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Development of an Industrial Climate-Risk Quantification Framework Linking Physical and Transition Risks with Operational and Financial Exposure

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Abstract - Industrial companies describe climate risks in words but rarely translate them into comparable financial exposure. This study builds a scoring framework on the taxonomy of the Task Force on Climate-related Financial Disclosures (TCFD): six risk sub-categories (acute and chronic physical risk; policy, technology, market and reputation transition risk) and four financial-impact channels (revenues, expenditures, assets and liabilities, capital and financing). Four Indian sectors (steel, oil and gas, automotive, cement) are scored on a five-point scale, and the scores combine into Climate Risk Exposure, Financial Sensitivity and Financial Exposure indices. Oil and gas ranks first and automotive last, although automotive carries a maximum technology score. Exact enumeration shows that no single one-point score change alters the ranking, that oil and gas stays first under moderate reweighting almost always, and that the lower positions are less secure. A carbon-price test applies the emission intensities that ten Indian companies disclosed in their reports. A price of USD 50 to 150 per tonne on every emitted tonne would cost steel 18% to 54% of turnover and cement more than 45%, oil and gas 1.5% to 4.4% and automotive under 0.3%. The framework is a screening tool; its scores are analyst judgements.

Key Words: Climate risk quantification, TCFD, physical risk, transition risk, carbon price sensitivity, India.

I. INTRODUCTION

A steel producer's sustainability report and an automotive manufacturer's both state that climate change is a material risk to the business. Neither statement tells an investor, a lender or the company's own capital-allocation committee how large that risk is in financial terms, or how it compares with the risk facing a cement producer or an oil and gas company. The Task Force on Climate-related Financial Disclosures (TCFD) set out in 2017 to close this gap by recommending that organisations disclose the financial impact of climate-related risks within a common framework rather than in free-form narrative (Task Force on Climate-related Financial Disclosures [TCFD], 2017). The Task Force has since disbanded and its monitoring role has passed to the IFRS Foundation (TCFD, n.d.), whose International Financial Reporting Standards (IFRS) S2 Climate-related Disclosures standard builds on the TCFD recommendations (IFRS Foundation, 2023). Neither the TCFD recommendations nor IFRS S2 supplies a worked quantitative method that an industrial organisation can apply to its own risk categories to obtain one comparable measure of financial exposure. This paper builds such a method.

The gap is visible in practice. The TCFD itself lists the difficulty of quantifying financial effects among the three main obstacles to disclosure, alongside limited knowledge within organisations and a focus on near-term risks (TCFD, 2017). Lee et al. (2024) examined the sustainability and TCFD reports of the 100 largest firms in Taiwan by market capitalisation and found extremely low use of transition-risk assessment tools. In India, the Business Responsibility and Sustainability Report (BRSR) asks each listed company to state the financial implications of its material risks, but the BRSRs read for this study answer with a qualitative sign (positive, negative or mixed) and not with an amount. JSW Steel's climate web page does give rupee estimates for one transition risk and one physical risk, but the page does not confirm the year of those estimates (JSW Steel Limited, 2026b).

This study has four objectives. The first is to identify the physical and transition risks facing four Indian industrial sectors, steel, oil and gas, automotive and cement, using the six TCFD risk sub-categories and not an independently built taxonomy. The second is to map these risks to operational exposure through a Climate Risk Exposure (CRE) score. The third is to carry the risks through the four TCFD financial-impact channels into a Financial Sensitivity (FS) score and combine both scores into one reproducible Financial Exposure (FE) index. The fourth is to test how far the FE ranking depends on the scoring and weighting choices, and how far the carbon-cost exposure of each sector follows from the emission intensities its companies disclose.

II. LITERATURE REVIEW

A. Disclosure Frameworks

The TCFD (2017) divides climate-related risk into physical and transition risk. Physical risks are acute when they are driven by events such as cyclones, hurricanes or floods, and chronic when they arise from longer-term shifts in climate patterns, such as sustained higher temperatures, that may cause sea level rise or chronic heat waves. Transition risk has four sub-categories: policy and legal, technology, market and reputation. The same report names four categories through which risks and opportunities reach an organisation's

finances: revenues, expenditures, assets and liabilities, and capital and financing. These ten items are the scoring grid of this paper.

IFRS S2 keeps the physical and transition distinction (paragraph 10) and asks for the effects of climate-related risks on financial position, financial performance and cash flows (paragraphs 15–21), for scenario analysis of climate resilience (paragraph 22) and for cross-industry metrics that include capital deployment and an internal carbon price (paragraph 29) (IFRS Foundation, 2023). The standard therefore asks for the translation from risk to finance, but it prescribes no scoring method for sector comparison.

