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# Energy-transition risks create uneven financial impacts across India's power sector

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India's power sector faces significant climate transition risks due to its reliance on coal. Here we assess these risks using a forward-looking, microeconomic climate transition model, integrating two modeling scenarios across two pathways—Below 2 °C and Net Zero Emissions 2050—for transition shock years 2025 and 2030, covering 1703 companies across coal, gas, renewables, nuclear, hydro, and oil. Projections reveal that coal and gas companies would experience substantial net present value losses (85%–90% and 29%–75%, respectively). Delayed transition amplifies impacts by 10%–15% when shock year shifts from 2025 to 2030. Renewable companies are projected to realize moderate gains (14%–30%), while hydropower remains largely unaffected and nuclear outcomes are mixed. Overall, dominance of fossil fuels results in a negative sectoral outlook, with aggregate losses of 48%–54%. Our findings suggest that early policy intervention and accelerated transition could influence financial losses in fossil fuel sectors.

Climate financial risks refer to the financial impacts of climate change, including physical risks (e.g., extreme weather events) and transition risks (e.g., policy changes, market shifts towards sustainability)<sup>1,2</sup>. For climate risk assessment, the power sector has received greater scrutiny due to its dual role as a major emitter and a critical lever for decarbonization. The potential introduction of delayed, strong, and abrupt regulatory corrective actions aiming to meet the Paris Agreement targets could negatively impact the power sector<sup>3–5</sup>. For power firms, the transition risks are specifically related to shifting from fossil fuels to renewable energy, carbon pricing, regulatory changes, and the increasing pressure to decarbonize<sup>6,7</sup>. Scenario-based tools like the Network for Greening the Financial System (NGFS) pathways and integrated assessment models (IAMs) also suggest that delays in implementing climate policy significantly increase financial risks<sup>8</sup>. These risks arise because the required emission reductions must then occur over a much shorter timeframe, leading to abrupt changes in asset valuations and potentially triggering stranded assets and systemic financial disruptions<sup>9,10</sup>. Therefore, as the global economy shifts toward decarbonization, the power sector faces significant climate transition risks<sup>11,12</sup> which needs detailed examination.

Transition risks flow from the real economy (which includes industries like energy, power, manufacturing, transportation and others) into the

financial economy (banks, insurers, investors, asset managers etc.) and back again, impacting the entire economic ecosystem<sup>13</sup>. Over the past decade, a growing body of literature has examined the implications of climate-related transition risks for financial institutions in terms of their exposure to carbon-intensive sectors like energy, power utilities, transportation and others<sup>14–16</sup>. However, most studies have focused on developed economies, with limited empirical research on real-sector firms, particularly in emerging markets like India. Real-sector firms, particularly carbon-intensive industries like power, while facing transition risks directly lack the data, expertise, or frameworks to examine these risks effectively. Evidence suggests that globally coal continues to be deeply entrenched in power systems, and the fossil dominated utilities have been slow in their transition to renewables<sup>17,18</sup>. Alovera<sup>18</sup> analyzed over 3000 electric utilities worldwide to energy transition between 2000–2018 and found that 60% of the renewables continued to expand fossil fuel capacity concurrently, compared to 15% reducing it, suggesting a significant inertia within the sector, where electric utilities are investing in long-term fossil fuel infrastructure<sup>11</sup>. Bauri et al. investigated the impact of climate risks on the financial performance of 48 energy companies from G-20 countries for the period 2017–2021 and found that climate risks negatively impacted the financial performance. Further, the study concluded that firms which operated in a less climate-risky

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country, financially performed better than the firms that operated in a more climate-risky country<sup>19</sup>.

India one of the world's fastest-growing economies and among the three largest emitters of greenhouse gases globally<sup>20,21</sup> has a predominance of coal in power generation. With over 70% of electricity generated from coal<sup>22</sup>, and continued public investment in coal-based infrastructure, Indian power companies remain acutely vulnerable to the transition risks associated with potential regulatory changes aimed at reducing emissions<sup>23,24</sup>. India's Net Zero goals create risks for coal-based power companies which are particularly more vulnerable to rising carbon prices and where delay in transitioning could lead to stranded assets, high operational costs, and financial losses<sup>25</sup>. With such a heavy dominance of coal in Indian power sector, the transition risks facing the power firms also pose a risk for workers and communities that rely on them for jobs and income<sup>26,27</sup>. With Indian fossil power firms being vulnerable to growth and asset quality risks from climate change in the long run, these needs to be examined closely. India, therefore, is an interesting case study due to its significant exposure to climate transition risks<sup>28</sup> and its critical role in global emissions reduction<sup>29</sup>.

Much of the existing research focuses on the global<sup>18</sup> or developed market perspectives<sup>7,30–33</sup>, and our study uniquely addresses the challenges faced by power companies in a rapidly growing, developing economy like India, where the dynamics of climate transition risks are particularly complex and multifaceted. Against this global backdrop, an India-specific analysis is essential because India is simultaneously one of the world's fastest-growing energy markets and one of the most fossil-fuel-dependent economies. India is the world's third-largest energy consumer, yet its per-capita energy use remains far below the global average<sup>34</sup>, implying a sustained trajectory of rapid demand growth over the coming decades. This demand is currently met predominantly by fossil fuels—coal supplies more than 70% of electricity generation India's coal-dominated power system<sup>22</sup>, rapidly expanding energy demand, capital-intensive industrial base, and large state-owned energy enterprises imply that transition risks may manifest differently than in advanced economies. While future pathways consistent with climate targets e.g., NGFS scenarios assume rapid scale-up of renewables, storage, and declining role for unabated fossil capacity, this dual reality—of the need to expand access and consumption, while rapidly reducing emissions—may be vital while examining transition risks for India. Studying India is therefore essential not only to illuminate transition-risk pathways in emerging economies, but also to inform global climate-finance assessments, given India's centrality to the world's decarbonization trajectory.

Not only that, the Institutional frameworks for transition risk assessment in India also remain nascent<sup>28</sup>. While the Reserve Bank of India (RBI)<sup>35</sup>, the Indian Central Bank has acknowledged the importance of assessing climate-related financial risks, there is limited availability of granular firm-level data, forward-looking financial models, or standardized scenario analysis protocols tailored to emerging economies. Knowledge gaps also persist around the timing of policy interventions in India—whether early or delayed—and their distinct implications across power technologies.

As a result, there is a growing need to examine climate transition risks for emerging and developing economies like India which face greater challenges to transition due to constraints on frontier technology, material capital and human capital<sup>36,37</sup>. However, even as the urgency for firm-level transition risk assessments is clear for Indian power sector, there is a paucity of studies in this domain. To our knowledge, Köberle et al.<sup>38</sup>, which assessed the financial risks to India's coal value chain, highlighting significant potential losses in the net present value (NPV) for three coal dependent firms in India is the only related study. We believe this is one of the first analysis for the real sector in India, which utilizes a forward looking, bottom-up methodology to examine the climate transition risk for Indian power companies across all major power generation technologies viz. coal, gas, oil, hydropower, nuclear, and renewables.

Understanding the potential impacts of climate transition risks is essential for policy makers, investors, and power companies to make

informed decisions about future investments, risk management, and strategic planning. Intuitively renewable companies could gain from this transition in the future, but whether the gain is substantial or marginal and as much as what the coal firms lose or otherwise. How different climate transition pathways and modeling scenarios affect the financial outcomes for power companies in India? How delayed transition shocks and related policies affect the financial risks for companies? Would other power generation technologies, such as hydropower, nuclear, and oil, get impacted as much as coal and gas? Our study answers these and other related questions and provides critical insights into how climate transition risks and opportunities affect the financial stability of India's power sector.

We use an asset-level, forward-looking, bottom-up microeconomic climate transition risk stress test, initially developed by Baer et al.<sup>39</sup> to construct multiple scenarios of varying climate ambition at the company level, assessing the financial risks associated with late and abrupt transitions. Specifically, it propagates the climate-adjusted economic impacts of these scenarios to firms' asset values through a set of transmission channels, estimating potential changes in market valuation (NPV) between business as usual (BAU) and ambition scenarios which enables the measurement of transition risk<sup>39</sup>. This integrates firm-level financial and environmental data and employs two modeling scenarios *Global Change Assessment Model (GCAM)* and *Regional Model of Investment and Development (REMIND)* across two NGFS pathways i.e., Beyond 2 °C Scenario (*B2DS*) and *Net Zero Emissions by 2050 Scenario (NZE2050)* for two different shock years 2025 and 2030.

We utilize asset-based production data which provides an in-depth look at individual production facilities, their activities, production plans, and ownership structures within Indian power companies. Our dataset includes a total of 1972 unique assets which are associated with 1703 distinct companies, offering a detailed representation of production facilities diversified across multiple sectors and technologies, such as coal, gas, renewables, nuclear, hydro, and oil. This approach will ensure a comprehensive assessment of climate transition risks in the Indian power sector, providing valuable insights for stakeholders and policymakers while establishing a foundation for identifying firm-level climate vulnerabilities and opportunities, business strategies, and the role of climate policy in shaping their practices.

To support the above analysis, we provide illustrative case studies for six leading Indian power firms to demonstrate the financial impact of transition risks. These case studies represent a spectrum of portfolio diversity in India which are all leaders in their domain, from fully renewable (*Adani Green*<sup>40</sup>, *ReNew Power*<sup>41</sup>) to predominantly fossil based (*NTPC*<sup>42</sup>, *Adani Power*<sup>43</sup>) and mixed portfolios (*Tata Power*<sup>44</sup>, *JSW Energy*<sup>45</sup>). The case studies were selected based on their market share and installed capacity, which together account for a significant portion of India's electricity generation and play a critical role in the energy transition. For analyzing these case studies, we use conventional cash flow discounting techniques to estimate Cash flow at risk (CfaR) and showcase how these leading Indian power firms could lose or gain value with the impending transition.

