Research Article

QUANTIFYING PHYSICAL CLIMATE RISK IN EXTRACTIVE INDUSTRIES: STRESS-TESTING FRAMEWORK FOR FINANCIAL DISCLOSURE AND ESG GOVERNANCE

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ABSTRACT

Background: Hydropower-dependent mining is exposed to hydrological variability, yet methods for translating hydrological conditions into traceable financial estimates remain limited. As a result, physical climate risk is often disclosed qualitatively.
Purpose: This study develops a stress-testing framework to express physical climate risk in financial terms for disclosure and risk management.
Design/methodology/approach: A deterministic single-case study combines public reports and measured rainfall summaries. A U-shaped function links inflow ratios to production losses using US$888,6 million in exposed revenue. Five-year discounted losses and indicative asset exposure are calculated from stated scenarios, assumptions, and disclosed carrying values.
Findings/Results: At a 10% discount rate, four scenarios yield five-year discounted revenue losses of US$168.4–2,021.1 million and indicative asset exposure of US$23.1–925.4 million. At equal deviations from normal inflow, dry conditions produce greater assumed losses; wet conditions act through a different operational channel.
Conclusion: The framework translates stated hydrological scenarios into transparent and reproducible financial estimates, subject to the assumptions and data limitations disclosed.
Originality/value: The study links physical climate-risk scenarios to financial estimates relevant to IFRS S2-informed disclosure and Indonesian sustainable-finance reporting. It also highlights the different transmission channels of dry- and wet-condition risks.

ARTICLE INFO

Keywords:
climate risk disclosure, stress testing, ESG governance, extractive industries, IFRS S2

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INTRODUCTION

Climate change creates two broad classes of corporate risk. Transition risks arise from policy, technology, and market changes associated with a low-carbon economy; physical risks arise from changing biophysical conditions, whether chronic (such as shifts in rainfall patterns) or acute (such as floods and droughts). Indonesian climate-related disclosures have tended to emphasise transition risks, while physical risks are less frequently translated into financial estimates that lenders and assurance providers can evaluate. This gap is particularly important for water-dependent operations: hydropower may reduce purchased-electricity emissions while exposing operational reliability to hydrological conditions beyond the company's control. These conditions matter for enterprise risk management, disclosure, and access to sustainable finance.

Prior research identifies the hazards but offers a less direct link to accounting measures. Mavrommatis et al. (2019) propose an integrated climate-risk framework for mining, while Li (2025) shows that physical climate exposure shapes corporate adaptation. For hydropower, Gaudard et al. (2016) link long-term revenue uncertainty to climate and electricity prices, and van Vliet et al. (2016) document reductions in output during drought and warm years. Huang et al. (2025) identify vulnerability to abrupt alternation between drought and flooding, while Wasti et al. (2022) find that assessments still emphasise mean flows despite risks at both extremes.

Regional evidence reinforces the need to assess wet as well as dry extremes. Kurniadi et al. (2021) identify independent effects of the El Niño–Southern Oscillation and Indian Ocean Dipole on Indonesian rainfall extremes. Ge et al. (2021) project changes

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in extreme precipitation over Southeast Asia using a CMIP6 ensemble, and the IPCC (2021) documents the intensification of heavy precipitation under warming. Where energy generation and ore supply depend on the same catchment, both tails of the distribution merit examination.

Climate-related reporting frameworks provide a basis for examining these risks. The Task Force on Climate-related Financial Disclosures (TCFD, 2017) sets out four disclosure pillars, and TCFD (2021) provides guidance on scenario analysis. IFRS S2 addresses climate-related risks and opportunities that could reasonably be expected to affect an entity's prospects, including their current and anticipated financial effects (IFRS Foundation, 2023). In Indonesia, POJK 51/ POJK.03/2017 establishes sustainable-finance and sustainability-reporting requirements for relevant entities (Otoritas Jasa Keuangan [OJK], 2017). The Indonesia Taxonomy for Sustainable Finance, Version 3, provides a related classification and assessment framework (OJK, 2026). Nevertheless, Lee et al. (2024, 2025) report weaknesses in scenario design and information sourcing, while Dilling et al. (2024), Aldoseri and Albaz (2023), and Nugrahani et al. (2023) link disclosure quality to governance, strategy, and institutional pressures. Quantification can inform corporate responses (Li et al.2024), but the practical challenge remains developing transparent methods that connect hazards with financial consequences.