B. Empirical Evidence on Climate Risk and Firm Finance

Studies of financial effects fall into three groups. The first measures how markets price climate risk. Investors surveyed by Krueger et al. (2020) believe that climate risks, regulatory risks in particular, already affect their portfolio firms. Bolton and Kacperczyk (2021) find that stocks of firms with higher carbon dioxide emissions earn higher returns, and Sautner et al. (2023) show that firm-level climate exposure measures contain information priced in options and equity markets. The second group measures physical damage. Pankratz et al. (2023) find that exposure to extremely high temperatures reduces firms' revenues and operating income, and Barrot and Sauvagnat (2016) show that natural-disaster shocks to suppliers impose substantial output losses on their customers. The third group builds system-level estimates. Dietz et al. (2016) put the expected climate value at risk of global financial assets at 1.8% along a business-as-usual emissions path, Battiston et al. (2017) show that the timing of climate policy matters for financial stability, and the European Central Bank's economy-wide stress test finds that costs to companies from extreme weather would rise substantially (Alogoskoufis et al., 2021). Fiedler et al. (2021) argue that business-level risk assessment needs climate information at scales that differ between business entities.

Evidence on disclosure quality points the same way. Lee et al. (2024) report weak use of transition-risk tools among Taiwan's largest firms, and Guruprasad et al. (2024) analyse the BRSR disclosures of 150 Indian companies. None of these studies offers a sector-level method that holds the TCFD taxonomy fixed and carries each risk category through to a financial channel.

C. Carbon Prices and Indian Policy

Internal carbon pricing is the practice by which companies voluntarily attach a hypothetical cost to their carbon emissions to help prioritise low-carbon investment projects (Trinks et al., 2022). External benchmarks for a carbon price span a wide range. The High-Level Commission on Carbon Prices called for at least US dollars (USD) 40–80 per tonne of CO_2 by 2020 and USD 50–100 per tonne by 2030 (Stiglitz et al., 2017), and Rennert et al. (2022) estimate a mean social cost of CO_2 of USD 185 per tonne (5%–95% range USD 44–413). The USD 50 and USD 100 scenarios used in Sec. III-F lie within the Commission's 2030 range, and the USD 150 scenario lies within the range of social-cost estimates of Rennert et al. (2022).

India prices carbon through the Carbon Credit Trading Scheme (CCTS), notified in June 2023, under which obligated entities must meet greenhouse gas emission intensity targets (Ministry of Power, 2023). Target rules issued on 8 October 2025 cover aluminium, cement, chlor-alkali and pulp and paper (Ministry of Environment, Forest and Climate Change [MoEFCC], 2025), and an amendment of 13 January 2026 added petroleum refining, petrochemicals, textiles and secondary aluminium (MoEFCC, 2026a). A draft notification for iron and steel was published in June 2026 and was still a draft when this paper was prepared (MoEFCC, 2026b); the trade press reports draft steel targets of 2.1%–9.3% below baseline intensity, with a median near 5.5% (Goyal & Kumar, 2026). Targets are set per plant as an emission intensity, per unit of product or, for refineries, of throughput, so only emissions above the target carry a cost. Abroad, the European Union's Carbon Border Adjustment Mechanism (CBAM) applies in its definitive regime from 1 January 2026 to cement, iron and steel, aluminium, fertilisers, electricity and hydrogen (European Parliament & Council of the European Union, 2023; European Commission, n.d.).

D. Research Gaps

Four gaps follow. First, many climate-risk studies model hazards in isolation and do not connect results to company financial information. Second, corporate disclosures describe climate risks qualitatively but rarely quantify a comparable financial exposure. Third, few studies combine physical risk, transition risk, operational disruption and financial sensitivity in one sector-level model that keeps the TCFD taxonomy throughout. Fourth, public disclosures hold more risk and financial information than comparative cross-sector models use, particularly for Indian industrial organisations. The contribution of this paper is a reproducible scoring framework that addresses the third gap, tested against exact robustness checks and against emission intensities that Indian companies disclosed themselves.

III. METHODOLOGY

A. Research Design

The framework proceeds in six stages (Fig. 1): identify the climate risks with the TCFD taxonomy; score each sector on every sub-category; compute the CRE; compute the FS; combine both into the FE; and stress-test the result. Two features distinguish the design. Every score is accompanied by an evidence log, and the stress tests use exact enumeration and disclosed company data, not expert ratings or assumed emission intensities.

B. Sectors, Risk Categories and Scoring

Four sectors were chosen because each has a large Indian industrial presence and a distinct climate-risk profile: steel, oil and gas, automotive and cement. Each sector is scored on the six TCFD risk sub-categories (acute physical, chronic physical, policy and legal, technology, market, reputation) and the four financial channels (revenue, expenditure, assets and liabilities, capital and financing), each on a five-point scale (1 = low, 5 = high). The 40 scores are the author's judgements, made after reading the BRSRs, factsheets and reports of the ten companies in Table V and the policy documents cited in Sec. II-C. The evidence log (Supplementary File S1) records for each score the documents behind it and a grade: S when a located document directly supports the direction of the score (12 scores), P when it supports it in part (10 scores), and J when the score is judgement and no sector-specific source was located (18 scores). Of the 18 J grades, 8 are in automotive, and reputation risk is graded J in all four sectors, because no

source separated one sector from another. Readers should treat the scores as structured judgement, not as measurement.



