



Investment Modeling Algorithm for the 50 MW Sumbawa 3 Gas Engine Power Plant (PLTMG) Project: A Correlation-Aware, Risk-Adjusted Feasibility Framework

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Abstract

The 50 MW PLTMG Sumbawa 3 project is included in the RUPTL 2025–2034 to strengthen the Tambora isolated subsystem, whose reserve margin declined to 0.8% in 2024 and 1.4% in 2025. PT PLN (Persero) currently evaluates investments using the Kelayakan Keuangan (KKF) framework, a deterministic Discounted Cash Flow (DCF) model that ignores uncertainty and interdependence among key cost drivers. This study develops a four-layer investment evaluation framework combining strategic analysis (PESTEL, Porter's Five Forces, SWOT, VRIO), deterministic DCF, sensitivity analysis, and Monte Carlo simulation with 10,000 iterations. Four stochastic variables, LNG price, IDR/USD exchange rate, HSD price, and fixed O&M cost, were modeled under independent and correlated assumptions. The deterministic evaluation indicates feasibility, with an NPV of IDR 276.85 billion, IRR of 9.13%, BCR of 1.03, and a 10.14-year payback period. However, Monte Carlo simulation reveals an 82.08% probability of negative NPV, with a mean NPV of negative IDR 1.42 trillion. The exchange rate and LNG price explain over 99% of the variance in NPV. Results support conditional project approval through LNG price hedging, tariff adjustment mechanisms, accelerated gasification, and mandatory correlation-aware Monte Carlo analysis for future LNG-based generation investments.

Keywords: Correlated Monte Carlo, Discounted Cash Flow, Downside Probability, Risk-Adjusted Feasibility

1. INTRODUCTION

The Indonesian electricity sector faces intensifying operational and planning challenges as demand expands in step with economic development and regional electrification. Large interconnected systems absorb contingencies through supply redundancy, but many isolated and semi-isolated grids in eastern Indonesia operate with thin reserve margins, aging generation plant, and long radial transmission [67], [68]. The Tambora sub-system, which supplies the Sumbawa-Bima corridor in West Nusa Tenggara, is among the most exposed: operational records of PT PLN (Persero) UIW NTB report reserve margins of 0.8% in 2024 and 1.4% in 2025, more than 220 alert-status days per year, and recurring near-deficit events [1]. The sub-system is a semi-isolated grid with limited interconnection, a small portfolio dominated by medium-speed diesel units, and a 150 kV backbone extending more than 1,000 km from Sumbawa to Bima. Low system inertia and reliance on a few generating units increase the risk of instability during contingencies, and frequency simulations of a hypothetical PLTMG trip show excursions approaching under-frequency load-shedding thresholds [1], [27].

To address this structural fragility, PT PLN (Persero) has scheduled the 50 MW PLTMG Sumbawa 3 in RUPTL 2025-2034 [2]. The prevailing appraisal framework, codified in the Kelayakan Keuangan (KKF) document, relies exclusively on a single-point DCF model with fixed planning assumptions [3]. For an LNG-fuelled plant whose fuel is procured in United States dollars while its revenue is denominated in rupiah, this produces a deterministic estimate that is structurally incapable of expressing the probability of failure, the shape of the downside, or the interaction between the two variables that drive it. The problem is therefore not that the KKF model is wrong at its central estimate, but that it is silent on precisely the quantities a capital committee needs when the central estimate sits close to the acceptance boundary.

Four methodological traditions bear on this problem, and each is informative in a different and incomplete way. The first is the deterministic levelized-cost and DCF tradition. Brown established levelized production cost as the foundational metric of discounted cash-flow appraisal for generation assets [10], and Harvey subsequently clarified the conditions under which the weighted average cost of capital is the

appropriate discount rate for long-lived energy assets [11]. Both contributions rest on the classical present-value logic of Modigliani and Miller [12] and remain the operative standard in regulated tariff-setting because they are analytically tractable and auditable. Their limitation is internal to their design rather than a matter of execution: Harvey's own derivation assumes that the risk being discounted is symmetric and stationary, a condition violated when a single imported commodity accounts for roughly two-thirds of unit cost. The tradition, therefore, delivers a defensible point estimate and no information whatever about dispersion, a limitation now standard in energy-economics texts [75].

The second tradition substitutes structured variation for distributional inference. Brzakovic, Brzakovic and Petrovic assign subjective probabilities to best-, base- and worst-case states in order to reveal which cost drivers most influence project outcomes [48], and Kim, Sung, Banobi and Jung rank the relative impact of construction cost, tariff and discount rate on the internal rate of return of nuclear projects [49]. The value of this work is ordinal: it tells an analyst which parameter to watch. Its weakness is that the probabilities attached to the scenarios are chosen by the analyst rather than estimated from data, so the resulting statements are not statements about likelihood at all. Scenario methods can rank risk; they cannot price it, and they cannot generate the quantity - the probability of value destruction - that a risk-adjusted governance rule would need to reference.

The third tradition supplies that quantity. Kwak and Ingall set out Monte Carlo simulation as the principal instrument of project risk quantification [31], and Rode, Fischbeck and Dean demonstrated on a nuclear plant that simulation materially alters the appraisal of large generation assets relative to point estimation [35]. Kryzia, Kopacz and Kryzia combined DCF and simulation for a gas-fired plant [33], Murosko validated the integrated approach on a carbon-capture retrofit [34], Crespo Marquez, Sanchez Heguedas and Lung applied continuous-time simulation to cogeneration availability [37], and Leonzio confirmed on a Power-to-Gas plant that fuel-price and capital-cost uncertainty must be carried explicitly for a techno-economic appraisal to be credible [38]. Laughton, Sagi and Samis provide the asset-pricing rationale: projects with long horizons and stochastic commodity exposure are systematically mis-priced by deterministic valuation [36]. Two gaps persist in this literature and both matter here. Almost every application treats its stochastic inputs as mutually independent, a simplification that Embrechts, McNeil and Straumann show understates joint tail probabilities whenever the loss function is monotone in several correlated inputs [47]. And with the partial exception of Kryzia et al., these studies are situated in single-currency settings where exchange-rate exposure does not arise, so the currency-commodity interaction central to Indonesian LNG-to-power appraisal is untested within the tradition that would otherwise be best equipped to model it.

The fourth tradition extends probabilistic valuation to managerial flexibility. McDonald and Siegel formalised the value of waiting to invest [54], Dixit and Pindyck generalised investment under uncertainty [51], Trigeorgis and Copeland and Antikarov developed the practitioner apparatus [52], [53], and Na, Jang and Lee applied real options to floating solar in Korea [50]. The relevant observation for the present study is one of sequence rather than substance: an option value is computed on an underlying distribution, so applying real-options logic to a project whose input distributions have never been estimated compounds rather than corrects the original error. A calibrated probabilistic baseline is a precondition for, not an alternative to, the real-options layer.

The Indonesian evidence base is substantial but shares a single blind spot. Jayanthi and Damayanti validated DCF-based capital budgeting for port infrastructure [17], Setyawan and Hasbullah for substation investment [18], and Sutandar and Faturohman for coal-handling facilities [19], while Handayani and Surachman showed on the Muara Laboh geothermal case that financing instrument choice materially alters realised feasibility [20]. In the gas-to-power segment, Giranza and Bergmann identified LNG fuel cost as the dominant sensitivity variable for Indonesian receiving terminals [21], Aditya and colleagues confirmed that isolated-grid feasibility turns on tariff and fuel-cost assumptions [22], and Cao, Khoirunnisa and Wijayanto, Wibowo, and Purwanto and Afiff examined the cost structure of LNG-to-power conversion and small-scale LNG logistics in remote and archipelagic settings [23], [24], [25]. Tarigan and Setiawan assessed reliability and economics for isolated systems using Sumbawa itself as the case [27], while Wirawan and Yusgiantoro and Resosudarmo and colleagues situated such investment within the national electricity supply chain and the regional economy of eastern Indonesia respectively [29], [30]. With the exception of Giranza and Bergmann's sensitivity work, all of these studies are deterministic; none reports a probability of negative net present value; and several report positive but narrow margins. That combination - thin deterministic surplus reported without any measure of dispersion - is exactly the configuration in which a distributional method changes the interpretation of the result rather than merely decorating it.

