Differentiated impacts of climate physical risks on the Indian power sector

Executive Summary

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Abstract

As India confronts the dual challenge of decarbonization and escalating climate hazards, understanding the financial implications of climate-related risks on the power sector is imperative. The Indian power sector is increasingly vulnerable to acute climate hazards like extreme floods, cyclones, and heatwaves that produce not just operational disruptions but severe financial shocks. This study presents a forward-looking, location focused, technology-wise analysis of physical climate risks for Indian power companies using novel asset-level methodologies. To assess physical risks, particularly flood exposure, we use spatially explicit modeling across 424 power-generating assets representing over 90% of India's fossil and non-fossil capacity. Monte Carlo simulations reveal that in the absence of protective infrastructure, average asset losses exceed 19%, with 99th percentile tail risks surpassing 24%. However, investment in 100-year flood protection reduces average losses to under 1% and tail risks to below 2%. Results further show that the effectiveness of risk mitigation varies significantly by technology and geography, with coal and gas assets benefiting most from protective investments, and coastal regions like Kerala and Gujarat showing the highest vulnerabilities. This study provides the first comprehensive empirical quantification of physical climate risks for Indian power firms at asset levels.

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Executive summary

Climate change presents significant challenges for businesses globally, particularly in India. India faces a diverse range of physical hazards, including floods, droughts, cyclones, and heatwaves. The Indian power sector is increasingly vulnerable to acute climate hazards like extreme floods, cyclones, and heatwaves that produce not just operational disruptions but severe financial shocks. The Indian power sector forms part of the nation's critical infrastructure, where disruptions can cascade into economic and social consequences. Addressing these risks is crucial for long-term business sustainability.

This paper offers a novel, data-driven evaluation of flood-related physical climate risks in the Indian power sector using spatially explicit, asset-level modelling. India's diverse geography and rapidly expanding power infrastructure make it particularly vulnerable to extreme climate events like floods, cyclones, and droughts. Yet current investment strategies and regulatory frameworks often overlook these risks, especially their extreme tail-end impacts.

The research employs a forward-looking Monte Carlo simulation framework, mapping flood exposures for 424 fossil and non-fossil power assets across India under various protection and insurance scenarios. Financial impacts are quantified through a discounted cash flow model, considering direct damages, disruptions, and insurance dynamics.

Key findings show average losses of 19% and extreme losses exceeding 24% without resilience investments. Strategic adaptation, such as 100-year flood protection, reduces average and extreme losses to under 1% and 2%, respectively. Results also demonstrate differentiated impacts based on technology (coal, gas, bioenergy, etc.) and geography (state, river basin, and district). The study concludes that granular, asset-level climate risk assessments are essential to guide resilience investments, regulatory planning, and investor disclosures.

Key Findings

First, the Indian power sector faces substantial exposure to physical climate risks from flooding (Table 1)**.** Without any protective measures, the average projected asset-level financial loss is approximately 19.5%, with tail risks (defined as losses in the 99th percentile of scenarios) exceeding 24%. These risks are alarming, especially considering India's large-scale, capital-intensive, and long-lived energy infrastructure.

However, the study finds that targeted adaptation strategies can substantially reduce these losses. Installing 100-year flood protection measures decreases average losses to below 1% and tail risks to under 2%. Even moderate investments—such as infrastructure designed for 25-year flood events—deliver major reductions in extreme risk exposure, suggesting that the benefits of resilience investments far outweigh their costs.

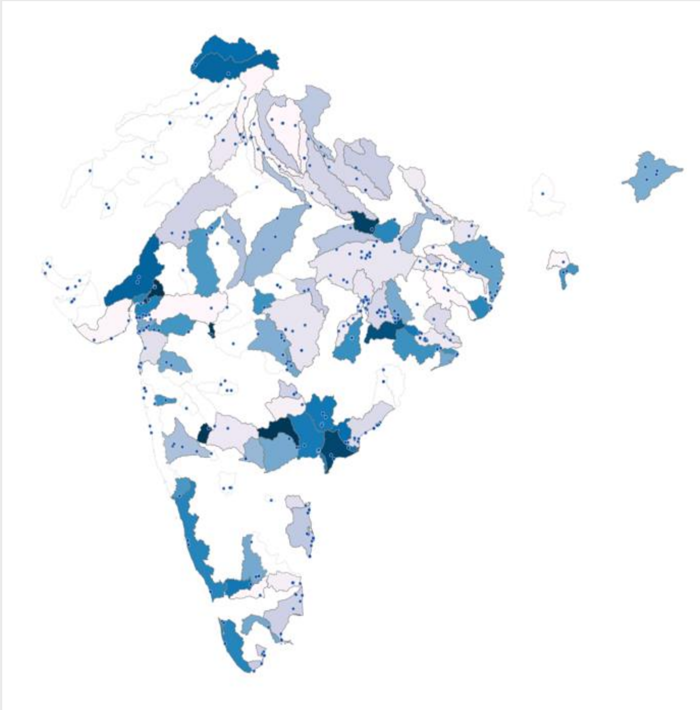
Second, financial impact of flood risk varies sharply across different types of power generation technologies. Coal and gas assets show the highest vulnerability in the absence of flood protection but also respond most significantly to adaptation measures. Under high-protection scenarios, the 99th percentile tail risks for these assets decline to 1.34% and 1.62%, respectively, with protection multipliers dropping below 0.04—indicating that over 95% of the extreme risk is mitigated. In contrast, bioenergy assets exhibit relatively higher residual risks despite protective measures. Even under 100-year protection, tail risks for bioenergy assets remain around 4.2%, more than double those for coal and gas.