Fig. 1. Industrial climate-risk quantification framework.

C. Climate Risk Exposure

The Physical Risk Score (PRS) and the Transition Risk Score (TRS) are the unweighted means of their sub-categories, and the CRE is the mean of the two. For sector *i*, Acute and Chronic are the two physical scores, and Policy, Tech (technology), Market and Rep (reputation) are the four transition scores:

$$\mathrm{PRS}_i = \frac{\mathrm{Acute}_i + \mathrm{Chronic}_i}{2} \quad (1)$$

$$\mathrm{TRS}_i = \frac{\mathrm{Policy}_i + \mathrm{Tech}_i + \mathrm{Market}_i + \mathrm{Rep}_i}{4} \quad (2)$$

$$\mathrm{CRE}_i = \frac{\mathrm{PRS}_i + \mathrm{TRS}_i}{2} \quad (3)$$

Equal weights treat the physical and transition dimensions as parallel, as the TCFD does in presenting both as categories of climate-related risk. Equal weights are a common default in linear scoring models, and Dawes (1979) found that such models often predict nearly as well as optimally weighted ones, although that result concerns prediction and not an exposure index. The effect of weights on a multi-criteria ranking should in any case be tested (Triantaphyllou & Sánchez, 1997), and Sec. IV-G does so.

D. Financial Sensitivity

FS is the unweighted mean of the four channel scores, each reflecting how exposed that channel is to climate-related disruption in the sector. Rev, Exp, AL and CF denote the revenue, expenditure, assets and liabilities, and capital and financing scores:

$$\mathrm{FS}_i = \frac{\mathrm{Rev}_i + \mathrm{Exp}_i + \mathrm{AL}_i + \mathrm{CF}_i}{4} \quad (4)$$

E. Financial Exposure

FE combines CRE and FS and is divided by 5 so that it cannot exceed 5, the top of the scale of its inputs:

$$\mathrm{FE}_i = \frac{\mathrm{CRE}_i \times \mathrm{FS}_i}{5} \quad (5)$$

A sector with high CRE but low FS returns a moderate FE, because strong hazard exposure that does not reach revenue, cost, balance sheet or financing matters less. A sector that scores high on both returns the highest FE. This reproduces the two-stage logic of the TCFD: identify the risk, then assess its financial effect. All indices are reported to two decimals, rounded half up from exact fractions.

F. Carbon-Price Sensitivity

The carbon-price model is built on disclosed data. Table V lists the Scope 1 and Scope 2 emission intensity, in tonnes of CO_2 equivalent per Indian rupee (INR) crore of turnover (1 crore = 10^7 INR), that ten companies disclosed in their BRSRs or environmental, social and governance (ESG) factsheets for the financial year (FY) 2025-26, except Maruti Suzuki, whose FY2024-25 report is used because its FY2025-26 report could not be read. The sources are JSW Steel Limited (2026a), Tata Steel Limited (2026a, 2026c), Indian Oil Corporation Limited (2026), Oil India Limited (2026), Bharat Petroleum Corporation Limited (2026), Mahindra & Mahindra Limited (2026), Bajaj Auto Limited (2026), Hero MotoCorp Limited (2026), Maruti Suzuki India Limited (2025) and UltraTech Cement Limited (2026a). Where a filing prints the intensity, the printed value is used; where it does not, the intensity is Scope 1 plus Scope 2 divided by printed turnover. The sector intensity I_i is the unweighted mean across the sector's companies. For a carbon price p in USD per tonne and an exchange rate F in INR per USD, the gross carbon cost as a percentage of turnover is

$$G_{i,p} = \frac{p \cdot F \cdot I_i}{10^5} \quad (6)$$

where the divisor 10^5 combines the INR crore (10^7 INR) and the conversion to percent. This is a deliberate upper bound: every tonne of Scope 1 and Scope 2 emissions is priced, with no free allocation, abatement or pass-through. The rate F = 88.35 is the mean of the twelve monthly average INR/USD rates for April 2025 to March 2026 in Table 205 of the Reserve Bank of India (RBI) statistical handbook (RBI, 2026a); it is the author's calculation, as the Bank prints no fiscal-year average. The cost is mapped to a five-point carbon-cost band by fixed edges:

$$E_{i,p} = \begin{cases} 1, \text{ if } G_{i,p} < 0.5 \\ 2, \text{ if } 0.5 \le G_{i,p} < 2 \\ 3, \text{ if } 2 \le G_{i,p} < 10 \\ 4, \text{ if } 10 \le G_{i,p} < 30 \\ 5, \text{ if } G_{i,p} \ge 30 \end{cases} \quad (7)$$

