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Financial risks to coal value chain from a cost-conscious shift to renewables in India

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Supplementary material for this article is available online

Abstract

A realignment of the financial sector is necessary to both enable the energy system transformation and manage financial risks implied by a transition to net-zero emissions. These include transition risks stemming from policies that limit or price greenhouse gas emissions. The financial sector has turned to scenarios developed by the research community for information on how transitions may unfold. Emerging methodologies linking transition scenarios to risk assessment are in their early stages but are key to enable financial institutions (FIs) to carry out the task at hand. Commercial FIs are exposed to transition risks primarily through their portfolio holdings and how assets therein may fare in a transition. Understanding this counterparty risk is key for development and interpretation of climate-financial scenarios. FIs will need to consider how the firms in a portfolio—the counterparties—will react to the transition and their capacity to navigate the changes involved. Here we apply a transparent and flexible framework to explore transition risks to corporate firms from low-carbon transition scenarios. We show that considering firms' strategic responses to the changes in their operating environment is an important determinant of the resulting transition risk estimates. We provide an illustrative case study of the coal value chain in India to demonstrate how the framework can be applied to both risk assessment and business strategy setting.

1. Introduction

There is growing concern over the implications of climate action for financial sector performance and stability (Carney 2015, TCFD 2018). Central banks and regulators are asking financial institutions (FIs) to assess exposure of their portfolios to climate-related financial risks (BoE 2019), including from transition risks stemming from policies that limit or price greenhouse gas (GHG) emissions (TCFD 2017). To this end, myriad tools and methods have emerged to enable the financial sector to assess such risks, but the wide scope of possible risks means there is no single best approach. Rather, exposure depends on the specific characteristics of portfolio holdings and how they are inserted into geographic, temporal and technological assumptions and narratives (Köberle *et al* 2020). A recent assessment of 16 financial risk tools found none of them fully met standards for coverage, usability and transparency (Bingler and Senni 2022).

Recent proposals (e.g. Battiston *et al* 2017, 2021) to integrate financial risk assessment into long-term climate transition scenarios focus on portfolio-level financial risk from sectoral-level changes. These studies focus on the exposure of FIs to transition risks assuming the firms whose assets are held in the portfolio—the counterparties—will not change their behaviour (static balance sheets) or do so homogeneously by reacting similarly to transition risks irrespective of individual circumstances. While this approach is valid for global or economy-wide transition scenarios meant to inform climate policy and systemic financial stability concerns, it falls short of the requirements of individual FIs to recalibrate their risk appetite with respect to climate action. This is because the main determinant of FI's portfolio risk is counterparty risk and emerging scenarios developed by the research community will need to explicitly account for it. Importantly, the exposure to climate change risks and counterparties' ability to hedge these risks are heterogenous across firms within the same industry. While static balance sheets are useful in exploring worst-case scenarios and their potential impact on financial stability, individual commercial FIs trying to set business strategy require dynamic balance sheets to identify not only the high-risk assets, but also those offering opportunities for positive returns during the transition.

Understandably, dynamic balance sheets add much uncertainty into the analysis since the behaviour of each counterparty is itself scenario dependent. However, risk assessment by individual FIs can leverage knowledge of assets held in their portfolios to assess exposure to their largest and most material counterparties (to which portfolio has largest exposures). Here we demonstrate how the framework proposed by Battiston *et al* (2021) to link climate transition scenarios with financial risk modelling can be expanded to explore transition risks to firms while considering their potential differentiated strategic responses to the changes in their operating environment. We provide methodological details of scenarios developed in Köberle *et al* (2020) and demonstrate how challenges from linking dynamic balance sheets can be addressed to extract useful information from IAM scenarios to inform risk assessment and business strategy for FIs grappling with climate-related financial risk.

While our approach is generalisable, firms operate within specific sectors and jurisdictions, so it is important to expand sector-level modelling to include more granular firm-level and regional information. The coal sector is highly exposed to transition risks which are evident in India, so we use the coal value chain in India as a case study to illustrate how this can be accomplished. We focus on three hegemonic firms in that value chain as it reduces the influence of non-climate policy risk drivers such as competition and market power. We explore the financial implications of future scenarios for three of the largest actors in the Indian coal supply chain (see supplementary note 1 for details on all three):

- Coal India Limited (CIL)
- NTPC Limited (National Thermal Power Corporation Limited), and
- Indian Railways (IR).

The first step in our framework is to develop scenarios for the evolution of the transitioning sector (in this case power generation in India). The second step establishes how sectoral transitions impact each firm's operations. In our case study, changes in power generation mix will affect operations of all three firms through their value chains. Third, we develop scenario variants describing each firm's strategic responses to the changes in their operating environments. These changes are then linked to each firm's financial performance, by mapping these changes to a proforma cash flow model to estimate financial impacts using the metric of cash flow at risk (CFaR) as an aggregate measure of transition risk for each firm. Although we use CFaR, other models and metrics could be used instead to suit individual users' needs.

Figure 1 shows a conceptual diagram of the framework as it is applied here. We seek to assess the financial risk to the three coal-dependent firms of a transition away from coal that is driven by changing technology costs and energy sector policies. These risk drivers are modelled in an energy system model (ESM) to generate sector level transition scenarios which are then combined with firm-level narratives to provide needed input for the financial modelling (see section 2).

In the remainder of this section, we provide the context for the transition narratives underpinning our transition scenarios for the Indian power sector. Section 2 describes the methods used to develop the scenarios, the financial modelling approach and the methods used to connect the various parts. Section 3 provides the results as well as a discussion of the implications. Section 4 provides conclusions.

