

# Differentiated Impacts of Climate Transition Risks on the Indian Power Sector

Corresponding Author: Dr Abhinav Jindal

This manuscript has been previously reviewed at another journal. This document only contains information relating to versions considered at Communications Earth & Environment.

**This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.**

**Attachments originally included by the reviewers as part of their assessment can be found at the end of this file.**

Version 0:

Decision Letter:

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Dear Dr Jindal,

Please first accept our apologies for the delay in reaching a decision on your submission.

Your manuscript titled "Differentiated Impacts of Climate Transition Risks on the Indian Power Sector" has now been seen by 3 reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript.

For publication in Communications Earth & Environment to be appropriate, your study must:

- \* provide compelling novel insights on climate transition risks for the power industry that constitute a clear advance over prior works in the Indian context;
- \* transparently report methods to enable reproducibility of your findings, including about model selection, scenario explanation, choice and definition of parameters such as discount rates.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file.

Please note that without substantial revisions, we will not send the manuscript back to review.

Please submit your point-by-point responses as a separate file, distinct from your cover letter where you can add responses to the Editors' comments that you do not want to be made available to the reviewers. Word files are preferred. We recommend that any figures, tables or graphs that are included in the response to reviewers are also included in the main article or Supplementary Information.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and the completed checklist:

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We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so

that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Vaibhav Chaturvedi, PhD  
Editorial Board Member  
Communications Earth & Environment  
orcid.org/0000-0001-5370-8772

Yann Benetreau, PhD  
Consulting Editor, Communications Earth & Environment  
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DATA SOURCES: All new data associated with the paper should be placed in a persistent repository where they can be freely and enduringly accessed. We recommend submitting the data to discipline-specific, community-recognized repositories, where possible and a list of recommended repositories is provided at <http://www.nature.com/sdata/policies/repositories> <http://www.nature.com/sdata/policies/repositories>.

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## REVIEWER COMMENTS:

### Reviewer #1 (Remarks to the Author):

Your paper addresses an important and underexplored issue in the Indian electricity market: how power generation firms may be financially impacted under climate mitigation scenarios. While the study provides some insights into technology-specific vulnerabilities, the manuscript requires further development and deeper exploration before it can be considered for publication. Below, I outline my main concerns and offer suggestions for improvement.

1. **Limited Novelty of Key Findings.** The main results—fossil fuel firms facing significant NPV losses—are consistent with existing literature and international projections. While the range of losses is notable, especially for gas, the paper lacks a breakdown of transmission channels or assumptions that could enrich the interpretation. Interestingly, yourselves acknowledge this limitation in the last part of results section.
2. **Methodological Ambiguity.** The methodology section lacks clarity regarding the rationale behind model and scenario selection. The justification for using GCAM and REMIND is not well articulated, nor are the assumptions underlying each scenario. A simplified partial equilibrium approach, in the same spirit of Acharay et al. 2025 might offer clearer insights into the transmission mechanisms affecting NPV. Moreover, the paper does not compare the scenarios in terms of their structural differences, which is crucial to understanding the divergence in results.
3. **Lack of Coherence and Readability.** The manuscript is difficult to follow. The introduction lacks a clear narrative arc, with paragraphs shifting topics abruptly. The overall structure does not guide the reader through the logic of the analysis. For instance, the methodology and data section are after the results, which is very confusing. I strongly recommend a thorough editorial review by a native English speaker or professional editor with expertise in academic writing.
4. **Figures and Tables: Poor Quality and Documentation.** Figures and tables lack units, clear labels, and descriptive captions. Some graphics are of low resolution and difficult to interpret. For example, Figure 1 fails to distinguish between models and shock years due to poor color and shape coding. I suggest standardizing colors by model and using distinct shapes or line styles for shock years. Additionally, ensure all figures are legible and properly formatted for publication.

### Reviewer #2 (Remarks to the Author):

The authors analyze energy transition risks to the coal-dependent economy of India, through two established models and two established scenarios. At a granular level, six power generation sectors are assessed for their risks by encountering two shocks at 2025 and 2030. The study is surely interesting, but quite a few adjustments need to be made to the manuscript to be considered for publication.

#### Introduction:

1. The construction of the introduction is very haphazard. Often, it seems that there is a lack of clear focus of what the paper actually wants to achieve. GCAM and REMIND are introduced in three distinct paragraphs, which are not consecutive. This makes it extremely unreadable.
2. The consideration of India in the study is based upon: "Research has not been done on a developing economy like India." This is quite a weak premise for novelty, as the papers that the authors cited do recommend adopting the methodology for developing economies. But is it worthy of an academic venture in Nature communications? Any industrial/govt. body could easily adopt the study and produce these results. "A firm-level transition risk assessment" is broadly not academic.
3. When the authors say "case studies were selected based on their market share and installed capacity", even in the supplementary information- It seems quite random. Concrete justification for the six case-studies is missing.
4. The introduction should be much less about India and talk about the nature of the financial risks of energy transition, citing the relevant research. There should be one distinct paragraph, where the necessity for an Indian perspective should be outlined.
5. There is a clear lack of global applicability, or at least the authors should argue on it.

#### Research Structure:

1. Why are the GCAM and REMIND models selected? Also, how do these models enable the numerical approach shown in the results?
2. Why are the years for the shocks selected as 2025 and 2030? Why not 2040 and so on?

3. The results are quite affected by the carbon tax component. We are already in 2025, and yet there is no carbon tax in India. Both the models should be adjusted to account for a delayed start of carbon taxation, and there should be a section to analyze the effect on the gains and losses therein.

4. The clear definition of variables are missing in the 'methods' section.

#### Results:

1. Why are the peaks of gas companies at more negative values than coal companies, when emission factor of gas is considerably less than coal? Moreover, multiple developing nations are aiming at transitioning to NG for an intermediate step.

2. What is the fundamental reason for the loss in 2030 for coal companies and gain in 2030 for RE companies to be greater?

3. There should be clear list of policy recommendations in the discussion section. The current description is too long, and must be presented concisely.

#### Reviewer #3 (Remarks to the Author):

The research questions addressed are pertinent. The energy sector is obviously exposed to climate change and related risks. The authors have used modelling-based approach using popular tools to quantify the extent of the risks in a few scenarios in Indian context. I have thoroughly read the paper and have found a few critical issues to be addressed before consideration for publication from my perspective.

1. The claim that this is the only study addressing the issue of climate risk in the context of developing countries is too strong. For example, see this one by Bauri et al. (2025): - "Impact of climate risk on financial performance – evidence from select energy companies from select G-20 countries".