This inquiry is novel in many respects. First, to the best of our knowledge this is first attempt to quantify the climate transition risk for Indian power firms in the future. Research work on the subject in India remains in a nascent stage and a broader understating of how transition risk can impact the power sector in financial terms going forward remains an unexplored domain. Second, the dataset utilized in this study is quite comprehensive and covers a diverse range of technologies, including coal, gas, oil, hydro, nuclear and renewable power generation. This broad sectoral scope ensures that the study captures the multifaceted nature of India's power sector, reflecting key trends and dynamics across various technologies. Third, the focus of most prior studies has been on the analysis of transition risks for the financial sector and less on the real sector in general and power sector in particular.

Further, the study's contribution extends beyond applying transition-risk analysis to an emerging economy like India. Its novelty lies in developing a systematic, multi-layer framework that translates global integrated-

assessment-model (IAM) pathways into firm-level financial impact assessments. While IAMs provide regional energy-system transitions, they do not directly yield asset-level financial impacts. We construct a replicable mapping from IAM outputs and embed these into discounted-cash-flow (DCF) valuations for various generation technologies viz. coal, oil, gas, hydro, nuclear and others. This approach reveals transition-risk heterogeneity that is invisible in macroeconomic modeling and provides a scalable methodology for any emerging economy where capital stock is concentrated in fossil-dependent corporate structures. India serves as a critical empirical case not because it is understudied, but because it exemplifies an energy system in which global transition forces, local regulatory frictions, and firm-level financial realities intersect.

Our results provide evidence that coal, gas and oil companies in India face substantial NPV losses across all scenarios, whereas renewable companies gain value albeit moderate. Interestingly, even as the losses for fossil companies are substantial, the gain for non-fossil companies is moderate. The empirical findings demonstrate that the financial impacts vary by technology or company type, i.e., hydropower (<1%), nuclear (mixed), renewables (moderate) and coal, gas and oil companies (5–90%). We find that selection of the model choice significantly affected results for the companies. Finally, the study concludes that the later the transition shock, the more intense the impact on fossil and non-fossil companies in terms of losses and gains respectively. Our findings provide evidence for robust and immediate climate policies to phase out coal to reduce losses and diversify portfolios to renewables, hydro power and other clean energy technologies to foster a more climate-resilient power sector in India, contributing to the global effort in mitigating the financial risks posed by climate change. Findings also highlight the urgent need for prompt policy action as an early onset of the transition shock can help reduce some of the financial losses for coal companies.

### Results

We present the result for the NPV changes across different company types in India, analyzing the effects of two models, GCAM and REMIND, under different shock years (2025 and 2030) and NGFS target pathways (B2DS and NZE2050) which act as ambition scenarios. NPV changes are computed between target (ambition) and baseline (BAU) scenarios. First, we present the aggregate results for all companies and then individual company type, such as fossils (coal, gas, oil), renewables and others. Tables 1 and 2 provide results for all companies (aggregate) as well as individual company type for transition shock years 2025 and 2030 respectively.

Clearly, at an aggregate level, the impact on India’s power sector shows a mixed but predominantly negative financial outlook with losses ranging from 48%–54%, driven by heavy losses in the coal and gas sectors which dominate power generation. However, the positive NPV changes for renewables provide a partial offset, suggesting that a shift toward renewable energy could help mitigate some of the financial losses in the long term. Comparing Tables 1 and 2, we found that the aggregate losses increase from 48.24% (2025) to 53.96% (2030), suggesting that a delayed transition shock from 2025 to 2030 worsens the financial outlook for the power sector in general and coal and oil companies in particular.

### All companies: model choice matters

We look at NPV change between target and baseline scenarios. Figure 1 provides a distribution of NPV change for all power generation companies. Shaded areas highlight 4 clusters of NPV % Change peaks identified across two dimensions- first, power generation technology, either high-carbon (oil, gas, coal) or low-carbon technology (hydropower, nuclear, renewables), and second, model type either GCAM or REMIND. Colored lines track NPV Change (%) for the two scenarios B2DS/NZE2050 for the two models- GCAM/REMIND and line styles indicate the two shock years (2025, tracked with solid lines, and 2030, tracked with dashed lines).

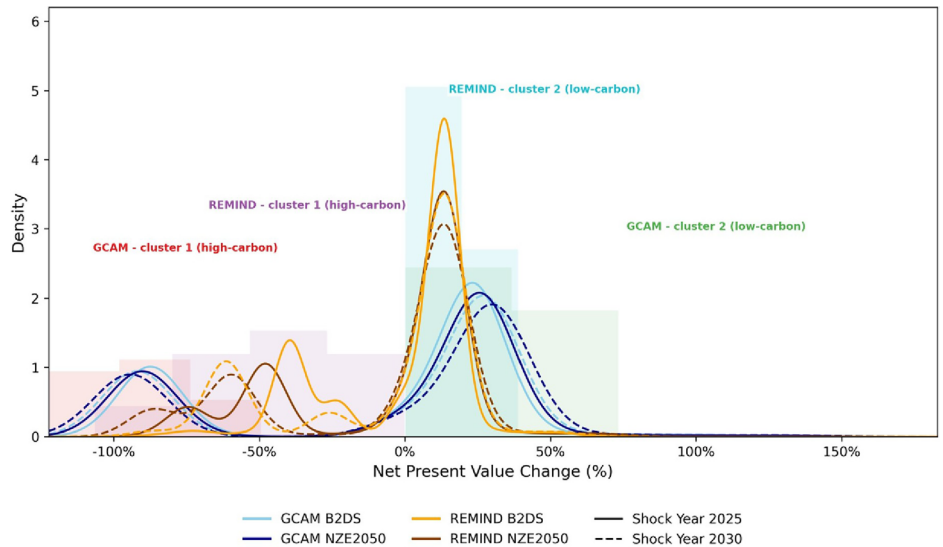
Cluster 1 (Red): fossil companies with loss -GCAM (High Carbon-oil, gas, coal)

**Table 1 | All companies (Aggregate): India-NPV Change (%) with shock year 2025**

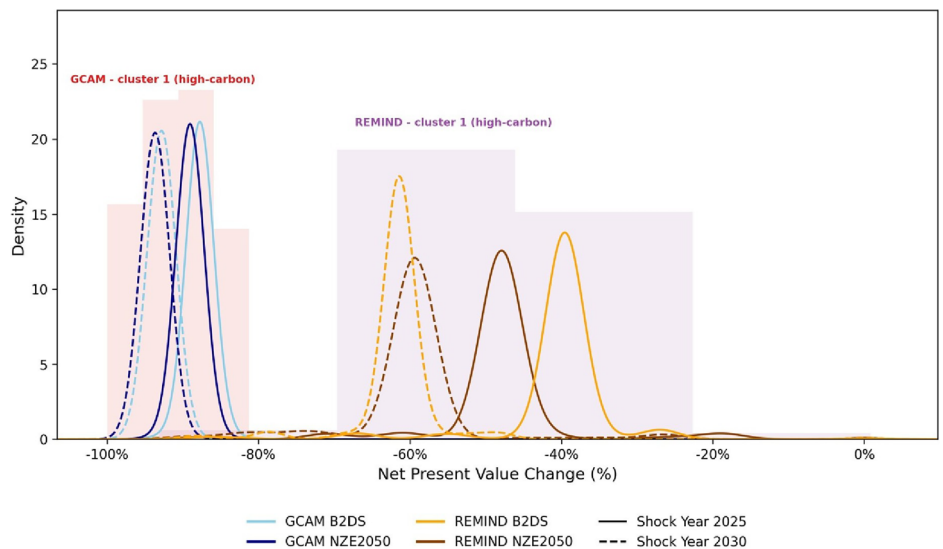
Company type	NPV change (%)											
	B2DS- GCAM-2025			B2DS- REMIND-2025			NZ 2050- GCAM-2025			NZ 2050- REMIND-2025		
	Weighted Average	Average	Median	Weighted Average	Average	Median	Weighted Average	Average	Median	Weighted Average	Average	Median
Coal	-86.938	-87.322	-87.720	-50.703	-40.617	-39.573	-88.111	-88.603	-89.033	-55.908	-48.069	-47.914
Gas	-86.146	-85.855	-86.932	-29.459	-24.760	-22.756	-93.397	-93.027	-94.002	-75.361	-74.528	-74.779
Hydro	-0.062	-0.013	0.000	0.563	0.111	0.000	-0.081	-0.017	0.000	0.594	0.126	0.000
Nuclear	-69.624	-66.544	-64.881	-3.031	-1.684	-1.206	-69.625	-66.544	-64.882	-2.763	-1.535	-1.099
Oil	-85.823	-85.823	-85.823	-74.088	-74.088	-74.088	-93.753	-93.753	-93.753	-74.088	-74.088	-74.088
Renewables	40.905	25.052	23.865	24.448	14.646	13.533	48.941	27.893	26.279	27.113	14.925	13.533
<b>India</b>	-47.948	-50.084	-50.249	-22.045	-21.065	-20.682	-49.338	-52.342	-52.565	-30.069	-30.528	-30.725



**Fig. 1 | Distribution of NPV change (%)—all power generation technologies.** Distribution of Net Present Value (NPV) change (%) for all power generation technologies across Beyond 2 °C Scenario (B2DS) and Net Zero Emissions by 2050 Scenario (NZE2050) for GCAM and REMIND.