1.1. King coal faces headwinds

Goods and services with GHG-intensive value chains may face near-term transition risks, especially if low-carbon alternatives are commercially available. Low-cost renewables already challenge the hegemony of fossil fuels across several sectors, particularly in power generation. In spite of India's intervention to change the text of the Glasgow Climate Pact from 'phaseout' to 'phasedown' of unabated coal power, the risk for Indian firms dependent on coal value chain is substantial. FIs will want to understand the transition risk associated with specific assets and placing them within the context of the wider sectoral transition requires firm-level information and analysis. Although we take the case of coal in India as an example, the steps described here can be applied to any jurisdiction, sector or firm.

Globally, the reduction and phase-out of coal use in power generation has been identified as a key near-term strategy to enable the rapid decrease in GHG emissions required to meet globally-agreed objectives of the Paris Agreement (Rogelj *et al* 2018). This strategy includes potential early retirement of existing assets like power plants that are still economically viable (Johnson *et al* 2015, Climate Analytics 2016,

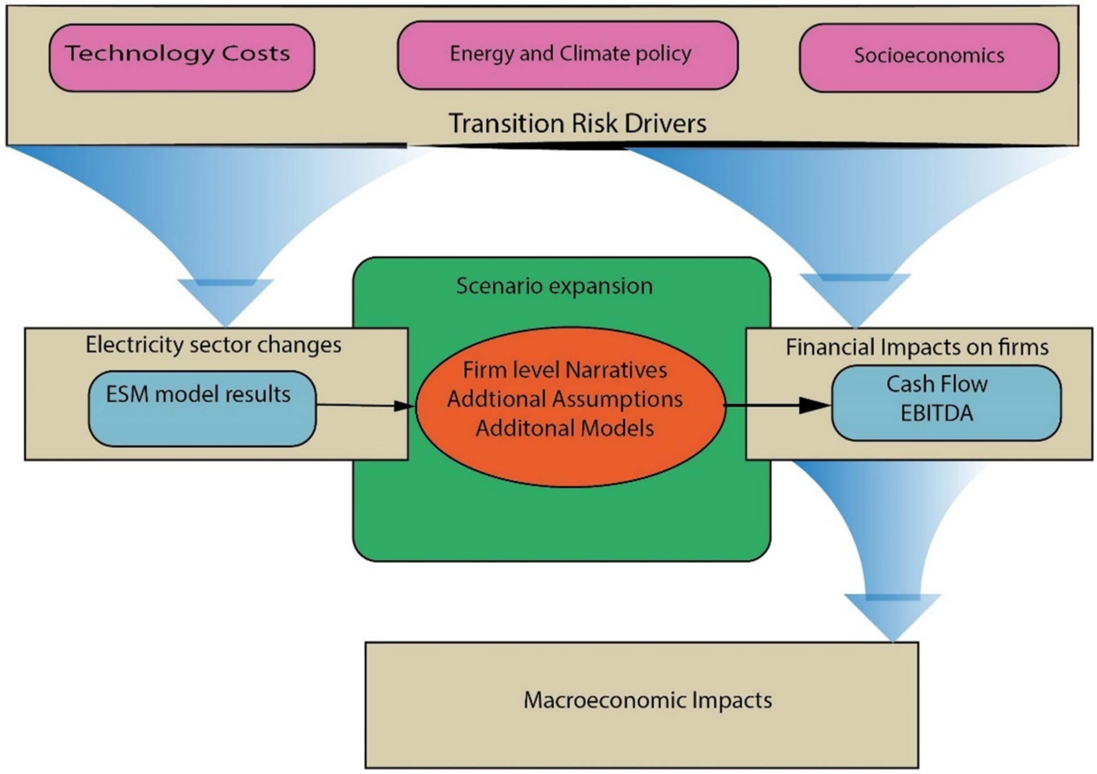

Figure 1. Framework modelling workflow.

Fofrich *et al* 2020), giving rise to transition risks associated with stranded assets in the coal value chain.

Although the coal sector may face headwinds, it does not mean all firms everywhere are affected proportionally. Exposure of specific firms to transition risks depend not only on (a) how the transition affects the sector, but also on (b) how the firm is placed within its sector, and (c) the capacity of the firm to navigate the changes in its operational environment (Köberle *et al* 2020). These risk factors are all location specific and tend to be uncertain in their future evolution. Scenario analysis can explore various alternatives to help the financial sector assess climate-related risk and set business strategy, especially under such uncertainties.

Beyond climate action, the global coal value chain is exposed to several types of environment-related risks (Caldecott *et al* 2016) including environmental change, government regulation and technological change. The combination of government environmental regulation and technological change amplify transition risks. Environmental regulation such as for air pollution and water access constrain coal-based electricity generation as do any GHG emissions constraints or public support for low-carbon alternatives. In addition, public policy past and present have spurred deep cost reductions of low-carbon energy sources, and innovation is currently driving structural change in the global energy sector (IRENA 2016, Daszkiewicz 2020). Costs of low-carbon power technologies have fallen faster than expected in recent years (Verdolini 2021, Wiser *et al* 2021), reaching cost-parity with fossil-fuelled alternatives like coal (IRENA 2021a), with solar being declared the cheapest electricity in history by the IEA in many regions (IEA 2020). These developments have increased pressure on coal use globally with investments into low-carbon capacity additions outpacing that for coal at both the global level (IRENA 2021b) and in many countries. In our framework, global trends need to be put in the context of the specific jurisdiction a FI has exposure to.