Table 1: Average and Tail Impacts for Power Assets Aggregated.

Technology	Flood protection	Average Impact	90% Tail Risk	95% Tail Risk	99% Tail Risk	Protection multiplier	Number of assets
Low Flood Protection levels (5-year return period)							
Bioenergy	Low	14.05%	16.72%	17.46%	19.32%	0.4202	19
Coal	Low	15.97%	17.29%	18.01%	18.43%	0.5127	638
Gas	Low	22.06%	25.09%	26.36%	27.66%	0.5380	380
Nuclear	Low	17.24%	21.29%	23.66%	24.47%	0.5557	11
Oil	Low	17.36%	22.49%	24.34%	25.64%	0.7266	8
Medium Flood Protection levels (25-year return period)							
Bioenergy	Medium	3.33%	4.70%	5.11%	6.54%	0.1422	19
Coal	Medium	1.50%	1.96%	2.12%	2.44%	0.0678	638
Gas	Medium	1.58%	2.34%	2.62%	3.24%	0.0630	380
Nuclear	Medium	0.84%	1.39%	1.74%	2.60%	0.0595	11
Oil	Medium	1.79%	3.29%	3.86%	5.41%	0.1533	8
High Flood Protection levels (100-year return period)							
Bioenergy	High	1.83%	2.56%	2.98%	4.16%	0.0905	19
Coal	High	0.72%	0.99%	1.13%	1.34%	0.0373	638
Gas	High	0.62%	1.10%	1.25%	1.62%	0.0315	380
Nuclear	High	0.32%	0.70%	0.88%	1.37%	0.0314	11
Oil	High	0.86%	1.90%	2.33%	2.34%	0.0663	8

Third, there exist sharp geographic disparities in flood-related risks. Coastal and riverine states like Kerala, Puducherry, Gujarat, and Odisha are among the most exposed (see Figure 1), with Kerala showing an extreme tail risk close to 58% in the baseline scenario. These regions often combine high flood hazard with inadequate localized protection, compounding their vulnerability. Inland states such as Chhattisgarh and Arunachal Pradesh also show high exposure due to riverine flooding, while northern hill states like Himachal Pradesh are increasingly at risk from glacial melt and hydrological instability. Conversely, regions like Rajasthan, Delhi, and Haryana exhibit significantly lower tail risks, generally under 17%, benefiting from geographic advantages or favourable asset siting. These findings underscore the need for spatially targeted resilience planning and investment.

Figure 1: Geographic Distribution of tail risks across river basins in India.



Fourth, insurance alone offers limited protection from physical damage or service disruptions. While insurance plays an important role in managing financial risk post-disaster, in scenarios without flood protection, full insurance reduces 99th percentile losses by only about 9%. However, when combined with physical flood protection, the effectiveness of insurance improves dramatically. In high-protection scenarios, the same insurance arrangement brings an additional 22.8% reduction in tail risks. This clearly demonstrates that physical infrastructure and insurance function best when integrated. Resilience investments improve not only asset stability but also enhance the cost-effectiveness and impact of insurance, creating a mutually reinforcing strategy for climate risk mitigation.

Finally, there is a need for fine-grained, asset-level risk analysis to accurately assess and manage climate risk. Using district-level flood fatality data, the authors find meaningful differences in resilience even within the same state or technology type. For example, many coal and nuclear assets are located in moderately to highly protected districts, contributing to their lower residual risks. In contrast, bioenergy and oil assets are often found in poorly protected areas and remain highly vulnerable.

Implications

First, regulators should require asset-level climate risk disclosures for critical infrastructure to better assess and manage vulnerabilities. National and state-level planning must incorporate spatial climate risk analysis to guide infrastructure investments toward high-risk areas and ensure resilience is embedded in long-term energy strategies.

Second, investors, utilities, and lenders must adopt climate-adjusted valuation frameworks, recognizing that risks vary significantly across technologies and regions. Insurance should be paired with targeted resilience measures—such as flood protection—to reduce both physical losses and financial exposure, and to enhance the effectiveness of risk transfer mechanisms.

Third, infrastructure planning must be tailored to specific context. Investments in 25- to 100-year flood protection offer substantial risk reduction and are cost-effective. Infrastructure planning must be tailored to specific technologies—for example, coal and gas assets benefit greatly from protection, while bioenergy may need alternative strategies due to its location-based vulnerabilities.

Fourth, firms should align disclosures with global standards like the TCFD, reporting asset-level exposure and resilience measures to improve transparency and support informed decision-making by regulators and investors. India currently lags in incorporating physical climate risk into corporate reporting.

Finally, climate resilience must become a core element of energy planning. Strengthening the resilience of the power sector is essential for economic stability and national security. As extreme weather events grow more intense, climate resilience must become a core element of energy planning, ensuring continuity of supply and protecting critical infrastructure from disruption.

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