The extractive sector faces particular scrutiny. Nickel is important for the energy transition, yet mining in Indonesia has been associated with forest loss and mixed local welfare outcomes (Lo et al.2024). Sustainability initiatives in battery-mineral mining are receiving increasing attention (Severiano et al.2025). Water-use data, however, can remain incomplete even where mining is regulated (Atakhanova et al.2024). Hydropower-related environmental claims therefore warrant supporting evidence about operational resilience and exposure to hydrological extremes.

This study develops a deterministic stress-testing framework for one operating site, extending a method more commonly used in financial portfolios (Reinders et al. 2023). Its calculations can be reproduced using published inputs and summary statistics reported in the manuscript; the underlying non-public rainfall observations cannot be independently inspected. The selected nickel operation provides a case for demonstrating the approach, not an audit of the company. The objectives are to (1) formulate a nonlinear production-loss function linking inflow ratios with losses in a hydropower-dependent operation; (2) translate those losses into five-year discounted revenue-loss estimates and screen asset-side exposure using disclosed carrying amounts; and (3) interpret the resulting estimates for enterprise risk management and climate-related financial disclosure.

The design is deterministic, so no statistical hypothesis is tested. Instead, two propositions guide the analysis. Proposition 1: departures from normal inflow affect financial outcomes through different channels electricity generation under dry conditions, and ore supply and processing under wet conditions. Proposition 2: both channels can be expressed in a common financial metric, while asset-based risk registers alone may overlook one pathway. The study examines whether these propositions produce transparent, reproducible stress estimates and useful disclosure insights, without treating the scenarios as forecasts.

METHODS

This study applies a deterministic, scenario-based single-case design. It does not estimate scenario probabilities or statistically infer causal effects. Instead, it illustrates how specified hydrological conditions can be translated into financial estimates using disclosed inputs, explicit calibration assumptions, and reproducible calculations.

Company information was drawn from three public documents: the operator's 2024 and 2025 sustainability reports and its audited financial statements as at 31 December 2025. Parameters not reported by the company were obtained from an engineering study (Prasetio & Ashar, 2022). A measured monthly rainfall series for 2015–2025, obtained by the author through professional work from a gauge within the Sorowako operating area, was also used; the raw observations cannot be publicly redistributed. Annual totals are complete for 2015–2024, while November and December 2025 are missing, so 2025 is excluded from the reference normal. The sum of twelve monthly normals is 3,296.2 mm, differing by 0.21% from the mean of complete annual totals (3,289.2 mm). The driest year was 2019 (2,766.1 mm) and the wettest was 2016 (4,008.6 mm). These summary values are sufficient to reproduce the calculations presented here, but not to

verify the underlying rainfall record independently. The seasonal pattern is consistent with the published description of the catchment (Syaifullah, 2013).

The case is a nickel-processing operation in South Sulawesi supplied by a three-plant hydropower cascade (471 MW) drawing on three lakes in a 2.477 km² catchment (runoff coefficient 0.535; Figure 1). Prasetio and Ashar (2022) report 420 MW, whereas the operator later reports 471 MW across seven units. This difference does not affect the calculations.

Financial inputs were taken from the audited statements; energy, emissions, and water metrics from the sustainability reports; and cascade characteristics from the engineering literature. Where reports present different values for the same period, the later restated figure is used and identified.

Figure 2 summarises the five-stage analytical framework. Stage 1 specifies a climate driver (an ENSO phase or precipitation extreme) as a scenario analogue, not a forecast. Stage 2 converts this driver into a hydrological condition, measured by the scenario-to-normal inflow ratio and compared with canal capacity. Stage 3 separates the transmission channels: under dry conditions, reduced inflow affects electricity generation; under wet conditions, disruption arises through mining and ore processing. Stage 4 translates the resulting production-loss fraction into discounted revenue losses and indicative asset-side exposure. Stage 5 considers the relevance of these estimates to IFRS S2-informed disclosures, POJK 51/2017 reporting, and taxonomy assessment. The separation and subsequent convergence of the two channels form the framework's central proposition.

