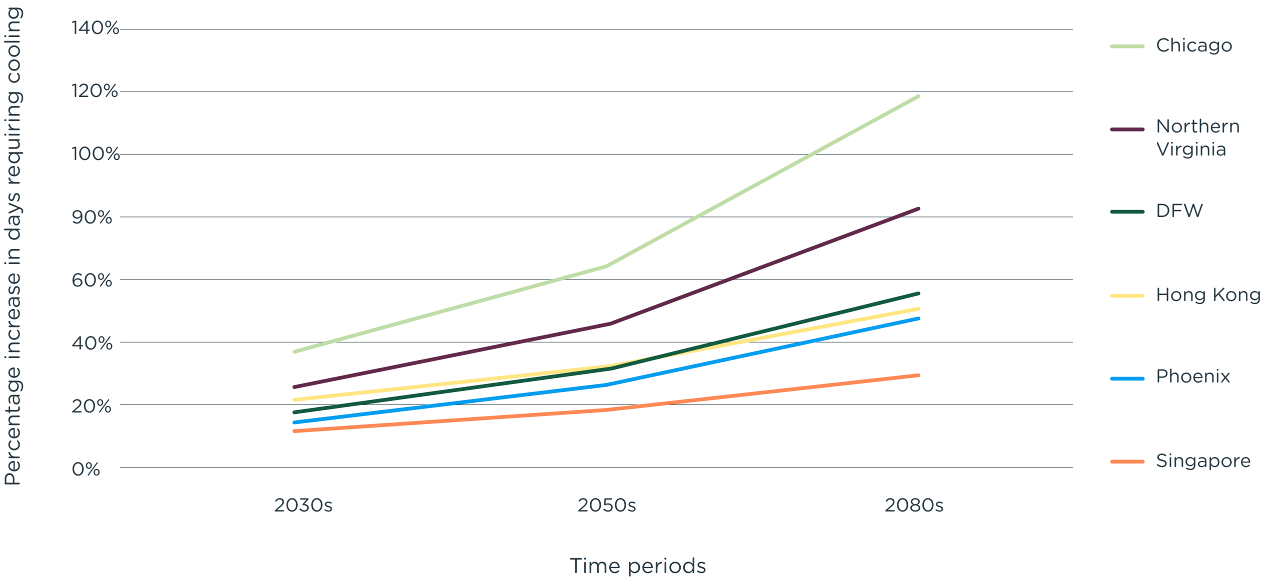


Figure 1: Cooling degree days (% change) relative to 1995-2014 across three time periods for key data center locations
Explanation: Cooling Degree Days (CDDs) represent the demand for cooling in data centers

[1] Goldman Sachs Research, "AI Is Poised to Drive 160% Increase in Data center Power Demand," Goldman Sachs Insights (2025), accessed 12 May 2025.

[2] At present, data centers worldwide consume 1–2% of overall power, but this percentage will likely rise to 3–4% by the end of the decade." Goldman Sachs

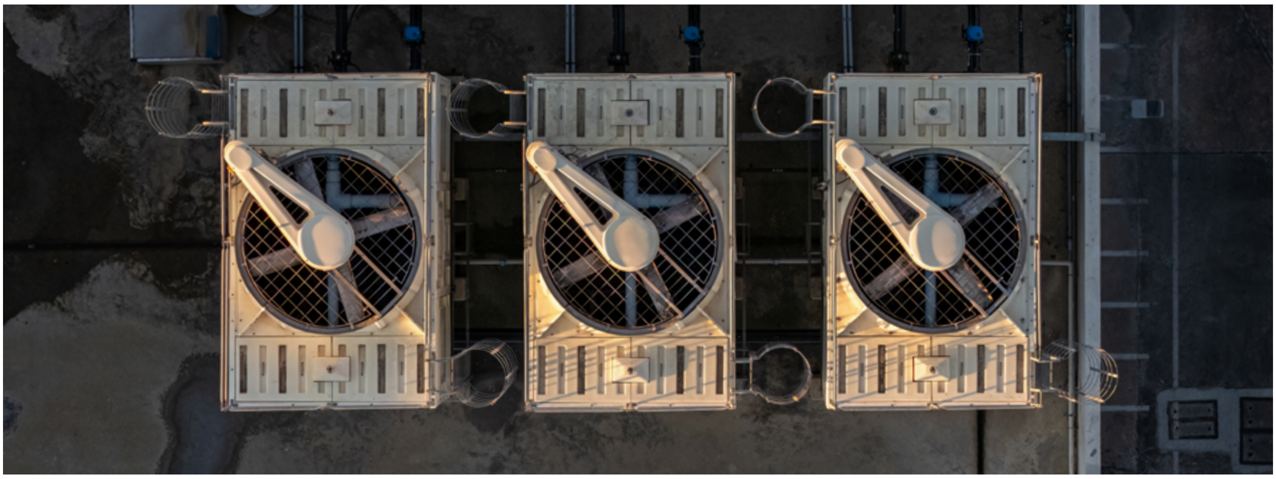
Cooling, power, and resilience under rising temperatures

Cooling server racks already account for ~40% of a typical data center's electricity use, a share confirmed by the U.S. Department of Energy[3]. As rack densities climb to satisfy AI and cloud workloads, that fraction rises, making reliable, efficient heat removal mission critical.

Why today's load forecasts are incomplete

Most capacity planning models simply add the power required for new servers to yesterday's cooling figures, as if the hottest day used to size chillers in 2005 will be exactly the same in 2035[4]. That logic ignores a rapidly warming climate: the ten hottest years on record all occurred between 2014 and 2024, and Intergovernmental Panel on Climate Change (IPCC) scenarios point to further rises in both average temperatures and extreme heat events. Higher mean ambient temperatures lift baseline chiller and fan power, while longer heatwaves erase the overnight "free cooling" window. Northern latitude regions, from the Nordics to the Pacific Northwest and Northern UK, have lured fresh development on the promise of cool air and low-carbon hydropower; but as those areas warm, their competitive edge narrows and weather volatility increases.