The band edges are the author's choice, and the band is a separate screening output: it does not feed the FE, and the Expenditure score in Table III is the author's wider judgement, which also covers compliance, capital and energy-cost effects. To avoid depending on the edges, the carbon price at which the gross cost equals 10% of turnover is also reported:

$$p_i^* = \frac{0.10 \times 10^7}{F \cdot I_i} = \frac{10^6}{F \cdot I_i} \quad (8)$$

G. Robustness Tests

Three exact tests examine the ranking; they need no external ratings. First, every admissible change of one point in one score (a score of 5 cannot rise and a score of 1 cannot fall) is applied one at a time, giving 71 scenarios, and the ranking is recomputed. Second, all 40 scores are perturbed together: each independently moves down one point, stays, or moves up one point with equal probability, clipped to the 1–5 scale. Because the FE of a sector depends only on its own ten scores, the exact distribution of each sector's FE is obtained by enumerating all 3^{10} = 59,049 combinations, and the probabilities of the ranking events follow from independence across sectors. Third, the weights are varied over deterministic grids (Supplementary File S3): the physical weight in CRE, the acute weight in PRS, and the four weights in TRS and in

FS. The moderate grid keeps every weight within ±50% of its equal-weight value, in steps of 0.05, and has 874,225 combinations; the full grid uses steps of 0.1 over the whole simplex, including extreme weights, and has 9,897,316 combinations. No random numbers are used, so every figure reported can be reproduced exactly.

IV. RESULTS

A. Physical Risk by Sector

Table I and Fig. 2 report the acute and chronic scores and the PRS from Eq. (1).

TABLE I. PHYSICAL RISK SCORES BY INDUSTRIAL SECTOR

Sector	Acute	Chronic	PRS
Steel	3	4	3.50
Oil & Gas	4	3	3.50
Automotive	2	2	2.00
Cement	3	4	3.50

Steel, oil and gas and cement tie for the highest PRS (3.50), but the composition differs. Oil and gas leads on acute risk, in line with the cyclone and flood exposure of a 7,516 km coastline whose east coast is more cyclone-prone (National Cyclone Risk Mitigation Project, n.d.) and with the statements of Bharat Petroleum Corporation Limited (BPCL) and Oil India that floods and extreme weather threaten their operations (BPCL, 2026; Oil India Limited, 2026). Steel and cement lead on chronic risk. JSW Steel names five water-stressed sites and Tata Steel lists water stress and extreme heat (JSW Steel Limited, 2026a; Tata Steel Limited, 2026b), and India ranked thirteenth among countries with extremely high water stress in an assessment of the World Resources Institute (2019). The chronic score for cement is the least supported of the eight physical scores: UltraTech reports that 8% of its facilities are in water-stressed regions (UltraTech Cement Limited, 2026b), which argues for a lower score. Section IV-G tests that score. Automotive has the lowest PRS (2.00) and scores identically on both sub-categories; this rests on the judgement that vehicle assembly is less site-constrained and less process-water-intensive, since no source separating the sectors was located.

B. Transition Risk by Sector

Table II and Fig. 3 report the four transition sub-categories and the TRS from Eq. (2).

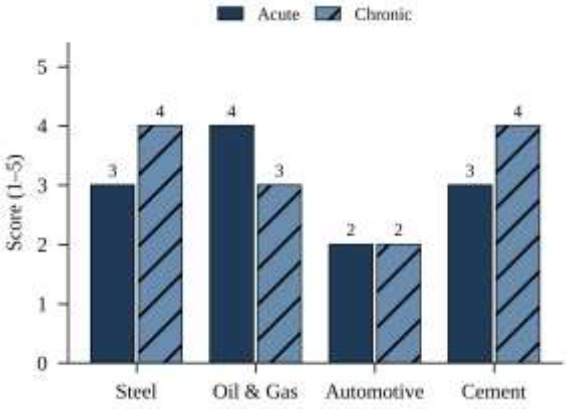


Fig. 2. Physical risk sub-components by industrial sector.

TABLE II. TRANSITION RISK SCORES BY INDUSTRIAL SECTOR

Sector	Policy	Tech.	Market	Reput.	TRS
Steel	5	4	3	3	3.75
Oil & Gas	5	3	5	4	4.25
Automotive	3	5	4	3	3.75
Cement	5	4	2	2	3.25

Policy = policy and legal; Tech. = technology; Reput. = reputation.

Oil and gas has the highest TRS (4.25), combining the sample maximum on policy and legal risk with the sample maximum on market risk. Refining is among the sectors with final CCTS targets (MoEFCC, 2026a), and the product of the sector faces long-term demand erosion; Scope 3 emissions, mostly from use of sold products, average about 88% of the value-chain footprint of oil and gas companies (DNV, n.d.). Automotive has the most distinctive profile. It carries the maximum technology score (5), reflecting electric vehicles at about 8.5% of registrations across all vehicle categories in FY2025-26, mostly two- and three-wheelers (JMK Research & Analytics, 2026), and only moderate scores on the other three sub-categories, so its transition risk is concentrated in the pace and cost of electrification. Steel and cement both score 5 on policy and legal risk: steel because CBAM covers it from 2026 and CCTS targets are in draft, and cement because it is already covered by final CCTS rules with 186 obligated entities (MoEFCC, 2025).