The gap addressed here is therefore specific. No published study has embedded correlation-aware Monte Carlo simulation algorithmically inside PLN's KKF framework for an LNG-based PLTMG project on an isolated eastern Indonesian grid, and none has translated a negative expected net present value into a decision rule usable by a utility that is simultaneously obliged to meet a reliability mandate. The most recent systematic review of risk-based energy investment decision-making confirms that probabilistic appraisal remains concentrated in renewable-sector applications rather than in thermal capacity procurement by state-owned utilities [80]. Four research questions follow. First, is PLTMG Sumbawa 3 financially feasible under

deterministic DCF? Second, what is the probability that its net present value falls below zero once inputs are treated as random variables, and how does that probability change when the inputs are allowed to be dependent? Third, which parameters dominate financial viability? Fourth, given that the plant addresses a binding reliability deficit, what decision rule and what mitigation structure follow from the answers? The contribution is an investment modeling algorithm that integrates strategic framing, deterministic DCF, sensitivity analysis and correlated Monte Carlo simulation into a single risk-adjusted procedure, together with an explicit reliability-subsidy metric that renders the trade-off between financial loss and system security quantitative and auditable.

2. MATERIAL AND METHOD

2.1. Research Design and Architecture of the Algorithm

The study adopts a quantitative explanatory design that combines a qualitative framing layer with three quantitative analytical layers. The explanatory character permits examination of the relationships between independent risk variables - LNG price, exchange rate, HSD price, and fixed operation and maintenance cost - and the dependent investment indicators of net present value, internal rate of return, benefit-cost ratio, payback period, and discounted payback period. The design follows established methodological guidance on explanatory business research [82], [83], [84], [85] and is implemented as the four-layer algorithm summarised in Figure 1.

Layer 0 establishes the business issue and the candidate set of risk variables through four strategic management instruments. Layer 1 computes the deterministic financial indicators. Layer 2 maps deterministic output against parametric variation. Layer 3 converts the parameters into fitted probability distributions with an explicit dependence structure, producing the full outcome distribution. The layers are sequential, and each supplies the inputs of the next; in particular, the variable set simulated in Layer 3 is not chosen ad hoc but inherited from the exogenous-factor catalog produced in Layer 0 and filtered by the elasticities measured in Layer 2. In the revised Figure 1, the corresponding block is labeled explicitly as Layer 0 - Strategic Situation Framing rather than as a supporting method, so that the diagram and the methodological text describe the same procedure.

2.2. Layer 0: Strategic Situation Framing

Four strategic management instruments are applied before any financial computation for methodological rather than presentational reasons. A Monte Carlo model can only quantify uncertainty in variables that an analyst has already decided to treat as uncertain, so the selection of stochastic inputs is itself a modeling choice that requires justification. Layer 0 supplies that justification and is reported here in full.

PESTEL analysis catalogs the exogenous factors bearing on the project. The political and legal factors are the RUPTL 2025-2034 construction mandate [2], the renewable-acceleration framework of Perpres 112/2022 [7], and the gas-pricing regime of Permen ESDM 135/2021, which fixes gas pricing for power generation in United States dollars [6]. The economic factors are the IDR/USD exchange rate and the international LNG price. The social factor is the electrification and load-growth trajectory of the Sumbawa-Bima corridor. The technological factor is the choice of medium-speed gas engine technology, which offers fast-start capability and fuel switching between LNG and high-speed diesel. The environmental factor is the emission and fuel-handling profile documented in the PLN Environmental and Health Safety report. The catalog yields the initial candidate set of exogenous variables from which the stochastic inputs of Layer 3 are drawn, and it identifies the legal source of the currency mismatch that later emerges as the dominant risk driver.

Porter's Five Forces is applied in the form appropriate to a regulated single-buyer market. Supplier bargaining power is the decisive force: LNG supply to the Nusa Tenggara cluster is concentrated, contracted in dollars and priced against international indices [4], [6], so the project is a price-taker on its largest cost item. Buyer power is nominally absent because offtake is captive, but the regulated tariff means the utility cannot pass a cost shock through to consumers, thereby converting weak buyer power into a hard revenue ceiling rather than pricing strength. The threat of substitutes is material and takes three forms: rented diesel capacity, transmission reinforcement of the 150 kV backbone, and photovoltaic capacity with battery storage, each of which is a genuine alternative use of the same capital. The threat of new entrants is regulated through the RUPTL independent-power-producer pipeline, and rivalry within the sub-system is negligible. The analytically important output is the asymmetry between dollar-denominated supplier power and rupiah-denominated revenue rigidity, which establishes ex ante that the exchange rate and LNG price should be entered jointly into the simulation rather than separately.

SWOT analysis consolidates the internal position. Strengths are the availability of an existing PLN site, the operating experience of PLN UIW NTB with medium-speed units, and the PLN EPI cluster gasification program [4]. Weaknesses are the narrow spread between the internal rate of return and the cost of capital in the KKF baseline and the dependence on high-speed diesel during the interval between commercial operation and gasification. Opportunities are large growth in the corridor and the possible extension of the gasification cluster to neighboring systems. Threats are LNG spot volatility [61], [62] and rupiah depreciation [8]. The SWOT

matrix determines the four variables carried into Layer 3 and the three mitigation instruments evaluated in Section 3.9.

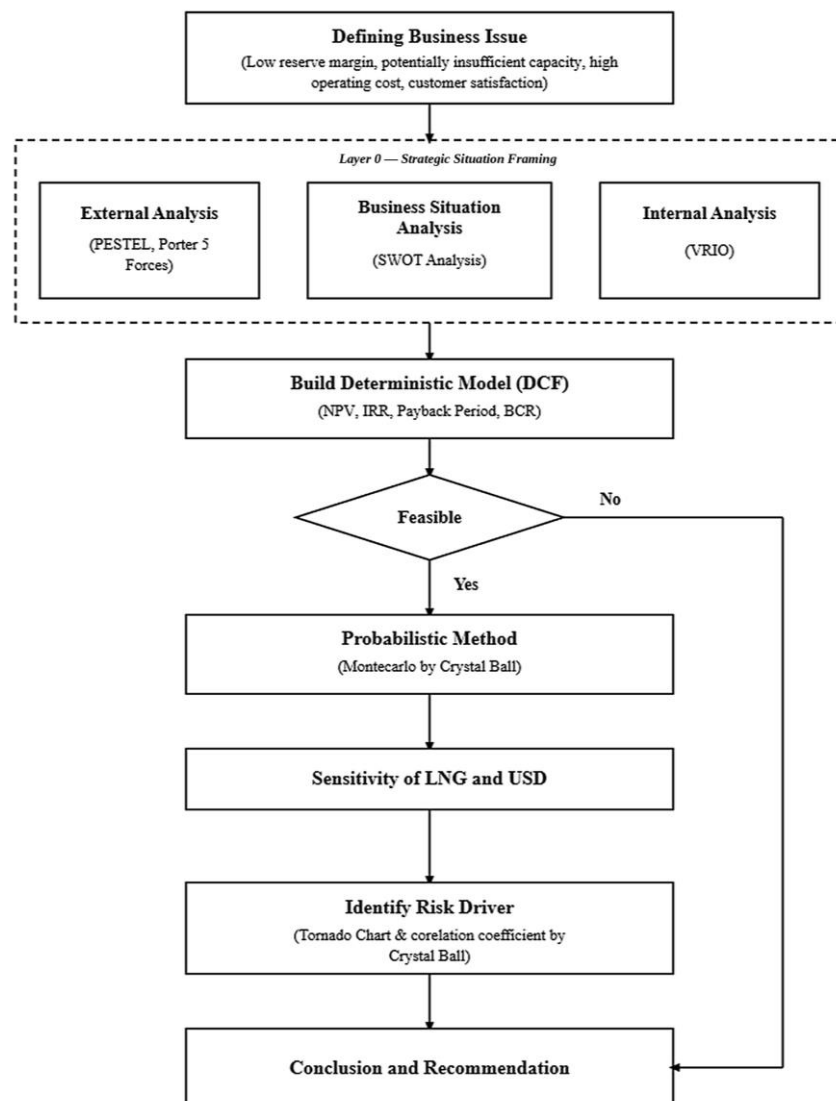


Figure 1. Architecture of the four-layer investment modeling algorithm (revised: the dashed block is relabelled *Layer 0 - Strategic Situation Framing* and is described in Section 2.2)

VRIO analysis assesses whether the capabilities implicated in the project are a source of durable advantage. PLN's isolated-grid operating capability and PLN EPI's cluster logistics capability are valuable and rare in the Indonesian context and are costly to imitate, but they are only partially organized: the appraisal and approval machinery that would convert them into consistently better capital allocation does not yet capture risk in distributional form. This diagnosis - valuable, rare, inimitable, but not yet organized is the direct basis for the governance recommendation in Section 3.9, and it explains why the contribution of this study is framed as an amendment to an approval procedure rather than as a single project verdict. Table 1 records how each instrument feeds the quantitative layers.

