

GRAPI and GRAPI-N for Green Enterprise Risk Management in Four Indonesian Companies

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Abstract

This study evaluates the proposed Green Risk-Adjusted Productivity Index (GRAPI) and normalized GRAPI-N using 2024-2025 sustainability data from PT Vale Indonesia Tbk, PT Pertamina (Persero), PT Astra International Tbk, and PT Medco E&P Indonesia. Because entity-specific Medco E&P data are incomplete, traceable MedcoEnergi oil-and-gas segment and combined safety disclosures are used as a bounded proxy. The exploratory longitudinal multiple-case design integrates economic productivity with energy, greenhouse-gas, waste, and occupational-safety indicators. Equal intra-domain weights are the primary specification; CRITIC, entropy, and 60:40/40:60 scenarios assess sensitivity. Heterogeneous reporting boundaries preclude cross-company ranking, so interpretation is limited to within-entity change from each 2024 baseline. Raw GRAPI changed by +0.5% for Vale, -11.6% for Pertamina, -7.9% for Astra, and -3.6% for Medco. Against the common GRAPI-N baseline of 0.5000, equal-weight 2025 scores were 0.2414, 0.2969, 0.4751, and 0.3067. Vale, Pertamina, and Medco remained below baseline in every scenario; Astra ranged from 0.4699 to 0.5223. GRAPI-N is more dimensionally coherent for internal trend monitoring but requires component disclosure, sensitivity analysis, assured data lineage, and non-compensable risk controls.

Keywords: Green Productivity; Environmental Management; Enterprise Risk Management; Composite Indicator; Normalization

INTRODUCTION

Background. Environmental productivity and occupational safety are often governed through separate dashboards even though both can constrain enterprise value. Energy and carbon inefficiency can raise operating cost and transition exposure, while hazardous waste and injuries can interrupt production, create liabilities, and weaken the social licence to operate. Green Productivity links productivity improvement with environmental performance; enterprise risk management (ERM) adds governance, uncertainty, risk appetite, and response. Corporate disclosure standards also strengthen the demand for traceable sustainability and climate information (Global Reporting Initiative, 2021; IFRS Foundation, 2023). The managerial problem is therefore not the absence of indicators, but the lack of a transparent synthesis that can signal whether economic productivity is improving without shifting risk to environmental or worker outcomes.

In Indonesia, sustainable-finance regulation requires public companies to connect environmental and social responsibility with governance, strategy, and reporting (Otoritas Jasa Keuangan, 2017). This institutional setting increases the value of a traceable internal KRI, while also making it essential to distinguish a

managerial screening index from statutory disclosure, external assurance, or a regulatory rating.

Composite indicators are attractive because they compress multiple signals into a tractable measure, but the compression creates methodological risks. Scaling, normalization, weighting, correlation, and aggregation can each change the resulting ranking or trend. The OECD–JRC handbook therefore treats conceptual coherence, data quality, normalization, weighting, uncertainty analysis, and transparent decomposition as integral parts of index construction rather than optional refinements (OECD & European Commission Joint Research Centre, 2008). Later reviews reach the same conclusion: a composite index is a model whose assumptions must be made visible and stress-tested (Greco et al., 2019).

Research Gap. The earlier GRAPI formulation combines an economic-intensity numerator with environmental and safety denominators. Its intuitiveness is also its central vulnerability: the raw indicators retain incompatible units. A numerically large energy or emissions series can dominate a numerically small injury-frequency series even if the latter deteriorates sharply. In addition, a raw score has no common baseline, so changes

across entities with different reporting boundaries can be falsely read as rankings. A normalized form, GRAPI-N, was proposed to address dimensional incoherence, but it requires an explicit empirical test that compares the raw and normalized signals, discloses the data boundary, and examines sensitivity to weights.

Objective and Contribution. This paper has four objectives. First, it operationalizes GRAPI and GRAPI-N with reproducible formulas and traceable data. Second, it tests whether normalization materially changes the signal in four major Indonesian companies representing nickel mining, integrated energy, a diversified conglomerate, and upstream oil and gas. Third, it evaluates stability under equal, CRITIC/entropy, and alternative top-level weights. Fourth, it translates the findings into ERM governance guidance. The contribution is methodological rather than predictive: the paper tests whether the proposed index behaves coherently as a key risk indicator (KRI); a two-year, four-case sample cannot establish a universal theory or causal relationship.