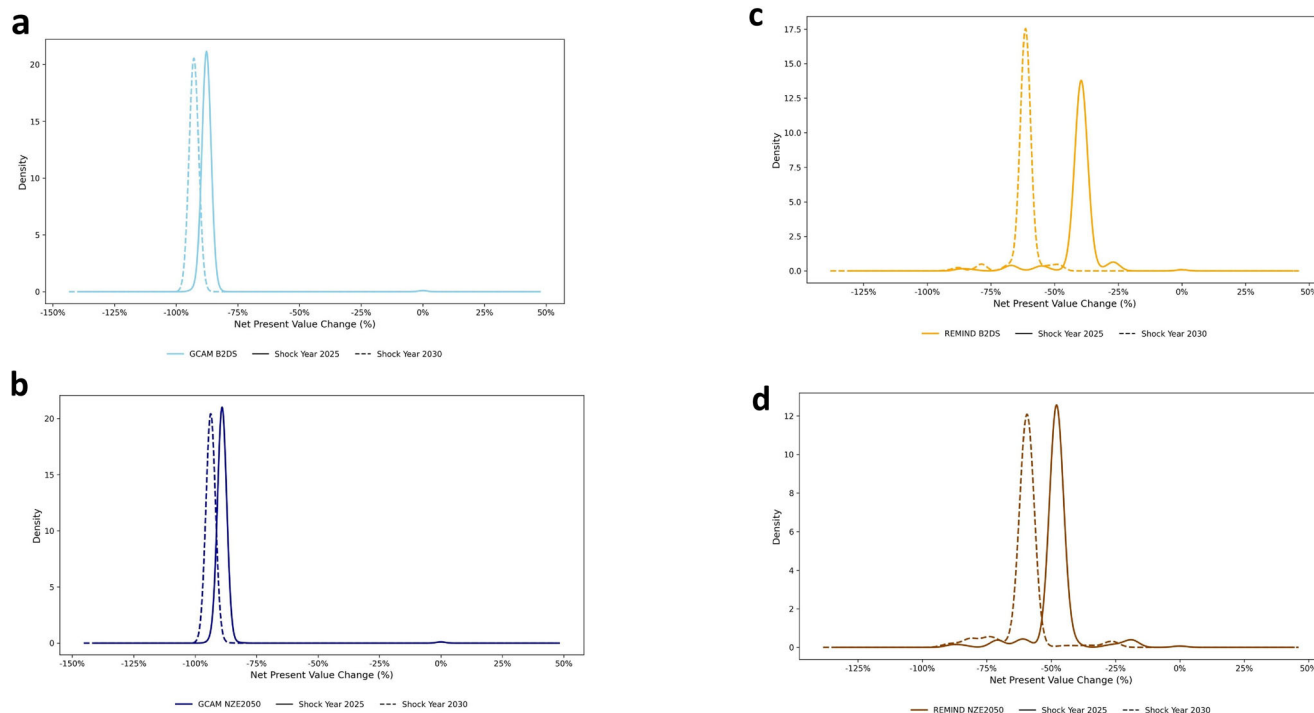


**Fig. 2 | Distribution of NPV change (%)—coal companies—all models and scenarios.** Distribution of Net Present Value (NPV) change (%) for Coal Companies—All Models and Scenarios. Colored lines track NPV (%) change plots across 2 shock years (2025—solid lines & 2030—dashed lines).



**Coal power companies face heavy losses in transition scenario**  
 Findings reveal significant losses for all coal companies in all cases, with the severity of these losses varying depending on the model and shock year applied. Figure 2 presents the results for NPV changes in coal companies across different models (GCAM and REMIND), target years (B2DS and NZE2050) and shock years (2025 and 2030). Model choice significantly affects the results wherein GCAM consistently predicts substantial losses for coal companies, approximately 90–100% more than those projected with REMIND (Fig. 2, GCAM Cluster 1 & REMIND Cluster 1), irrespective of the target or shock years. While less severe with GCAM, REMIND also forecasts notable losses. Choice of shock year appears pronounced with REMIND as losses are 25–50% higher when the shock year is 2030 compared to 2025 suggesting that delayed intervention results in higher financial penalties. Target year (NZE2050 versus B2DS) has less impact and even REMIND which showed high sensitivity to shock year, shows limited sensitivity to changes in the target year, indicating that while the timeline for achieving targets matters, the immediate impact of shock years is more critical. Overall, we find that the trajectories of coal companies remain consistent across both target and shock years, indicating a pervasive trend of declining value.

With GCAM B2DS, the shock year’s effect is small but consistently negative, with average NPV changes ranging from –85 to –90% (Fig. 3a). While the shock year has a modest effect, the overall trend indicates a significant decline in coal value under the B2DS scenario, underscoring the gradual but severe impact on coal companies. Similar to the B2DS scenario, the impact with GCAM NZE2050 is close to –100% across different shock years. The average NPV changes range from –85 to –90% (Fig. 3b). The consistency in severe losses suggests that under the NZE2050 scenario, coal companies face near-total value erosion regardless of shock year timing.  
 In REMIND B2DS, the average NPV impact is –40% with a shock year of 2025 which worsens to –60% with a shock year of 2030 (Fig. 3c). Clearly REMIND shows a higher sensitivity to the timing of the shock year compared to GCAM, indicating that delayed interventions lead to significantly higher losses. The inclusion of CCUS in REMIND’s modeling could possibly mitigate the impact on coal but highlights the escalating risks with delays. With REMIND NZE2050, the average NPV impact is –47% with a 2025 shock year and –60% with a 2030 shock year (Fig. 3d). The difference between shock years is narrower in NZE2050 compared to the B2DS scenario, but the loss remains consistent at –60% for 2030. The tighter variance in NPV changes between 2025 and 2030 shock years underlines a persistent



**Fig. 3 | Distribution of NPV change (%)—Coal Companies.** a–d Present plots for distribution of Net Present Value (NPV) Change (%) for coal companies across 2 shock years (2025—solid lines & 2030—dashed lines).

vulnerability for coal companies, with significant losses materializing regardless of minor delays.

**Gas and oil-based power companies lose significant value similar to coal companies**

Gas companies experience value declines (29–75%) with both GCAM and REMIND models, regardless of the scenario (B2DS or NZE2050) or shock year (2025 or 2030). The GCAM model indicates higher overall losses compared to REMIND, with minimal sensitivity to the timing of shock years (Fig. 4a, GCAM Cluster 1). In contrast, the REMIND model shows a significant impact of target year, with the most pronounced differences observed between the B2DS and NZE2050 scenarios (Fig. 4a, REMIND Cluster 1). The REMIND NZE2050 results align more closely with GCAM’s (B2DS and NZE2050) projections, indicating converging risks with aggressive decarbonization. Across both models (GCAM and REMIND), the shock year does not have a substantial impact on the NPV outcomes for gas companies. This consistency suggests that the financial losses for gas companies are primarily driven by the broader decarbonization pathways rather than the timing of specific shocks. Unlike gas companies which are less impacted by shock years, coal companies show a distinct pattern where the timing of shocks plays a crucial role in determining the extent of financial loss. Overall, we found that similar to coal companies, the distribution of NPV changes for gas companies also illustrates the uniform negative impact across different scenarios and models, reinforcing the sector’s systemic vulnerability.

Gas companies experience deeper negative NPV peaks than coal companies in spite of their lower emission factor and global positioning of natural gas as a transition fuel. We attribute this to two main reasons. First, gas demand declines more abruptly than coal in climate-aligned scenarios across NGFS pathways due to rapid penetration of renewables and declining battery/storage costs. In comparison to gas which not only declines but also faces demand cliffs due to price and substitution shocks, coal declines steadily which is partially cushioned by long-term PPAs and regulated tariff recovery. Therefore, even with lower emissions, profit erosion is sharper for gas as gas margins compress faster than coal in Indian context. Second, GCAM/REMIND model assumptions treat natural gas as a transitional but

temporary technology and not a long-term backbone. Therefore, we see faster substitution of gas by renewables plus storage in net-zero pathways.

Oil-based power companies also face substantial NPV declines (50–65%) across all scenarios and models, indicating high vulnerability to both GCAM and REMIND frameworks (Fig. 4b). The significant losses are consistent regardless of the target or shock year, reflecting the broader industry risks associated with declining demand and stringent decarbonization policies. The severe and pervasive losses underlining the systemic risks point to a rapidly diminishing financial outlook for fossil companies under climate-aligned pathways as markets transition towards cleaner alternatives.

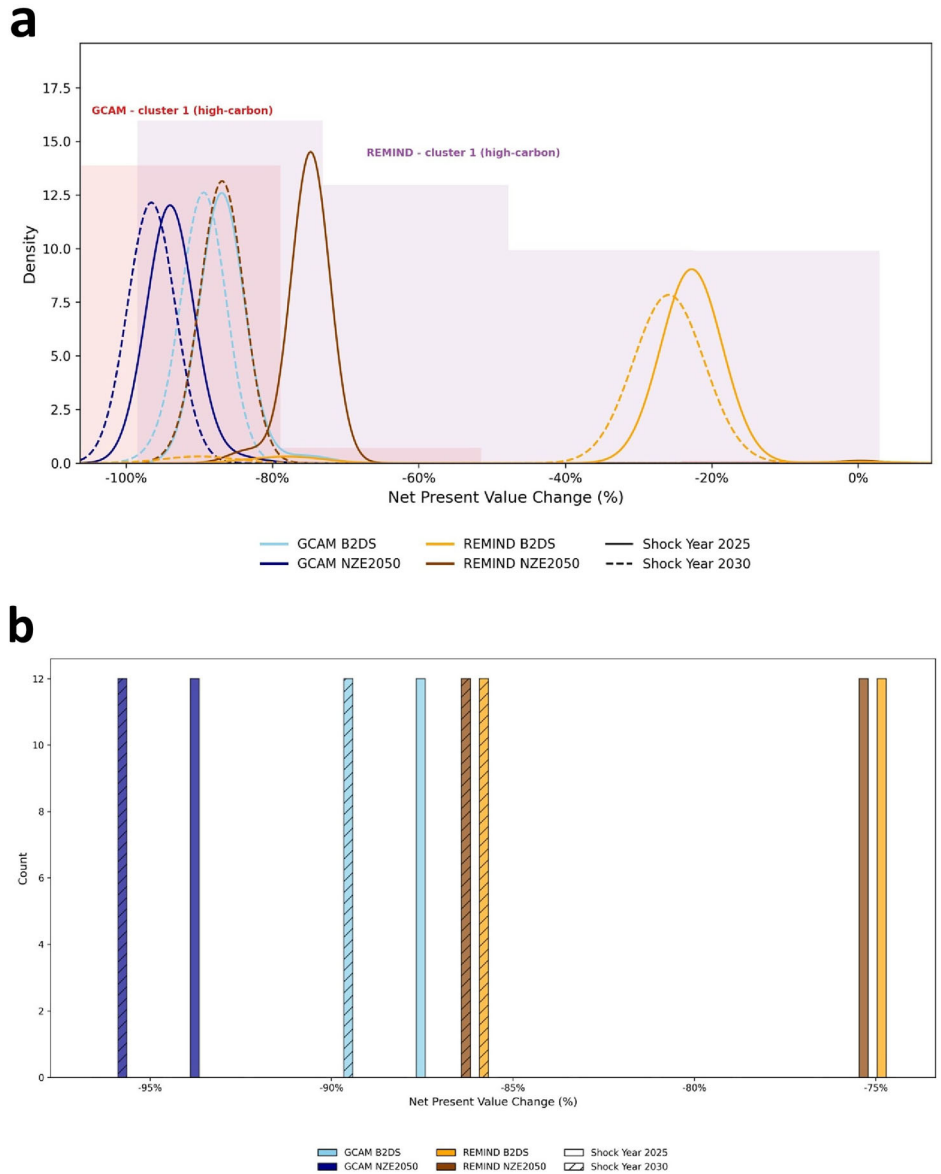
**Renewable companies have consistent but moderate gains**