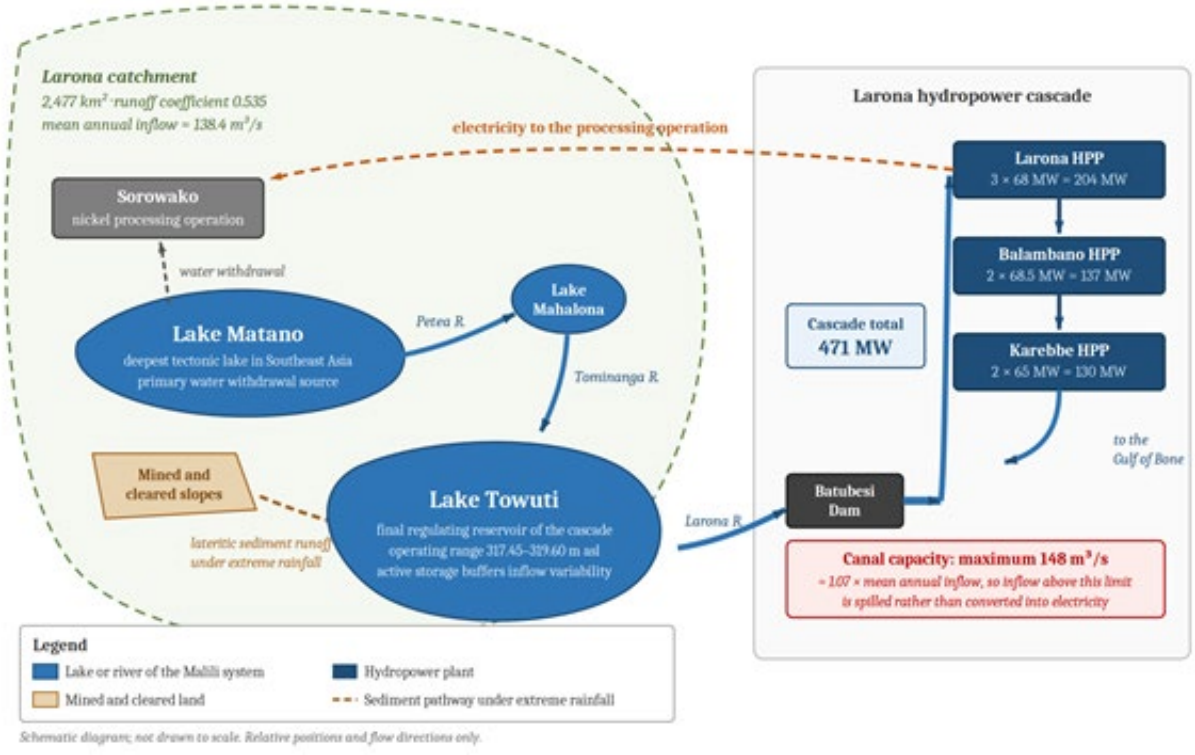


Figure 1. Lake system, hydropower cascade, and processing operation at the study site (Prasetio and Ashar (2022); PT Vale Indonesia Tbk (2025, 2026a).