2. The arguments presented by the authors may be countered by the fact that the per capita energy consumption is too low in India and the conventional sources may still have to stay in foreseeable future. It is advised that the issue of low energy consumption may be included in the paper.

3. Huge difference in results between the two modelling approaches is a matter of concern. Of course, both cannot be correct. One possible explanation is offered (REMIND takes into account the Carbon Capture) but that alone is not a sufficient explanation. Further, based on current trends, Carbon Capture and Storage is not going to be a decisive factor in India in next few years.

4. The extent of loss in NPV is too dramatic and clearly depends on model parameters. The paper is silent on those parameters (one such example is the discount rate). It is advised that certain parameters should be declared (certain other aspects of modelling will remain inside black box but currently it is too vague).

5. The case studies surely add value to the study. If possible, include one from state owned power generating utilities (for example, UPRVUNL from Uttar Pradesh – it has capacity of more than 7 GW). The dynamics in the state-owned power generating companies are of interest in the context of the study and may add strength to authors' arguments.

6. As per the study, hydropower is immune to the changing dynamics. It may not be so. Consider the likely climate catastrophes and complex geopolitics in the subcontinent (Landslides and cloudbursts in the Himalayan region, China is making large dams and India's relationship with Pakistan is too volatile).

7. In the Tables (see 1 and 2), multiple digits after the decimal makes the table less readable. It is suggested to report numbers in percentage with 2 digits after decimal only (or maximum of 3 digits when the current number is too small).

8. Some of the arguments are repetitive. The paper could be shortened by avoiding repetitions.

9. I find it strange to see the results too early in the paper and to wait for the methods till the very end. It is advised to put the methodology before the results.

10. Lines 129/130: GCAM and REMIND are frameworks or models and not the scenarios. The sentence may be rephrased.

11. Line 649-652: Strange texts appearing. Please check

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href="http://www.nature.com/authors">www.nature.com/authors</a> for information about policies, services and author benefits\*\*

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Decision Letter:

**\*\* Please ensure you delete the link to your author home page in this e-mail if you wish to forward it to your coauthors \*\***

Dear Dr Jindal,

Your manuscript titled "Differentiated Impacts of Climate Transition Risks on the Indian Power Sector" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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Please review our specific editorial comments and requests regarding your manuscript in the attached "Editorial Requests Table".

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If you have any questions or concerns about any of our requests, please do not hesitate to contact me.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Vaibhav Chaturvedi, PhD  
Editorial Board Member  
Communications Earth & Environment  
[orcid.org/0000-0001-5370-8772](https://orcid.org/0000-0001-5370-8772)

Yann Benetreau, PhD

Consulting Editor, Communications Earth & Environment  
Deputy Editor, Communications Sustainability  
Nature Portfolio  
NY office

REVIEWERS' COMMENTS:

Reviewer #2 (Remarks to the Author):

The authors have successfully addressed all the comments raised in the previous round. I have one doubt with regards to Fig. 1. When the authors say that "filter companies for ones with assets in India", I wonder what is the total set of companies considered. In a minor revision, an appendix/SI should be included to list all the companies considered before filtering.

Reviewer #3 (Remarks to the Author):

The issues pointed out are addressed in the revised manuscript. I would suggest to recheck for minor issues like missing articles and missing punctuations.

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Dear Editor and Referee(s),

Please find below our detailed responses to the review team comments. The comments are in blue colour font, and our responses are in black colour font.

Regards,

Abhinav Jindal, Gireesh Shrimali, Bertrand Gallice, Antonio Buller, Jakub Cervenka, Arnab Sarkar and Marcin Borsuk

### **Comments and Responses**

#### **Editor comments:**

Your manuscript titled "Differentiated Impacts of Climate Transition Risks on the Indian Power Sector" has now been seen by 3 reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in *Communications Earth & Environment*, but would like to consider your responses to these concerns and assess a revised manuscript.

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- transparently report methods to enable reproducibility of your findings, including about model selection, scenario explanation, choice and definition of parameters such as discount rates.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file.

#### **Response:**

At the outset, we would like to thank you and your review team for the valuable time and effort in reviewing the manuscript and providing us with valuable comments.

We have implemented all the suggestions outlined in the comments and have revised the paper substantially. As a result of this, we believe that the manuscript has further improved significantly and hope that the revised manuscript now meets the requirements for publication in *Communications Earth & Environment*.

## **Reviewer 1:**

### **General Comments:**

Your paper addresses an important and underexplored issue in the Indian electricity market: how power generation firms may be financially impacted under climate mitigation scenarios. While the study provides some insights into technology-specific vulnerabilities, the manuscript requires further development and deeper exploration before it can be considered for publication.

### **Response:**

Thank you for the time and effort that you have taken to go through our manuscript and for providing us with valuable suggestions. We sincerely appreciate your comprehensive and thought-provoking comments. We have now implemented all the suggestions outlined in your comments and have revised the paper accordingly. The manuscript has improved significantly as a result, and we are grateful to you for this.

### **Specific Comments:**

1. *Limited Novelty of Key Findings.* The main results—fossil fuel firms facing significant NPV losses—are consistent with existing literature and international projections. While the range of losses is notable, especially for gas, the paper lacks a breakdown of transmission channels or assumptions that could enrich the interpretation. Interestingly, yourselves acknowledge this limitation in the last part of results section.

### **Response**

We appreciate the reviewer's valuable feedback.

We agree that the broad directional finding—that fossil-fuel-based firms face NPV losses under climate-aligned scenarios—is consistent with existing literature. However, our study provides granular, technology-differentiated impacts for an emerging-market power sector viz. India, which the global literature does not currently offer. Further, our study's methodological innovation lies in linking forward-looking production pathways to company-level valuation at scale using a bottom-up stress-test framework.

We acknowledge that the earlier version could not provide a closer look at the transmission channels and regret the same. Literature suggests that an inter play of several factors viz. model assumptions, model uncertainties and technology mixes lead to the differences in inter-model results and comparisons (Durga et al., 2022). Following referee's suggestion, we have now incorporated the following in the revised manuscript.



The major difference in results is driven by the choice of the scenarios (*NZE2050/B2DS*) and the models (GCAM/REMIND). Regarding scenarios, while NZE2050 Scenario (Net Zero Emissions by 2050 Scenario) is closer in ambition to what the world needs to meet  $\sim 1.5^\circ\text{C}$ , the B2DS Scenario (Beyond  $2^\circ\text{C}$  Scenario) is more modest targeting well-below  $2^\circ\text{C}$  ( $1.75^\circ\text{C}$ -  $2^\circ\text{C}$ ) 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.