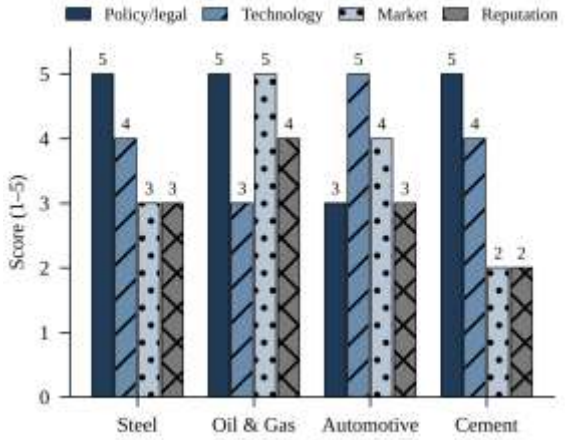


Fig. 3. Transition risk sub-components by industrial sector.

C. Financial Sensitivity by Sector

Table III and Fig. 4 report the four channel scores and FS from Eq. (4).

TABLE III. FINANCIAL SENSITIVITY BY INDUSTRIAL SECTOR

Sector	Rev.	Exp.	A&L	C&F	FS
Steel	3	5	4	4	4.00
Oil & Gas	5	4	5	4	4.50
Automotive	4	3	3	3	3.25
Cement	2	5	3	3	3.25

Rev. = revenue; Exp. = expenditure; A&L = assets and liabilities; C&F = capital and financing.

Oil and gas has the highest FS (4.50): it scores the maximum on revenue and on assets and liabilities and 4 on the other two channels, consistent with a sector whose refining and upstream assets carry stranded-asset exposure under accelerated transition. Cement's profile is uneven. Its expenditure score ties the sample maximum with steel, reflecting the highest emission intensity in the sample (Table V), while its revenue score is the sample minimum because UltraTech's exports are only 0.25% of turnover (UltraTech Cement Limited, 2026a) and demand is domestic. Tata Steel

states that climate regulation and disclosure standards may reduce access to capital and raise the cost of funding (Tata Steel Limited, 2026b), which is the clearest financing statement among the companies read.

D. Financial Exposure

Table IV and Fig. 5 rank the sectors by FE from Eq. (5).

TABLE IV. FINANCIAL EXPOSURE BY INDUSTRIAL SECTOR, RANKED

Sector	CRE	FS	FE
Oil & Gas	3.88	4.50	3.49
Steel	3.63	4.00	2.90
Cement	3.38	3.25	2.19
Automotive	2.88	3.25	1.87

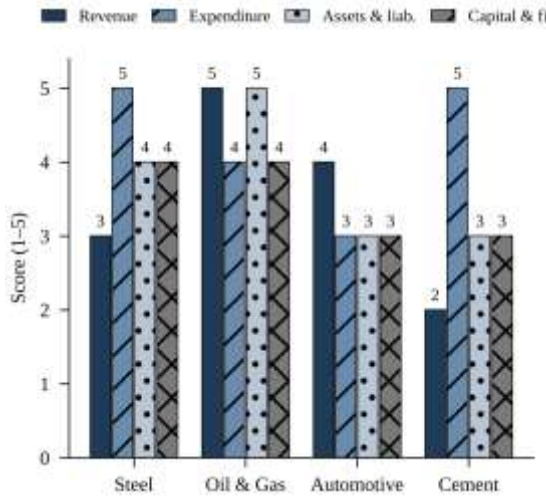


Fig. 4. Financial sensitivity by TCFD channel and industrial sector.

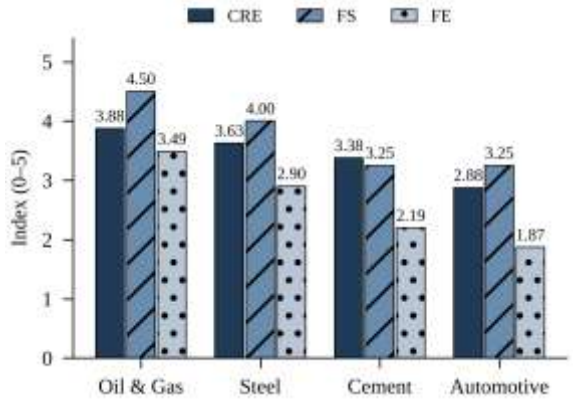


Fig. 5. Climate Risk Exposure, Financial Sensitivity and Financial Exposure by sector, ranked by Financial Exposure.

Oil and gas ranks first (FE = 3.49), followed by steel (2.90), cement (2.19) and automotive (1.87). The gaps between neighbours are about 0.6, 0.7 and 0.3. The narrowest gap is therefore between cement and automotive at the bottom of the ranking, a point that matters for the robustness results in Sec. IV-G.