1.2. India is at the forefront of these trends

Although coal is still king in India's power sector, capacity additions of renewable energy (RE) sources have outpaced that of coal since around 2015 (figure 2(a)). However, coal accounts for 54% of installed capacity (figure 2(b)) and 75% of electricity generation (CEA 2018), coal mining employs about half a million people, and coal transportation cross-subsidises passenger rail transport in India (Kamboj and Tongia 2018). This poses political economy challenges making it unlikely that a full phase-out of coal will occur in India in the next 10 or even 15 years. Nevertheless, continued policy support for renewables and new air pollution regulation are expected to add to the woes of India's coal plants (Fernandes and Sharma 2020).

The most salient drivers of risk for coal-fired capacity in India result from increasing pressure exerted by RE sources through (a) their

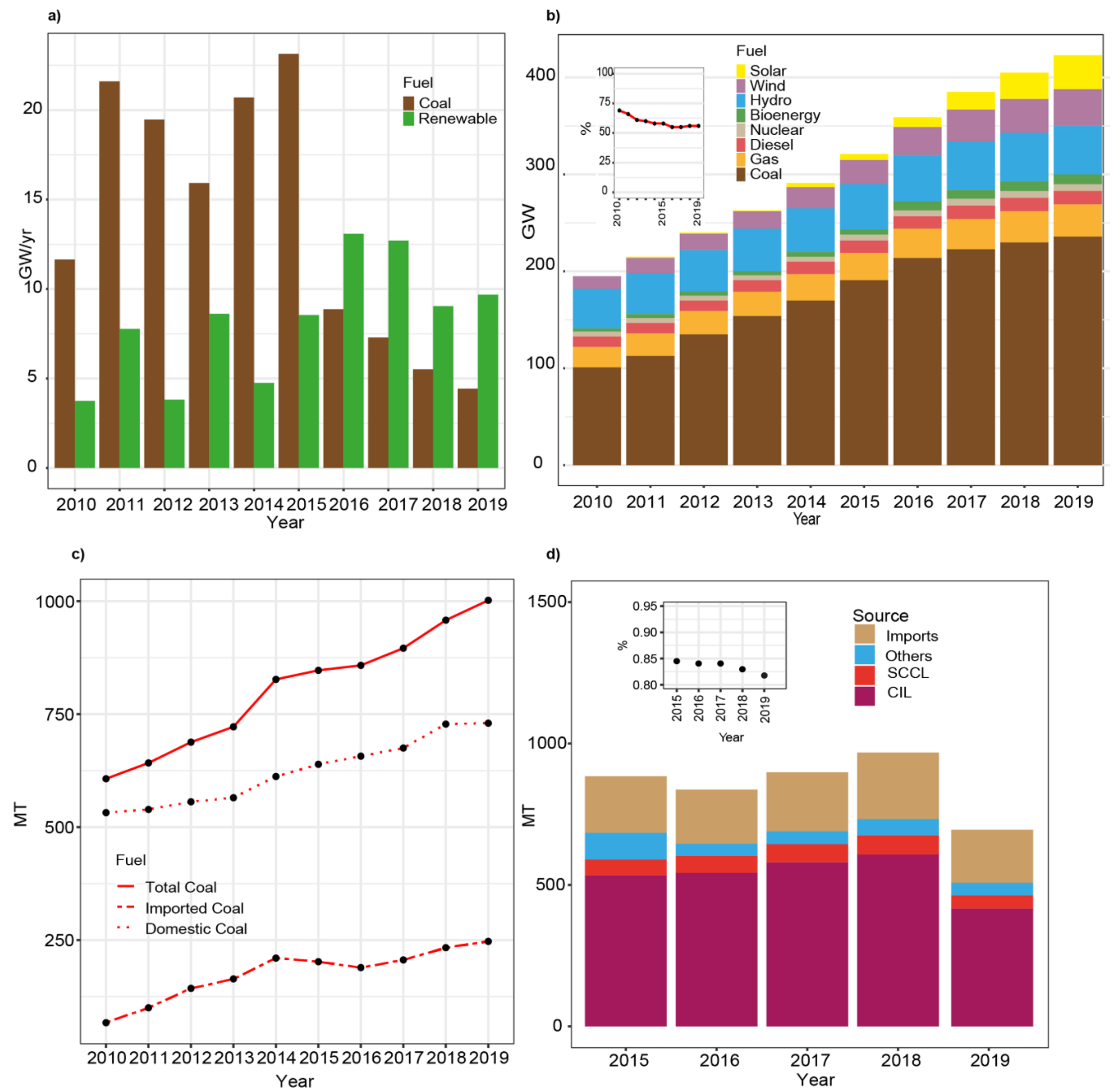

Figure 2. Historical installed power generation capacity and coal production indicators. (a) Historical capacity additions of coal and renewables (solar, wind, hydro and biomass). (b) Installed capacity by source in GW; inset: coal power plant load factors in operational time percentage. (c) Coal supply: domestic production, imports and total. (d) Domestic coal production by producer firm; inset: CIL share of domestic production (Data sources: MOSPI 2020).

cost-competitiveness and (b) the supportive role they receive from the government (Spencer *et al* 2018). These are in turn exacerbated by the financial distress of India's electricity distribution companies (DISCOMs)—the main power offtakers—and recently introduced air pollution regulation (Worrall *et al* 2018, Fernandes and Sharma 2020). Declining plant load factors (PLFs) (figure 2(b) inset) point to these challenges and the heightened risk of asset stranding.