Regarding Models, GCAM (Global Change Analysis Model) provides recursive dynamic energy-system pathways, whereas REMIND (Regional Model of Investment and Development) offers intertemporal optimization pathways. Both these being Integrated Assessment Models (IAMs), provide India-specific outputs for fuel demand, sectoral energy use, technology costs and carbon prices. GCAM combines economic, energy, land -use, and climate systems to analyse the interactions between human activities and global environmental changes, whereas REMIND has a special focus on the development of the energy sector (NGFS, 2025).

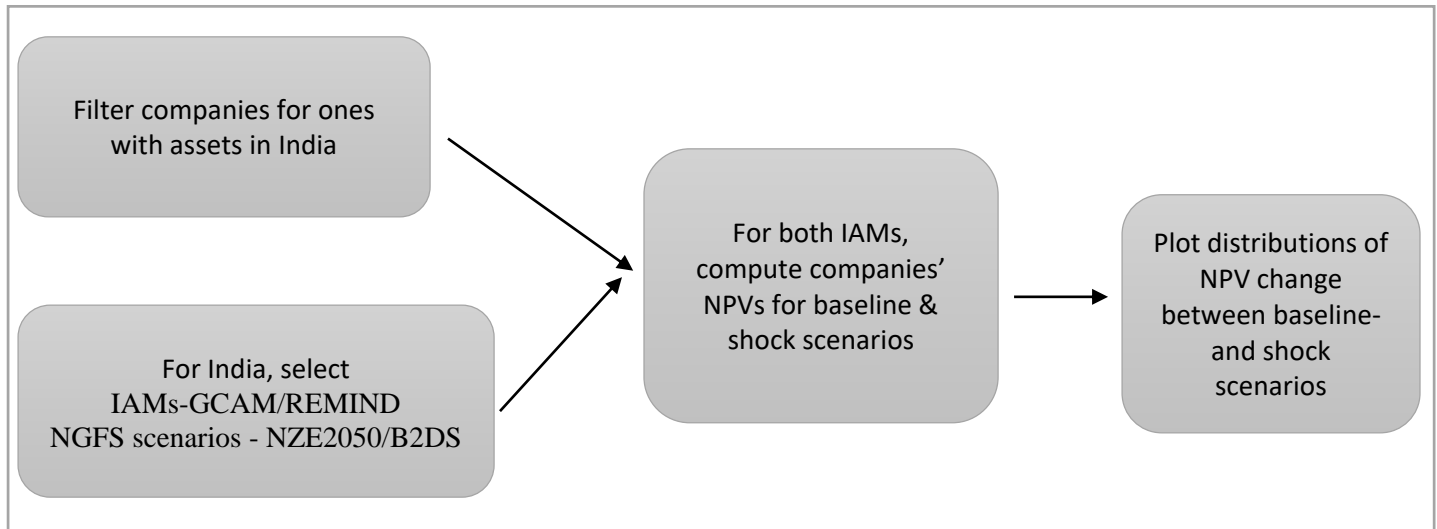
The transmission channels causing GCAM to show more extreme financial implications (for fossil vs renewables) in India are likely:

- (i) REMIND is an intertemporal, perfect-foresight optimization model in which agents minimize total system costs over the entire model horizon, allowing decisions to anticipate future policies, prices, and constraints. As a result, investment and technology choices in REMIND are globally optimal and forward-looking, often leading to smooth and early transitions when future signals are expected. In contrast, GCAM is a recursive-dynamic simulation model that does not solve a global optimization problem. Instead, it makes decisions sequentially in each time period based on current and past conditions, without perfect foresight (Krey et al., 2019). Outcomes in GCAM are therefore more path-dependent reflecting adaptive responses rather than globally optimal trajectories.
- (ii) *Stranded capital risk due to path dependence:* In GCAM, fossil plants especially coal/gas may stay on the books longer, so when carbon pricing or transition shocks hit, much of their value is “locked in” but uncompetitive. The delay in switching leads to path dependence, which alongwith policy tightening leads to large NPV losses. In contrast, in REMIND, agents know future carbon prices/transition paths, so they may invest (or disinvest) more “optimally” ahead of time, smoothing out the shock.

- (iii) *Renewables favored in GCAM*: REMIND uses nested Constant Elasticity of Substitution (CES) production functions to model substitutability between energy technologies / inputs. GCAM, in contrast, uses a logit discrete choice for technology investment. The logit investment structure favors low-cost new technologies; if renewables become cheaper or carbon price penalizes fossil, GCAM reallocates new investment strongly toward renewables giving high gains for renewable firms.

Regarding how the scenarios and models translate to results, we have provided **Figure 1** which explains the flow. Both GCAM and REMIND provide quantitative trajectories for various power generation technologies for India that serve as the foundational quantitative inputs required to construct discounted cash flow valuations for firms under each scenario i.e., baseline and shock, whose difference yield financial impacts.

**Figure 1:** Analysis workflow: Our Study.



Our analysis follows a **three-layer mapping** from IAM models to firm-level impacts:

- **IAM outputs → sectoral transition shocks**: GCAM and REMIND provide quantitative trajectories for coal, oil and gas demand, renewable expansion, carbon pricing, and electrification. These are converted into sector-specific changes in revenues, fuel costs, capacity utilisation, and investment requirements.
- **Sector shocks → firm-level cash-flow adjustments**: The IAM-derived shocks are mapped to firm-specific variables such as production volumes, input costs, technology mix, PPA structures, capex schedules, and operating margins.
- **Firm-level impacts → NPV-based valuation**: Using discounted cash-flow (DCF) models, the difference between the baseline NPV and the scenario-adjusted NPV provides the quantified transition-risk impact for each company.

We have added the above and revised the manuscript suitably.

2. *Methodological Ambiguity.* The methodology section lacks clarity regarding the rationale behind model and scenario selection. The justification for using GCAM and REMIND is not well articulated, nor are the assumptions underlying each scenario. A simplified partial equilibrium approach, in the same spirit of Acharay et al. 2025 might offer clearer insights into the transmission mechanisms affecting NPV. Moreover, the paper does not compare the scenarios in terms of their structural differences, which is crucial to understanding the divergence in results.

## Response

Thank you for raising this point.

We acknowledge that the earlier version did not sufficiently articulate the rationale behind selecting the models and scenarios. Following referee's suggestion, in the revised manuscript, we have added explicit explanations for scenario and model selection in the *methods* section and how it impacts the results in the *results* section.