NPV change for renewables shows a positive shift albeit less than the losses for coal companies (Fig. 5). The GCAM model shows a substantial increase in NPV, ranging from 25 to 35%, which is approximately twice the increase seen with the REMIND model. GCAM Model also exhibits a more significant impact of earlier target and shock years (Fig. 5, GCAM Cluster 2). In contrast, the REMIND model presents a more conservative estimate of NPV change, clustered around a modest 10% increase, with minimal variation in response to target and shock years. This suggests that the GCAM model may be more responsive to early transitions in energy policy or market shocks, whereas REMIND reflects a more gradual and steady transition scenario.

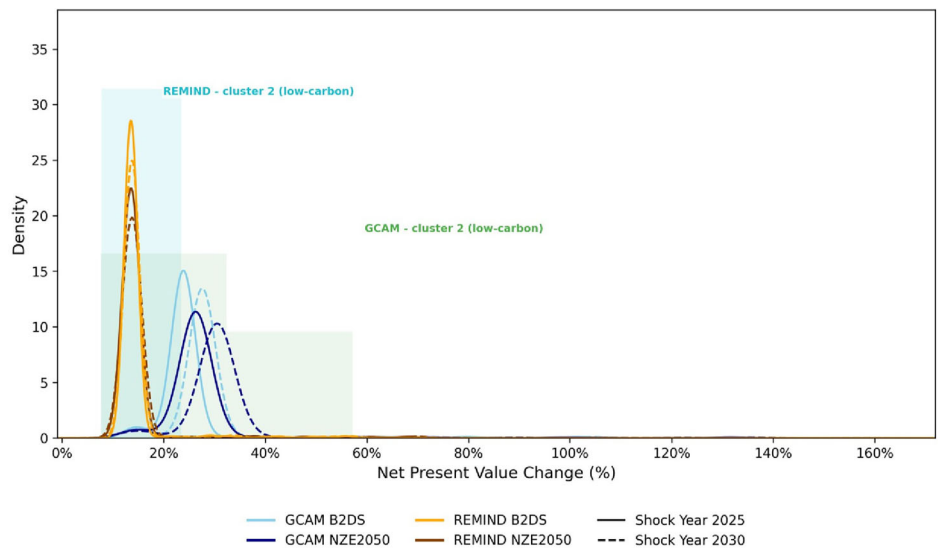
The timing of shocks plays a crucial role in determining the magnitude of financial impacts on the renewable sector, with later shocks potentially leading to more significant fluctuations in NPV. Finally, renewable companies exhibit a longer tail in NPV distribution compared to other technologies. While the average NPV changes for renewables are moderate and positive, there are outliers with an extended tail like *Adani Green Energy* experiencing significant gains.

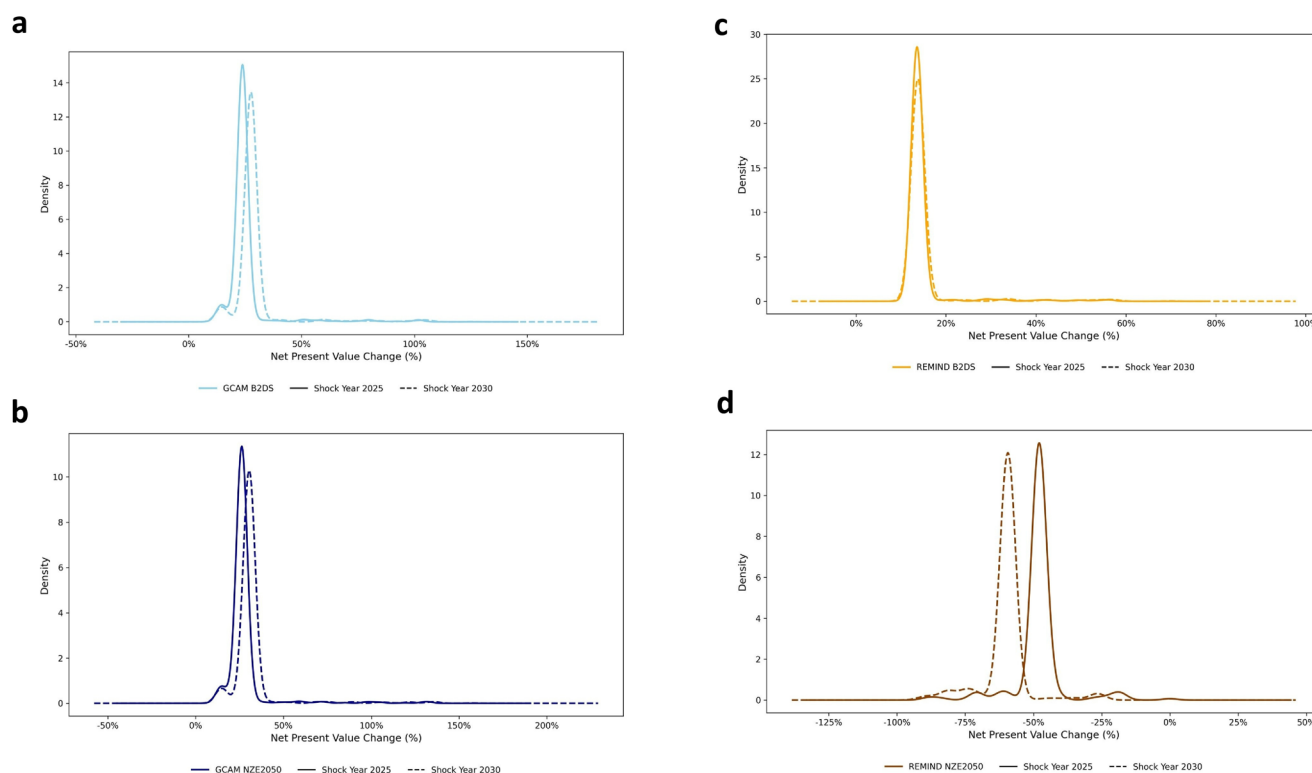
With GCAM B2DS, a positive NPV change of nearly 30% for renewable companies (Fig. 6a) is observed. NPV increases slightly when the shock year is delayed from 2025 to 2030, suggesting that the renewable sector may benefit from delayed policy shocks, allowing for more time to adapt to transitions. With GCAM NZE2050 also, the positive NPV changes for renewable companies increase as the shock year is delayed (Fig. 6b).

**Fig. 4 | Distribution of NPV change (%)—gas and oil companies.** **a, b** Present plots for distribution of Net Present Value (NPV) Change (%) for gas-based power companies and oil-based power companies (Grouped Bar) respectively.



**Fig. 5 | Distribution of NPV change (%) renewable companies—all models and scenarios.** Distribution of Net Present Value (NPV) change (%) for Renewable Companies-All Models and Scenarios. Colored lines track NPV (%) change plots across 2 shock years (2025—solid lines & 2030—dashed lines).





**Fig. 6 | Distribution of NPV change – Renewable Companies.** a–d Presents plots for distribution of Net Present Value (NPV) Change (%) for Renewable companies across 2 shock years (2025–solid lines & 2030–dashed lines).

With REMIND B2DS and REMIND NZE2050, the positive NPV change is lower than in GCAM, at approximately 14% for B2DS (Fig. 6c, d) and shows no significant impact of the shock year.

Overall, results reveal that renewable companies can maintain financial stability amidst external shocks and could even improve their position with delayed shocks supporting the long-term viability of renewables in achieving net-zero targets. The incremental NPV improvement suggests that renewable investments are robust and could become more attractive with time, as the renewable sector continues to grow and adapt to shifting market dynamics and policy frameworks.

**Differentiated financial impacts varying by technology/ company type**

In contrast with the more significant losses observed in gas and coal companies, nuclear companies generally experience minor declines in NPV across most scenarios and models, and do not exhibit clustering, suggesting a broader distribution of financial impacts depending on specific scenario conditions (Fig. 7a). Clearly, the most pronounced negative impact is observed in the GCAM NZE2050 scenario, where NPV decreases exceed 60%. Changing the shock year from 2025 to 2030 exacerbates this decline, with losses deepening to over 80%. This may be due to significant pressure on nuclear companies, possibly due to increased competition from renewable technologies and policy shifts favoring non-nuclear low-carbon solutions to achieve net-zero emissions by 2050 in the GCAM NZE2050 scenario. Notwithstanding the variability in outcomes, to ensure viability, there is a need for policy support for the nuclear sector in a rapidly decarbonizing world.