The three state-owned enterprises in question are heavily dependent on coal to support their business, each in its own way. CIL is the world's largest coal producer with a current output above 600 million metric tonnes per year (Mt yr^{-1}) accounting for around 83% of India's domestic coal production (Ministry of Coal 2020). NTPC, the largest power company in India, generates almost a quarter of the country's power with an installed capacity of about 63 GW, about 90% from coal plants (NTPC 2020). Indian Railways (IR) is one of the largest in the world in terms of network length, passenger numbers, and freight services. It carries more than a billion tonnes of freight each year and is heavily dependent on coal, which is its top freight commodity both in terms of volume (48%) and revenue (45%) (Kamboj and Tongia 2018). While CIL and IR operations rely on sustained domestic coal demand, NTPC relies on sustained demand for the electricity it produces from coal. Changes to coal-fired power demand impacts performance of all three.

2. Methods

2.1. Scenarios for a power sector transition

Based on current policies and technological trends, we propose two energy system scenarios, a *Trend* and an *Aspirational*, that differ between them only in a few power sector policy levers while holding all else constant. The narratives differ across scenarios in how RE energy and environmental regulation are assumed to evolve in the future. First, we set capacity targets for RE penetration in India consistent with government plans and recent announcements. And second, we explore potential impacts of local air pollution regulation on the closure of old coal fired plants before the end of their economic lifetimes. Both scenarios include the interim 2022 target of 175 GW of RE capacity established by the national electricity plan (NEP) of 2018 (CEA 2018). The *Aspirational* scenario adds the 450 GW by 2030 announced by PM Modi at the UN Climate Summit of 2019 which has since become an established target (PIB 2019), as well as the forced refurbishing or early retirement of all coal plants built before 2011 to represent compliance with air pollution standards; both of which are not in the *Trend* scenario.

We intentionally avoid implementing a system-wide carbon tax as a policy instrument and choose to focus instead on established power sector targets. Importantly, future cost reductions of RE sources are the same across scenarios and were projected using a learning rate approach consistent with global capacity additions in the recent past and expected for the next decade.

The *Trend* and *Aspirational* energy system scenarios differ between them by only changing a small number of key parameters (a) RE targets, and (b) effects of local air pollution regulation on operation of old coal power plants. All other parameters are the same. All power technology costs are assumed to remain constant except wind and solar which, as immature technologies, their costs will continue downward trend in the near future. Importantly, future cost reductions of RE sources are the same across scenarios and were projected using a learning rate approach consistent with global capacity additions in the recent past and expected for the next decade as shown in equation (1):

$$C_Q = C_1 * Q^b \tag{1}$$

where C_Q = cost at cumulative production Q, C_1 = cost of first unit produced ($Q = 1$).

Parameter b is the experience parameter given by equation (2):

$$\mathrm{LR} = 1 - 2^b \tag{2}$$

where LR is the learning rate (Junginger and Louwen 2020).

Assuming a conservative 6% learning rate for both wind and solar, we get a 2030 cost of solar that is 18% lower than in 2020. Similarly, we get a 2030 cost of wind that is 11% lower than in 2020 for capacity doubling every five years (supplementary table 3). We assume a doubling of global capacity every three years for solar and every 5 years for wind, as seen in the last decade (IRENA 2020). Higher LRs have been proposed for solar (e.g. Witajewski-Baltvilks *et al* 2015), but global LR averages differ from country-specific estimates and the decline of PV costs in India have been among the fastest in the world, suggesting some saturation is likely. To explore the impacts of faster cost reductions than those provided by our LR assumptions, we conducted sensitivity analysis (supplementary note 5).

A maximum growth rate is implemented to represent non-cost constraints in India such as limited solar manufacturing capacity (currently at 3 GW per year)[5], reliability of supply, and bureaucratic hurdles. For the FY 20–25 period, we assume the maximum growth rates do not depart significantly from the FY 19 growth rates, namely 6% for wind and 28% for solar (see supplementary table 2). For the post-2025 period, the maximum growth rates for wind and solar were set at high enough levels to enable achieving the 450 GW target but capped at 30% to avoid excessive implementation in any given year. This lower annual addition rate reflects not only the larger installed capacity on which it is applied, but also potential policy changes that may begin to remove some of the privileges of RE sources (e.g. ending the exemption on the customs duty on imported equipment[6]). The choice for this value is supported by and follows from comprehensive sensitivity analysis performed on this parameter choice in the model, as explained below. In contrast, coal power has no constraints on capacity additions and its cost remains constant through the period of analysis.

The TIMES-India ESM is used to produce the sectoral projections. (see supplementary note 3 for model information). Both scenarios had the interim 2022 capacity target for 175 GW of RE including the share of each technology (Wind 34%, Solar 57%, Biomass 6% and Small hydro 3%), as stated in the Indian NDC (Mittal *et al* 2018).

For both scenarios, we estimate solar and wind costs to be 18% and 11% lower, respectively, in 2030 compared to 2020 (see section 2 and supplementary note 4). Table 1 shows key elements of the energy system scenario design as well as a summary of the resulting power sector configuration from the ESM. We have implemented the Clean Energy Cess tax on coal[7] in both scenarios as part of existing policies so it creates no difference across scenarios.

2.2. Scenario expansion

While energy systems models (ESM) can elucidate the structural changes required to decarbonise economic

[5] www.livemint.com/industry/energy/india-gets-10-gw-proposals-for-setting-up-solar-equipment-manufacturing-capacity-11599569420346.html.

[6] https://energy.economictimes.indiatimes.com/news/renewable/india-to-lose-rs-50 000-crore-in-forex-if-solar-developers-given-exemption-from-customs-duty-on-chinese-imports-aisia/76 903 196https://energy.economictimes.indiatimes.com/news/renewable/70-per-cent-safeguard-duty-on-solar-will-put-rs-12000-crore-projects-at-risk/62535567.