### *Rationale for Model Selection (GCAM/REMIND)*

1. **Alignment with global standards:** GCAM and REMIND are two of the three primary Integrated Assessment Models (IAMs) used by Network for Greening the Financial System (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 Reserve Bank of India (RBI), the European Central Bank (ECB) and BIS for supervisory stress-testing exercises.
2. **India-specific granularity:** Both models generate detailed India-level trajectories for fuel demand, electricity mix, emissions, technology costs, and carbon-price pathways—inputs essential for sector- and firm-level financial stress testing.
3. REMIND is an intertemporal, perfect-foresight optimization model in which agents minimize total system costs over the entire model horizon, allowing decisions to anticipate future policies, prices, and constraints. As a result, investment and technology choices in REMIND are globally optimal and forward-looking, often leading to smooth and early transitions when future signals are expected. In contrast, GCAM is a recursive-dynamic simulation model that does not solve a global optimization problem. Instead, it makes decisions sequentially in each time period based on current and past conditions, without perfect foresight (Krey et al., 2019). Outcomes in GCAM are therefore more path-

dependent reflecting adaptive responses rather than globally optimal trajectories, leading to extreme losses/gains.

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 (DCF) 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.

### *Rationale for Scenario Selection (NZE2050/B2DS)*

#### **1. Represent Distinct but Policy-Relevant Climate Pathways:**

NZE2050 and B2DS scenarios are widely used in regulatory climate-stress testing and allows evaluation of risk for varying levels of stringency.

While NZE2050 Scenario (Net Zero by 2050 Scenario) is closer in ambition to what the world needs to meet  $\sim 1.5^{\circ}\text{C}$ , the B2DS Scenario (Beyond  $2^{\circ}\text{C}$  Scenario) is more modest targeting well-below  $2^{\circ}\text{C}$  ( $1.75^{\circ}\text{C}$ -  $2^{\circ}\text{C}$ ) 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.

#### **2. Provide Contrasting Stress Intensities**

While NZE2050 produces smoother, predictable sectoral adjustments, B2DS induces steeper reductions in fossil-fuel demand, faster renewable penetration, and more aggressive carbon pricing. This contrast allows us to examine how different transition speeds affect firm-level NPVs.

#### **3. Consistency Across IAMs**

Both GCAM and REMIND provide harmonised versions of NZE2050 and B2DS, ensuring comparability across models and avoiding mismatched assumptions.

The assumptions, structural differences and transmission channels have been mentioned in response to Comment 1 earlier.

3. **Lack of Coherence and Readability.** The manuscript is difficult to follow. The introduction lacks a clear narrative arc, with paragraphs shifting topics abruptly. The overall structure does not guide the reader through the logic of the analysis. For instance, the methodology and data section are after the results, which is very confusing. I strongly recommend a thorough editorial review by a native English speaker or professional editor with expertise in academic writing.

## Response

We acknowledge that the earlier version required clearer narrative flow and better structural coherence. In the revised manuscript, we have substantially reorganised the *Introduction* to establish a logical narrative—from the global relevance of transition risks to the specific research gap after analysing the literature, to the rationale for focusing on India, and finally to the objectives and contributions of the study for India and other countries. Further, abrupt topic transitions have been removed and repetitive passages merged.

In addition, the full manuscript has undergone a thorough proofread and editorial revision to improve clarity, grammar, and readability. These changes have significantly improved the manuscript's coherence, and we thank the reviewer for the constructive feedback.

Regarding the placement of the *Methods* section, the earlier version followed the Nature-format requirement, in which *Methods* appear after the *Results* and *Discussion*. However, to address the reviewer's concern, we have now placed the *Methodology and Data* Section after *Introduction* and before *Results* so as to provide a more logical flow and better understanding.

4. **Figures and Tables: Poor Quality and Documentation.** Figures and tables lack units, clear labels, and descriptive captions. Some graphics are of low resolution and difficult to interpret. For example, Figure 1 fails to distinguish between models and shock years due to poor color and shape coding. I suggest standardizing colors by model and using distinct shapes or line styles for shock years. Additionally, ensure all figures are legible and properly formatted for publication.

## Response

Thank you for pointing this out.

This is a very useful comment, and we have now revised the figures following your suggestion. The revised manuscript has clear figures and images. Different colours have been used to represent different models and distinct line styles have been used to represent shock years (2025, tracked with solid lines and 2030, tracked with dashed lines).

## **Reviewer 2:**

### **General Comments:**

The authors analyze energy transition risks to the coal-dependent economy of India, through two established models and two established scenarios. At a granular level, six power generation sectors are assessed for their risks by encountering two shocks at 2025 and 2030. The study is surely interesting, but quite a few adjustments need to be made to the manuscript to be considered for publication.

### **Response:**

Thank you for the time and effort that you have taken to go through our manuscript and for providing us with valuable suggestions to improve the manuscript. We have done our best to implement all your suggestions and believe that the manuscript has further improved as a result.

We have added the above and revised the manuscript suitably.

### **Specific Comments- Introduction:**

1. The construction of the introduction is very haphazard. Often, it seems that there is a lack of clear focus of what the paper actually wants to achieve. GCAM and REMIND are introduced in three distinct paragraphs, which are not consecutive. This makes it extremely unreadable.

### **Response**

Thank you for pointing this out. We apologize and sincerely regret this and have revised the introduction section in the amended manuscript following the referee's suggestion. Now we have substantially restructured the entire Introduction to improve clarity, readability, and conceptual flow.

In the revised manuscript, we have substantially reorganised the *Introduction* to establish a logical narrative—from the global relevance of transition risks to the specific research gap after analysing the literature, to the rationale for focusing on India, and finally to the objectives and contributions of the study for India and other countries. GCAM and REMIND are introduced in one unified paragraph rather than across three scattered locations. These revisions remove fragmentation, clarify the purpose of the study, and significantly strengthen the narrative focus of the Introduction.

2. The consideration of India in the study is based upon: "Research has not been done on a developing economy like India." This is quite a weak premise for novelty, as the papers that the authors cited do recommend adopting the methodology for developing economies. But is it worthy of an academic venture in Nature communications? Any industrial/govt. body could easily adopt the study and produce these results. "A firm-level transition risk assessment" is broadly not academic.

## Response

Thank you for this important critique. Regarding this, we would like to mention the following:

*This 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 modelling 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.*

3. When the authors say "case studies were selected based on their market share and installed capacity", even in the supplementary information- It seems quite random. Concrete justification for the six case-studies is missing.

## Response

Thank you for pointing this out. This is a very useful comment, and we have now significantly expanded the justification for case-study selection in the revised manuscript in the Methods – Case Study Selection subsection. These additions strengthen the justification of our case-study selection (see **Table 1**).