Extreme heat places significant stress on the power networks that underpin modern digital infrastructure. As temperatures rise, cooling demand from households, industry, and commercial buildings accelerates, driving systemwide electricity consumption to record levels. Simultaneously, higher conductor temperatures reduce the capacity of transmission lines, while wildfires, equipment overheating, and convective storms jeopardize generation and distribution assets. The result is a challenging paradox: data center operators require additional megawatthours for cooling precisely when the grid's ability to supply reliable and affordable power is most constrained. Recent events illustrate the stakes. In July 2022, unprecedented 40°C conditions in London forced simultaneous shutdowns at Google Cloud's europe-west2 and Oracle's UK South facilities after their cooling systems failed. Two months later, an intense California heatwave took X (formerly Twitter)'s primary U.S. data center offline, forcing rapid traffic rebalancing. Each incident resulted in remediation costs of several million dollars, penalties for missed service levels, and reputational damage—costs that far exceed the incremental investment required to design for enhanced thermal resilience.



[3] U.S. Department of Energy "DOE Announces $40 Million for More Efficient Cooling for Data Centers." Press release, 9 May 2023. "Data center cooling can account for up to 40 % of data center energy usage overall."

[4] 1 ASHRAE Weather Data Viewer v6.0 (Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers, 2021); T. Hong et al., "Implications of Climate Change on Building Energy Consumption," Energy & Buildings 226 (2020): 110392; NASA GISS Surface Temperature Analysis (GISTEMP v4), data retrieved 12 May 2025; IPCC, Sixth Assessment Report, Working Group I, The Physical Science Basis (Geneva: Intergovernmental Panel on Climate Change, 2023).

Weathering the storm
Data centers and extreme weather events

Climate events that impact site selection aren't just limited to extreme heat events:

Flooding risks

Flooding is one of the fastest growing threats to data center continuity, yet many facilities are still designed around historical flood maps rather than forward looking climate projections. A warmer atmosphere can hold roughly 7% more water vapour for every 1°C of temperature rise[5], making heavy rainfall events both more intense and more frequent. The result is a widening gap between yesterday's "100 year storm" and the precipitation extremes a site may face over its 15 to 25 year operating life. Figure 1 illustrates this point: HazAtlas (Ramboll's physical climate risk screening service) uses Fathom's high resolution flood risk data to model a 1 in 500 year fluvial event for a Novato, California facility in 2050, revealing inundation levels well beyond the thresholds employed in many current designs.

Effective assessments distinguish among coastal, fluvial, and pluvial mechanisms. Coastal flooding, driven by sea level rise, storm surge, and tidal amplification, threatens low lying sites near shorelines and estuaries. Fluvial flooding arises when rivers overtop their banks, a risk that is shifting inland as heavier rainfall pushes hydrographs beyond existing levee or channel capacity. Pluvial flooding is geographically ubiquitous: intense downpours can overwhelm storm water systems anywhere, pooling water in parking lots, loading bays, or below grade plant rooms.

Each mechanism demands a tailored response. Coastal and fluvial hazards call for strategic site selection, elevated finished floor levels, and perimeter defenses such as berms or sheet pile walls. Pluvial risk is best mitigated through robust site hydrology, enlarged culverts, engineered swales and retention basins, and hard stand gradients that channel runoff away from critical halls and switchgear. Incorporating future rainfall projections and adequate freeboard into these measures is essential. By embedding such climate adjusted standards into both site selection and engineering, owners can safeguard uptime, protect capital assets, and ensure long term resilience against an increasingly water charged atmosphere.

High-resolution flood mapping reveals future risks

Detailed site-level mapping of extreme flood events, like those projected through 2050 in Novato, California, helps improve spatial planning and strengthen resilience.

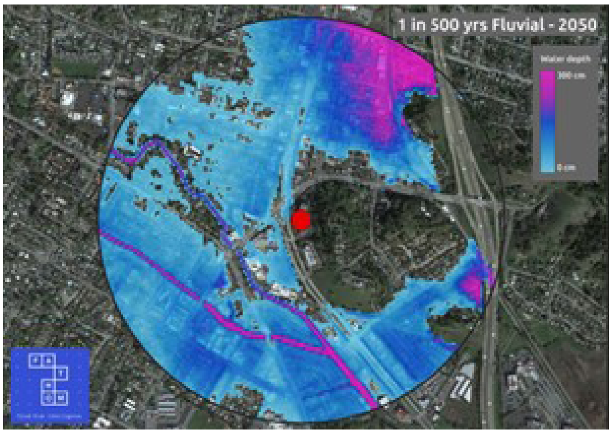


Figure 2: 2050 Flood map for facility in Novato, California provided by FATHOM

[5] IPCC, Sixth Assessment Report, Working Group I, Chapter 8 "Water Cycle Changes" (Geneva: Intergovernmental Panel on Climate Change, 2021), 8 15; see also K. E. Trenberth, "Changes in Precipitation with Climate Change," Climate Research 47 (2011): 123–138, both noting that saturation vapour pressure—and therefore the atmosphere's moisture holding capacity—increases by roughly 7% per °C of warming.

Wildfire threats

Wildfire is now a first order continuity risk for data center operators. Climate change is lengthening fire seasons, drying vegetation and creating more days with “high fire danger,” as illustrated in Figure 3 for the Dallas–Fort Worth market—today the United States’ second largest data center hub. When blazes approach, smoke, soot, and corrosive gases can infiltrate intake air and foul IT equipment long before flames reach the site, while heat related grid failures or precautionary shutdowns can cut utility power for hours or days, which can impact uptime.