E. Worked Example: Oil and Gas Versus Automotive

The calculation chain for the highest and lowest sectors shows how CRE and FS combine; the subscript OG denotes oil and gas. Oil and gas scored acute = 4 and chronic = 3, so by Eq. (1):

$$\mathrm{PRS}_{OG} = \frac{4+3}{2} = 3.50 \qquad (9)$$

With policy and legal = 5, technology = 3, market = 5 and reputation = 4, Eq. (2) gives

$$\mathrm{TRS}_{OG} = \frac{5+3+5+4}{4} = 4.25 \qquad (10)$$

and Eq. (3) gives

$$\mathrm{CRE}_{OG} = \frac{3.50+4.25}{2} = 3.88 \qquad (11)$$

With revenue = 5, expenditure = 4, assets and liabilities = 5 and capital and financing = 4, Eq. (4) gives FS = 4.50 and Eq. (5) gives

$$\mathrm{FE}_{OG} = \frac{3.88 \times 4.50}{5} = 3.49 \qquad (12)$$

Automotive carries a technology score of 5, the same as the highest single sub-category score of oil and gas, yet its CRE of 2.88 and FS of 3.25 combine to an FE of 1.87, about half of oil and gas. The reason is not that automotive's transition risk is unreal. It is that this risk is not reinforced by comparable physical exposure or by uniformly high scores across the four financial channels. In this framework, which averages over sub-categories, one severe sub-category does not determine a sector's FE; breadth of exposure across both taxonomies counts as much as the peak.

F. Carbon-Price Sensitivity

Table V lists the disclosed intensities, and Table VI and Fig. 6 report the gross carbon cost from Eq. (6), the band from Eq. (7) and the break-even price from Eq. (8).

TABLE V. DISCLOSED SCOPE 1+2 EMISSION INTENSITY (TONNES OF CO_2 EQUIVALENT PER INR CRORE OF TURNOVER)

Sector	Company	Basis	FY	Intensity
Steel	JSW Steel	Stand.	2025-26	461.2
	Tata Steel	Cons.	2025-26	360.0
	Sector mean			**410.6**
Oil & Gas	Indian Oil	Stand.	2025-26	24.89
	Oil India	Stand.	2025-26	55.76
	BPCL	Stand.	2025-26	20.03*
	Sector mean			**33.56**
Automotive	Mahindra & Mahindra	Stand.	2025-26	2.21
	Bajaj Auto	Stand.	2025-26	1.84
	Hero MotoCorp	Stand.	2025-26	1.94*
	Maruti Suzuki	Stand.	2024-25	2.90
	Sector mean			**2.22**
Cement	UltraTech Cement	Cons.	2025-26	1,030.0
	Sector mean			**1,030.0**

Stand. = standalone; Cons. = consolidated. * Derived: Scope 1+2 divided by printed turnover (BPCL; Hero MotoCorp, whose printed intensity reads 0.00). Sources: BRSRs and factsheets of the companies (see References).

TABLE VI. GROSS CARBON COST BY SECTOR AND CARBON PRICE

Sector	Mean *I*	USD 50	USD 100	USD 150	p^* (USD)
Cement	1,030.0	45.5 [5]	91.0 [5]	136.5 [5]	11
Steel	410.6	18.1 [4]	36.3 [5]	54.4 [5]	28
Oil & Gas	33.56	1.5 [2]	3.0 [3]	4.4 [3]	337
Automotive	2.22	0.10 [1]	0.20 [1]	0.29 [1]	5,093

Cells: gross cost in % of turnover, band score in brackets, at USD 50, 100 and 150 per tonne and INR 88.35 per USD. *I* in tCO_2e per INR crore; p^* = price at which gross cost equals 10% of turnover.

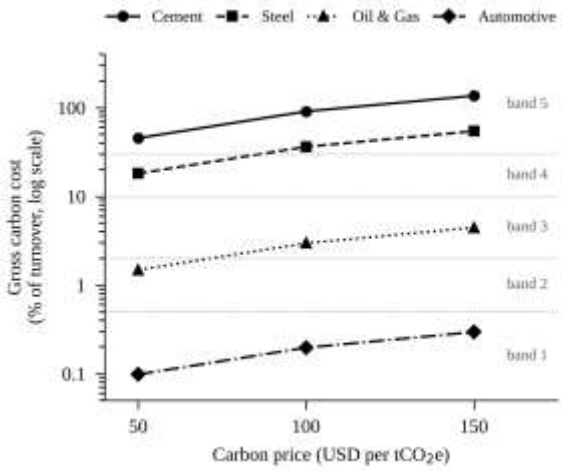


Fig. 6. Gross carbon cost as a share of turnover under three carbon-price scenarios; dotted lines mark the band edges of Eq. (7).