The six case-study firms were selected based on three explicit criteria:

i. **System Relevance (Market Share & Installed Capacity):**

We selected firms that together account 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) modelling 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.

**Table 1:** Justification for case study firms' selection.

S. No.	Firm	Nature	Installed Capacity	Financial/Data Availability	Justification for case study firms selection
1.	NTPC Ltd.	Predominantly coal (public sector)	80 GW	Yes, Annual Report	Largest coal generator in India.
2.	Adani Power	Coal-based private player)	15.25 GW	Yes, Annual Report	Largest private coal generator in India.
3.	JSW Energy	Mixed portfolio	7.24 GW (3.5 GW coal, 3.73 GW RE)	Yes, Annual Report	Influential private player transitioning to renewables
4.	Tata Power	Mixed portfolio	14.22 GW (8.8 GW coal; 5.4 GW RE)	Yes, Annual Report	India's largest integrated private power utility
5.	ReNew Power	Fully renewable (RE)	9.5 GW RE	Yes, Annual Report	India's 2nd largest RE producer
6.	Adani Green Energy	Fully renewable (RE)	10.93 GW RE	Yes, Annual Report	India's largest RE developer

4. The introduction should be much less about India and talk about the nature of the financial risks of energy transition, citing the relevant research. There should be one distinct paragraph, where the necessity for an Indian perspective should be outlined.



## Response

Thank you for pointing this out. We agree that the Introduction should first establish the global context of transition-related financial risks—drawing on international literature—before motivating the India-specific analysis. In the revised manuscript, we have made these changes and have now revised the introduction section accordingly.

One paragraph with the necessity for an Indian perspective has been added which is as follows:

*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 (ET, 2025), 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 (PIB, 2024), 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. Therefore, an India-focused assessment—grounded in globally harmonised NGFS scenarios—is necessary to understand how global transition risks may translate into firm-level value impacts in a major emerging economy like 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 decarbonisation trajectory.*

5. There is a clear lack of global applicability, or at least the authors should argue on it.

## Response

Thank you for pointing this out. Following referee's suggestion, we have added the following:

*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 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 materialise in similar economies globally.*

We have now added the above in the revised manuscript.

## Specific Comments- Research Structure:

1. Why are the GCAM and REMIND models selected? Also, how do these models enable the numerical approach shown in the results?

## Response

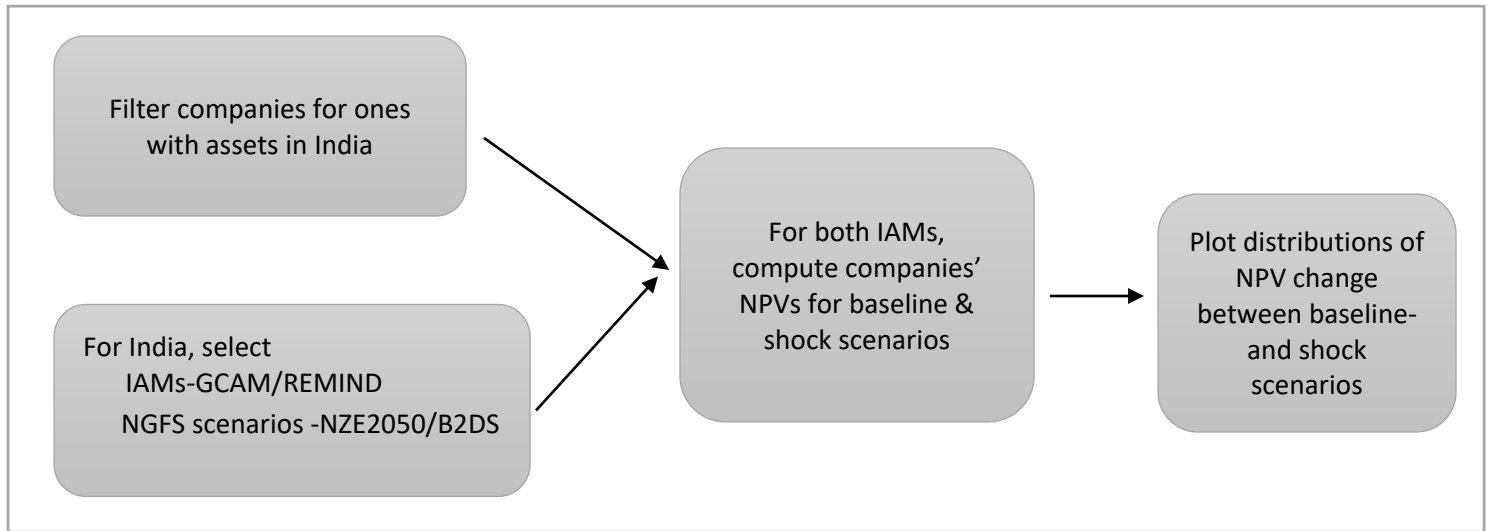
Thank you for pointing this out.

We employ GCAM and REMIND for three main reasons:

1. **Alignment with global standards:** GCAM and REMIND are two of the three primary Integrated Assessment Models (IAMs) used by Network for Greening the Financial System (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 Reserve Bank of India (RBI), the European Central Bank (ECB) and BIS for supervisory stress-testing exercises.
2. **India-specific granularity:** Both models generate detailed India-level trajectories for fuel demand, electricity mix, emissions, technology costs, and carbon-price pathways—inputs essential for sector- and firm-level financial stress testing.
3. GCAM provides recursive dynamic energy-system pathways based on a simulation approach, while REMIND offers intertemporal optimization pathways, together capturing a broad range of plausible transition dynamics with better foresight (Krey et al., 2019). 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 (DCF) 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.

Regarding how the models enable the numerical approach in the results, we have provided **Figure 1** which explains the flow. GCAM and REMIND do not produce firm-level valuations themselves; rather, they provide quantitative trajectories for various power generation technologies for India that serve as the foundational quantitative inputs required to construct discounted cash flow valuations for firms under each scenario i.e., baseline and shock, whose difference yield financial impacts.

**Figure 1:** Analysis workflow: Our Study.



Our analysis follows a **three-layer mapping** from IAM models to firm-level impacts:

- **IAM outputs → sectoral transition shocks:** GCAM and REMIND provide quantitative trajectories for coal, oil and gas demand, renewable expansion, carbon pricing, and electrification. These are converted into sector-specific changes in revenues, fuel costs, capacity utilisation, and investment requirements.
- **Sector shocks → firm-level cash-flow adjustments:** The IAM-derived shocks are mapped to firm-specific variables such as production volumes, input costs, technology mix, PPA structures, capex schedules, and operating margins.
- **Firm-level impacts → NPV-based valuation:** Using discounted cash-flow (DCF) models, the difference between the baseline NPV and the scenario-adjusted NPV provides the quantified transition-risk impact for each company.