Research Questions and Propositions. RQ1 asks whether raw GRAPI and GRAPI-N provide materially different within-entity signals. RQ2 asks whether the GRAPI-N direction is robust to

reasonable weight choices. RQ3 asks how component diagnostics explain each aggregate result. Three testable propositions guide the analysis: P1, normalization reduces unit-scale dominance; P2, Vale, Pertamina, and Medco remain below their 2024 baselines across reported weighting scenarios; and P3, a result close to baseline is more likely to be weight-sensitive than a result dominated by broad component deterioration.

From Green Productivity to Green Enterprise Risk Management

Green Productivity originated as an integrated approach to productivity and environmental improvement and is institutionalized in APO practitioner requirements (Asian Productivity Organization, 2023). The numerator–denominator logic is related to eco-efficiency: organizations seek more valued output per unit of resource use and environmental burden. For a corporate KRI, however, the denominator should not be interpreted as a monetized loss function unless all terms have been valued consistently. GRAPI instead functions as a relative signal in which higher undesirable intensity or injury frequency lowers the score. This distinction matters because a monitoring indicator supports investigation

and escalation; it does not automatically estimate economic value at risk.

Recent eco-productivity research confirms that efficiency signals can shift under shocks, technology change, and the selection of inputs and undesirable outputs (Sağlam, 2025). GRAPI-N responds to this measurement challenge by separating benefit and burden ratios before aggregation. It does not monetize externalities; it asks whether economic productivity is improving relative to environmental and worker-safety burdens within one governed reporting boundary.

ISO 31000 and COSO ERM as Governing Frameworks

ISO 31000:2018 defines risk management as coordinated activities to direct and control an organization with regard to risk and emphasizes integration, structured processes, customization, inclusiveness, dynamism, best available information, human and cultural factors, and continual improvement (International Organization for Standardization [ISO], 2018). COSO ERM similarly links risk with strategy and performance (Committee of Sponsoring Organizations of the Treadway Commission [COSO], 2017). A GRAPI dashboard is consistent with those frameworks only when responsibilities, data ownership, risk appetite, escalation

thresholds, and response decisions are established. The formula itself cannot supply governance.

Recent sector evidence motivates, but does not validate, the proposed index. Shah et al. (2025) report a positive association between ESG-oriented ERM and green-growth dimensions in oil-and-gas companies, while Pacagnella et al. (2026) find that operational and financial efficiency is associated with differentiated ESG performance in the sector. These studies support integrated measurement and governance, but neither establishes GRAPI's criterion validity; that requires longer panels and external outcomes.

This positioning is consistent with contemporary risk scholarship. Risk assessment should make assumptions, uncertainty, and the strength of knowledge explicit rather than present a score as objective truth (Aven, 2016). ERM can support sustainability-oriented decisions when the metric is embedded in governance and review processes (Liu, 2019), while embedded risk governance requires clear ownership, information flows, and escalation mechanisms (Gleißner & Berger, 2024). Green-governance evidence in oil and gas also supports combining ERM, sustainability indicators, and board oversight rather than

operating parallel systems (Shah et al., 2022).

Composite-Indicator Design and Normalization

A composite indicator maps a vector of observations into a scalar. This makes communication easier but can conceal trade-offs. Normalization places variables on a comparable scale; weighting encodes importance or information content; aggregation determines whether a strong result in one component may compensate for a weak result in another. Saisana, Saltelli, and Tarantola (2005) show why uncertainty and sensitivity analysis are essential to quality assessment. Paruolo, Saisana, and Saltelli (2013) further demonstrate that weights and aggregation can influence ratings and rankings in ways that are easily overlooked.

GRAPI-N uses ratio-to-baseline normalization. This choice has three advantages for the present study. It is dimensionless, preserves the direction of change, and fixes a transparent reference point. It also has limitations. If the baseline is abnormally high or low, the ratio may exaggerate or suppress later performance. Structural breaks, acquisitions, divestments, restatements, changes in emission factors, and changes in

recordability rules can invalidate the comparison. Accordingly, baseline governance is part of index governance.