The pace of change is striking. In the United States, the National Interagency Fire Center records[6] show that ~166 million acres have burned since 2000, and nearly one fifth of that total—about 32 million acres—was lost in just the past five fire seasons (2019-2023). Europe is seeing a similar surge: European Forest Fire Information System (EFFIS) data indicate that 2022 and 2023 alone consumed more than 1.3 million hectares, roughly one third of everything burned on the continent since the system began keeping harmonized statistics in 2000.[7]

For data center developers and investors, these numbers underscore the need to embed wildfire resilience into siting, design, and operations: enhanced air filtration trains and pressurization strategies, redundant utility feeds or onsite generation that can ride through public safety shutoffs, and detailed emergency response plans that address both staff safety and rapid cleaning after smoke pollution. By treating wildfires as a rising baseline hazard rather than a remote possibility, operators can protect uptime and assets as fire weather intensifies.

Annual number of days with high fire danger

Projected high-fire-risk days under two scenarios:
SSP2-4.5 (moderate-emissions path) and SSP3-7.0 (high-emissions path)

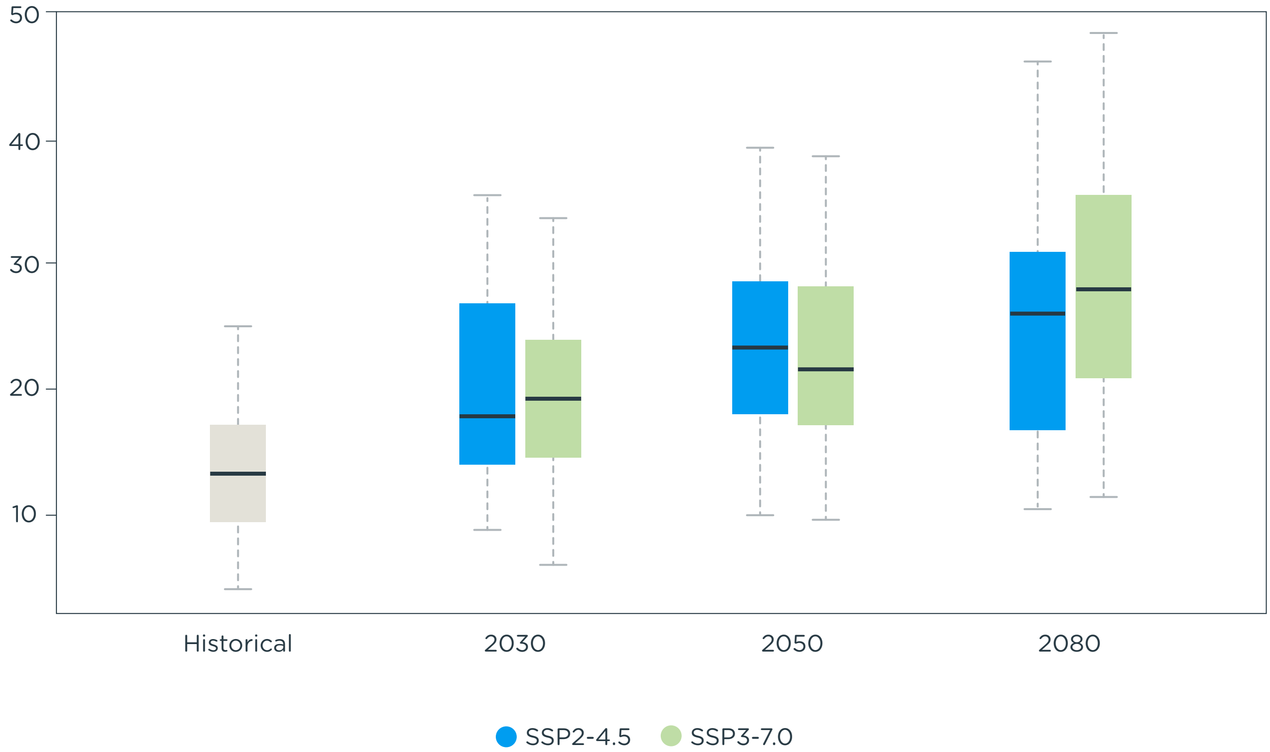


Figure 3: Increasing number of days facing high fire danger for Dallas Fort-Worth, TX

[6] National Interagency Fire Center, “Total Wildland Fires and Acres (1983 2024),” Boise, ID, accessed 13 May 2025. Annual acreages for 2000 2023 sum to ≈ 165 million acres; 2019 2023 alone account for ≈ 32 million acres (≈ 19 %).

[7] European Commission Joint Research Center, Forest Fires in Europe, Middle East and North Africa 2022 (Luxembourg: Publications Office of the EU, 2023), 11; European Commission Joint Research Center, Advance Report on Forest Fires 2023 (Brussels, 2024), 8. EFFIS data indicate 837,212 ha burned in 2022 and 504,002 ha in 2023—together > 25 % of the cumulative EU total mapped since 2000.