4. Why are the years for the shocks selected as 2025 and 2030? Why not 2040 and so on?

**Response**

Thank you for pointing this out. This is a very useful comment, and we have now incorporated various points.

In this regard, we would like to mention that as the study was carried out in 2024, we analysed the financial risk resulting from a sudden and mid climate transition in India with these modelled 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.

5. The results are quite affected by the carbon tax component. We are already in 2025, and yet there is no carbon tax in India. Both the models should be adjusted to account for a delayed start of carbon taxation, and there should a section to analyze the effect on the gains and losses therein.

## Response

Thank you for pointing this out.

In this regard, we would like to mention that in Integrated Assessment Models (IAMs) such as GCAM & REMIND, a carbon price serves as a proxy for modelling 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 (Nordhaus, 2007, 2017). 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. In other words, as the reviewer rightly states that there is no carbon tax in India or delayed start of carbon taxation, the models used in the study utilize suitable carbon prices that is given exogenous by scenario providers based on the scenarios chosen for transitioning and provide estimates for the resulting losses and gains.

Further, the primary objective of the study is to provide a directional impact of choosing different policies and scenarios for Indian power firms and not precise numbers under the actual policy paradigm. In any case, it would not be possible to model or incorporate the actual prevailing carbon tax (or lack of carbon tax) in Indian context in these models to estimate the losses/gains.

6. The clear definition of variables are missing in the 'methods' section.

## Response

Thank you for pointing this out. We have now incorporated the following Table in the revised manuscript, which defines and describes the variables and parameters used in the study.

**Table 2:** Key Variables and Parameters: Our study.

Sl. No.	Parameter	Value	Justification
1.	Discount rate (WACC)	9%	Consistent with Indian regulated utility benchmarks.
2.	Risk-free rate	4%	Risk-free interest rate used in the Merton credit risk model: reflects the long-term yield on Indian government securities.
3.	Growth rate	3%	Long-run growth rate in the discounted cash-flow model; must be positive and lower than the discount rate: consistent with India's expected real GDP growth
4.	Dividend payout ratio	1	Share of net present value used to compute dividends, influencing equity value
5.	Market passthrough	0	Firm's ability to pass carbon taxes to consumers
6.	Valuation horizon	25 years	Typical economic life of power assets in India.
7.	Terminal value	Zero	Aligns with declining fossil-asset usefulness under NZE2050/B2DS.
8.	Depreciation	Straight Line Depreciation over 25 years.	Consistent with Indian regulated utility benchmarks.
9.	Tax	25 % plus surcharge	Consistent with Indian Corporate Tax regime.
10.	Fuel cost pass through	Allowed	Consistent with Power Purchase Agreements (PPAs)

**Specific Comments- Results:**

1. Why are the peaks of gas companies at more negative values than coal companies, when emission factor of gas is considerably less than coal? Moreover, multiple developing nations are aiming at transitioning to NG for an intermediate step.

**Response**

Thank you for pointing this out.

The reviewer rightly points out that 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.” While this may appear counter-intuitive, we would like to mention that our results

reflect economic–technological dynamics of the NGFS-GCAM/REMIND transition pathways for India and not only direct emissions intensity for gas/coal fuel. Also, in Indian context, gas has limited role as a transition fuel due to higher price sensitivity and availability issues.

Two major factors explain why gas companies show greater sensitivity in specific transition scenarios for India. 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.

## 2. What is the fundamental reason for the loss in 2030 for coal companies and gain in 2030 for RE companies to be greater?

### Response

Thank you for this observation.

The reviewer is right in pointing out that the loss in 2030 for coal companies and gain in 2030 for RE companies to be greater. In this regard, we would like to mention that as per model construction, firms remain on their business-as-usual production trajectories until initiation of a shock in 2025 or 2030 (as the case may be) which then necessitates firms to shift production to the ambition pathway requiring production changes across technologies. In other words, the initiation of shock i.e. 2025 or 2030 is the introduction of climate action for firms to comply with carbon budgets.

Intuitively, as firms may continue to stay longer and misaligned with the climate ambition in shock in 2030 vis-à-vis 2025, they may also require steeper and faster adjustment in production levels in 2030 than in 2025. This leads to the transition becoming increasingly disorderly when the transition policies are introduced later.

In our study, we find a significant impact of shock year as a later shock year (2030) reflects an even more disruptive transition and hence much higher losses/gains for fossils/renewables.

3. There should be clear list of policy recommendations in the discussion section. The current description is too long, and must be presented concisely.

## Response

Thank you for pointing this out.

Following referee's suggestion, we have now removed the redundancies and focused only on the essential interpretation of results and their implications in the Discussion section. At the same time, because a Nature-style Discussion must articulate both the meaning of the findings and their policy relevance, we have retained some parts for contextualizing why specific recommendations follow from the modelling outcomes. Importantly, we have now added a distinct and concise bullet-point list of policy recommendations separate from the discussion of results, ensuring readability and direct accessibility. These include:

- ***Strengthen transition-risk disclosures*** - Securities and Exchange Board of India (SEBI) and Reserve Bank of India (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 and MNRE should publish predictable decarbonisation 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 modernisation to smooth transition impacts.
- ***Integrate firm-level modelling 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.

## Reviewer 3:

### General Comments:

The research questions addressed are pertinent. The energy sector is obviously exposed to climate change and related risks. The authors have used modelling-based approach using popular tools to quantify the extent of the risks in a few scenarios in Indian context. I have thoroughly read the paper and have found a few critical issues to be addressed before consideration for publication from my perspective.



**Response:**

Thank you for the time and effort that you have taken to go through our manuscript and for providing us with valuable suggestions to improve the manuscript. We have done our best to implement all your suggestions and believe that the manuscript has further improved as a result.

**Specific Comments:**

1. The claim that this is the only study addressing the issue of climate risk in the context of developing countries is too strong. For example, see this one by Bauri et al. (2025): - “Impact of climate risk on financial performance – evidence from select energy companies from select G-20 countries”.

**Response**

Thank you for pointing this out. We regret this remark and following referee’s suggestion, we have now dropped the same. We have also included the suggested study in our referenced literature and added the following:

Bauri et al. (2025) 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 country, financially performed better than the firms that operated in a more climate-risky country.

2. The arguments presented by the authors may be countered by the fact that the per capita energy consumption is too low in India and the conventional sources may still have to stay in foreseeable future. It is advised that the issue of low energy consumption may be included in the paper.