Hydropower companies experience negligible financial impacts (<1%) across both GCAM and REMIND models, irrespective of target or shock years (Fig. 7b). This stability suggests that hydroelectric power sector in India is resilient to the economic and policy shocks modeled in various decarbonization scenarios. It also posits hydro as a low-risk, stable energy source in the transition to a low-carbon economy and underscores hydro’s role as a reliable component of the future Indian energy mix. While our

transition-risk results indicate only negligible NPV changes for hydropower under NGFS-GCAM/REMIND pathways, this finding reflects transition risk drivers rather than physical or geopolitical hazards. Hydropower in India—particularly Himalayan storage and cascade projects—faces distinct physical risks e.g., landslides and cloudbursts causing catchment damage, as well as geopolitical risks arising from upstream developments in trans-boundary basins notably the Brahmaputra and Indus systems. These hazards can reduce available generation, raise repair and resilience costs, and cause prolonged multi-year outages—outcomes not captured by the IAM-driven transition scenarios used here. We acknowledge that hydropower may face physical and geopolitical hazards which however falls outside the pure transition-risk scenarios used here and the scope of this study. We suggest capturing the localized physical or geopolitical shocks alongside transition risk analysis as extensions for future work.

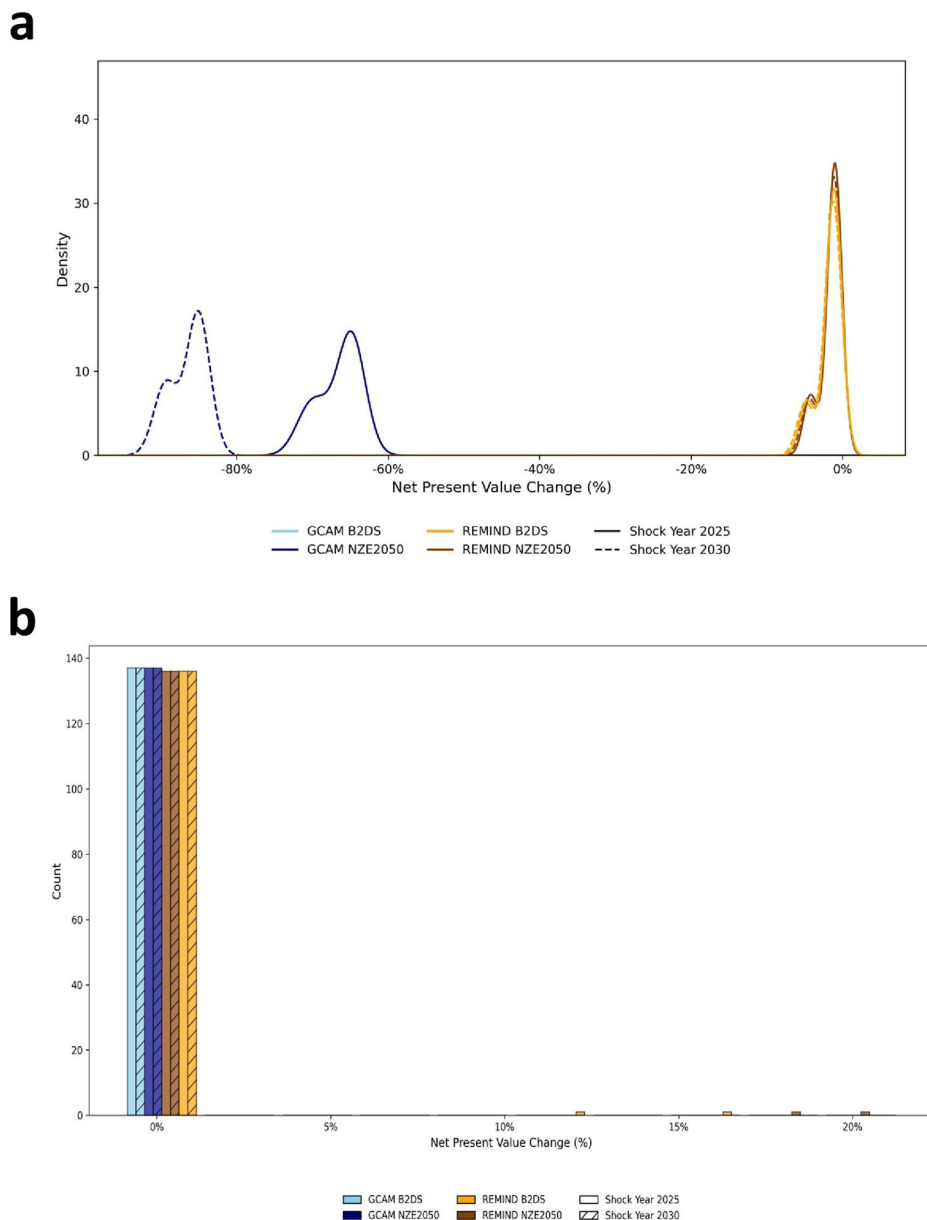
We observe that the financial impacts of climate transition risks are well differentiated which vary as per technology type, a finding rather intuitive. While hydropower companies maintain financial stability (< 1% NPV loss), nuclear companies experience mixed outcomes with losses ranging from minor to major, renewables consistent yet moderate gains, and fossil dominated companies i.e. coal, gas and oil-based power firms see steep declines, with NPV reductions (> 50%) signaling systemic risks.

**Discussion and conclusion**

Insights gleaned from the findings in this study are useful not only for utilities but also for investors and policy makers. Driven by heavy losses in the coal and gas sectors which dominate power generation, India’s power sector reveals a predominantly negative financial outlook with losses ranging from 48 to 54%. These findings hold significant implications for investors who are interested in increased cash flows and minimizing losses, as well as for policy makers who are seeking to establish climate risk regulatory policies. Our analysis underscores the negative financial outlook for coal companies under varying scenarios, with the model choice and timing of interventions (shock years) being pivotal factors. These losses deepen as policy and market shocks are delayed, emphasizing the need for immediate

**Fig. 7 | Distribution of NPV change (%) – Other Companies (Nuclear and Hydropower).**

**a, b** Present plots for distribution of Net Present Value (NPV) Change (%) for Nuclear and Hydro-power companies (Grouped Bar) respectively.

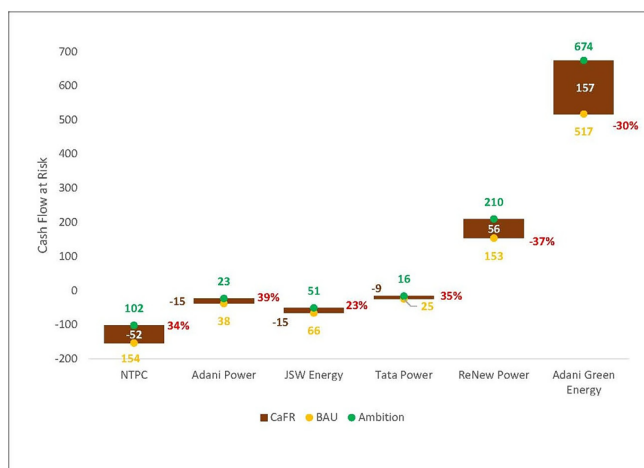


adaptation and strategic shifts. GCAM’s more severe projections point to the urgency of immediate action, while REMIND’s sensitivity to shock years highlights the consequences of delayed responses<sup>48</sup>. The severe and consistent decline in NPV across all scenarios signals an inevitable downturn for coal companies which also see near-total value erosion in few instances, emphasizing the critical need for robust and immediate climate policies to phase out coal.

Our results are consistent with other recent studies which also point out that coal companies lose value as India transitions to clean energy sources<sup>49–52</sup>. Policymakers must focus on supporting the transition of coal-dependent regions and industries to prevent economic dislocation. Immediate action is essential to mitigate the adverse impacts on coal companies and the broader energy market. For investors, their investments in coal companies face significant risks as the sector’s financial viability continues to erode under stringent climate scenarios. Coal companies must urgently rethink their business models, focusing on decarbonization strategies, diversification into renewable energy, and leveraging technologies like CCUS to remain viable in a rapidly changing energy landscape<sup>48</sup>.

Our analysis also revealed a challenging outlook for gas and oil companies under both GCAM and REMIND models, with consistent NPV declines irrespective of shock year timing, suggestive of broader systemic risks in the sector. While gas is often seen as a transitional fuel, our findings suggest that its long-term viability may be compromised under aggressive decarbonization pathways<sup>53</sup>. Policymakers need to reconsider the role of natural gas in future energy strategies and focus on supporting the transition of gas companies towards lower-carbon alternatives, such as hydrogen or bio-methane, and encourage investments in carbon capture technologies to mitigate value erosion. The uniform losses across models and shock years present a strong signal to investors about the declining financial prospects of the gas sector. Gas companies need to reassess their long-term strategies to adapt to the shifting energy landscape, which includes exploring investments in renewable energy, developing CCUS capabilities, and pursuing alternative low-carbon energy solutions. For power companies to decarbonize and diversify their portfolios, changes in policy incentives and regulation may be needed<sup>53</sup>.

Across different models and target/shock years, the NPV for renewable companies demonstrates positive value change, though the magnitude of



**Fig. 8 | Case Studies Analysis: Cash Flow at Risk (CfaR).** Cash flow at risk (CfaR) for six leading Indian power firms—NTPC (coal), Adani Power (Coal), JSW Energy (mixed portfolio), Tata Power (mixed portfolio), ReNew Power (renewable), and Adani Green (renewable)—under business-as-usual (BAU) and ambition scenarios.

this change is generally less than the losses observed for coal power companies. The magnitude of the gains for renewables is predominantly driven by the choice of models with GCAM showing higher impact as well as sensitivities to earlier target and shock years<sup>54</sup>. The findings suggest that renewable energy companies are well-positioned to benefit under various climate scenarios and undertake strong financial growth going forward. Policymakers can take confidence in the sector’s ability to withstand and even thrive under delayed shocks, supporting the push for robust and forward-thinking climate policies<sup>55,56</sup>. From investor’s standpoint, the positive NPV changes across scenarios indicate a strong financial case for investment in renewables with the sector being stable and attractive for long-term investments, even in uncertain economic conditions. For renewable companies, their consistent positive outlook across scenarios supports efforts to expand their capacity and innovation, knowing that financial returns are likely to remain favorable regardless of the timing of external shocks.