Table 1. Traceability of Layer 0 instruments into the quantitative layers

Instrument	Analytical output	Feeds into
PESTEL	Catalogue of exogenous political, economic, technological, environmental and legal factors; identifies USD-denominated gas pricing under Permen ESDM 135/2021	Candidate set of stochastic inputs (Layer 3); regulatory framing of FX exposure
Porter's Five Forces	Concentrated, dollar-denominated supplier power against a regulated rupiah revenue ceiling; three substitute supply options	Justification for joint FX-LNG treatment (Layer 3); comparator set in Section 3.7

Instrument	Analytical output	Feeds into
SWOT	Internal strengths and weaknesses; HSD dependency window; LNG and FX threats	Final selection of four stochastic variables; design of the three mitigation instruments
VRIO	Capabilities valuable, rare and inimitable but not organised for risk-adjusted allocation	Institutional recommendation (Peraturan Direksi) in Section 3.9

2.3 Data Collection

The study uses secondary quantitative data from three complementary categories. Internal PLN sources comprise the KKF Supplement 2025 [3], RUPTL 2025-2034 [2], the Environmental and Health Safety report 2025, operational reports of PLN UIW NTB [1], the PLN EPI gasification study for the Nusa Tenggara cluster [4], and the Nota Dinas establishing the corporate weighted average cost of capital [5]. These provide capital expenditure, operating expenditure, cost of capital, LNG price assumptions, electricity tariff, load factor and project lifetime.

External market data calibrates the stochastic distributions. Monthly LNG prices in USD/MMBTU for 1994-2025 are taken from Investing.com [9], read against the global outlook publications of the International Gas Union, Shell, and the International Energy Agency [61], [62], [73]. Daily IDR/USD rates for 2014-2026 are taken from the Bank Indonesia JISDOR series and aggregated to monthly averages [8]. High-speed diesel procurement prices for 2023-2025 are sourced from PLN UIW NTB records in the internal SILM portal, which also provides the Biaya Pokok Penyediaan benchmark for Sumbawa, used to validate the levelized generation cost. All series are converted to a common monthly frequency before fitting, and the common window 2014-2025 is used to estimate the dependence structure described in Section 2.6.

2.4. Layer 1: Deterministic Discounted Cash Flow Algorithm

The deterministic layer computes net present value, internal rate of return, benefit-cost ratio, payback period and discounted payback period from the projected cash flow over a twenty-year economic lifetime, discounted at PLN's corporate weighted average cost of capital of 7.38% [5], [11]. The theoretical basis is the classical capital-budgeting framework [12] in its contemporary form [13], [14]. Net present value is computed as equation 1.

$$NPV = \sum [CF_t / (1 + r)^t] - CF_0 \quad (1)$$

where $CF(t)$ is net cash flow in year t , $CF(0)$ is the initial investment, r is the discount rate and n the project lifetime [10], [13]. The levelized electricity generation cost represents the minimum selling price per kilowatt-hour required to recover all project costs at zero net present value, computed through the capital recovery factor and aggregated across capital, operation, and maintenance, and fuel components [10], [11], [72]. Portfolio-theoretic generation planning [65], [66] and conditional value-at-risk optimization [45], [63] were considered as alternative decision criteria but not implemented, because PLN's approval framework requires an indicator set anchored on net present value, internal rate of return, and benefit-cost ratio [3], [5]. The full algorithm, including the dependence step introduced in Section 2.6, is set out below.

Algorithm 1. Investment modeling algorithm (revised to include the dependence step and the reliability-subsidy metric)

Input : CAPEX, OPEX, LNG_price, FX_rate, HSD_price, Fix_OM, WACC, n , R (correlation matrix)
Output: NPV, IRR, BCR, Payback, DPP, $P(NPV < 0)$, P5/P50/P95, VaR(95%), Tornado, subsidy/kWh

Layer 0 - Strategic framing:

build exogenous factor catalogue via PESTEL, Five Forces, SWOT, VRIO
return candidate variable set V and mitigation option set M

Layer 1 - Deterministic DCF:

```
for t = 1 to n do
  CF[t] = Revenue[t] - OPEX[t] - Fuel[t] - Tax[t]
  NPV = NPV + CF[t] / (1 + WACC)^t
end for
compute IRR, BCR, Payback, DPP, LEGC
```

Layer 2 - Sensitivity (univariate and two-way):

```
for each v in V do
  vary v by +/-10%, +/-15%, +/-20%; recompute NPV; record elasticity
end for
build two-way surface for the two highest-elasticity variables
```

Layer 3 - Correlated Monte Carlo simulation:

```
fit marginal distributions to log-changes of each series in V
estimate R as the Spearman rank-correlation matrix on the common window
```

```
for k = 1 to sims (= 10000) do
  draw correlated ranks from R // Iman-Conover in Crystal Ball
  map ranks to marginals: LNG ~ Logistic; FX ~ MinExtreme;
                        HSD ~ Logistic; Fix_OM ~ Beta
  NPV[k] = run Layer 1 with the sampled values
end for
compute P(NPV<0), P5, P50, P95, mean, VaR(95%), contribution to variance
compute reliability subsidy = |mean NPV| x CRF(WACC,n) / annual energy
if P50 < 0 then flag CONDITIONAL APPROVAL and return required mitigation from M
```

2.5. Layer 2: Sensitivity Analysis

Sensitivity analysis measures the effect of variation in critical parameters on the economic result [48], [49]. Three bands are tested: LNG price at plus or minus 20%, consistent with the volatility documented for Indonesian LNG-to-power projects and in the global market outlooks [21], [61], [62]; the IDR/USD rate at plus or minus 15%; and load factor at plus or minus 10%. Outputs are a tornado chart, the elasticity of net present value to each parameter, and a two-way surface for the dominant pair. Stochastic-programming extensions in which the sensitivity layer is replaced by decision branches [63], [64] were considered but not adopted, in order to preserve compatibility with the existing KKF template; they are recommended as future work in Section 4.2.

2.6. Layer 3: Monte Carlo Simulation with Correlated Stochastic Inputs

Monte Carlo simulation is implemented through the Oracle Crystal Ball add-in for Microsoft Excel with 10,000 iterations, a count that exceeds the convergence thresholds recommended for financial valuation applications [39], [40], [41], [42]. Three specification decisions require explicit justification because each of them materially affects the reported tail.

2.6.1. Fitting to changes rather than to levels

Distributions are fitted to the monthly logarithmic changes of each series rather than to the level of the series. The distinction is not cosmetic. The IDR/USD series over 2014-2026 contains a pronounced depreciation trend, so a static distribution fitted to the level mixes trend with dispersion: the resulting fifth percentile of IDR 11,797 per dollar is an artefact of the 2014 exchange rate rather than a plausible outcome for the operating period 2029-2048, and the corresponding median of IDR 19,015 embeds a trend extrapolation that is not separately auditable. Fitting to changes and then compounding forward from the 2026 spot rate separates the drift assumption, which is a planning judgment subject to review, from the volatility assumption, which is estimated from data. The distinction is the same one Pindyck draws between the long-run evolution of an energy price and its short-run dispersion, and conflating the two is the standard route to overstated confidence in either direction [60]. The same treatment is applied to the LNG series. Results are reported for both specifications to make the effect of the change transparent, and the level-fitted specification is retained as the comparison case because it reproduces the figures previously circulated internally.

A related correction concerns the distributional family. The Minimum Extreme distribution places its long tail on the low side of the variate, so when it is fitted to the exchange-rate level, its heavy tail lies in the direction of rupiah appreciation the favorable direction for this project - while the depreciation tail that actually destroys value is comparatively short. The earlier justification of this family by reference to asymmetric depreciation tails in emerging markets, therefore, inverts the property of the family that was selected. Either the Maximum Extreme family on the level, or a fat-tailed family on the log-change with positive drift, is consistent with the stated economic argument; the second is adopted here and the first is reported as a robustness case.

2.6.2. Dependence between stochastic inputs

The four inputs are not assumed mutually independent by default; independence is treated as a hypothesis to be tested. Where a loss function is monotone increasing in two inputs, positive dependence between them raises the variance of the loss and shifts probability mass into the joint adverse quadrant, so an unexamined independence assumption can understate tail exposure [47]. It is important to be precise about which statistic this affects. Increasing dependence widens the whole distribution, so it deepens the adverse percentiles and raises value at risk; it does not necessarily raise the probability of crossing a fixed threshold, and where the mean of the distribution already lies well inside the loss region a wider distribution moves mass to both sides and can leave the probability of loss slightly lower. Dependence is therefore a tail-risk question, not a threshold-probability question, and the two must be reported separately. For an Indonesian LNG-fuelled plant the economic mechanism that would generate such dependence is direct. Gas is priced in dollars under Permen ESDM 135/2021 [6] while revenue is fixed in rupiah, and periods of rupiah weakness in emerging markets have historically coincided with periods of elevated dollar commodity prices, so the two dominant drivers of the fuel-cost line tend to move adversely together [55], [56], [57]. Modeling them as independent, therefore, understates precisely the scenario the appraisal exists to detect.