**Response**

Thank you for pointing this out. Following referee’s suggestion, we have now added the following:

*While India is undertaking rapid decarbonization efforts, its per capita energy consumption remains relatively modest in comparison with developed economies. Large sections of households and firms continue to face reliability and affordability challenges. India’s per capita electricity consumption reached 1,538 kWh in 2024–25 (ET, 2025) suggesting significant room for future demand growth as economic development continues, meaning that conventional energy sources especially coal may still be needed in the near- to medium-term to meet increasing demand even under ambitious decarbonization pathways. 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.*

3. Huge difference in results between the two modelling approaches is a matter of concern. Of course, both cannot be correct. One possible explanation is offered (REMIND takes into account the Carbon Capture) but that alone is not a sufficient explanation. Further, based on current trends, Carbon Capture and Storage is not going to be a decisive factor in India in next few years.

## **Response**

Thank you for pointing this out.

We agree with the reviewer that Carbon Capture and Storage (CCS) uptake in India will be limited in the near future due to exorbitant costs and other constraints such as geological issues.

We also agree that the divergence between the two modelling approaches is not only due to Carbon Capture and Storage (CCS) alone. Literature suggests that an inter play of several factors viz. model assumptions, model uncertainties and technology mixes lead to differences in inter-model results and comparisons (Durga et al. 2022).

GCAM is a Global Change Analysis Model that provides recursive dynamic energy-system pathways, whereas REMIND offers intertemporal optimization pathways (NGFS, 2025). In the revised manuscript, we have now clarified that the variation in results arises from structural differences between the two models- GCAM and REMIND and the transmission channels rather than a single factor such as CCS availability, which leads to visibly different transition pressures even for the same target i.e. NZE2050 or B2DS.

We would now like to point out the structural differences between the two models. Global Change Analysis Model (GCAM) is a dynamic recursive partial equilibrium model where agents make decisions (e.g., investments) based on current market conditions and expectations of the future, but without perfect foresight of the entire time horizon. GCAM often uses a less granular, more aggregated simulation of the electricity grid at the regional level. The less detailed representation of power infrastructure and potential market rigidities can potentially lead to higher losses for fossil fuel companies and greater gains for renewable companies, as investments respond more acutely to current price signals and policies.

In contrast, Regional Model of Investment and Development (REMIND) is an inter-temporal optimization model that aims to find the optimal mix of investments and energy pathways across the entire time horizon, assuming perfect foresight to minimize total system costs or maximize welfare over time (Krey et al., 2019). REMIND typically incorporates a more detailed and integrated representation of the entire energy system including power generation allowing for the

optimal planning and costing of necessary infrastructure to meet future demand and climate goals efficiently. The inter-temporal optimization framework in REMIND allows for a smoother, more efficient, and potentially less disruptive transition path.

For the same NGFS scenario, REMIND typically generates higher and earlier carbon prices compared with GCAM. As a result, REMIND tends to produce sharper declines in fossil-fuel demand, while GCAM produces smoother transitions.

These structural features amplify the risk for fossil firms in GCAM and favor rapid deployment of renewables, leading to more extreme financial outcomes. However, it is pertinent to mention that both GCAM and REMIND are widely used as legitimate interpretations of global decarbonisation pathways and the difference in results do not necessarily imply inconsistency or error.

4. The extent of loss in NPV is too dramatic and clearly depends on model parameters. The paper is silent on those parameters (one such example is the discount rate). It is advised that certain parameters should be declared (certain other aspects of modelling will remain inside black box but currently it is too vague).

## Response

Thank you for pointing this out.

While certain Integrated Assessment Model (IAM) specific parameters remain inherent for GCAM/REMIND architecture such as the emission intensity factors and utilization factors for various technologies, other parameters that impact firm-level valuation are now provided in the Methods section (see **Table 2**).

**Table 2:** Key Parameters: Our study.

Sl. No.	Parameter	Value	Justification
1.	Discount rate (WACC)	9%	Consistent with Indian regulated utility benchmarks.
2.	Risk-free rate	4%	Risk-free interest rate used in the Merton credit risk model: reflects the long-term yield on Indian government securities.
3.	Growth rate	3%	Long-run growth rate in the discounted cash-flow model; must be positive and lower than the discount rate: consistent with India's expected real GDP growth
4.	Dividend payout ratio	1	Share of net present value used to compute dividends, influencing equity value
5.	Market passthrough	0	Firm's ability to pass carbon taxes to consumers

6.	Valuation horizon	25 years	Typical economic life of power assets in India.
7.	Terminal value	Zero	Aligns with declining fossil-asset usefulness under NZE2050/B2DS.
8.	Depreciation	Straight Line Depreciation over 25 years.	Consistent with Indian regulated utility benchmarks.
9.	Tax	25 % plus surcharge	Consistent with Indian Corporate Tax regime.
10.	Fuel cost pass through	Allowed	Consistent with Power Purchase Agreements (PPAs)

The aspects related to scenario (NZE2050/B2DS) and model (GCAM/REMIND) definitions, assumptions and transmission channels have already been mentioned in detail in response to 1<sup>st</sup> reviewer comments 1 and 2.

Following reviewer's suggestion, we have now included a list of model parameters, scenario assumptions (NZE2050/B2DS), and a summary of modelling differences (GCAM/REMIND) in the revised manuscript.

5. The case studies surely add value to the study. If possible, include one from state owned power generating utilities (for example, UPRVUNL from Uttar Pradesh – it has capacity of more than 7 GW). The dynamics in the state-owned power generating companies are of interest in the context of the study and may add strength to authors' arguments.

## Response

Thank you for pointing this out.

Regarding referee's suggestion of including UPRVUNL from Uttar Pradesh for case study based analysis, we would like to mention that three main criteria were used by the authors 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) modelling 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.

Therefore, a full quantitative case study analysis for a state-owned firm such as UPRVUNL is currently constrained by limited availability of consistent, firm-level financial data required for our CfaR estimation.

However, we have noted 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, and identify the inclusion of such firms as a priority area for future extensions of this work.

6. As per the study, hydropower is immune to the changing dynamics. It may not be so. Consider the likely climate catastrophes and complex geopolitics in the subcontinent (Landslides and cloudbursts in the Himalayan region, China is making large dams and India's relationship with Pakistan is too volatile).

### **Response**

Thank you for pointing this out.