3-5
mil. gallons
daily water usage of large data centers for cooling purposes[12]

1 in 5
data centers
source water from watersheds under moderate to high stress[13]

80-130
million gal/yr
data centers source water from watersheds under moderate to high stress[14]

Water-stress risks

Cooling technology now sits at the nexus of two scarce resources: energy and water. Most hyperscale facilities still rely on evaporative chillers or cooling tower loops because they deliver the lowest Power Usage Effectiveness (PUE) on the market. The trade off is water. A single hyperscale campus can withdraw 1–5 million gallons of water per day for evaporative cooling—roughly the demand of a small U.S. town.[8] Even a modest 1 MW data hall, if it relies on a traditional wet cooling system, can still use about 18,000 gallons per day.[9] Operators therefore face a classic resource pivot: reducing electricity and carbon through wet cooling, or preserving water by shifting to air-cooled chillers, liquid loops, or fully closed systems that carry a higher energy premium.[10]

The urgency of that choice is amplified by a warming climate. Higher temperatures accelerate the hydrological cycle, intensifying evaporation and tightening freshwater supplies just as demand from cities, agriculture, and industry grows. Since 2000, the share of the contiguous United States classified as "abnormally dry" or worse has fluctuated between about 20% and 55% in any given week, peaking at 54.8% in September 2012.[11] Similar trends are emerging worldwide, from prolonged drought across southern Europe to multiyear deficits on China's Yangtze River. In water-stressed regions, tighter withdrawal permits or outright moratoria on new allocations can limit a data center's ability to operate wet systems at full load, turning water into a hard capacity constraint.

Forward-looking site selection and design must therefore weigh both kilowatt-hours and kiloliters. Best practice is to pair climate-adjusted water-stress indices with detailed forecasts of local electricity emissions: where water risk is high, air- or liquid-cooled systems with waste-heat recovery can offset the energy penalty; where grids are carbon intensive but water is abundant, a well-managed evaporative approach may still be acceptable. By treating water and energy as a coupled optimization problem, and documenting that calculus for regulators and investors, owners can safeguard uptime and license to operate as global water scarcity accelerates.

[8] Brown Advisory, "The Data Center Balancing Act: Powering Sustainable AI Growth," 18 Sept 2024, notes average hyperscale facilities consume 3–5 million gal day^{-1} for cooling.

[9] D. Mytton, "Data Center Water Consumption," npj Clean Water 4, 11 (2021): fig. 3, stating a 1 MW data center can use ~25.5 million L yr^{-1} under traditional wet cooling.

[10] A. Higgins, "What Is Water Usage Effectiveness (WUE) in Data Centers?," Equinix Blog, 13 Nov 2024, emphasises the energy versus water trade off between evaporative and air cooling.

[11] National Integrated Drought Information System (NIDIS), "Historical Data and Conditions," drought.gov (accessed 13 May 2025), reporting 54.8% of the U.S. in drought in Sept 2012 and weekly minima near 20 % since 2000.

[12] Brown Advisory, "The Data Center Balancing Act: Powering Sustainable AI Growth," Sept 2024; Axios, "Midwest Data center Boom Comes to Indiana," 9 May 2025—both cite 3–5 million gal day^{-1} for hyperscale facilities. Brown AdvisoryAxios

[13] M. A. B. Siddik et al., "The Environmental Footprint of Data Centers in the United States," Environ. Res. Lett. 16 (2021) 064017, finding ~20 % of servers' direct water footprint originates in moderately to highly stressed watersheds. VTechWorks

[14] Jon Y., "The Big Data Center Water Problem," Asianometry Newsletter, 20 Nov 2024, estimating 80–130 million gal yr^{-1} for a 15 MW facility. Asianometry

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Hurricanes and severe storms

Tropical cyclones are growing stronger, wetter and more destructive as ocean heat content and atmospheric moisture rise. Globally, the proportion of storms that reach at least Category 3 intensity climbed markedly between 1979 and 2017, a trend the IPCC now judges "detectable" above natural variability[15]. In the Atlantic basin, NOAA projects roughly a 10% increase in Category 4 and 5 hurricanes and about 15% higher rainfall rates within storms by the late 21st century under a warming world scenario.[16] The operational risks are already visible: in 2023 a series of tropical storm driven power surges and brownouts forced the University of Maryland Baltimore County to take its main campus data center offline for several hours, despite on-site backup systems.[17]

Storm impacts extend far beyond the data hall walls. A nationwide study of outage records from 2018 to 2020 found that 62% of all power cuts lasting eight hours or more coincided with severe weather events, and tropical cyclones were the single most outage prone hazard.[18] When wind-borne debris or salt spray contamination coincides with a loss of grid power, cooling towers and makeup water pumps can fail at the same time, compounding downtime and recovery costs.

Because cyclone behavior is highly regional, siting decisions must be informed by local scale projections. Downscaled climate models for the western North Pacific—home to Hong Kong's fast growing data center cluster—indicate a ~10% increase in mean typhoon peak wind speeds by the late 21st century, along with heavier rain bands and higher storm surge potential.[19] Figure 4 (below) visualizes this intensification for Hong Kong. Ramboll's HazAtlas screening service combines such forward looking wind, storm surge, and precipitation data with site specific exposure metrics, enabling owners and investors to compare candidate locations, harden existing assets and design for resilient uptime throughout a facility's 15-25 year lifespan.