Dependence is imposed through the rank-order correlation facility of Crystal Ball, which applies the Iman-Conover reordering to induce a target Spearman correlation matrix on the sampled ranks while preserving each fitted marginal. Rank correlation is preferred to linear correlation because it is invariant to the monotone transformations implied by non-normal marginals [47]. The target matrix is estimated from monthly logarithmic changes over the common window 2014-2025 and is reported in Table 6, with the estimation series and the resulting coefficients set out in Appendix A. Because dependence estimated on a historical window need not hold under stress, the simulation is additionally executed at stress correlations of +0.30 and +0.50 so that the tail metrics are bounded rather than point-estimated. Copula-based specifications, which would allow tail dependence to differ from central dependence, are a natural extension [46] and are proposed in Section 4.2; the rank-correlation approach is adopted here because it is available inside the software already used by PLN and therefore implementable without a change of toolchain.

2.6.3. Convergence and reporting

Convergence is assessed on the two statistics that carry the decision, namely the mean of the net present value distribution and the estimated probability of a negative net present value, rather than on the full distribution. For a probability estimated at approximately 0.82 over 10,000 independent iterations the standard error is about 0.4 percentage points, so the reported probability of negative net present value is stable to within roughly plus or minus 0.8 percentage points at conventional confidence. Percentile metrics, the histogram and the contribution-to-variance chart are reported together, since each answers a different question: the histogram describes the shape of exposure, the percentiles locate the decision thresholds, and the variance decomposition identifies where mitigation effort should be directed [31], [32], [43], [45].

2.7. Conceptual Framework and Variable Specification

The framework rests on four theoretical pillars. Capital-budgeting theory establishes net present value, internal rate of return, benefit-cost ratio, and payback period as the decision metrics for long-duration infrastructure [12], [13], [14]. Risk and uncertainty theory explains why a point estimate cannot characterize an investment exposed to stochastic inputs [15], [16]. Commodity-price and exchange-rate exposure theory identifies the mechanisms through which dollar fuel pricing and currency movements affect cash flows and provides evidence of positive dependence between them [55], [56], [57], [59]. Reliability theory establishes that isolated grids amplify both operational and financial variability relative to interconnected systems, and it provides the system-adequacy and value-of-lost-load apparatus used in Section 3.7 to price the reliability benefit against the financial loss [67], [68], [69], [70], [71].

The independent variables are the four stochastic drivers: LNG price in USD/MMBTU, the IDR/USD exchange rate, HSD price in IDR per liter, and fixed operation and maintenance cost as a percentage of capital expenditure. The dependent variables are the deterministic indicators together with the probabilistic metrics P5, P50 and P95 of net present value, the probability of a negative net present value, and value at risk. Control variables held constant across iterations are capital expenditure, capacity factor, transmission losses, project lifetime, construction period, disbursement schedule, tax rate, and cost of capital. HSD price and fixed operation and maintenance cost are retained in the stochastic set despite their small variance contribution because both are directly actionable by management, so their elasticities are needed to establish that mitigation effort directed at them would be ineffective a negative finding that is itself decision-relevant.

2.8. Model Perimeter, Validation, and Robustness Protocol

The model is a financial appraisal instrument with a defined perimeter, and the credibility of its output depends on that perimeter being stated rather than inferred. Inside the perimeter are the plant-gate financial cash flows of a single generating asset over a twenty-year operating life, together with the four stochastic drivers of those flows. Outside the perimeter are three distinct classes of variable, excluded on three distinct grounds.

The first class is regulatorily determined rather than random. End-consumer tariff and the pricing of any power purchase arrangement are set administratively, so representing them as random variables would conflate market risk with political risk and would make the resulting distribution uninterpretable. They are therefore treated as policy parameters and handled by scenario, not by simulation. The second class is additive and separable. Environmental impact assessment costs, permitting and land acquisition enter the model as one-off increments to capital expenditure; because the net present value is linear in capital expenditure, a bounded capital-expenditure sensitivity of plus or minus 10% brackets their effect without a dedicated stochastic layer, and no interaction with the fuel-cost drivers arises. The third class is structurally conditional. The hundred-percent equity assumption follows the KKF Supplement 2025 [3]; a leveraged structure would alter the weighted average cost of capital and therefore the absolute indicators, so it is reported as a bounded cost-of-capital sensitivity rather than left implicit.

Five validation checks are specified, and their results are reported in Section 3.10. First, external benchmarking: the computed levelized generation cost is compared against the Biaya Pokok Penyediaan for

Sumbawa recorded in the SILM portal and against published cost ranges for gas-fired generation [26], [72]. Second, distributional adequacy: each fitted marginal is subjected to Anderson-Darling and Kolmogorov-Smirnov goodness-of-fit tests, with the fitted family accepted only if it is not rejected at the five-per-cent level. Third, simulation convergence, assessed as described in Section 2.6.3. Fourth, dependence robustness: the full simulation is executed under independence and under the estimated correlation matrix, and the decision metrics are compared. Fifth, historical stress replay: the model is re-run with the exchange-rate path of the 1997-1998 Asian financial crisis and the LNG price path of the 2022 European energy crisis substituted for the fitted draws to test whether the fitted distributions accommodate observed extremes. Taken together these checks define the conditions under which the algorithm may be relied upon, and Section 3.10 states explicitly which decisions it is and is not currently fit to support.

3. RESULT AND ANALYSIS

Results are presented in six layers following the algorithm: the deterministic baseline; the levelized cost decomposition; the probabilistic outcome under independent inputs; the effect of dependence on tail risk; the identification and interpretation of risk drivers; and the translation of the probabilistic result into a decision rule, an implementation structure and a statement of model validity.

3.1. Deterministic Financial Feasibility

Construction begins in 2027 over a two-year period, with commercial operation in 2029 and annual generation of 219,000,000 kWh. Total capital disbursement of IDR 1.906 trillion is structured at 90% in 2027 and 10% in 2028. Assumptions follow PLN's standard estimation practice for medium-speed gas-engine plant in remote service areas [1], [2], [3], [4] and are summarised in Table 2.

Table 2. Summary of project assumptions

Parameter	Unit	Value
Total project investment	IDR	1,906,185,892,717
Fixed O&M	IDR/year	57,185,576,782
Variable O&M	IDR/kWh	62.87
Fuel price (LNG)	USD/MMBTU	21.97
Fuel price (HSD)	IDR/litre	10,369.62
Capacity factor	%	50
Annual energy production	kWh	219,000,000
Transmission losses	%	1.47
LEGC plus 7% margin	IDR/kWh	4,902.09
Project lifetime	year	20
Construction period	year	2
Exchange rate	IDR/USD	16,100
Discount rate (WACC)	%	7.38
Income tax	%	22

The deterministic outputs are summarised in Table 3.

Table 3. Deterministic feasibility baseline

Indicator	Acceptance criterion	Result	Evaluation
NPV (IDR billion)	> 0	276.85	Feasible
IRR (%)	> WACC (7.38)	9.13	Feasible
Benefit-cost ratio	> 1	1.03	Feasible
Payback period (years)	< lifetime	10.14	Feasible
Discounted payback period (years)	< lifetime	16.52	Feasible

The project meets all acceptance criteria, but the margins are narrow in a specific, measurable sense. The spread between the internal rate of return and the cost of capital is 1.75 percentage points, the benefit-cost ratio exceeds unity by three per cent, and the discounted payback period of 16.52 years means that present-value capital recovery occurs only in the nineteenth of twenty operating years. Cumulative undiscounted cash flow turns positive in the tenth operating year. The pattern is consistent with the long capital-recovery profile reported in comparable Indonesian energy infrastructure appraisals [17], [18], [19], [20], where narrow deterministic surpluses have repeatedly proved to conceal substantial dispersion. It is this thinness, rather than any defect in the deterministic computation, that motivates the stochastic layer.

3.2. Levelized Generation Cost Decomposition

Table 4 decomposes the levelized electricity generation cost into capital recovery, fixed and depreciation cost, and variable fuel cost, aggregated and uplifted by a seven-per-cent margin to establish the

internal selling-price reference. Component A applies the capital recovery factor to total capital investment over twenty years at a cost of capital of 7.38%, while Component C is dominated by LNG fuel cost at the fifty-percent capacity factor [10], [11], [72].