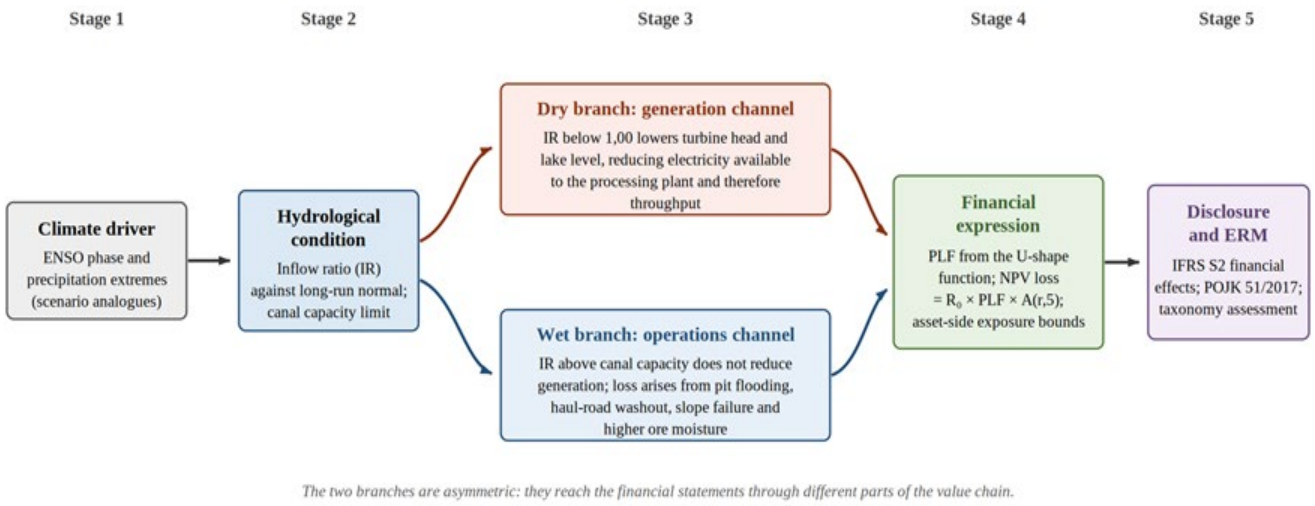


Figure 2. Analytical framework linking climate drivers, transmission channels, and financial estimates

First, a U-shaped function relates the inflow ratio (IR) scenario inflow divided by long-run normal inflow to the production-loss fraction (PLF). PLF equals zero at IR = 1.00 and increases on either side. Linear interpolation is used between the calibration points in Table 1.

$$PLF(IR) = PLF_i + (IR - IR_i) \times (PLF_{i+1} - PLF_i) / (IR_{i+1} - IR_i) \quad (1)$$

for $IR_i \leq IR < IR_{i+1}$, where consecutive pairs (IR_i, PLF_i) are given in Table 1. Outside the calibrated range, PLF is held at the respective endpoint. Figure 3 is generated from Equation 1 and the calibration values.

For the dry branch, lower inflow reduces turbine head and may bring lake levels closer to the minimum operating threshold. With annual rainfall of 3,296.2 mm, the reported catchment area, and the adopted runoff coefficient, estimated mean annual inflow is approximately 138.4 m³/s. A proportional interpretation would imply a 20% loss at IR = 0.80, but the model assumes 10% to reflect the buffering effect of active lake storage within a 2.15 m operating range. This is an author-defined calibration, not a measured production response.

For the wet branch, the principal channel is mining and processing rather than foregone hydropower generation. Canal capacity (148 m³/s) is approximately 1.07 times the estimated mean annual inflow; additional water above turbine capacity cannot be converted into extra generation. Instead, high rainfall is assumed to disrupt ore supply through flooding, road damage, slope instability, and increased ore moisture. The wet-branch loss fractions in Table 1 are illustrative operational assumptions, not hydraulically estimated effects.

Second, annual revenue loss is estimated as baseline exposed revenue multiplied by PLF. The annual amount is then discounted over five years:

$$NPV = R_0 \times PLF \times A(r, 5) \quad (2)$$

where A(r, 5) is the five-year annuity factor at discount rate r. Baseline exposed revenue (R_0) is US$888,584 million, rounded elsewhere to US$888.6 million, representing 2025 matte sales to principal buyers. Because the product is manufactured at the study site, this is the closest publicly disclosed proxy for site-exposed revenue. Consolidated revenue is 11.4% higher and is used only as a sensitivity check. The baseline discount rate is 10%, with 8% and 12% alternatives. These figures are discounted gross revenue-loss scenarios, not estimates of net income, cash-flow losses, or recognised impairment.

All parameters required to reproduce the published calculations are specified in the text, tables, and equations. The raw rainfall observations are not publicly redistributable; consequently, readers can reproduce the arithmetic but cannot independently verify the underlying gauge series. The study uses public corporate reports and the summary statistics described above.