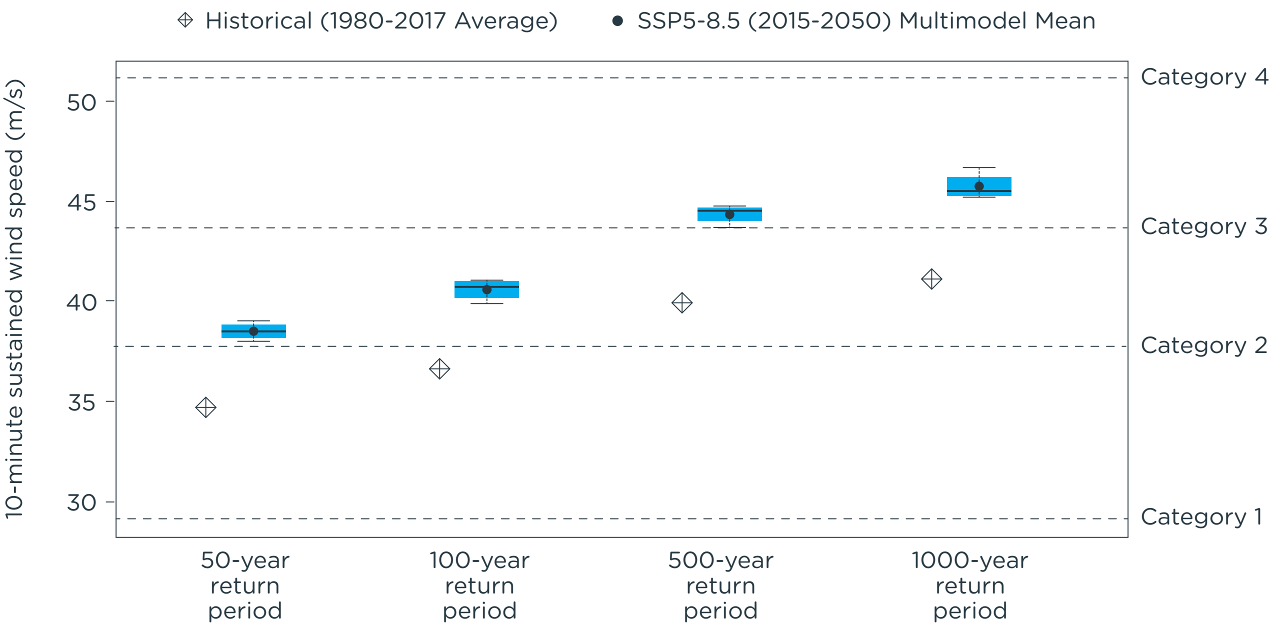


Figure 4: Increasing Hurricane Speeds Forecasted for Data Center Location in Hong Kong
SSP5-8.5 is a "worst-case" climate scenario with high fossil fuel use, little action to cut emissions, and possible warming over 4°C (7°F) by 2100, causing extreme heat and stronger storms.

[15] IPCC, Sixth Assessment Report, Working Group I, Chapter 11 "Weather and Climate Extremes" (2021), 11 73 – 11 75. The report concludes it is likely the global share of Category 3–5 tropical cyclone instances increased over 1979 2017 and judges the signal "detectable" above natural variability.

[16] NOAA Geophysical Fluid Dynamics Laboratory, "Global Warming and Hurricanes—State of the Science Fact Sheet" (rev. 20 Nov 2024). Model ensembles project a 1–10 % rise in mean TC intensity and ≈ 14% higher near storm rainfall rates for a 2°C warmer world; the proportion of Category 4–5 storms is very likely to increase.

[17] Division of Information Technology, University of Maryland Baltimore County, "Campus Data Center Outage from Storms Last Night" (system notice, 2023). The post reports multiple power surges and brownouts that forced an emergency shutdown of UMBC's primary data center hall during a tropical storm event.

[18] Q. Shen et al., "Spatiotemporal distribution of power outages with climate events in the United States," Nature Communications 14 (2023): Article 38084. Analysis of 2018 2020 utility records finds that 62.1% of outages ≥ 8 h co occurred with severe weather, with tropical cyclones the most outage prone hazard

[19] Hong Kong Observatory, "Global Climate Projections – Tropical Cyclones" (accessed 14 May 2025). Downscaled studies for the western North Pacific indicate a ~10 % increase in peak typhoon wind speeds and higher rain rates by late century under a 2°C warming scenario. 4, 11 (2021): fig. 3, stating a 1 MW data center can use ~25.5 million L yr^{-1} under traditional wet cooling.

Integrating physical risks into site selection and risk planning

Long term uptime starts with putting a data center in the right place. Planners now recognize that site selection for digital infrastructure must do more than balance land cost, fiber proximity, and grid capacity; it must also account for future physical climate risks. Ramboll has developed a service to integrate the various data sources needed during data center location optimization: HazAtlas. HazAtlas screens any parcel worldwide against a full suite of forward-looking hazards—heat, drought, inland and coastal flooding, wildfire, extreme rainfall, sea level rise, storm surge, hurricane wind and other severe storms—using peer-reviewed datasets provided by the IPCC, NASA, Copernicus and leading national agencies. The output is a transparent, location-specific risk picture that owners can apply directly to design criteria and budgeting considerations, rather than a generic "traffic light" score.

A typical engagement begins with a rapid climate risk screening, in which HazAtlas ranks candidate sites by the frequency and intensity of hazards most relevant to digital infrastructure—e.g., peak wet bulb temperatures for cooling load, daily water stress indices for evaporative systems, or return periods for 10 minute sustained hurricane winds. Sites showing material exposure move to detailed evaluation, where Ramboll's engineers test envelope strength, freeboard, utility resilience and mechanical redundancies against future climate projections. Finally, our adaptation design teams translate those stress tests into practical measures, ensuring that capital investments match the real hazard profile rather than historical averages. HazAtlas adds value to data center site development because it is:

- Fast (portfolio scale screens in days rather than months),
- Data rich (millions of gridded climate points in one interface),
- Sector specific (risk metrics tuned to data center thresholds), and
- Cost-effective (the tool's efficiency in processing large datasets makes it a cost-effective solution for multiple diverse sites in a geographic region).