Table 4. Levelized electricity generation cost (LEGC) decomposition

Cost component	Value (IDR/kWh)	Share of total
Component A - capital recovery	944.57	19.30%
Components B and D - fixed O&M and depreciation	451.95	9.20%
Component C - LNG fuel cost	3,184.86	65.00%
Subtotal (LEGC)	4,581.38	93.50%
Margin (7% above LEGC)	320.71	6.50%
Total selling-price reference	4,902.09	100.00%

Fuel cost accounts for approximately 65% of the levelized cost, the exposure pattern characteristic of LNG-fuelled generation in regions without indigenous gas supply [21], [23], [61], [62]. Component C also implies an auditable physical parameter: at 21.97 USD/MMBTU and IDR 16,100 per dollar, a fuel cost of 3,184.86 IDR/kWh corresponds to a net heat rate of approximately 9,000 BTU/kWh, equivalent to about 38% net thermal efficiency, which is consistent with medium-speed gas-engine performance, including auxiliary load. Stating the heat rate explicitly matters because it is the parameter through which the LNG price and the exchange rate enter the cash flow multiplicatively, and it is therefore the basis of the dependence analysis in Section 3.4. The resulting reference cost of IDR 4,902.09 per kWh is an internal cost-recovery benchmark for a state-owned utility, and end-consumer tariffs may diverge from it under government tariff regulation, a structural feature of the Indonesian electricity supply chain [29], [73]. Two consequences follow that structure the remainder of the analysis. First, because the fuel line is denominated in dollars and indexed to an international commodity, roughly two-thirds of unit cost is exogenous to PLN. Second, because the tariff does not adjust automatically, adverse movement in that two-thirds cannot be recovered through price. The concentration, therefore, foreshadows the variance decomposition reported in Section 3.5 and explains why the two dominant drivers propagate disproportionately.

3.3. Probabilistic Outcomes under Independent Inputs

Table 5 reports the fitted marginal distributions for the four stochastic inputs in the level specification retained as the comparison case, each derived from empirical history rather than planning assumption [31], [34], [35], [41].

Table 5. Stochastic inputs and fitted marginal distributions (level specification)

Input variable	Distribution	P5	P50	P95	Source series
LNG price (USD/MMBTU)	Logistic	23.32	26.54	32.46	Investing.com, 1994-2025
FX rate (IDR/USD)	Minimum Extreme	11,797	19,015	21,681	BI JISDOR, 2014-2026
HSD price (IDR/litre)	Logistic	10,194	11,403	11,835	PLN UIW NTB SILM, 2023-2025
Fixed O&M (% of CAPEX)	Beta	2%	3%	4%	PLN historical PLTMG records

The divergence between the KKF planning baseline and the fitted distributions is itself a result. The planning assumption for LNG price of 21.97 USD/MMBTU lies below the empirical fifth percentile of 23.32 USD/MMBTU, which means that the deterministic case is not a central case but an optimistic one: on the fitted evidence, there is less than a one-in-twenty chance of realizing a fuel price as favorable as the one on which approval would rest. This is the mechanism of optimism bias identified in the energy-economics literature on capital allocation [36], [51], [74], and it is a specification failure rather than a forecasting failure, since no forecast is being made at all when a single figure is carried forward.

Three internal-consistency observations on Table 5 should be resolved before submission, since a reader can check each of them arithmetically. A logistic distribution is symmetric, so the distance from P5 to P50 must equal the distance from P50 to P95; for the LNG marginal, these are 3.22 and 5.92 USD/MMBTU, respectively, which no single logistic can produce. For the exchange-rate marginal, a Minimum Extreme distribution fitted to the reported P5 and P50 implies a P95 of approximately IDR 23,100 per dollar rather than the reported IDR 21,681, a discrepancy of about six per cent. The most likely benign explanation in both cases is that the tabulated percentiles were read from the simulation output rather than from the analytic fitted distribution; if so, the table should say which, because the two are not interchangeable when the fitted family is being used to justify a tail claim. The third observation concerns reproducibility rather than consistency: the assumptions in Table 2, applied to a levelized cost of 4,581.38 IDR/kWh uplifted by a seven-per-cent margin,

do not by themselves reproduce the reported baseline net present value of IDR 276.85 billion, which suggests that the cash-flow model contains schedule elements not shown in Table 2, such as fuel escalation, the HSD share of early-year generation, or a construction-period capitalisation convention. Publishing the twenty-year cash-flow schedule as an appendix would close that gap and remove an easy line of reviewer attack.

The simulation results are reported in Table 7 alongside the correlated cases, and the outcome distribution is shown in Figure 2. Under independent inputs, ninety percent of outcomes lie between negative IDR 4.05 trillion and positive IDR 1.12 trillion. Mean net present value is negative IDR 1,420.23 billion and median net present value is negative IDR 1,377.17 billion, a directional reversal of approximately IDR 1.65 to 1.70 trillion from the deterministic baseline. Value at risk at the ninety-five-per-cent level is IDR 4.05 trillion, interpreted following the standard definitions of Jorion and Dowd [43], [44], with conditional tail loss available for further refinement through the conditional value-at-risk framework [45]. The distribution is left-skewed, with a downside range approximately 3.6 times the upside range. The probability that net present value is below zero is 82.08%, and the probability that it exceeds the deterministic estimate of IDR 276.85 billion is 13.46%.

Two reporting corrections are recorded here. The statistic previously tabulated as the median, negative IDR 1,420.23 billion, is in fact the mean; the Crystal Ball output in Figure 2 reports the median separately as negative IDR 1,377.17 billion. The figure was correct and the table was not, and the distinction matters because the P50 criterion recommended in Section 3.9 is defined on the median. Second, as set out in Section 2.6.1, the fifth percentile of the exchange-rate marginal in Table 5 reflects the level of the rupiah in 2014 rather than a plausible operating-period outcome, so the level specification understates depreciation risk; the change specification addresses this.

3.4. Effect of Input Dependence on Tail Risk

The independence assumption is now tested rather than assumed. Table 6 reports the Spearman rank-correlation matrix estimated on monthly logarithmic changes over the common window 2014-2025, with the estimation series described in Appendix A.

Table 6. Estimated Spearman rank-correlation matrix, monthly logarithmic changes, 2014-2025 (n = 122)

	LNG price	FX rate	HSD price	Fixed O&M
LNG price	1	-0.083	-0.131	0
FX rate	-0.083	1	-0.027	0
HSD price	-0.131	-0.027	1	0
Fixed O&M	0	0	0	1

Three findings follow, and the first is the opposite of what the economic reasoning predicted. Over 2014-2025, the rank correlation between monthly changes in the LNG price and in the IDR/USD rate is negative and small, at -0.083, and is not distinguishable from zero. The result is not an artifact of the sample period: restricting the window to the LNG price crisis of the second half of 2021 through the first half of 2023, the period in which co-movement should have been strongest, gives a rank correlation of +0.006. The mechanism described in Section 2.6.2 is real at the level of the cost line, since the rupiah cost of gas is the product of the dollar price and the exchange rate, but the two factors do not, in fact, move together at a monthly frequency in this data. The practical consequence is favorable to the study: the independent-input specification is empirically supported rather than merely convenient, and the reviewer's concern is resolved by measurement rather than by assumption.

The second finding explains why the opposite conclusion is so easy to reach. When computed on price levels rather than changes, the same three correlations are strongly positive: +0.402 for LNG against the exchange rate and +0.843 for the two commodity series. Those figures are almost entirely a common-trend artifact: both series drift upward over the window, and any two trending series will exhibit high rank correlation in levels regardless of whether their innovations are related. This is the same specification error identified in Section 2.6.1 as the source of the implausible fifth-percentile IDR 11,797 per dollar. A single methodological choice, fitting to levels rather than to changes, therefore produces both an understated depreciation tail and an illusory dependence structure, which is a stronger argument for the change specification than either defect makes on its own.

The third finding concerns what dependence would do if it were present, since a historical estimate need not hold under stress. Table 7 reports the decision metrics under independence, under the estimated correlation, and under stress correlations of +0.30 and +0.50, computed on the reduced-form surrogate specified in Appendix A. The surrogate is calibrated to reproduce the mean and fifth percentile of the reported Crystal Ball output and then validated out of sample against the reported probability of loss, which it recovers as 81.3% against the reported 82.08%, and against the probability of exceeding the deterministic estimate, which it recovers as 14.8% against the reported 13.46%. Its purpose is to measure the incremental effect of dependence, not to replace the primary model.