[7] www.iisd.org/system/files/publications/stories-g20-india-en.pdf.

Table 1. Power sector scenario design elements and summary of energy system-model results.

Scenario	Assumptions, targets and constraints	Energy system results
Trend	Learning rates for wind and solar: 6% Cost reduction by 2030 wrt 2020: • Wind: 11% • Solar: 18% Maximum capacity growth 2020–2025: • Wind: 6% • Solar 28% Maximum capacity growth 2020–2025: • Wind & Solar: 5% Targets: • RE capacity by 2025: 175 GW	• Coal continues to dominate the power mix in both capacity and generation. • RE share approaches 50% of capacity by 2030, although its share of the total power generated is much lower due to lower capacity factors. • The 40% non-fossil capacity target is reached.
Aspirational	• Same learning rates, cost reductions, maximum capacity growth constraints, and capacity target as in the *Trend* scenario. Additional targets: • RE capacity by 2030: 450 GW • Retirement or refurbishment of sub-critical coal-fired power plants built before 2011	• RE generation gains much higher shares. • There is a significant drop in coal demand. • The PLFs of coal power plants increase to more financially sustainable levels. • India sees a peak in carbon dioxide emissions from energy use by 2030.

activities at the sectoral level, their sector-level outputs are not granular enough for analysing corporate operations. Firms will react differently to changes in their exposures to emerging risks. Some may stick to past investment plans while others may take a more forward-looking approach. A central aspect of our approach involves mapping exposures and exploring alternative strategic responses of each firm to external shocks represented by the changes across scenarios. We bridge the gap between power sector results from the ESM and the proforma cash flow model by transparently creating scenario variants that include specific narratives describing changes in each firm's operating environment and their strategic responses.

In our illustrative case, we explore two alternative responses to the changes projected by *Aspirational*. In *Response A* firms maintain the same near-term strategy they would in *Trend* (as if no shocks occurred), while *Response B* reflects a realignment with the changes projected by *Aspirational* (figure 3).

Two major firms i.e. CIL and IR are sensitive to changes in coal demand across scenarios, and NTPC to changes in electricity generation mix. These variables form the starting point of the expansion. To understand how they translate to impacts on company operations, depends on how each performs relative to its sector. For this, additional assumptions are needed. CIL revenues depend on coal sales. While CIL domestic market share has held steady at around 80% in recent years, cheap and higher quality imports threaten that position, with the outcome not completely under CIL's control (see supplementary note 3). We examined three possible cases for how coal imports will evolve: a central, a low and a high imports case, and settled on a central case in which current shares are maintained and a low-imports case in which CIL gains market share by displacing additional imports. In the low-import case, import volumes remain at levels comparable to 2020.

NTPC revenues depend heavily on sales of coal-fired electricity due its high share of coal power plants. Its plans to expand its coal capacity increase its risk profile in a scenario of high RE penetration and reduction in PLF of coal plants. In both scenarios, we assume the PLF of NTPC's coal power plants falls in proportion by same percentage as the national coal fleet. This lower PLF was used in both strategic Responses *A* and *B* to changes in the *Aspirational* scenario. The resulting PLF was then applied to the installed capacity of coal power plants to derive the electricity produced (in kWh) under each strategic response option.

IR revenues depend on gross tonnage of coal transported. The strategic response scenario draws guidance from the renewed focus on non-coal traffic by diversifying the freight basket to think beyond coal and concentrate on other cargo for boosting freight revenue (Ministry of Railways 2020). Responses are summarised in table 2 along with the additional assumptions needed to implement each firm's response. To be relevant with the short time horizon of the financial sector, we focus our analyses on the shorter-term milestone year 2030.

2.3. Financial modelling

The CFaR metric captures impairments on revenue streams and profitability that serve as indicators of how a firm performs in relation to its sector and against its peers, as well as its capacity to make any necessary investments to change its business model. CFaR for each firm was derived from the impacts on earnings before interest, taxes, depreciation and amortization (EBITDA) projected to change proportionally to the firms' activities within each scenario as