Case study – Future proofing digital infrastructure

A global technology firm asked Ramboll to identify safe, future ready locations for a fleet of hyperscale data centers in a hurricane-prone market. HazAtlas fused historic observations (NOAA Atlas 14 rainfall, The Tropical Cyclone Extended Best Track Dataset (EBTRK) hurricane tracks) with high resolution climate projections and 10,000 year synthetic storm datasets to show where today's 100 year rainfall becomes tomorrow's 20 year event. Utility resilience scores, evacuation bottlenecks, regulatory constraints and geotechnical factors were layered onto the same GIS frame, creating a multi hazard optimization model to inform the site selection strategy. The analysis narrowed an initial search area of more than 200 counties to six inland sites that cut projected downtime risk by up to 63% and reduced storm mitigation CAPEX by 18% compared with coastal alternatives. By demonstrating that some parcels would experience today's 100 year rainfall every 35–45 years within the facility's design life, the study justified higher freeboard, dual feed substations and redundant cooling loops, investments projected to save US $14 million in avoided outages over 25 years.

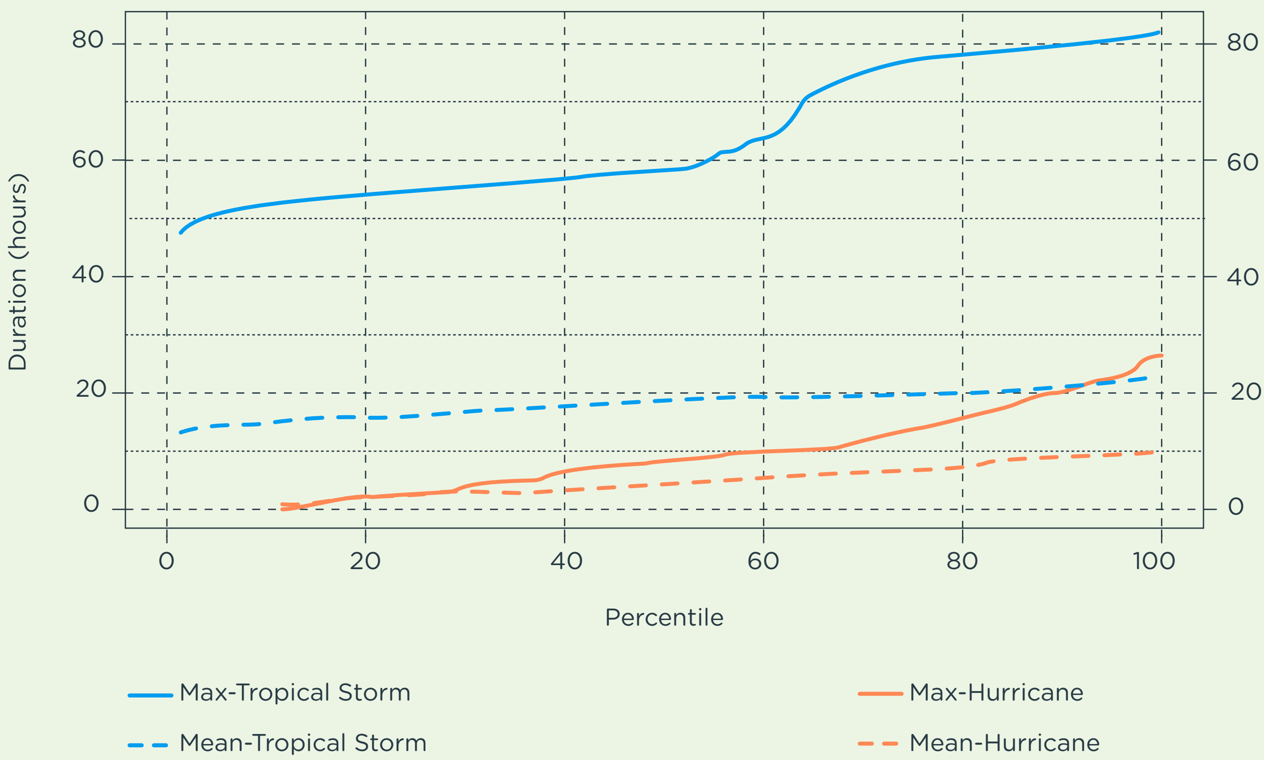


Figure 5: Duration of strong winds by storm intensity
This chart shows the distribution of maximum and mean wind durations for tropical storms (blue) and hurricanes (orange) across U.S. counties, expressed by percentile. While most counties experience under a day of strong winds, the most extreme tropical storms have lasted over 80 hours, and the most intense hurricanes have maintained hurricane-force winds for more than 24 hours.

Inland counties can face prolonged storm winds

This chart shows how long inland areas can face strong winds from hurricanes. The green bars mark the shorter bursts of the strongest hurricane-force winds, while the blue bars highlight tropical-storm-force winds that can linger for more than three days.