Weighting: Equal, CRITIC, and Entropy

Equal weights provide a neutral and easily audited primary specification. They do not prove that every indicator is equally important; they avoid imposing unsupported preference differences. CRITIC derives weights from contrast intensity and conflict among criteria: a variable receives more weight when it varies and is less redundant with others (Diakoulaki et al., 1995). Entropy weighting assigns more weight to indicators that contain greater cross-sectional information, following Shannon's information measure (Shannon, 1948). Both objective procedures are data-dependent, and with only four companies their estimates are exploratory. They are used here to test sensitivity, not to override management judgement or materiality assessment.

Recent Advances in Composite Sustainability Metrics and Objective Weighting

The methodological literature after 2015 places particular emphasis on robustness. Becker et al. (2017) distinguish

a nominal weight from a criterion's effective importance after normalization, correlation, and aggregation. Burgass et al. (2017) show that environmental composite indicators should expose uncertainty rather than conceal it, and Gan et al. (2017) demonstrate that the suitability of weighting and aggregation methods depends on the decision context. These findings support the present hierarchy: equal weights for a transparent primary estimate, objective weights only as exploratory stress tests, and mandatory presentation of component ratios.

CRITIC and entropy remain useful because they are reproducible, but they answer an information-content question rather than a normative materiality question. Energy-sector comparisons (Ersoy & Taslak, 2023) and newer hybrid CRITIC–entropy applications (Tajik et al., 2024) illustrate their analytical value. With only four cases, however, a single observation materially affects dispersion and correlation; management-approved materiality weights and stakeholder judgement remain indispensable for operational use.

Hazard-Control Hierarchy and Non-Compensable Risk Controls

Outcome rates such as LTIFR, LTIR, TRIFR, and TRIR should be

interpreted with exposure hours, recordability rules, severity, and the hierarchy of controls. GRI 403 requires a management-system view of occupational health and safety, while industry benchmarking depends on consistent definitions (Global Reporting Initiative, 2018; International Association of Oil & Gas Producers, 2023). Indonesian HIRARC studies similarly show that risk reduction should progress from elimination and substitution to engineering and administrative controls before relying on personal protective equipment (Ramadhan et al., 2025; Nasikhah & Milad, 2026).

Green investment can also introduce new risk pathways. Project-level evidence on photovoltaic deployment highlights construction, electrical, operating, and maintenance hazards that need explicit treatment (Mardiansyah et al., 2025). Accordingly, a favorable environmental sub-index cannot compensate for a fatality, major process-safety event, serious legal breach, or uncontrolled new technology risk; these events require separate veto or escalation rules outside the arithmetic index.

Aggregation, Compensation, and Non-Negotiable Controls

The GRAPI family uses additive sums within the environmental and safety

domains and a ratio between the economic numerator and total risk denominator. Additive aggregation is compensatory: improvement in energy intensity can partly offset deterioration in emissions or safety. That property can be useful for trend synthesis but is unacceptable for certain controls. Fatalities, catastrophic process-safety events, legal non-compliance, and breaches of absolute environmental limits should remain separately escalated irrespective of the composite score. GRAPI-N should therefore sit beside, not above, mandatory controls and component-level KRIs.

Research Model

The conceptual model links economic productivity (a benefit indicator) with environmental and occupational-safety burdens (cost indicators). The model expects the normalized score to decline when productivity weakens or burdens rise, and to improve when productivity rises relative to the baseline while burdens fall. Weight sensitivity is expected when improvements and deterioration coexist. The empirical test examines internal mathematical behaviour and robustness; criterion validity against losses, incidents, cost of capital, or market valuation remains a future research requirement.

METHODS

Research Design

The study uses an exploratory multiple-case, two-period design consistent with case-study replication logic rather than statistical sampling (Yin, 2018). The cases were selected because their 2025 sustainability disclosures contain sufficient paired 2024–2025 information to operationalize the economic, environmental, and safety domains. PT Vale Indonesia Tbk represents nickel mining; PT Pertamina (Persero), integrated energy; PT Astra International Tbk, a diversified group; and PT Medco E&P Indonesia, upstream oil and gas. For Medco, public MedcoEnergi oil-and-gas segment data and combined safety disclosure are used as a transparent proxy and are not represented as legal-entity-only assured data. The unit of inference is each case's change from its own 2024 baseline to 2025. No cross-company ranking is attempted.