Our analysis of nuclear companies illustrates the variability in outcomes, with significant declines particularly in the GCAM NZE2050 scenario, and less severe but still negative impacts in other scenarios. Policy support for nuclear energy’s role in providing stable, baseload power alongside intermittent renewables may be necessary. Indian Government has opened nuclear sector for private players and is initiating regulatory reforms and public engagement recognizing its key role<sup>57,58</sup>. Further, policies promoting innovation in nuclear technology, such as next-generation reactors or small modular reactors (SMRs)<sup>59</sup>, could mitigate financial declines and enhance the sector’s resilience<sup>39</sup>. Nuclear companies also need to adapt to the shifting energy landscape by investing in innovative technologies and diversifying their energy portfolios. Developing partnerships with renewable energy providers and focusing on hybrid energy systems may offer new avenues for stability and growth.

Hydro-power companies show minimal fluctuations, reinforcing the negligible impact on this sector across scenarios. Given hydro-power’s resilience, policymakers can view hydroelectric power as a cornerstone of the renewable energy transition in India. Efforts should focus on optimizing hydro infrastructure and integrating it with variable renewable sources like wind and solar to enhance grid stability. For investors, hydroelectric power remains a low-risk asset with stable returns, even in the face of aggressive decarbonization policies.

To validate our results for financial impact, we estimated Cash flow at risk (CfaR) using discounted cash flow (DCF) techniques for six leading Indian power firms—NTPC (coal), Adani Power (Coal), JSW Energy (mixed portfolio), Tata Power (mixed portfolio), ReNew Power (renewable), and

Adani Green (renewable)—under business-as-usual (BAU) and ambition scenarios (see Fig. 8). Firms heavily reliant on coal, such as NTPC and Adani Power, faced significant financial risks with CfaR of 33.9% and 39.0% respectively, despite short-term stability. Firms like ReNew Power and Adani Green, which pursue aggressive renewable energy expansion, show substantial long-term benefits with negative CfaR of 36.8% and 30.4% respectively although they may face short term financial pain. Firms with mixed portfolios like JSW Energy and Tata Power with CfaR of 23.2% and 35.0% respectively, also face financial strain albeit less than pure fossil companies and must navigate the transition carefully, balancing immediate financial stability with long-term decarbonization goals.

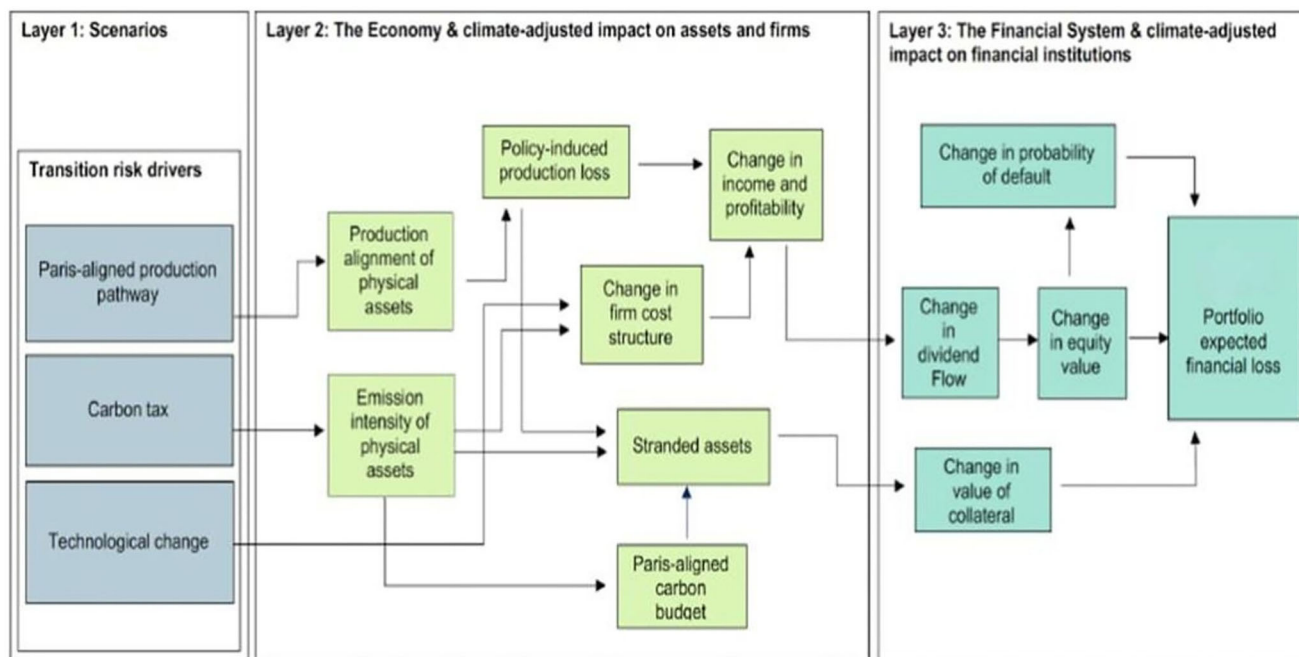
Individual firm-level analysis for six leading power firms confirms our earlier aggregate results obtained using the microeconomic climate transition risk stress test. For instance, the results for ReNew Power and Adani Green Energy validate our aggregate results for renewable companies which exhibit an average 30–40% increase in NPV. Further, results for coal firms, such as NTPC and Adani Power, as well as mixed portfolio firms, such as JSW Energy and Tata Power, all of which witness substantial decline in value, also reinforce our earlier aggregate results for power companies.

Our findings underscore the importance of model selection in evaluating NPV impacts across companies. GCAM tends to display more extreme changes, while REMIND offers more moderate results. The shock year and target scenario also play critical roles in shaping the financial outlook, necessitating careful consideration in strategic planning. Delayed policy shocks worsen financial risks for coal companies, with NPV losses increasing by 10%–15% and intensify financial gains for renewables, with NPV increasing by 7–12%, when the shock year shifts from 2025 to 2030. Notably, the intensity of the shock, whether positive or negative, becomes more pronounced the later the shock year occurs. These findings highlight the urgent need for prompt policy action, as an early propagation of the transition shock can help reduce some of the financial losses for coal companies.

We have summarized the following key implications emanating from our analysis for policy makers.

- **Strengthen transition-risk disclosures**—Securities and Exchange Board of India (SEBI) and RBI should mandate sector-specific transition-risk reporting aligned with NGFS pathways to ensure consistent assessment across firms and lenders.
- **Provide stable long-term policy signals**—The Ministry of Power should publish predictable decarbonization and capacity-addition roadmaps to reduce uncertainty for capital-intensive energy investments.
- **Manage stranded-asset risks proactively**—The Ministry of Finance, along with public financial institutions, should create refinancing or repurposing mechanisms for vulnerable coal and gas assets.
- **Support low-carbon technology adoption**—Regulators should expand incentives for storage, industrial electrification, and grid modernization to smooth transition impacts.
- **Integrate firm-level modeling into supervision**—RBI and SEBI should incorporate firm-level valuation shocks into climate-stress tests to capture heterogeneity beyond sector averages.
- **Improve data governance and transparency**—A unified national database for plant-level operational, emissions, and contract data could be established to strengthen risk assessment.

While the analysis is conducted using data from Indian companies but using NGFS pathways, the underlying transition mechanisms, sectoral risk drivers, and scenario pathways used in this study have strong global relevance. Although sectoral shocks are calibrated to the Indian context, the direction and structure of the risks for coal/oil/gas and gains for renewables—mirror global transition patterns and therefore support broader applicability. The pathways through which transition risks manifest—such as changes in fossil fuel demand, renewable penetration, technology cost curves, carbon pricing, and investor preferences are also applicable globally. Thus, while the analysis uses Indian firms, the underlying risk transmission



**Fig. 9 | Three-layer framework of the climate transition risk test: our study.** The model framework composed of the three methodological layers for the bottom-up microeconomic climate transition risk stress test used in this study.

mechanisms are globally comparable. Power sectors globally face similar transition pressures, particularly across emerging and developing economies with comparable energy structures. Therefore, the insights provide not only India-specific implications but also a broader understanding of how transition risks may materialize in similar economies globally.

One limitation of this study is the inability to comment on the drivers and causes of the varying performance of companies with model, shock and target year changes. Future research could investigate the granularities of model-specific variations and the role of shock year timing so as to develop more informed strategies regarding financial impact of these climate transition risks on the performance of companies. Given the importance of state-owned generating companies and the unique transition challenges they face, such as regulated tariff structures, legacy fleet characteristics, and financing constraints, these firms could be included as a priority area for future extensions of this work.

## Methods

### Climate transition risks using microeconomic climate transition risk stress test

We use an asset-level, forward looking, bottom-up microeconomic climate transition risk stress test, initially developed by Baer et al.<sup>39</sup> to construct multiple scenarios of varying climate ambition at the company level, assessing the financial risks associated with late and abrupt transitions. Specifically, it propagates the climate-adjusted economic impacts of these scenarios to firms’ asset values through a set of transmission channels, estimating potential changes in market valuation which enables the measurement of transition risk. The model framework is composed of the three methodological layers (see Fig. 9).