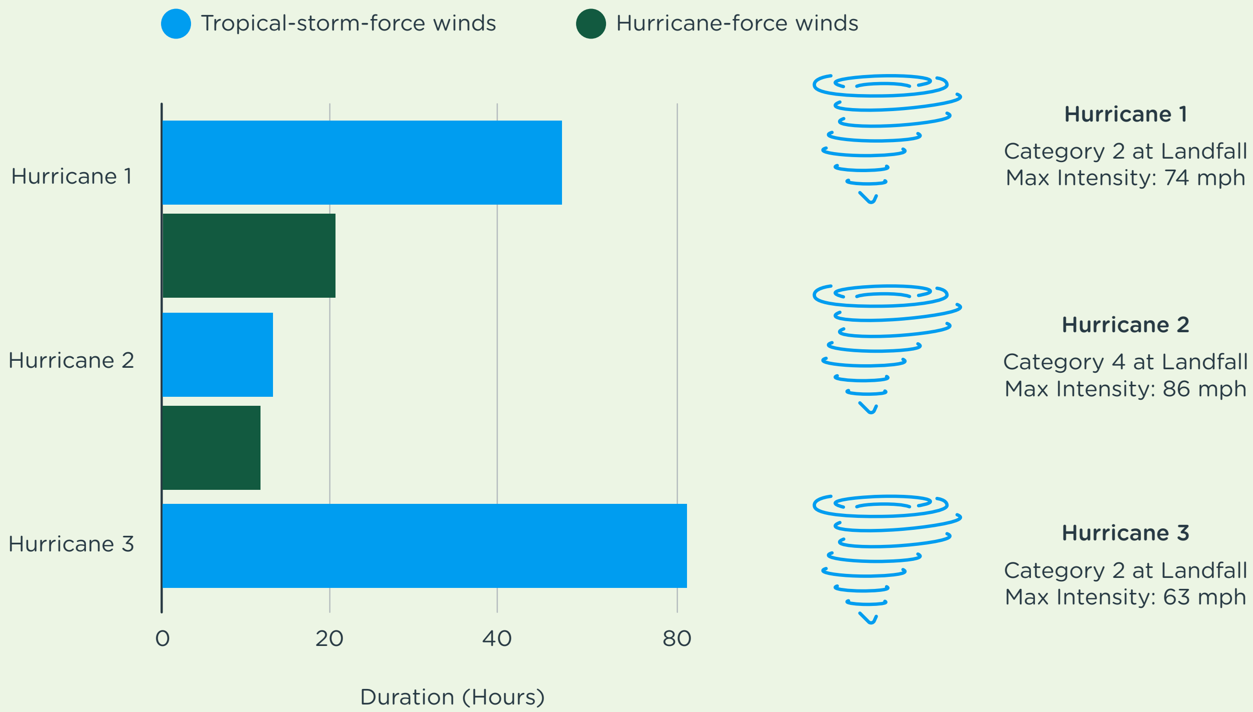


Figure 6: Wind duration data distils 70 years of storm records into a single insight: even counties far from the coast can endure tropical storm winds for more than three days. Those durations set the minimum fuel, battery and cooling redundancy a site needs if the grid fails.

Together, these visuals reinforce the project's guiding principle: design decisions must rest on real exposure times and future climate trends, never solely on historical means or single hazard metrics. By embedding such evidence into every stage from site selection to commissioning, Ramboll deploys HazAtlas to help planners secure reliable, climate ready digital infrastructure without unnecessary capital spend.

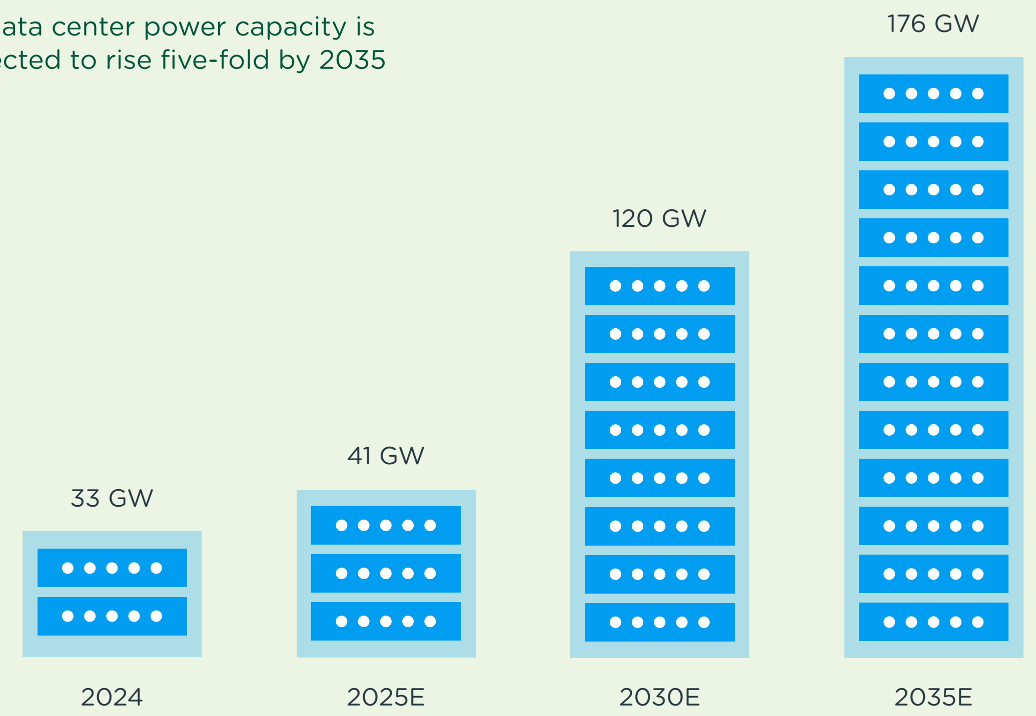
Climate transition risks and opportunities

Climate transition risks are most commonly considered in four different categories: policy & legal, technology, market, and reputation. For data centers, a key driver of risks and opportunities is the significant energy use inherent to the operation of a data center.

With carbon taxes and other financial incentives driven by government policy, there is significant climate transition risk associated with data centers' high power load, even with large operators seeking to source[20] increasing amounts of energy from carbon-free sources. For lower-carbon data centers, there are still policy-related risks, both from overall increases in energy costs as well as from potential grid disruptions, as electricity providers seek to install new carbon-free capacity and manage the impacts of renewables on the grid. Policy-related risks can include difficulty in maintaining the necessary personnel and processes to adapt to changing regulations and compliance requirements.

Technology risks for data centers involve the development and adoption of sustainable energy sources and innovations to reduce overall power load. Investing in renewable energy technologies like solar, wind, and hydropower is essential to meet regulatory demands and enhance operational efficiency. Conversely, reliance on non-renewable or controversial energy sources—such as nuclear energy, which can have waste disposal issues, or coal-fired power plants, which contribute significantly to greenhouse gas emissions—poses the risk of future stranded assets due to shifts in regulations and market dynamics favoring sustainable practices. Strategic investments in renewable energy infrastructure and advanced technologies can align with long-term sustainability goals.