Intensity differs by orders of magnitude. Cement (1,030 tCO_2e per INR crore) is 2.5 times steel (410.6), and steel is 185 times automotive (2.22). Because Eq. (6) is linear in price, the cost in percent of turnover triples between USD 50 and USD 150 for every sector; what separates the sectors is the level. At USD 50 the gross cost is 45.5% of turnover for cement, 18.1% for steel, 1.5% for oil and gas and 0.10% for automotive. Cement is already in band 5 at USD 50 and steel moves from band 4 to band 5 between USD 50 and USD 100; oil and gas moves from band 2 to band 3; automotive stays in band 1. Gross cost reaches 10% of turnover at USD 11 per tonne for cement and USD 28 for steel, against USD 337 for oil and gas and about USD 5,093 for automotive.

The result holds across the companies in each sector. Using the lowest or the highest company intensity in place of the mean leaves every band for steel, cement and automotive unchanged, while oil and gas lies in band 2 or band 3 at USD 50 and USD 100 depending on the company (Supplementary File S2). A weaker rupee raises every cost in proportion; at the RBI reference rate of INR 96.61 per USD on 9 October 2026 no sector changes band (RBI, 2026b).

The upper bound overstates cost under India's actual design, in which only emissions above a plant's intensity target are priced. If a shortfall of 5% of emissions were priced, an order of magnitude consistent with the reported draft steel targets, the cost at USD 100 would be 4.6% of turnover for cement, 1.8% for steel, 0.15% for oil and gas and 0.01% for automotive. This arithmetic is illustrative and not a forecast.

G. Robustness of the Ranking

Table VII summarises the three exact tests.

TABLE VII. SHARE OF CASES THAT KEEP THE RANKING (%)

Test (cases)	O&G first	Auto. last	Order kept
Single ±1 change (71 cases)	100.0	100.0	100.0
All 40 scores ±1, exact	79.8	70.4	48.6
Moderate weights (874,225)	99.7	87.5	87.2
Full-simplex weights (9,897,316)	81.3	67.7	50.1

O&G = oil and gas; Auto. = automotive; Order kept = oil and gas, steel, cement, automotive.

No single one-point change in any of the 40 scores alters the order of the four sectors (0 of 71 scenarios). The closest case is shared by four changes, each lowering one of cement's channel scores by a point (for example revenue, from 2 to 1), which leaves cement at 2.03 and automotive at 1.87, an adjacent gap of 0.16. For example, lowering steel's chronic score from 4 to 3 reduces its FE from 2.90 to 2.70, lowering cement's chronic score from 4 to 3 reduces its FE from 2.19 to 2.03, and raising automotive's market score from 4 to 5 raises its FE from 1.87 to 1.95; none changes a rank.

The joint test is less reassuring and shows where the framework is weak. When all 40 scores are perturbed by up to one point at the same time, oil and gas stays first with probability 79.8% and automotive stays last with probability 70.4%, and the complete order oil and gas, steel, cement, automotive is kept with probability 48.6%. The weakest link is the cement–automotive pair: cement stays above automotive with probability 71.0%, against 91.1% for steel above cement and 80.2% for oil and gas above steel. Simultaneous one-point errors on most of the 40 scores are a severe test, so the ranking should not be read as insensitive to simultaneous scoring errors.

The effect of weights depends on how far they move. Under the moderate weight grid oil and gas stays first in 99.7% of combinations, automotive stays last in 87.5% and the full order is kept in 87.2%; steel stays above cement in every combination. Over the full simplex, which includes weight vectors that put all weight on one sub-category, the shares fall to 81.3%, 67.7% and 50.1%. Over the full simplex the weight effect is therefore as large as the score effect (Table VII). Equal weighting is defensible as a neutral default, and the top position of oil and gas is robust to moderate reweighting, but the bottom position is not robust to extreme weights.

V. DISCUSSION

A. Breadth of Exposure Versus Peak Severity

The worked example generalises. A climate-risk review that stops at the most severe risk, as narrative disclosure does when it names a "key risk", would treat automotive's technology risk and oil and gas's market or policy risk as equally urgent, since each reaches 5 on a single sub-category. Only by scoring all six risk sub-categories and all four financial channels together does the gap between FE of 3.49 and 1.87 appear. This is a portfolio argument applied to risk sub-categories instead of financial assets: a sector concentrated in one severe risk is not automatically more exposed than a sector with moderate risk spread across both dimensions and all four channels. This result is partly a property of the averaging in Eqs. (1)–(5), which rewards breadth by construction, so it illustrates the framework and does not test it independently. The joint robustness test qualifies the argument further. The gap between the top and bottom sectors is wide enough to survive moderate reweighting, but the framework should not be read as proving that automotive is less exposed than cement.

B. Relation to Prior Evidence

Lee et al. (2024) find weak use of transition-risk assessment among Taiwan's largest firms, and the TCFD (2017) names quantification as a main obstacle. The comparison of automotive with oil and gas shows what is lost when quantification stops at the risk rating: a single maximum score, such as automotive's technology risk, does not identify the sector with the greatest overall exposure. The framework's treatment of physical risk as a source of revenue and expenditure effects is in line with Pankratz et al. (2023), who find that extremely high temperatures reduce revenues and

operating income. Krueger et al. (2020) report that investors see regulatory risks as already beginning to materialise, and policy and legal risk carries the largest number of maximum scores in the sample (three of the nine scores of 5).