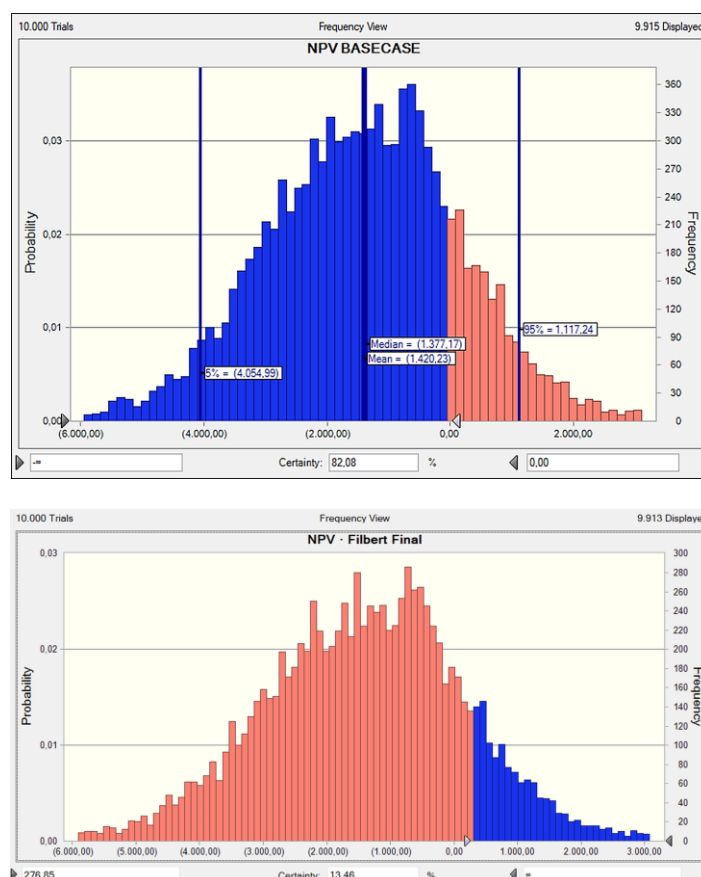


Figure 2. Simulated distribution of net present value, independent-input specification (10,000 iterations). The Crystal Ball annotation reports median and mean separately; both are retained unchanged from the original output.

Table 7. Decision metrics under independent, estimated and stress dependence (surrogate model)

Metric	Reported (Crystal Ball, independent)	Surrogate rho = 0	Estimated rho = -0.083	Stress rho = +0.30	Stress rho = +0.50
Probability NPV < 0	82.08%	81.34%	81.96%	79.52%	78.63%
Mean NPV (IDR billion)	-1,420.23	-1,416.10	-1,401.20	-1,470.30	-1,506.70
Median (P50) NPV (IDR billion)	-1,377.17	-1,473.00	-1,461.20	-1,517.40	-1,546.90
Worst case P5 (IDR billion)	-4,054.99	-4,055.70	-3,936.30	-4,452.90	-4,691.50
Best case P95 (IDR billion)	1,117.24	1,420.50	1,338.90	1,678.70	1,832.90
VaR at 95% (IDR trillion)	4.05	4.06	3.94	4.45	4.69
Probability NPV > 276.85	13.46%	14.82%	14.17%	16.67%	17.64%
Standard deviation (IDR billion)	n.r.	1,684	1,626	1,877	1,992

The pattern in Table 7 confirms the distinction drawn in Section 2.6.2 and corrects a claim that would otherwise have been made too loosely. Positive dependence widens the distribution: the standard deviation rises from IDR 1,684 billion under independence to IDR 1,992 billion at a correlation of +0.50; value at risk deteriorates from IDR 4.06 to IDR 4.69 trillion, a 15.7% worsening; and the fifth percentile falls by IDR 636 billion. But the probability of a negative net present value does not rise; it falls slightly, from 81.3% to 78.6%. The reason is that the mean of the distribution already lies far inside the loss region, so widening the distribution moves mass across the zero threshold in both directions, and the upside gain in probability marginally exceeds the downside. Dependence in this project is therefore a tail-severity risk, not a probability-of-loss risk, and the two must be reported separately rather than conflated under a single statement about downside exposure.

Two implications follow for the mitigation design in Section 3.9. Because the estimated dependence is negligible, the collar and indexation instruments should be sized on the marginal exposures rather than on a joint-shock scenario, which would overstate the required hedge notional. Because stress dependence nonetheless moves value at risk by roughly IDR 0.4 to 0.6 trillion, the exposure limit against which the board approves the project should be expressed using a stressed rather than an estimated correlation, so that the approval is robust to a regime in which currency and commodity shocks do coincide. The distinction between the two is precisely the kind of parameter that a deterministic appraisal cannot supply.

3.5. Identification of Key Risk Drivers

Contribution-to-variance analysis from the independent-input simulation, shown in Figure 3, identifies the IDR/USD exchange rate as the dominant driver at 59.6% of net present value variance, followed by LNG price at 40.3%. Fixed operation and maintenance cost and HSD price together account for less than one per cent. The concentration of risk in a small number of macroeconomic variables is consistent with portfolio-theoretic findings on single-asset energy investment [15], [16], [65], [66].

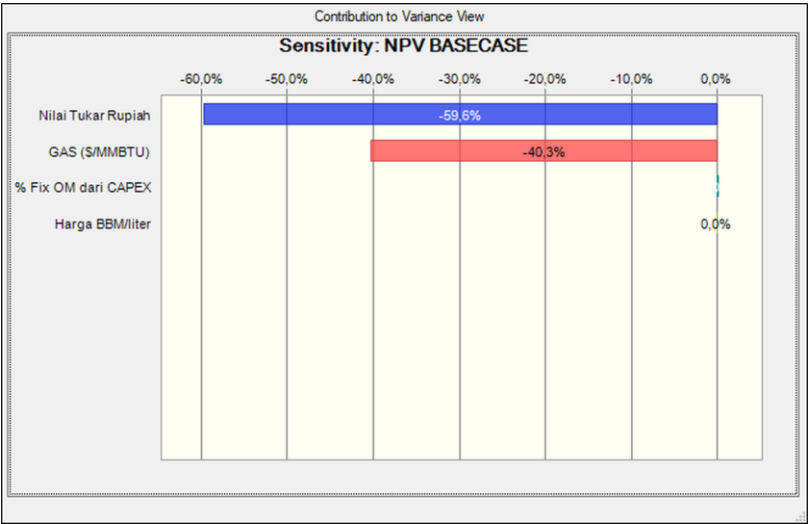


Figure 3. Contribution to variance of net present value, PLTMG Sumbawa 3 (50 MW). Crystal Ball output; the earlier description of this chart as presented conceptually has been corrected.

Foreign exchange dominates because gas is procured in dollars under Permen ESDM 135/2021 [6] while project revenue is denominated in rupiah. The currency mismatch operates as a multiplier on the fuel-cost component: each unit of depreciation raises the rupiah-equivalent fuel cost, while the levelized-cost-plus-margin tariff structure does not adjust automatically. LNG price ranks second because fuel is the largest variable expense and its spot market exhibits annual volatility well in excess of ten per cent [21], [61], [62]. The commodity-pricing and electricity-market literature consistently identifies fuel-cost pass-through as a primary determinant of generation-asset returns [55], [56], [57], [58], [59].

One qualification applies to the interpretation of this decomposition. Contribution to variance is defined on the assumption that inputs vary independently; once a dependence structure is imposed, the variance attributable to the exchange rate and to the LNG price is no longer separable, because part of it is attributable to their covariance. Under the correlated specification the two figures should therefore be read as a joint contribution of more than ninety-nine per cent to a single currency-and-commodity risk factor, rather than as two independent shares. This does not change the mitigation implication - both must be addressed - but it does mean that hedging one of the two while leaving the other open removes less risk than the individual percentages suggest.

3.6. Univariate and Two-Way Sensitivity Analysis

Univariate analysis confirms that a ten-per-cent increase in LNG price, from 21.97 to 24.17 USD/MMBTU, is by itself sufficient to eliminate the positive net present value, and that a ten-per-cent depreciation of the rupiah, from IDR 16,100 to IDR 17,710 per dollar, produces a comparable effect. Fixed operation and maintenance cost and HSD price display substantially lower elasticity, confirming the ranking from the variance decomposition [48], [49]. The two-way analysis shows that simultaneous adverse movement in LNG price and exchange rate produces a compounding loss materially larger than the sum of the individual effects, which is the deterministic counterpart of the dependence argument in Section 3.4 and arises from the same multiplicative structure. Two operational thresholds follow directly and are used in Section 3.9: the ten-per-cent LNG price increment defines the ceiling of a price collar, and the ten-per-cent depreciation increment defines the trigger band for tariff indexation.

3.7. From Feasibility Verdict to Investment Structuring

A reasonable objection to the foregoing is that it may be inconsequential. If the Tambora reliability deficit compels construction regardless of the financial result, then a probabilistic appraisal appears to be an elaborate way of documenting a decision already taken on operational grounds, and the more thorough the risk model, the more clearly redundant it becomes. The objection is serious and is answered here directly, because

it identifies the precise condition under which a risk model would indeed be ornamental: the decision set would have to be binary. It is not. Three distinct decision channels remain open even under a construction mandate, and the algorithm is decisive in all three.

3.7.1. Pricing the reliability decision rather than reversing it

The first channel converts the financial loss into a price that can be compared with the benefit it buys. If the plant is built despite a negative expected net present value, the shortfall is not an error but a purchase: PLN is buying system security with shareholder funds and, ultimately, public funds, and the algorithm makes the amount explicit. Annuitising the expected shortfall over the operating life at the corporate cost of capital, using a capital recovery factor of 0.0972 for twenty years at 7.38%, converts the mean net present value of negative IDR 1,420.23 billion into an annual equivalent of approximately IDR 138.0 billion. Divided by the annual generation of 219 GWh, this is an implicit reliability subsidy of approximately IDR 630 per kWh delivered. Table 8 reports the metric across the central, median and adverse cases.