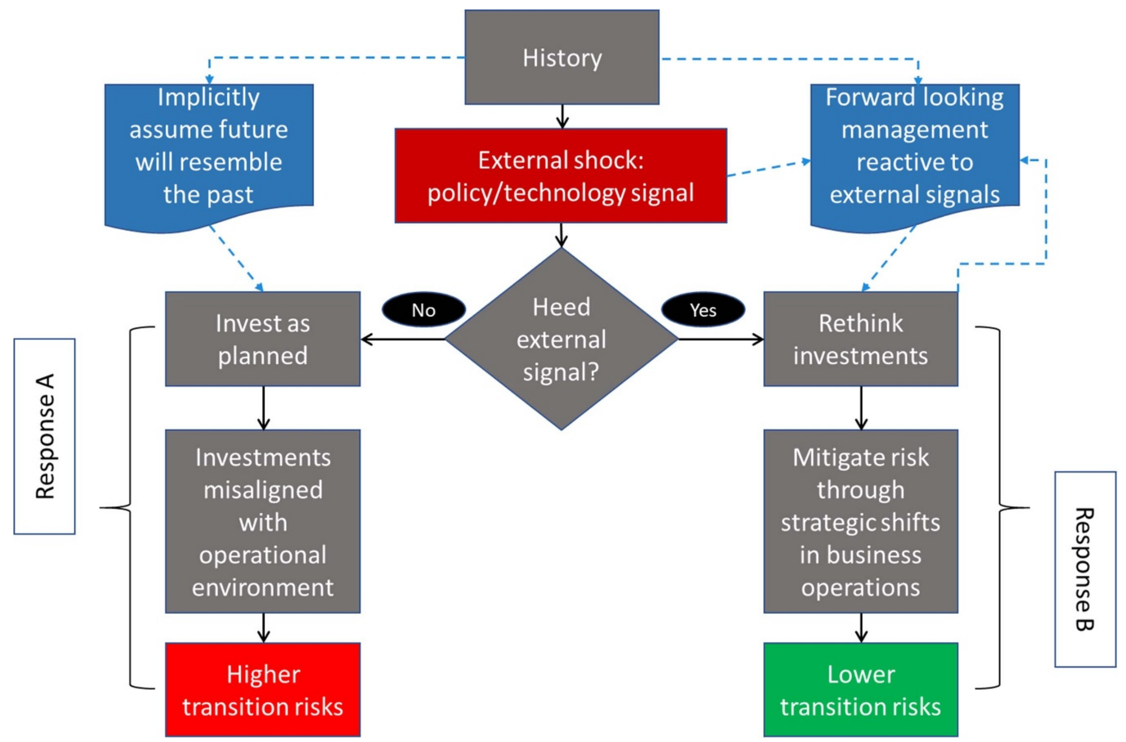

Figure 3. Conceptual representation of firms' alternative reactions to external shocks.

Table 2. Firm exposure to transition risk channels, their responses to the changes in the energy system, and the additional assumptions in the scenarios expansion. Response A implies not doing anything in response to policies (static), while Response B implies a reaction.

Firm	Exposure	Additional assumptions	Response A	Response B
CIL	Reduced coal demand	• Share of imports in domestic coal supply (see supplementary note 3.2) • Share of CIL in domestic coal production	Maintain 83% domestic production market share irrespective of the evolution of coal import levels	Increase domestic production to displace coal imports which remain at 2020 levels as a result.
NTPC	Reduced PLF coal plants	Changes to load factors of NTPC coal plants	Implement the Brighter Plan 2032: • 91 GW of new coal capacity • 39 GW of new RE capacity	Adapt the Brighter Plan 2032 to increase the share of RE capacity additions and reduce for coal by 10 GW and increase RE by 10 GW
IR	Reduced coal demand	Share of coal in freight	Do nothing	Diversify freight and shift spare capacity to transport other commodities

measured by the production level of its core product. Firm-level parameters needed to describe their operations were grounded in literature (Motilal Oswal 2020a, 2020b, 2020c) and expert judgement of current conditions in India.

To estimate CFaR, we adjusted available financial data from company financial statements to enable a calculation of financial flows on a per unit of activity basis, which we term the activity indicator (AI). For CIL, the AI is tons of coal produced while for NTPC, it is electricity generated in kWh and, for IR, tons of coal transported. Financial sector analyses often report financial performance and projections on the basis of such indicators (for example (Motilal Oswal 2020a)), making it a convenient metric. For example, for CIL, projections for EBITDA per ton of coal—adjusted EBITDA (EBITDAadj) are available from its financial statement (CIL 2021) for the years 2020, 2025 and 2030. The same for NTPC (NTPC 2021a). Although IR's financial statement (Indian Railways 2021) does not provide the adjusted EBITDA, we obtain it indirectly from other available variables and additional assumptions (see below). Additional assumptions needed to estimate impacts on each firm's CFaR from the changes across scenarios are described in detail in supplementary note 4.

This financial model uses the following variables as the starting point for financial analysis:

- adjusted EBITDA (INR/AI)
- ratio of operating cash flow to EBITDA (OCF/EBITDA) (%)
- Planned capex and loan repayment schedules (billion INR)

Based on TIMES-India results for coal and electricity demand, plus needed assumptions (see supplementary note 3 for more details), we derived each firm's activity indicator. For example, from CIL's share of domestic supply, we derived the volume of CIL coal production (in Mt) for each year in the period of analysis (see text). We multiply this value for the Activity Indicator by the adjusted EBITDA projections to get EBITDA in billion INR:

$$\mathrm{EBITDA} = \mathrm{Activity\ Indicator}_t * \mathrm{EBITDA}_{\mathrm{adj}}.$$

We multiply EBITDA by OCF/EBITDA to get the operating cash flow (OCF). Next, we calculate the free cash flow expected (FCFE) by subtracting capex and loan repayments from OCF:

$$\mathrm{FCFE} = \mathrm{EBITDA} * \frac{\mathrm{OCF}}{\mathrm{EBITDA}} - (\mathrm{capex} + \mathrm{loan}).$$

FCFE for the period 2020–2030 under each strategic response case were then brought to present value using a discount rate of 12% and CFaR was calculated by subtracting FCFE under Response A from that under Response B:

$$\mathrm{CFaR} = \mathrm{FCFE}_{\mathrm{Response\ A}} - \mathrm{FCFE}_{\mathrm{Response\ B}}.$$

See supplementary table 4 or the stepwise application of these equations.

For NTPC, a similar approach was used but using kilowatt-hours (KWh) of electricity produced instead of coal volume produced as the AI that served as input to the financial modelling. For IR, the AI was Mt of coal transported. Additionally, for IR, there are no interest payments and taxes during the period of analysis, therefore OCF becomes EBITDA. Further, no loan or additional capex is undertaken, so OCF becomes FCFE. For these reasons, EBITDA equals FCFE for IR.

Supplementary note 4 provides a detailed description of the steps taken in each firm's financial analysis. We provide a generalisable methodology (supplementary note 4.2) which can be followed in cases where all the data is available. Where data is missing, additional assumptions are needed in specific steps of the methodology. Supplementary note 4.2 detail how the generic methodology was adjusted to compensate for missing data in each firm's case. Table 3 summarises the key dependencies of each firm's activity indicator (AI).