The first layer of the framework involves constructing company-level climate financial scenario pathways. The model leverages the links between climate scenarios and company production plans to generate a range of late and sudden climate transition risk scenarios. These climate transition risk scenarios define how counterparties’ production plans should align within decarbonization pathways to meet global temperature targets. The process begins by translating climate financial scenarios into sector-level decarbonization pathways, which are further refined into technology-specific production pathways to derive relative company climate targets. A

company’s decarbonization effort is assessed based on the alignment of its forward-looking production plans with these pathways and its market share within the sector. Consequently, the model evaluates the misalignment of company’s planned carbon-intensive production with a Paris-aligned scenario pathway. Each company follows its own production pathway, adjusting to compensate for misaligned production. In aggregate, sector-level production aligns with scenario-based technology targets and the overall carbon budget.

The second layer interacts with the company’s decarbonization pathways with real economic projections on costs, price, and general economic developments, as well as the company’s financial risk profile. The production trajectories across various scenarios serve as the foundation for calculating firm net profits. For a given firm *i* and year *t*, net profit is derived by multiplying the production volume by the unit price and unit cost of the corresponding production technology *s*:

$$Net\ Profit_{i,t} = production\ volume_{i,t,s} \times (unit\ price_{t,s} - (unit\ cost_{t,s} + carbon\ tax_{t,s})) \quad (1)$$

Company production trajectories from climate scenarios drive majority of the impact on profits. Production trajectories are integrated into the model framework as shocks, with distinct approaches for carbon-intensive and low-carbon technologies. Carbon-intensive trajectories follow growth rates specified in the scenarios, while low-carbon trajectories are based on their relative share of total sectoral production. This method improves estimates for companies operating multiple technologies or planning future production expansions, even if they have no initial production.

In the third layer, the model estimates companies’ market risk or transition risk. Market risk is evaluated based on changes in a company’s NPV under different climate scenarios. Specifically, company-level impacts are translated into profit and cash flow projections based on technology-specific production shocks. These projections are then used in discounted cash flow (DCF) models to assess changes in asset and equity valuations. The discounted cash flow model translates net profit trajectories into expected company value.

Following Gordon's<sup>60</sup> approach to future dividend flows, future profits are assumed to be distributed as dividend payouts to investors. Consequently, the value of a company's equity is represented as the cumulative discounted sum of future net profits. The model applies the discount rate calculated based on the Capital Asset Pricing Model<sup>61,62</sup>.

For a given scenario, this value is simply the sum of all future discounted net profit for a given firm *i* and year *t* (see Eq. (3)), the discounted net profit is calculated using Eq. (2) below:

$$\text{Discounted net profit}_{i,t} = \frac{\text{Net profit}_{i,t}}{(1 + \text{discount rate})^t} \quad (2)$$

$$\text{Net Present Value}_t = \sum_{\text{shock\_year}}^{2050} \text{Div}_{\text{ratio}} \times \text{Discounted net profit}_{i,t} \quad (3)$$

The company equity value change due to transition shock is given as the percentage difference between NPV baseline and NPV shock. This metric constitutes a measure of company market risk as a result of transition shock:

$$\text{Equity value change} = \frac{\text{NPV shock} - \text{NPV baseline}}{\text{NPV baseline}} \quad (4)$$

Figure 10a illustrates the methodological flow of analysis for transition risk assessment.

Table 3 provides variable definitions and model parameters that impact firm-level valuation in this study.

We now discuss the rationale behind the scenario and model selection. The two scenarios used in this study are NZE2050 and B2DS, which are widely used in regulatory climate-stress testing and allows evaluation of risk for varying levels of stringency. While NZE2050 Scenario (Net Zero Emissions by 2050 Scenario) is closer in ambition to what the world needs to meet ~1.5 °C, the B2DS Scenario (Beyond 2 °C Scenario) is more modest targeting well-below 2 °C (1.75 °C–2 °C) above pre-industrial levels. Thus, B2DS represents a lower ambition scenario compared to NZE2050, especially in timing of reaching net-zero. Because India's 2070 net-zero target comes two decades later than the 2050 net-zero emissions, in global-climate-stabilization terms, India's 2070 goal is much closer to B2DS than to NZE2050. Intuitively, under the more stringent NZE2050 scenario, fossil fuel-heavy companies face greater financial risks and value decline, while renewable energy companies see significant gains.

The two models used in this analysis are GCAM and REMIND which are the primary IAMs utilized by NGFS and Intergovernmental Panel on Climate Change (IPCC) for its Assessment Reports (AR) to generate global transition pathways. Using GCAM and REMIND for our analysis ensures consistency with the frameworks employed by central banks and financial regulators worldwide viz. the RBI, the European Central Bank (ECB) and BIS for supervisory stress-testing exercises. Both these models provide India-specific outputs for fuel demand, sectoral energy use, technology costs and carbon prices, which we translate into quantitative sectoral shocks. These shocks are then mapped to firm-level financials in our discounted-cash-flow framework to estimate company-level transition risk. Their contrast provides a deliberate range of plausible transition outcomes in our study. Relying on a single IAM would risk model-dependence; using GCAM and REMIND allows us to quantify the divergence in transition pathways and identify how valuation outcomes vary under different transition dynamics. Both GCAM and REMIND provide harmonized versions of NZE2050 and B2DS, ensuring comparability across models and avoiding mismatched assumptions.

In IAMs, such as GCAM & REMIND, a carbon price serves as a proxy for modeling alternate policies and pathways, such as business as usual (i.e., current policies) and low transition (i.e. ambition). Such a carbon tax/price will directly affect the cost structure of firms in climate-critical sectors and

create incentives to change production composition across competing firms<sup>63,64</sup>. Accordingly, the models used in this study- GCAM & REMIND for the different scenarios B2DS and NZE 2050 uses different carbon prices so as to reflect these. These carbon prices have nothing to do with the current state of carbon market in India and are also not impacted by the prevailing carbon tax (or lack of carbon tax) in India; they only model the trajectory of chosen pathways/scenarios.

As the study was carried out in 2024, we analyzed the financial risk resulting from a sudden and mid climate transition in India with these modeled as shocks during 2025 and 2030 respectively. The shock years have been varied to reflect varying degrees of a disorderly transition. The primary objective of having selected 2025 and 2030 as shock years is to have early, mid shocks, not late; and examine how delaying the transition from 2025 to 2030 impacts the results (losses/gains) with the hypothesis being a delayed shock year manifests in an even more disruptive transition and hence higher risks. With NGFS NZE2050 being a key transition scenario, keeping shock years 2040 or later, may not be plausible and would only yield elevated losses/gains for fossils/renewables respectively. We thank an anonymous reviewer for pointing this out.

### Cash flow at risk (CfaR) analysis for leading indian power firms: case studies

Three main criteria were used for identifying case study firms-

- (i) System Relevance (Market Share & Installed Capacity), Firms were selected which accounted for a nationally significant share of India's total installed generation capacity and electricity output. These six firms collectively influence a large portion of India's power sector dynamics.
- (ii) Portfolio Diversity (Technology Mix): The firms represent the full spectrum of India's power-generation landscape which allows us to examine transition risks across distinct technological and ownership structures.

- Predominantly fossil-based: NTPC, Adani Power
- Mixed portfolios: Tata Power, JSW Energy
- Fully renewable: ReNew Power, Adani Green Energy

#### (iii) Data Availability & Financial Transparency:

Our Cash Flow at Risk (CfaR) modeling requires consistent, multi-year operational, and financial data. These six firms provide reliable annual reports, financial disclosures, and capacity/generation statistics necessary to parameterize the model. Many other firms—including state-owned utilities—lack the granular financial and plant-level disclosures needed to run Discounted Cash Flow (DCF)-based transition risk analysis.

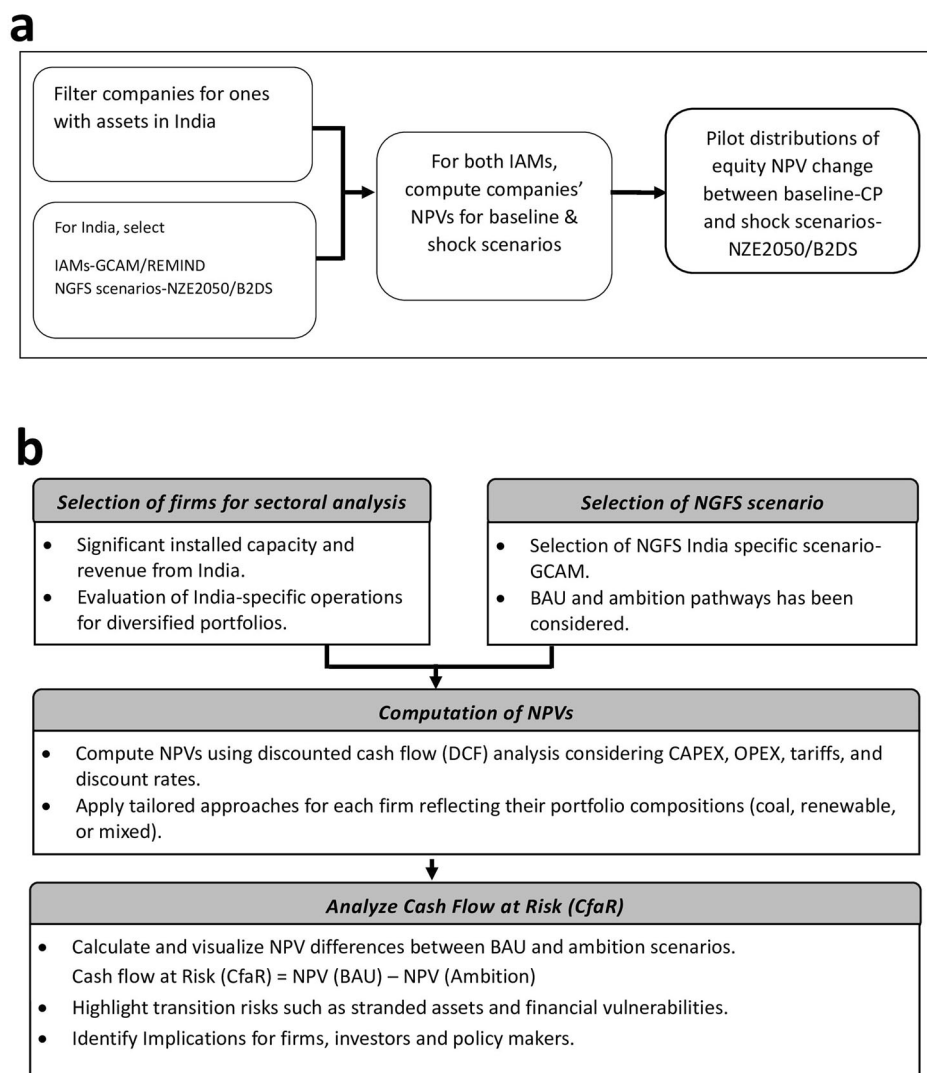
Overall, we selected six leading firms in Indian power sector across different technologies (Table 4). These include:

- *NTPC*: Largest coal power firm in India with over 76 GW capacity.
- *Adani Power*: Operates 15 GW of thermal generation capacity.
- *Tata Power*: Maintains a diversified 14 GW portfolio.
- *JSW Energy*: Operates 7 GW of capacity with a balanced portfolio.
- *Adani Green Energy*: Renewable-focused with an 11 GW capacity.
- *ReNew Power*: Renewable-focused, with 9.5 GW installed capacity.