US data center power capacity is expected to rise five-fold by 2035

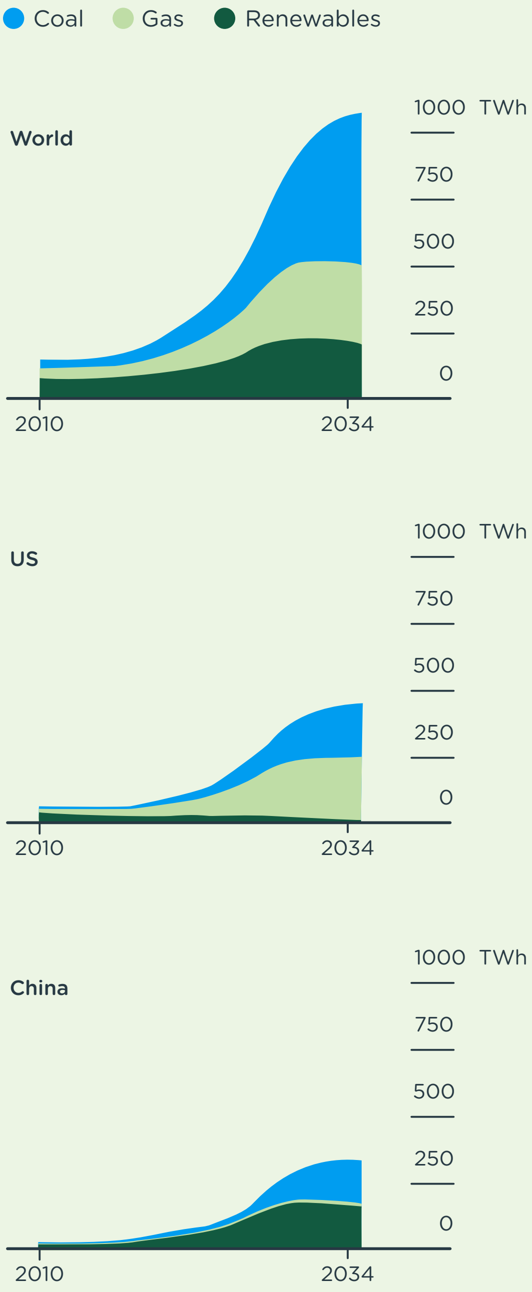


Note: "E" refers to estimated data center power capacity.
Source: Scaling Nuclear Energy to Power AI Data Centers: What it Will Take, The Wall Street Journal

[20] https://www.cedara.io/post/tracking-the-transition-to-renewable-energy-in-the-data-center-industry

Coal and gas dominate data center power in US and China

Annual electricity generation for data centers, 2020-2035



Source: IEA
Note: Data excludes nuclear energy
Visually adapted from Bloomberg

Reputational risks can be significant for data centers, particularly as they navigate transitions to lower-carbon energy sources. Moving away from non-renewable energy sources can enhance a company's reputation by demonstrating a commitment to sustainability. However, reliance on controversial energy solutions carries the potential for reputation damage and increased litigation exposure due to non-compliance with evolving environmental regulations. Prioritizing investments in environmentally friendly and socially accepted energy practices can safeguard reputation and mitigate potential risks.

Market risks can be present for data center operators that may not be responding as quickly to customer needs for low-carbon data centers and may be outcompeted by early movers to secure lower-carbon power.

There are specific opportunities for data centers that should be explored to capitalize on climate-related opportunities in preparation for a transition to a low-carbon economy. For energy source optimization, transitioning to renewable energy sources such as solar, wind, or hydropower can substantially reduce carbon footprints and align with increasing regulatory requirements. Enhancing resource efficiency through advanced cooling technologies, like liquid cooling systems or closed-loop cooling, can reduce water and energy consumption, leading to significant cost savings. Market opportunities arise as customers increasingly demand low-carbon data solutions; early adopters of sustainable practices can secure long-term contracts and foster customer loyalty. Additionally, developing innovative products and services, such as AI-driven climate risk management tools or energy-efficient data processing solutions, can address emerging customer needs while positioning data centers as leaders in climate resilience. Embracing these opportunities not only mitigates climate risks but also drives competitive advantage and sustainable growth in the digital infrastructure sector.

These are all important risks and opportunities for companies to plan for. To do so, Ramboll uses its expertise in both data centers and climate risk to tailor a 'long list' of potential risks and opportunities, and then prioritizes these based on the company's unique context. After the key risks and opportunities are identified, we use a variety of forward-looking scenarios to assess how likely and how impactful, these might be for the businesses over various time horizons. Ramboll supports company leaders as they think through the implications of these scenarios for their strategic planning and integrate these risk assessment processes into their internal governance.

Conclusion

The evolving climate landscape significantly impacts the reliability and operational costs of crucial data centers. These facilities face a myriad of risks, including increased cooling needs due to rising temperatures, threats from extreme weather events such as floods, wildfires, and hurricanes, as well as transition risks related to policies, technological advancements, market demands, and reputational considerations. Ramboll's HazAtlas tool offers a comprehensive approach to climate risk assessments, providing tailored insights that support informed decision-making in site selection, design, and planning, thereby enhancing resilience and sustainability. Effective planning and innovation in energy management will help mitigate these risks while capitalizing on emerging opportunities. As climate risks amplify, integrating adaptive and resilient strategies is crucial. Utilizing tools like HazAtlas and embracing climate risk assessments will safeguard data center operations, secure investments, and promote sustainability in the digital era.

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