Table 3. Activity indicators and the key dependencies in its calculation for each firm as used in the financial modelling.

Firm	Activity indicator	Key dependencies
CIL	Coal production in Mt	• National coal demand • Share of CIL's domestic coal supply
NTPC	Electricity generated in kWh	• National power demand • National share of RE generation
IR	Tons of coal transported	• National coal demand • Share of national coal transported by IR • Share of coal in IR's total freight revenues

3. Results

3.1. Energy sector transitions

Falling costs (figure 4(a)) and ambitious capacity targets (figure 4(b)), lead to a shift from coal to RE sources across scenarios by 2030 (figure 4(c)). This leads to plateauing of coal demand in the *Trend* scenario, and to its peak and decline in the *Aspirational* scenario (figure 4(d)). This may imply reductions in future cash flows for firms dependent on the volume of coal use in India, such as CIL and IR. The lower share of coal fired power generation (figure 4(c)) may impact NTPC. However, these changes in the coal value chain do not necessarily mean the firms will automatically face losses. Much depends on how they react to the changes, whether they manage to hold market share or diversify their revenue streams. That is, a firm's business strategy is central to how it fares, and we explore alternative strategic responses of each firm to the changes they face.

3.2. Financial risks of a shift to renewables

When faced with the changes in the *Aspirational* scenario, each firm faces significant transition risks from following a business-as-usual strategy (*Response A*), with potential CFaR of 16.3% for NTPC, 8.9% for CIL, and more than 100% for IR. The hit in CFaR is more severe for NTPC than for CIL due to two related causes: first, secular decline in coal plant utilization levels and associated revenues; and second, a change in the RE/coal mix for NTPC from less than 5% RE at present to 30% in 2030, along with a reduction in coal generation from its fleet and revenues to cover the costs of idling capacity. In contrast, CIL's CFaR is only affected by the fall in coal production and revenues.

We found that much of the CFaR can be mitigated for the three firms through a realignment of corporate plans to the *Aspirational* scenario. By adopting *Response B*, NTPC's CFaR falls to 7.81% and CIL's to 4.73%—less than half of what it would be for both firms if adopting *Response A* (table 4). For IR, the entire value could be recovered by diversifying into other commodities, increasing their share of freight

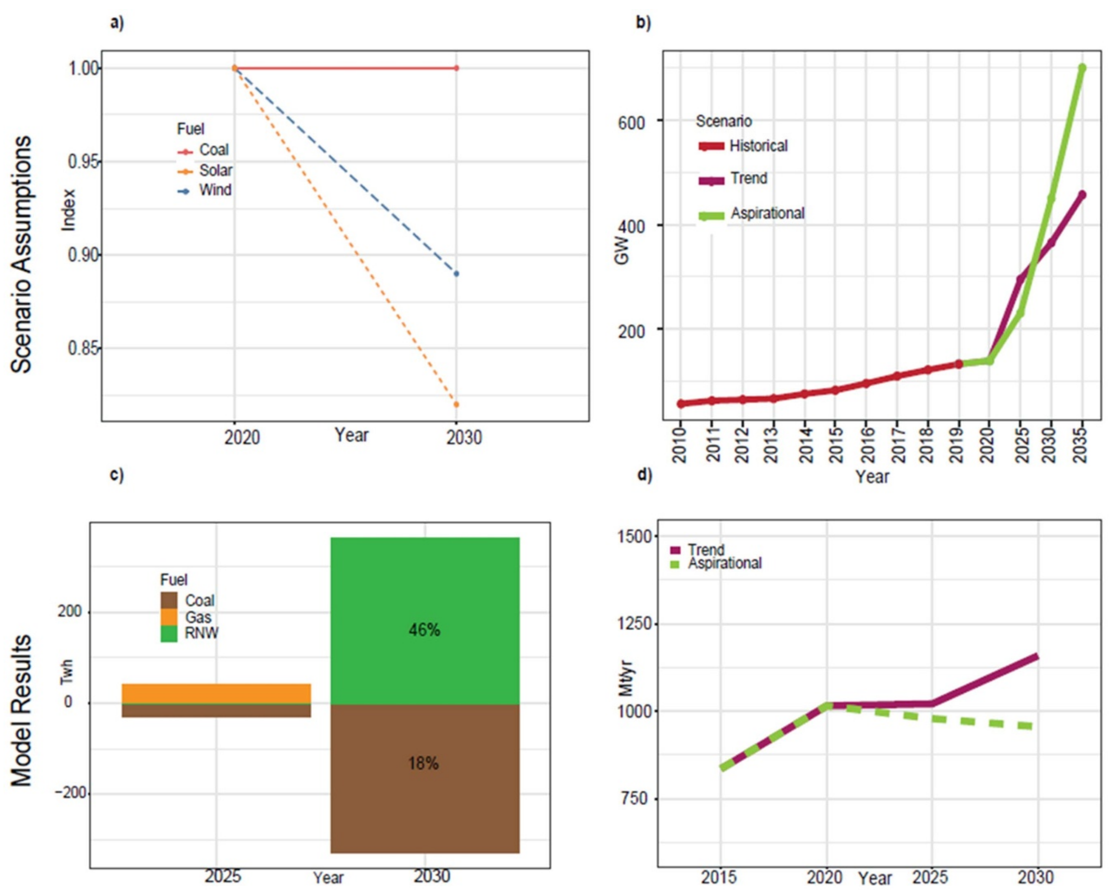

Figure 4. Energy system scenario design assumptions (top row) and results (bottom row). (a) Capital cost projections of coal, wind and solar power indexed to 2020 value. (b) RE capacity: historical installed and targets implemented in scenarios. (c) Difference across scenarios in coal and RE generation; percentage changes from trend in 2030. (d) Coal demand projections resulting from changes in power generation mix across scenarios.