Table 1. Calibration points for the U-shaped production-loss function

Hydrological condition	IR	PLF	Transmission channel
Acute drought	0.50	60%	Generation: level below minimum operating threshold
Chronic drought	0.80	10%	Generation: reduced head. buffered by lake storage
Normal	1.00	0%	Operation within design range
Moderately wet	1.30	5%	Operations: limited pit and haul-road disruption
Chronic wet	1.60	20%	Operations: pit flooding. slope failure. wet-ore penalty

RESULTS

Hydrological stress-testing results

Four stress cases are analysed using the non-normal calibration points in Table 1. Scenario A (IR = 0.80) is slightly drier than the observed minimum annual rainfall ratio of 0.84 (2019). Scenario D (IR = 1.30) is wetter than the observed maximum ratio of 1.22 (2016). Scenarios B (IR = 1.60) and C (IR = 0.50) are further outside the observed range. These cases illustrate stress conditions rather than predicted outcomes.

Applying Equation 2 to the US$888,6 million exposed revenue proxy yields Table 2. Estimated annual revenue losses range from US$44.4 million (Scenario D) to US$533.2 million (Scenario C). Corresponding five-year discounted losses at 10% range from US$168.4 million to US$2,021.1 million. Scenario C is 2.27 times the annual exposed revenue proxy and 0.87 times the disclosed net carrying value of fixed assets; these comparisons involve a five-year discounted flow and one-year revenue or balance-sheet stocks and should not be interpreted as equivalent accounting measures.

Because discounted losses are proportional to PLF, the ranking of scenarios reflects the calibration function. However, the scenarios differ in distance from normal inflow, so their absolute losses alone cannot establish whether wet or dry conditions are more consequential. Table 3 therefore compares equal deviations from IR = 1.00.

At each equal deviation, the assumed dry-branch loss is approximately three to five times the wet-branch loss. The more important finding is that wet conditions represent a separate potential pathway of disruption rather than an absence of risk. At a deviation of 0.30, the illustrative wet-branch five-year loss is US$168.4 million, transmitted through ore supply and processing rather than hydropower generation.

This channel distinction matters for risk classification and adaptation planning. Treating excess spillway discharge as foregone generation would attribute disruption to the wrong operational assets. Under the assumed calibration, drought has the larger loss at equal deviations from normal; excess rainfall nevertheless creates a separate potential source of disruption. This is consistent with studies identifying vulnerabilities to both drought and flood conditions (Huang et al. 2025; Wasti et al. 2022).

Third, asset-side exposure is screened by applying illustrative damage factors to net fixed-asset carrying amounts under moderate and extreme events. The factors reflect assumed hydraulic exposure and substitutability. Because the asset values are not disaggregated by exposure class, the analysis provides scenario bounds rather than a portfolio-weighted estimate (Table 4).

Asset-side exposure

At 31 December 2025, the reported net carrying amount of fixed assets was US$2,313.4 million. Applying the illustrative damage factors yields an estimated range of US$23.1–231.3 million for moderate events and US$115.7–925.4 million for extreme events (Table 5). These ranges reflect alternative whole-portfolio classifications, not observed damage or a probabilistic valuation.

The range depends mainly on how assets would be allocated among exposure categories. Without asset-level classification, the results cannot support a single portfolio-weighted estimate. In particular, a figure equal to 10% or 40% of the total carrying value corresponds to the strong assumption that the entire portfolio is classified as highly exposed.

Table 2. Estimated annual revenue losses and five-year discounted losses under three discount rates (US$ million)

Scenario	Condition	IR	PLF	Annual revenue loss	NPV, r = 8%	NPV, r = 10%	NPV, r = 12%
A	Chronic drought	0.80	10%	88.9	354.8	336.8	320.3
B	Chronic wet	1.60	20%	177.7	709.6	673.7	640.6
C	Acute drought shock	0.50	60%	533.2	2,128.7	2,021.1	1,921.9
D	Moderately wet	1.30	5%	44.4	177.4	168.4	160.2

Source: Author's calculations. Baseline exposed revenue (R_0) = US$888.584 million; annuity factors are 3.9927 (8%), 3.7908 (10%), and 3.6048 (12%). Losses scale with PLF in the ratio 2 : 4 : 12 : 1. Consolidated revenue would raise each estimate by 11.4% but is not used as the primary exposed revenue base.