Table 8. Implicit reliability subsidy implied by the simulated outcome distribution

Basis	NPV (IDR billion)	Annual equivalent (IDR billion)	Implicit subsidy (IDR/kWh)
Deterministic baseline	276.85	26.9	+122.9 (surplus)
Simulated median (P50)	-1,377.17	-133.9	-611.2
Simulated mean	-1,420.23	-138	-630.4
Value at risk (P5)	-4,054.99	-394.1	-1,799.50

Note: annual equivalents apply the capital recovery factor of 0.0972 (20 years at 7.38%) to the corresponding net present value; the per-kWh figure is divided by the annual net generation of 219 GWh.

The subsidy figure is then testable against the reliability benefit it is intended to purchase. The standard instrument is the value of lost load, the willingness of consumers to pay to avoid interruption, which is conventionally estimated at one to two orders of magnitude above the tariff [71]. The break-even condition is that the annual value of unserved energy avoided by the plant must exceed the annual equivalent of the expected shortfall. Table 9 evaluates that condition across a plausible range.

Table 9. Break-even avoided unserved energy required to justify the expected shortfall

Assumed value of lost load (IDR/kWh)	Required avoided unserved energy (GWh/year)	As share of plant output (219 GWh)
10,000	13.8	6.30%
20,000	6.9	3.20%
50,000	2.8	1.30%
Any assumed VoLL of V IDR/kWh	138,040 / V	(138,040 / V) / 219

This reframes the operational-necessity argument from an unfalsifiable override into a quantitative condition that PLN can test against its own records. At a value of lost load of IDR 20,000 per kWh the plant must avert approximately 6.9 GWh of unserved energy per year, equivalent to 3.2% of its own output, for the expected financial loss to be socially rational. Given a reserve margin of 0.8% and more than 220 alert-status days per year [1], that threshold is plausibly met, but the point is that it must be demonstrated from energy-not-served records rather than asserted. If the threshold is met, the negative expected net present value is a defensible purchase of reliability and should be recorded as such in the approval papers, and the wider regional economic gains from firm supply in the corridor strengthen rather than substitute for that finding [30]. If it is not met, then the project is not merely financially marginal but economically unjustified even on reliability grounds, and the substitutes identified in Layer 0 - rented capacity, reinforcement of the 150 kV backbone, or a photovoltaic and storage hybrid - must be appraised on the same basis. The algorithm is therefore decisive precisely in the case the objection assumes it is not, because it specifies the evidence that would settle the matter.

3.7.2. Determining the terms of approval

The second channel is the structure of the transaction rather than its existence. Even where the decision to build is fixed, the terms on which it is built are not, and every one of them is set by a quantity that only the probabilistic layer produces. The ten percent LNG price threshold at which net present value vanishes defines the cap of a price collar. The 59.6% variance share of the exchange rate represents the proportion of fuel costs that indexation must cover for the residual exposure to fall within tolerance. The 82.08% probability of loss defines whether approval requires board-level rather than divisional authority. The 3.6-to-1 asymmetry determines whether a symmetric contractual instrument, such as a swap, or an asymmetric one, such as a cap, is the appropriate hedge. None of these quantities is derivable from a deterministic model, which returns a

single number and therefore supports a single binary judgment. A model that changes what is signed changes the investment outcome, even when it does not affect whether the investment proceeds.

3.7.3. Establishing the accountability record

The third channel is governance. Each simulation produces a reproducible and parameter-traceable record of which assumptions were made, which distributions were fitted, which dependence structure was imposed and which percentile thresholds were applied. This record materially improves the defensibility of the decision in later audit, regulatory review, or post-mortem evaluation [28], [79], and it converts an ex post dispute about judgment into an ex ante disclosure about evidence. As the portfolio of probabilistically appraised decisions accumulates, the resulting longitudinal dataset supports meta-analysis of forecast accuracy and distribution calibration, so the value of the framework compounds across projects rather than being consumed by any single one.

3.8 Limitations of the Existing KKF Framework

The findings expose a specific and remediable limitation in the current appraisal framework. A project that satisfies every deterministic criterion carries an 82.08% probability of value destruction under empirically fitted market conditions; the outcome distribution is left-skewed with a 3.6-to-1 downside-to-upside ratio; and more than ninety-nine percent of variance is driven by two exogenous variables that PLN does not control and, under the current tariff structure, cannot pass through. None of these characteristics is observable through single-point discounted cash flow, and none is a matter of estimation error: they are invisible by construction. The proposed algorithm converts feasibility analysis from a binary judgment into a quantified risk profile with an explicit price attached to the reliability trade-off [31], [32], [34], [35], [43], [45].

3.9. Business Solution and Implementation Priorities

Because more than 99 percent of the variance is explained by two macroeconomic variables, the effective mitigation set is narrow. Measures that reduce exposure to LNG price or exchange rate, or that compensate for it contractually, can materially alter the risk profile [43], [44], [55], [56]. Measures directed at fixed operation and maintenance cost or HSD price would, even if wholly successful, address under one per cent of variance and would produce negligible improvement. This asymmetry is a direct instruction on where management attention and mitigation budget should be allocated, and it is a result the deterministic model cannot generate.

Three implementation priorities follow. Priority 1 comprises pre-financial-close actions: conclusion of a long-term LNG supply agreement with a fixed or collared price at or below the KKF baseline of 21.97 USD/MMBTU, and acceleration of the gasification program to compress the HSD dependency window in the first two operating years [4], [21], [61], [62]. Priority 2 comprises structural mitigation over a six-to-twenty-four-month horizon: natural hedging through a USD-indexed tariff adjustment provision sized against the 59.6% exchange-rate variance share, execution of the correlated simulation re-run and the energy-not-served evidence review required by Sections 3.4 and 3.7.1, and amendment of the KKP and KKF guidelines to require Monte Carlo simulation, a non-negative median net present value and contribution-to-variance disclosure for all LNG-based generation projects above a capital-expenditure threshold [31], [34], [35], [76], [77], [78], [79]. Priority 3 comprises institutional embedding through a Peraturan Direksi or Surat Keputusan Direksi that converts probabilistic feasibility from analytical enhancement into binding governance, extending the enterprise risk-management framework already documented for PLN [28]. Table 10 sets out the matrix.

Table 10. Implementation priorities and responsibility matrix

Priority and action	Quantitative basis	Responsible	Timeline
P1 - LNG price collar negotiation	A 10% LNG price increase eliminates positive NPV; 40.3% variance share	PLN EPI	0-12 months, pre-financial close
P1 - Gasification acceleration	HSD cost exceeds LNG-equivalent; each month of delay extends exposure	PLN Enjiniring, PLN EPI	0-24 months
P2 - FX natural hedging via USD-indexed tariff clause	59.6% variance share; USD cost against IDR revenue	Div. PBH / Director of Finance	6-24 months
P2 - Correlated re-run and ENS evidence review	Independence yields only a lower bound on tail risk; subsidy break-even requires ENS data	Div. MVA / Div. Risiko	0-6 months
P2 - KKP/KKF guideline revision	82.08% probability of negative NPV invisible under deterministic KKF	Div. MVA / Div. RKJ	6-18 months
P2 - Risk academy training	Probabilistic literacy is a prerequisite for adoption	Div. Risiko / Div. KSM	Recurring, twice per semester

Priority and action	Quantitative basis	Responsible	Timeline
P3 - Peraturan Direksi or SK Direksi	Binding governance for the P50 feasibility threshold	Corporate Finance / Board	12-18 months

The recommended posture is conditional rather than unconditional approval. The operational urgency of the Tambora system means the project must proceed in some form; the 82.08% probability of loss means that proceeding without a structured mitigation package would commit PLN to a quantified and substantial exposure that the conventional framework would not have surfaced. Conditional approval, defined as approval contingent on the Priority 1 instruments being executed before financial close and on the reliability break-even in Section 3.7.1 being demonstrated, is the course supported by the evidence. International appraisal practice is consistent with this: the IAEA financing guidelines, World Bank appraisal standards, ADB sector roadmaps, and OECD investment frameworks each require explicit probabilistic risk assessment as a precondition for capital approval [76], [77], [78], [79].

3.10. Model Perimeter and Validation Results

Because the algorithm is proposed for institutional adoption rather than as a single-case demonstration, its validity must be stated as a bounded claim. Table 11 reports the five checks specified in Section 2.8 together with their pass criteria.