Our results show minimal direct transition-driven NPV impacts for hydropower under the NGFS/GCAM/REMIND pathways even as the reviewer rightly states that hydro power may not be immune to the changing climate dynamics. We agree that this does not imply hydropower is immune to climate-related physical risks (e.g., altered streamflows, glacier retreat, landslides/cloudbursts causing dam damage) or geopolitical risks. However, these are not incorporated by model providers including Integrated Assessment Models (IAMs)-GCAM & REMIND for estimation of transition risk.

Our analysis for transition risk for hydro power companies is therefore not impacted by the likely climate catastrophes and complex geopolitics in the subcontinent; they only model the Net present Value (NPV) loss/gain for these firms under business as usual (i.e., current policies) and low transition (i.e. ambition) scenarios based on assumptions for various technologies in Integrated

Assessment Models (IAMs)-GCAM & REMIND. We have acknowledged in the revised manuscript that hydropower faces physical and geopolitical hazards analysing which falls outside the pure transition-risk scenarios used here.

Following referee's suggestion, we have now added the following in the revised manuscript:

*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 transboundary 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.*

7. In the Tables (see 1 and 2), multiple digits after the decimal makes the table less readable. It is suggested to report numbers in percentage with 2 digits after decimal only (or maximum of 3 digits when the current number is too small).

#### **Response**

Thank you for pointing this out. Following your suggestion, we have now revised the Tables (1 and 2) rounded upto 3 digits and incorporated the same in the revised Manuscript.

8. Some of the arguments are repetitive. The paper could be shortened by avoiding repetitions.

#### **Response**

Thank you for pointing this out. We regret the repetitions in the manuscript and have now proofread the entire manuscript to avoid any repetitions.

9. I find it strange to see the results too early in the paper and to wait for the methods till the very end. It is advised to put the methodology before the results.

#### **Response**

Thank you for pointing this out.

We fully agree that the placement of the Methods section can influence readability.

Regarding the placement of the Methods section, the earlier version of the manuscript followed the Nature-format requirement, in which *Methods* appear after the *Results/Discussion* and before the *References*. However, to address the reviewer's concern, we have now placed the *Methods* Section after *Introduction* and before *Results* so as to provide a more logical flow and better understanding.

10. Lines 129/130: GCAM and REMIND are frameworks or models and not the scenarios. The sentence may be rephrased.

### **Response**

Thank you for pointing this out. We regret this statement and have rephrased this in the revised manuscript following the referee's suggestion.

11. Line 649-652: Strange texts appearing. Please check

### **Response**

Thank you for pointing this out. Apologies, we regret the strange texts appearing in the manuscript and have now proofread the entire manuscript to avoid the same.

### **References:**

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## Comments and Responses

### Editor comments:

Your manuscript titled "Differentiated Impacts of Climate Transition Risks on the Indian Power Sector" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

### Response:

Thank you for accepting our Manuscript.

### Reviewer 2:

#### General Comments:

The authors have successfully addressed all the comments raised in the previous round. I have one doubt with regards to Fig. 1. When the authors say that "filter companies for ones with assets in India", I wonder what is the total set of companies considered. In a minor revision, an appendix/SI should be included to list all the companies considered before filtering.

### Response:

The data used by the authors in this study is proprietary in nature, sourced through **Asset Impact** (<https://asset-impact.gresb.com/>). While we are providing a list of the Indian entities for reference, we may not be able to share it publicly due to data proprietary issues. However, we would like to share the following summary statistics:

- The total set of companies considered: 31,380 companies worldwide in the Power sector in the *Asset Impact* database
- For India Analysis: 1,703 of those have assets in India

### Reviewer 2:

The issues pointed out are addressed in the revised manuscript. I would suggest to recheck for minor issues like missing articles and missing punctuations.

### Response:

Done. Thanks.



# Review of "Differentiated Impacts of Climate Transition Risks on the Indian Power Sector"

COMMSENV-25-3133-T

## 1 Summary

This study aims to evaluate the financial risks stemming from climate transition in India's power sector, using a firm-level microeconomic climate stress test based on [Baer et al. \(2022\)](#). The analysis covers 1,703 power generation companies (coal, gas, renewables, nuclear, hydro, and oil) under two integrated assessment models (GCAM and REMIND) and two transition pathways (Below 2°C and Net Zero 2050), with transition shocks activated in 2025 and 2030.

The paper presents three main findings: (i) Severe losses for fossil-based firms, with NPV reductions of 85–90% for coal and 29–75% for gas; (ii) moderate gains for renewable firms (14–30% NPV increase); (iii) Differentiated impacts across other technologies. Additionally, the study shows that early transition shocks reduce financial losses for fossil firms, and that model choice significantly affects outcomes.

## 2 Essential Points

This paper addresses an important and underexplored issue in the Indian electricity market: how power generation firms may be financially impacted under climate mitigation scenarios. While the study provides some insights into technology-specific vulnerabilities, the manuscript requires further development and deeper exploration before it can be considered for publication. Below, I outline my main concerns and offer suggestions for improvement.

1. **Limited Novelty of Key Findings.** The main results—fossil fuel firms facing significant NPV losses—are consistent with existing literature and international projections (e.g., [IRENA \(2020\)](#)). While the range of losses is notable, especially for gas, the paper lacks a breakdown of transmission channels or assumptions that could enrich the interpretation. Interestingly, the authors themselves acknowledge this limitation in the results section:

*"...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..."*

2. **Methodological Ambiguity.** The methodology section lacks clarity regarding the rationale behind model and scenario selection. The justification for using GCAM and REMIND is not well articulated, nor are the assumptions underlying each scenario. A simplified partial equilibrium approach, in the same spirit of [Acharya et al. \(2025\)](#) might offer clearer insights into the transmission mechanisms affecting NPV. Moreover, the paper does not compare the scenarios in terms of their structural differences, which is crucial to understanding the divergence in results.
3. **Lack of Coherence and Readability.** The manuscript is difficult to follow. The introduction lacks a clear narrative arc, with paragraphs shifting topics abruptly. The overall structure does not guide the reader through the logic of the analysis. For instance, the methodology and data section are after the results, which is very confusing. I strongly recommend a thorough editorial review by a native English speaker or professional editor with expertise in academic writing.
4. **Figures and Tables: Poor Quality and Documentation.** Figures and tables lack units, clear labels, and descriptive captions. Some graphics are of low resolution and difficult to interpret. For example, Figure 1 fails to distinguish between models and shock years due to poor color and shape coding. I suggest standardizing colors by model and using distinct shapes or line styles for shock years. Additionally, ensure all figures are legible and properly formatted for publication.

### 3 Bibliography

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- IRENA, I. R. E. A. (2020). Global renewables outlook: Energy transformation 2050. Technical report. [1](#)