Table 3. Production-loss fractions at equal deviations from normal inflow

Departure from IR = 1.00	Dry branch IR	PLF dry	Wet branch IR	PLF wet	Ratio dry: wet
0.20	0.80	10.0%	1.20	3.3%	3.0
0.30	0.70	26.7%	1.30	5.0%	5.3
0.50	0.50	60.0%	1.50	15.0%	4.0

Source: Author's calculations using Equation 1 and Table 1; values between calibration points are interpolated.

Table 4. Assumed damage factors for screening asset-side exposure

Exposure category	Damage factor, moderate event (M)	Damage factor, extreme event (E)	Classification criteria
High	0.10	0.40	In hydraulic contact or regulating the water system; no substitute
Medium	0.05	0.20	Exposed to inundation or slope failure; partly repairable
Low	0.01	0.05	Limited hydraulic exposure; readily substitutable

Source: Author-defined illustrative assumptions, informed by the scenario-analysis approach of TCFD (2021). The damage factors are not prescribed by TCFD and have not been calibrated to asset-specific fragility curves.

Table 5. Illustrative asset-side exposure ranges based on fixed-asset carrying amounts (US$ million)

If the whole asset base were classified as	Damage factor M / E	Loss, moderate event	Loss, extreme event
High exposure	0.10 / 0.40	231.3	925.4
Medium exposure	0.05 / 0.20	115.7	462.7
Low exposure	0.01 / 0.05	23.1	115.7

Hydropower-related structures dams, reservoirs, canals, and generating equipment may have concentrated exposure because the plants operate in sequence and their infrastructure is site-specific. The operator also reports limited reliance on purchased electricity and identifies hydropower operations as a major water requirement. These features indicate potential propagation of disruption, but asset-specific vulnerability must be established separately.

The revenue and asset screens therefore describe two different potential financial effects. Under an extreme high-inflow scenario, operating disruption and physical asset damage could occur in the same episode. They should not automatically be combined or netted, because revenue losses and asset damage can overlap economically and require careful separation to avoid double counting.

Cross-validation against corporate disclosure

The model relies partly on publicly disclosed engineering and financial information. Comparison with the operator's sustainability reports provides a consistency check, not independent validation. Table 6 summarises selected disclosures relevant to the model assumptions.

The reported renewable share of site energy increased slightly between 2024 and 2025 while hydropower generation declined. The reported change is attributed to the biodiesel blend rather than an improvement in hydrological performance. This illustrates why reporting hydropower generation separately from aggregate renewable-energy shares could improve transparency.

The operator identifies extreme rainfall, flooding, landslides, drought, and forest fires as physical climate risks and uses SSP2 and SSP5 scenarios. The inclusion of both wet and dry hazards is consistent with the directions considered in the stress-testing framework.

Water withdrawal and water intensity increased over the three reported years, with water intensity rising by approximately 84% between 2023 and 2025. Because the underlying values may also reflect changes in operational activity or production mix, the trend alone does not establish greater hydrological vulnerability.

The 2025 report restates the 2024 greenhouse-gas emissions figure from a previously disclosed 2.14 million tCO_2e to 2.05 million tCO_2e following independent verification under ISO 14064-1:2018. This is a revision of approximately 4% based on rounded figures; the exact percentage should be checked against the underlying unrounded data. The revision underlines the importance of identifying data vintages and assurance status. On the restated basis, emissions increased by 1.15% in 2025 while energy intensity fell by 1.61%. The operator partly attributes the latter to reduced ore moisture. Drying-furnace fuel use fell by 27.32%, a pattern consistent with the proposed ore-moisture channel but insufficient to establish causality.

Implications for enterprise risk management and ESG disclosure

The illustrative five-year discounted revenue-loss estimates range from US$168.4 million to US$2,021.1 million, compared with annual exposed revenue of US$888.6 million and net fixed assets of US$2,313.4 million. These comparisons indicate potentially decision-useful exposure, although formal materiality depends on the company's circumstances and the uncertainty of the assumptions. Presenting explicit physical-to-financial pathways can support climate-related financial-effects assessment and governance discussions (IFRS Foundation, 2023; Prawitasari et al. 2026; TCFD, 2017).

First, risk registers could be organised by transmission channel as well as asset class. For each pathway, the hazard, affected activities, financial mechanism, and exposed assets should be identified separately. Under the model assumptions, dry-condition adaptation centres on hydropower resilience, whereas wet-condition adaptation concerns mine drainage, slope stability, haul-road reliability, and ore handling. The appropriate capital allocation requires site-specific evaluation.