Figure 10b shows the methodological flow for analyzing these companies. The methodology captures the unique characteristics and transition readiness of each firm, providing a comprehensive view of how India's energy transition might affect their financial performance (see Fig. 10b). Given the diverse portfolio compositions and strategic priorities of the selected companies, we model each firm using a tailored approach. This ensures that the analysis captures firm-specific dynamics and aligns with their stated goals and market strategies.

We select NGFS GCAM scenarios: (i) BAU, and (ii) NZE2050, for Indian geography that explicitly address the Indian context to capture the impact of varying transition pathways. These NGFS pathways incorporate

**Fig. 10 | Methodological flow of analysis: our study. a, b** Present the methodological flow of analysis for transition risk assessment and for analyzing the Case study firms respectively.



**Table 3 | Variable Definitions and Model parameters**

Parameter	Value	Description / calibration
Production volume	Scenario- and firm-specific	Firm-level production pathways obtained by downscaling IAM technology trajectories using asset ownership and market-share weights.
Net profit margin (baseline)	Firm-specific	Baseline firm net profit margin used to calibrate the price–cost wedge in Eq. (1); unit prices and unit costs are not modeled separately.
Carbon tax	Scenario-specific	Scenario-implied carbon price entering Eq. (1) as an additional cost borne by the firm.
Discount rate	9%	Applied in Eq. (2); CAPM-based rate consistent with Indian regulated utility benchmarks.
Dividend payout ratio	1	Applied in Eq. (3); assumes full payout of discounted net profits to equity holders.
Shock year	2025; 2030	Determines the timing of the late and abrupt transition and the start of the summation in Eq. (3).
Valuation horizon	2050	End year of the discounted cash-flow summation in Eq. (3), aligned with scenario horizons.

global climate policies, technology costs, energy mix transitions, and macroeconomic impacts, offering a comprehensive framework to evaluate the financial implications of the energy transition. While the baseline scenario (BAU) assumes continuity of existing market trends, the ambition scenario (NZE2050) integrates factors, such as accelerated decarbonization, increased renewable adoption, and market shifts. This comparison allows us to analyze the financial outcomes under different transition trajectories.

We then employ Discounted Cash flow (DCF) techniques to compute the NPV under the BAU and NZE2050 scenarios and then evaluate the

Cash-Flow-at-Risk (CfaR) for each of these firms using Eq. (5) below.

$$Cashflow\ at\ Risk\ (CfaR) = NPV(BAU) - NPV(NZE2050) \quad (5)$$

**Data**

**Climate transition risks using microeconomic climate transition risk stress test.** We utilize asset-based production data sourced from the *Asset Impact database*, which provides an in-depth look at individual production

**Table 4 | Case studies on leading Indian power firms: Cash flow at risk (CfaR) Analysis**

Firm	Nature	Present capacity	Characteristics	CfaR (%)	Outlook
NTPC	Dominant coal capacity	74.64 GW (67.38 GW Thermal, 7.26 GW RE), generates 422 BUs annually	Largest power producer in India with the highest share of installed capacity and electricity generation.	33.9%	Long-term vulnerability due to coal reliance; needs aggressive renewable capacity growth.
Adani Power	Fossil fuel-based, primarily thermal power plants	15.25 GW (Thermal), generates 79 BUs annually	Largest private thermal power producer in India, with a substantial market share in coal-based generation.	39.0%	High-risk exposure under ambition scenarios due to limited diversification into renewables.
JSW Energy	Mixed portfolio of fossil fuel and renewable capacity	7.24 GW (3.5 GW Thermal, 3.73 GW RE), generates 27.9 BUs annually	Balanced portfolio with ongoing diversification, among top private players transitioning to renewables.	23.2%	Moderate risk; resilience increases with accelerated renewable investments.
Tata Power	Mixed portfolio with ambitious renewable targets	14.22 GW (8.81 GW Thermal, 5.41 GW RE), generates 64.6 BUs annually	One of the largest integrated power companies with significant renewable capacity expansion goals.	35.0%	Transition-ready with ongoing renewable investments; moderate risk from legacy thermal.
ReNew Power	Fully renewable portfolio	9.5 GW (Renewables), generates 19.5 BUs annually	Second-largest renewable energy company in India, leading in solar and wind generation.	-36.8%	Strong financial positioning; benefits from a renewable-focused strategy.
Adani Green Energy	Fully renewable portfolio	10.93 GW (Renewables), generates 21 BUs annually	Largest renewable energy developer in India, with aggressive capacity expansion plans to reach 50 GW by 2030.	-30.4%	Financially resilient under the ambition scenario due to a focused renewable strategy.

**Table 5 | Number of Assets under each technology: Summary of data**

Sl. No.	Technology	Number of Assets
1.	Coal	419
2.	Gas	127
3.	Hydro	137
4.	Nuclear	6
5.	Oil	12
6.	Renewables	1271
<b>Total</b>		<b>1972</b>

facilities, their activities, production plans, and ownership structures within Indian power companies. The dataset includes a total of 1703 unique assets which are associated with 1703 distinct power companies, offering a detailed representation of production facilities across a variety of sectors and technologies. Each asset corresponds to an individual production facility or plant, providing data on its operational status, output capacity, and forecasts for production over a 5-year period. Out of the 1703 companies, 1256 operate within a single technology or asset type, while 447 companies are diversified across multiple sectors and technologies. For financial analysis, the assets are mapped to companies. This dataset is quite comprehensive and covers a diverse range of technologies, including coal, gas, oil, hydro, nuclear and renewable power generation. Table 5 provides a summary of number of assets under each technology.

In addition, the scenario level data inputs which includes the climate–economy scenarios, which project the set of climate-adjusted economic parameters includes decarbonization and sectoral production pathways (across regions), unit cost projections and carbon tax pathways. The scenario parameters are exogenous and are sourced from the NGFS<sup>65</sup>. The third type of input data consists of company-level financial information and risk profiles provided by *Refinitiv Eikon*. This includes metrics, such as market capitalization, asset volatility, leverage ratio, and net profit margin. In our analysis, only the net profit margin impacts the results as we are not looking at probabilities of default.

**Cash flow at risk (CfaR) analysis for leading Indian power firms: case studies.** For analyzing case studies, three main data sources were used:

1. *Scenario Data*: we utilize NGFS GCAM scenarios for Indian geography that explicitly address the Indian context to capture the impact of varying transition pathways. In this study, we use two NGFS GCAM scenarios:
    - *Baseline Scenario (Business-As-Usual, BAU)*: Reflects existing policies and trends without significant policy intervention or market disruption. It assumes slow renewable adoption and continued reliance on fossil fuel-based generation.
    - *NZE2050 (Ambition Scenario)*: represents an aggressive decarbonization pathway with rapid renewable energy adoption, declining coal use, and increased climate-related policy measures. These NGFS pathways incorporate global climate policies, technology costs, energy mix transitions, and macroeconomic impacts, offering a comprehensive framework to evaluate the financial implications of the energy transition. This comparison allows us to analyze the financial outcomes under different transition trajectories.
- Firm-Level Data**
- *Annual Reports*: we sourced operational capacities, generation data, revenue, and expenditure details directly from company reports<sup>40–45</sup>. These reports served as the basis for deriving key metrics, such as tariffs, Plant Load Factor (PLF) values, and EBITDA percentages.
  - *Historical Financial Data (Past 5 Years)*: we analyzed revenue, costs, and financial trends from past reports to project future financial

statements, including cash flow, profit and loss (P&L), and balance sheet data.

2. *CEA Benchmarks*: we derived capital expenditure (CAPEX) estimates using technology-specific benchmarks published by the Central Electricity Authority (CEA)<sup>66</sup>.
3. *CERC Benchmarks*: we have factored tariff determination guidelines as specified in Central Electricity Regulatory Commission (CERC)<sup>67</sup>.

### Data availability

The data used by authors in this study is proprietary in nature, sourced through *Asset Impact* (<https://asset-impact.gresb.com/>). While the authors are not allowed to share the entire dataset publicly due to data proprietary and legal considerations, a representative dataset necessary to interpret, replicate and build upon findings is accessible at <https://doi.org/10.6084/m9.figshare.6025748>. However, eligible academic researchers can access Asset Impact's comprehensive dataset under its academic licensing program by contacting [info@asset-impact.com](mailto:info@asset-impact.com).

### Code availability

No custom code was created or utilized for the analyses in this study.

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## Author contributions

A.J. designed, conceptualized and analysed the research study as well as wrote the manuscript. G.S. conceptualized, supervised and coordinated the overall research. A.J. and B.G. performed the analysis. A.B. and J.C. provided the feedback to the manuscript. A.S. and M.B. provided inputs to methodology.

## Competing interests

The authors declare no competing interests.

## Additional information

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