C. What the Carbon-Price Test Shows

The carbon-price test shows that emission intensity, not sector size or FE rank, drives direct carbon-cost sensitivity. Oil and gas has the highest FE but a gross Scope 1 and 2 cost of only a few percent of turnover, because its turnover per tonne emitted is high (a mean intensity of 33.6 tCO_2e per INR crore, against 410.6 for steel). Scope 3 lies outside this measure and is likely to be a large part of the sector's footprint, mainly through the use of the products it sells (DNV, n.d.); a price on Scope 1 and 2 therefore captures only part of its exposure, and other channels may carry more of it. The Scope 3 figures of the oil and gas companies in Table V could not be read, so the size of that omission is not measured here. Automotive's exposure is likewise not through a carbon price on its own plants but through fuel-economy rules and electrification; for passenger cars, the Corporate Average Fuel Economy (CAFE) III norms were reported notified in September 2026 with a fleet target of 78.9 g CO_2 per km by FY2032 (Swarajya Staff, 2026), a figure the author could confirm only from news reports. For cement and steel the test points the other way: a price of USD 11 or USD 28 per tonne on every tonne would already cost a tenth of turnover. This is not what the CCTS will charge, since only the excess over a plant target is priced. It does mean that, for these two sectors, the targets, any move towards full pricing and CBAM are the transition variables that matter most for expenditure.

D. Implications

First, capital allocators comparing climate risk across an industrial portfolio may wish to treat a sector's single most-cited risk with caution, since the breadth of exposure can raise or lower the overall rank. Second, for cement and steel, direct carbon cost scales with intensity and the sample's highest intensities sit in these two sectors, so the pace of any move towards full carbon pricing is the variable to watch. Third, the evidence log shows where scoring needs better data. Of the 40 scores, 18 are judgement, and the missing information, such as water intensity by process and the financial amounts attached to each risk, sits largely with finance and operations teams. Quantification of the kind proposed here may therefore be best run jointly by sustainability, treasury and operations teams, and not by any one function. Disclosure standards could help by asking companies to state the amount, and not only the sign, of the financial implication of each material climate risk, as IFRS S2 paragraphs 15–21 already ask for the effects on financial position, performance and cash flows.

VI. CONCLUSION

A. Limitations

First, the 40 scores are structured judgement, and 18 of them have no sector-specific source behind them; a company applying the framework to its own data would obtain its own values. Second, the carbon-price model prices only Scope 1 and Scope 2 emissions, uses a gross upper bound and a mean of intensities that mix standalone and consolidated boundaries and, for cement, a single company. Disclosed intensities carry their own inconsistencies: the intensity printed by JSW Steel implies a turnover base about 3% above its reported turnover, and the turnover reported by UltraTech differs from the base implied by its printed intensity; the printed values are used, and substituting the alternative denominators (475.8 tCO_2e per INR crore for JSW Steel and 1,121 for UltraTech) changes no band (Supplementary File S2). Third, the equal weights are a neutral default and the exact tests show that the lower positions of the ranking are sensitive to the scores and to extreme weights. Fourth, steel targets under the CCTS were still in draft, cement target percentages differ between sources and the CAFE III figures rest on news reports, so none of them is used as an input. Fifth, the framework covers four industrial sectors and has not been tested for services or finance.

B. Future Research

Applying the framework to one company's audited emission and financial data would test whether the divergence between oil and gas and automotive holds at company level. Adding Scope 3, plant-level CCTS targets and technology-cost curves would turn the gross upper bound into a compliance-cost estimate. Replacing the author's judgements with ratings from a documented expert panel, if one is convened, would allow the scores to be validated against an independent source. Extending the grid to more sectors and to geography-specific physical risk would test whether the divergence between breadth and peak severity holds more widely.

C. Concluding Remarks

The TCFD recommendations gave industrial organisations a shared vocabulary for climate risk but left the translation into quantified financial exposure to each organisation. This paper scores four Indian sectors on all six TCFD risk sub-categories and all four financial channels and combines them into one reproducible FE index. Oil and gas carries the highest FE and automotive the lowest, although automotive carries a maximum technology score, because that risk is not reinforced elsewhere in either taxonomy. No single one-point change in any score alters the ranking, and oil and gas stays first under moderate reweighting in 99.7% of combinations, but the order of the lower sectors is less secure. A carbon-price test on disclosed emission intensities shows that direct carbon-cost sensitivity follows intensity: a price of USD 50 to 150 on every Scope 1 and 2 tonne costs steel 18% to 54% of turnover, cement more than 45% and automotive under 0.3%. The framework is a transparent screening tool. Its value lies in making every score, its evidence and its robustness visible, so that a company or an investor can replace the judgements with its own.

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