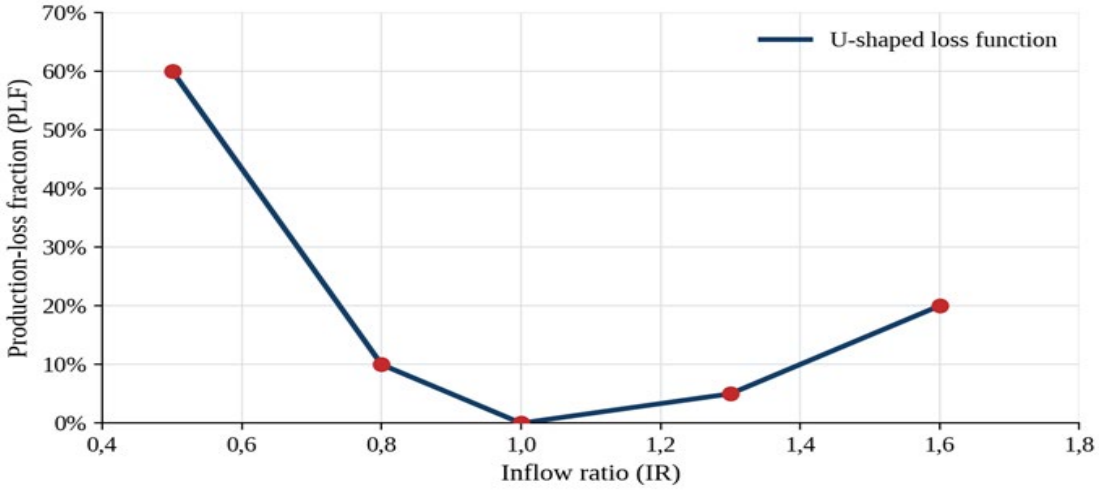


Figure 3. U-shaped production-loss function and calibration points

Table 6. Corporate disclosures relevant to the model assumptions

Disclosed item	2023	2024	2025	Direction
Renewable share of site energy (%)	–	30.60	30.87	Rising
Hydropower generation, change on prior year (%)	–	–	−0.86	Falling
Water withdrawal (million m³)	9.44	11.75	15.08	Rising
Water intensity (m³ per tonne of nickel)	113.50	164.75	209.35	Rising
Total GHG emissions (million tCO_2e)	–	2.05	2.07	Rising
Energy intensity (GJ per tonne of nickel)	–	445.73	438.57	Falling
Drying-furnace fuel, change on prior year (%)	–	–	−27.32	Falling

Source: Author's calculations using PT Vale Indonesia Tbk (2025, 2026a). The 2024 emissions figure is restated. The disclosed 2023 water-intensity value does not reconcile exactly with reported withdrawal and production figures

Second, scenario-based financial estimates may improve the evidence supporting sustainability disclosures under POJK 51/2017 and climate-related financial-effects disclosures consistent with IFRS S2 (OJK, 2017; IFRS Foundation, 2023). The Indonesia Taxonomy for Sustainable Finance, Version 3, provides a classification framework that may also be relevant to eligible activities and entity- or portfolio-level assessment (OJK, 2026). However, this illustrative analysis alone does not establish compliance, taxonomy alignment, or an effect on financing costs; those outcomes require assessment against the applicable criteria and supporting records.

Third, catchment conditions may influence operational, regulatory, and asset risks. Drawdown, sediment mobilisation, and slope degradation can affect the hydropower system and ore-supply routes, potentially creating remediation and impairment exposures. Catchment-scale measures, including erosion control, slope stabilisation, rehabilitation, and adaptive reservoir operations, could therefore support risk reduction (Nugroho et al. 2022; Leda et al. 2025). This perspective places catchment stewardship within enterprise risk management rather than treating it solely as an environmental narrative.

At governance level, the two-channel structure may require coordination across sustainability, engineering, mine operations, and finance. Separate reporting lines can obscure the combined consequences of a single hydrological event. A designated executive could coordinate exposure assessment, while the board risk committee reviews the assumptions, financial pathways, and proposed adaptation measures. These are practical recommendations derived from the framework, not observations of the company's existing governance arrangements (Pangestuti et al. 2023; Muthmainah et al. 2026).