Table 4. Results of the firms' strategic responses on their cash flow at risk (CFaR). For IR, Response A yields a positive CFaR greater than 100%, implying a negative NPV which is why it is shown as n/a.

	CFaR	
Firm	Response A	Response B
CIL	8.9%	4.7%
NTPC	16.3%	7.8%
IR	n/a	zero

and reducing reliance on coal, that is, by adopting its *Response B*.

These findings show that appropriately identifying long-term trends, and acting on them, helps reduce transition risks for corporate firms. In addition to highlighting the need for forward-looking corporate management, it also points to the importance of policy clarity in helping manage an orderly transition. The Indian government's targets are clear policy sign posts that firms can plan around. Recent actions by the three firms suggest management teams acknowledge the need for at least some realignment to the types of changes explored in this paper. CIL plans to contract 3 GW MW of solar power by 2024 to run its mining operations[8] (Coal India Signs First 100 MW Solar Power Purchase Agreement (2021)) and NTPC commits to new RE capacity (NTPC 2021b).

The three firms analysed are the hegemons in their sectors and are at least 50% owned by the Indian government. Such positions come with privileges not enjoyed by their competitors, who are potentially even more exposed to the transition risks identified here. For example, much of NTPC's electricity has guaranteed offtakers through long-term power purchase agreement contracts, a much sought-after arrangement in India that few independent power generators can secure (Debnath *et al* 2021). This suggests the respective sectors may be more at risk than the three state-owned firms are themselves, especially smaller enterprises. Investors and creditors should heed this warning and consider the financial risk to their positions on coal-dependent assets that result from a transition to a low-carbon power system in India, the early signs of which are already emerging. The methodology applied here to the hegemons, can

[8] 'Coal India Signs First 100 MW Solar Power Purchase Agreement,' 2021.

also be used to assess transition risk exposure of smaller players in India.

3.3. Accounting for uncertainty

Key assumptions in scenario design are important drivers of results. Sensitivity analysis on key parameters (such as future RE costs) helps identify the robustness of the results. For example, technological cost reductions are a function of capacity additions, meaning RE costs decrease faster in scenarios with higher RE penetration (Grubb *et al* 2021). Although costs are fixed across our scenarios, sensitivity analysis indicates further cost reductions of wind and solar beyond our 2030 central estimates do not result in more RE capacity beyond the 450 GW target imposed. We had to push 2030 costs to 60%–70% below what they were in 2020 to cause further coal demand reductions. This suggests a saturation in the penetration of RE as concerns costs, which is not completely surprising since RE is already competing with coal on costs basis.

On the other hand, we found that by increasing the maximum allowed *annual* growth rate of wind and solar to around 9%–10% in the ESM led to additional cost-driven RE capacity additions, resulting in further reductions in coal demand and higher RE penetration. This suggests that if RE capacity grows at values approaching 10% per annum for several consecutive years in the next decade, then coal demand may fall more quickly than shown here due to increased penetration of wind and solar (see supplementary note 5). While there are technical challenges to this happening) e.g. grid stability requires high capital investments into transmission infrastructure and/or battery storage (Spencer *et al* 2020), watching this indicator can help set risk appetite for coal-based assets.

Our approach to estimating financial performance through the adjusted EBITDA eliminates the need for price projections (of coal, electricity or freight), pegging the risk estimate to a reduction in the core physical activity of the firm. This forms the basis of a generalisable model that is simple and transparent. Importantly, it is free of market-related noise that would be caused by the inclusion of commodity price projections, although the model can be then expanded to assess the sensitivity of CFaR to commodity price fluctuations and projections. Nonetheless, uncertainties in the financial modelling arise from the assumption that EBITDA and EBITDAadj will scale in similar ways across scenarios and proportionally to the main product output by each firm. The chosen discount rate also affects results, although sensitivity analyses has shown it to not change the main conclusions.

4. Conclusions

We described and applied a framework linking transition scenarios, like those produced by IAMs, with an established method for financial risk assessment. Our approach complements other existing frameworks (Monasterolo *et al* 2017, Battiston *et al* 2021) by explicitly modelling scenario-dependent strategic responses by firms that are directly impacted by the transition. Such strategic responses may improve a firm's ability to navigate the transition but implementing and sustaining them depends on its financial health and management outlook. Using firms' generic responses defined at the sector level may be useful for capital adequacy and financial stability concerns but may be too coarse to be useful when setting business strategy of a FI. The steps we outline enable FIs to gauge transition risk of their portfolio in a dynamic manner by exploring how their most material counterparties can react to the changes in their operating environment in order to survive and thrive in the target conditions of the transition.

Our flexible framework can be applied to any sectors, jurisdictions and economic agents (corporates, households or sovereigns) to be relevant to the specific needs of FIs. While we followed a more elaborate approach to produce the energy system transition scenarios, FIs may choose from existing scenarios or use different approaches when producing theirs. While we used a proforma cash flow model, FIs can use their own in-house financial performance tools and methods. The key features of this framework are its internal consistency based on self-consistent narratives, the transparency of the steps followed, and the inclusion of possible strategic responses by the economic agents in question (corporates in this case) to the changes they see in their operating environments across scenarios. We hope this is a useful contribution to the ongoing effort by the financial sector to internalise climate-induced financial risk. More details of the framework can be found in (Köberle *et al* 2020).

Data availability statement

The data generated and/or analysed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

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