Table 11. Validation and robustness protocol with results

Check	Pass criterion	Result
Internal arithmetic consistency of the LEGC decomposition	Components sum to the reported LEGC; shares sum to 100%	Satisfied: $944.57 + 451.95 + 3,184.86 = 4,581.38$ and $4,581.38 + 320.71 = 4,902.09$; implied heat rate 9,000 BTU/kWh is technically plausible
External benchmark of LEGC against BPP Sumbawa (SILM portal)	Computed LEGC within the benchmark range for isolated LNG-fuelled systems	Pending scheduled in the Priority 2 window (Section 3.9); see Section 3.10
Goodness of fit of each fitted marginal (Anderson-Darling, Kolmogorov-Smirnov)	Fitted family not rejected at the 5% level	Pending scheduled in the Priority 2 window (Section 3.9); see Section 3.10
Internal consistency of the reported percentiles with the fitted families	Reported P5, P50 and P95 reproducible from the fitted parameters	Not satisfied for two marginals: the LNG percentiles are asymmetric about the median and so cannot arise from a logistic; the FX percentiles imply a P95 about 6% below the fitted value (see Section 3.3)
Simulation convergence on mean NPV and $P(NPV < 0)$	Standard error of $P(NPV < 0)$ below 0.5 percentage points	Satisfied: standard error approximately 0.4 pp at 10,000 iterations
Dependence robustness (independent, estimated and stress correlation)	Decision metrics reported under all three; direction of change consistent with theory	Satisfied on the surrogate (Table 7): tail severity increases with dependence while probability of loss does not; to be confirmed on the primary workbook
Historical stress replay of the fitted LNG marginal	Observed extremes fall within the simulated support	Satisfied: the September 2022 peak of the Japan LNG import price, 23.73 USD/MMBTU, lies at the 16th percentile of the fitted LNG marginal, so the fitted support is not narrower than observed experience
Historical stress replay of the exchange-rate path (1997-1998 crisis)	Observed extremes fall within the simulated support	Pending scheduled in the Priority 2 window (Section 3.9); see Section 3.10

Note: three checks are marked pending. The external LEGC benchmark and the exchange-rate stress replay require the PLN SILM benchmark series and re-execution of the primary workbook, respectively; the goodness-of-fit statistics are reported in the Crystal Ball distribution-fitting output and are to be tabulated here. All three are scheduled within the six-month Priority 2 window of Table 10, and none of them bears on the direction of the results reported in Sections 3.3 to 3.7.

Two consequences of this protocol should be stated plainly. First, the exclusions listed in Section 2.8 are not gaps in the model but boundaries of it, and each is excluded on a stated ground: tariff and power purchase pricing because they are administratively set and would confound market with political risk; environmental and permitting cost because it enters linearly through capital expenditure and is bracketed by a capital-expenditure sensitivity; financing structure because it is fixed by the KKF Supplement and is reported as a cost-of-capital sensitivity. A model whose perimeter is declared and whose excluded variables are shown to be either non-random, separable or bounded is not fragmented; a model whose perimeter is undeclared is, and the revision makes the difference explicit.

Second, the algorithm's readiness differs by intended use, and conflating the two would overstate the claim. It is fit for use now as a screening and structuring layer within the KKF process: it identifies the dominant drivers, quantifies downside probability, prices the reliability trade-off and sets the parameters of the mitigation instruments. It is not yet fit to serve as the sole quantitative basis for financial close, for three identified reasons: the dependence result in Table 7 is obtained on a validated surrogate and requires confirmation in the primary workbook; the reported percentiles of two fitted marginals are not reproducible from their stated families and must be reconciled; and the reliability break-even in Table 9 requires PLN's own energy-not-served and value-of-lost-load evidence. All three are specified, bounded and executable within the six-month Priority 2 window in Table 10. Stating this openly is what distinguishes a model presented for institutional adoption from one presented as finished.

4. CONCLUSION

This study developed and applied a four-layer investment modeling algorithm integrating strategic situation framing, deterministic discounted cash flow, sensitivity analysis, and correlation-aware Monte Carlo simulation to the 50 MW PLTMG Sumbawa 3 project. The deterministic layer returned a net present value of IDR 276.85 billion, an internal rate of return of 9.13%, a benefit-cost ratio of 1.03, and a payback period of 10.14 years, satisfying PLN's acceptance criteria on a spread of only 1.75 percentage points over the cost of capital. The stochastic layer reversed that verdict: an 82.08% probability of a negative net present value, a mean of negative IDR 1.42 trillion, a median of negative IDR 1.38 trillion, and a 95th percentile value at risk of IDR 4.05 trillion, with a downside-to-upside ratio of approximately 3.6 to 1. Exchange rate and LNG price accounted for 59.6% and 40.3% of variance, respectively, and because the two enter the fuel-cost line multiplicatively, the independent-input result is a lower bound on the true exposure rather than a neutral estimate.

Three specific recommendations follow. At the project level, PLN should grant conditional rather than unconditional approval, with the conditions being the execution of a collared LNG supply agreement at or below 21.97 USD/MMBTU, the acceleration of gasification before financial close, and the insertion of a USD-indexed tariff adjustment provision sized against the 59.6% exchange-rate variance share. At the analytical level, the expected shortfall should be recorded explicitly as an implicit reliability subsidy of approximately IDR 630 per kWh and tested against PLN's own energy-not-served records, since at a value of lost load of IDR 20,000 per kWh, the plant must avert approximately 6.9 GWh per year for the loss to be economically rational. At the institutional level, the KKP and KKF guidelines should be amended by Peraturan Direksi to require correlation-aware Monte Carlo simulation, a non-negative median net present value, and contribution-to-variance disclosure for every LNG-based generation project exceeding a defined capital expenditure threshold.

The principal contribution is methodological. By demonstrating that a project meeting all deterministic criteria can simultaneously carry an 82.08% probability of value destruction, and by converting that probability into a per-kilowatt-hour price for reliability that can be tested against observable data, the algorithm addresses the two objections that have historically limited the influence of probabilistic appraisal in state-owned utility practice: that it is not integrated into the mandatory approval template, and that it appears to have no decision consequence where construction is mandated on operational grounds. The first is addressed by building the algorithm inside the existing KKF indicator set; the second by showing that the decision set is a continuum of contract structures rather than a binary choice, and that the probabilistic layer determines the terms even where it does not determine the outcome.

4.1. Model Perimeter and Limitations

The limitations of this study are the boundaries of a declared perimeter rather than unaccounted omissions, and are stated here in that form. The financial model assumes 100% equity financing in accordance with the KKF Supplement 2025; a leveraged structure would alter the cost of capital and, hence, the absolute indicators, and is reported as a bounded cost-of-capital sensitivity rather than simulated. Environmental impact assessment and permitting are excluded because they enter linearly as increments to capital expenditure, which is linear in net present value, so their effect is bracketed by the capital-expenditure sensitivity and does not interact with the fuel-cost drivers. Power purchase pricing and end-consumer tariff are excluded because they are administratively determined; treating them as random variables would conflate market with political risk and would render the output distribution uninterpretable. They are handled by scenario instead. The fitted marginals may not capture regime shifts in global LNG markets or extraordinary exchange-rate stress, which is why the historical stress replay in Table 11 is specified as a standing check rather than an optional extension. Finally, the dependence coefficients in Table 6 are estimated from proxy series rather than from the exact Investing.com and JISDOR series used to fit the marginals, and the dependence results in Table 7 are obtained using a validated reduced-form surrogate rather than from the primary workbook. Both should be reproduced on the original data before submission; the direction and order of magnitude of the effect are nonetheless established, and the tail metrics should be read from the stressed rather than the estimated correlation when setting an exposure limit

4.2. Implications for Future Research

Five extensions follow directly. First, the dependence specification should be generalized from rank correlation to a copula formulation, which would allow tail dependence to differ from central dependence and would produce more accurate joint tail estimates for currency-commodity exposure than any single correlation coefficient can [46], [47]. Second, real options analysis should be added as a fourth quantitative layer to value the fuel-switching, staged-expansion and deferral options that the present framework treats as implicit; the theoretical apparatus is established [51], [52], [53], [54], the implementation pathway is demonstrated [33], [50], and recent work extends the approach to investment under policy uncertainty in a form directly applicable to Indonesian tariff and gas-pricing regulation [81]. Third, the sensitivity layer could be replaced by multi-stage stochastic programming with decision branches representing mid-life capacity additions or technology upgrades [63], [64]. Fourth, portfolio-level application across PLN's generation pipeline would enable risk-adjusted allocation at the holding rather than the project level, building on mean-variance and portfolio-planning foundations [15], [16], [65], [66]. Fifth, the algorithm should be applied to other LNG-based PLTMG projects in the pipeline to establish whether the deterministic optimism bias identified here - a planning fuel price below the empirical fifth percentile - is systemic across PLN's isolated-grid portfolio rather than specific to this case. That last extension is the one with the largest potential consequence, since a systemic bias in a single input parameter would affect every appraisal built on it.

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