Five limitations qualify the results. First, matte sales to principal buyers provide a proxy for site-exposed revenue but exclude other sales and do not represent profit or cash flow. Second, the asset screen uses depreciated carrying amounts and assumed damage factors without class-level allocation; its ranges are neither replacement-cost estimates nor necessarily lower bounds for realised damage. Third, the production-loss fractions are author-defined, particularly for wet-condition disruption, rather than calibrated against observed output losses. Fourth, the corporate-report comparison is a consistency check, not independent validation, and the underlying rainfall series is not publicly accessible. Fifth, estimated inflow is sensitive to the runoff coefficient: increasing it from 0.535 to 0.6 would raise mean annual inflow to approximately 155 m³/s, making canal capacity approximately 0.95 of mean inflow. Under that assumption, the wet branch could include a generation-related component as well as the assumed mining disruption.

The reported stress estimates are conditional, illustrative calculations not probability-weighted forecasts, independently validated asset valuations, or estimates prepared or endorsed by the operator. They do not replace site-specific hydrological, engineering, or financial modelling.

Future research should link calibrated rainfall–runoff and reservoir-operation models with downscaled climate projections to estimate scenario likelihoods; use asset-specific fragility curves rather than generic damage factors; and test the two-channel proposition across several companies.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study presents a deterministic framework that translates physical climate-risk scenarios into financial estimates for one extractive-industry operation. It addresses three research objectives and considers two propositions about the distinct transmission channels of hydrological risk.

First, a U-shaped production-loss function links inflow ratios to assumed production losses. The rainfall record provides a reference normal of 3,296.2 mm and estimated mean annual inflow of 138.4 m^3/s; the stress cases extend beyond the observed dry and wet extremes. The loss fractions themselves remain scenario assumptions rather than empirically estimated response coefficients.

Second, with an exposed annual revenue proxy of US$888.6 million and a 10% discount rate, the four stress cases yield estimated five-year discounted revenue losses of US$168.4–2,021.1 million. Asset-side screening produces illustrative ranges of US$23.1–925.4 million. Under the stated assumptions, the dry branch is larger at equal deviations from normal inflow. The two pathways differ: reduced generation under drought and disrupted ore supply or processing under excess rainfall. These results are consistent with Proposition 1 and provide a common financial representation of both pathways as proposed in Proposition 2.

Third, the framework can inform risk registers, financial-effects assessments, and governance discussions relevant to IFRS S2 and Indonesian sustainable-finance reporting. It does not, by itself, demonstrate regulatory compliance, future losses, or impairment. The analysis is most useful as an initial, reproducible screen that can be refined through site-level data and independent validation.

These findings are broadly consistent with Huang et al. (2025), who examine the effects of drought–flood alternation, and respond to the emphasis on mean-flow assessment identified by Wasti et al. (2022). The contribution is to distinguish transmission channels and show how conditional losses could be expressed in financial terms.

Recommendations

For boards, the practical recommendation is to document each climate hazard, transmission pathway, financial mechanism, and affected asset group; coordinate responsibility across operational and financial functions; and evaluate adaptation options against the risks they address. Preparers should separately disclose material hydropower-related metrics, identify data vintages and assurance status, and explain asset-allocation assumptions when reporting a portfolio screen. Regulators and lenders can use transparent scenario analysis as supporting evidence while applying their own compliance and materiality criteria.

The framework can be updated when the revenue base, asset values, and hydrological parameters change, provided that the calibration assumptions and discount rate are also documented. Its main limitation is that it estimates conditional financial consequences, not the likelihood of the scenarios.

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CONFLICTS OF INTEREST: The author has professional experience in climate-risk and sustainability advisory within the resource sector. The analysis uses the public sources cited and summary statistics from a measured rainfall series; the raw series is not publicly redistributable. No confidential client information has been included, according to the author's declaration.

USE OF GENERATIVE AI: During manuscript preparation, the author used Google Gemini for language translation, grammar, and formatting assistance. The author reviewed and revised the resulting material and takes responsibility for the content, accuracy, and integrity of the work.

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