Data Sources and Boundary Alignment

Data were transcribed from four 2025 corporate sustainability disclosures and the Medco case documentation, then reconciled in a companion audit workbook. Every input record contains the source, printed page, unit, boundary, value, and URL or document identifier. Calculated

cells are formula-driven; assumptions and proxies are separated from reported observations; and automated checks verify completeness, positive baselines, weight sums, formula reconciliation, and absence of spreadsheet errors. This provides computational transparency while recognizing that the study does not constitute external assurance of the underlying disclosures.

Table 1. Case boundaries and indicator operationalization

Case	Economic productivity (benefit)	Environmental burdens	Safety burdens	Boundary note
PT Vale Indonesia Tbk	1,000 / Sorowako unit production cost (USD/t)	Energy and GHG intensity per tonne matte; B3 waste per tonne production	Sorowako contractor LTIFR and TRIFR	Site/operating boundary; not consolidated revenue/assets
PT Pertamina (Persero)	Consolidated revenue / total assets	Energy and GHG intensity per USD million revenue; B3 waste per USD million revenue	Consolidated LTIR and TRIR per million work hours	Consolidated group measures
PT Astra International Tbk	Consolidated revenue / total assets	Energy, GHG, and waste intensity per Rp billion revenue	Combined employee + contractor LTIFR and recordable injury rate	Consolidated scope covering 198 companies
PT Medco E&P Indonesia	Annualized oil-and-gas production / oil-and-gas capital expenditure	Energy, GHG, and B3-waste intensity for the oil-and-gas case boundary	Contractor LTIFR and combined TRIR	MedcoEnergi oil-and-gas segment and combined public safety disclosure used as a transparent proxy; not legal-entity-only assurance

Model Specification

Let EI_{it} denote economic productivity for entity i in year t . Let x_{ijt} be undesirable environmental indicator j and s_{ikt}

undesirable safety indicator k . The raw formulation is:

$$GRAPI_{it} = EI_{it} / [\gamma^E \sum_j (w_j x_{ijt}) + \gamma^s \sum_k (v_k s_{ikt})]$$

where w and v are intra-domain weights and γ^E and γ^s are top-level environmental and safety coefficients. The primary specification uses $w_j = 1/3$, $v_k = 1/2$, and $\gamma^E = \gamma^s = 1$. The raw formula is retained as a diagnostic comparator; its components have incompatible units and its absolute value has no interpretable cross-company scale.

For GRAPI-N, the economic benefit ratio and undesirable burden ratios are normalized to the 2024 baseline (0):

$$r^{EI}_{it} = EI_{it} / EI_{i0} ; \quad r^{x_{ijt}} = x_{ijt} / x_{ij0} ; \quad r^{s_{ikt}} = s_{ikt} / s_{ik0}$$

$$GRAPI-N_{it} = r^{EI}_{it} / [\gamma^E \sum_j (w_j r^{x_{ijt}}) + \gamma^s \sum_k (v_k r^{s_{ikt}})]$$

With $\gamma^E = \gamma^s = 1$ and all baseline ratios equal to one, $GRAPI-N_{i0} = 1/(1+1) = 0.5000$ for every entity. The reported percentage change is $100 \times (GRAPI-N_{i2025}/0.5000 - 1)$. This common baseline is not a claim that all companies had equal sustainability performance in 2024; it is an index origin for measuring each entity's own change.

The economic numerator for Vale is the reciprocal of reported Sorowako unit production cost, scaled by 1,000 only for readability. Pertamina and Astra use

consolidated revenue divided by total assets. Medco uses annualized oil-and-gas production divided by oil-and-gas capital expenditure, consistent with operational-productivity logic for capital-intensive upstream activity. Vale and Pertamina hazardous-waste intensity is calculated using the relevant production or revenue denominator; Astra reports waste intensity directly; and Medco uses disclosed oil-and-gas B3-waste intensity. Astra's two safety rates are calculated by pooling reported employee and contractor cases and hours. Medco uses contractor LTIFR and combined TRIR because a consistently paired legal-entity-only safety series was not publicly available. No missing value was imputed, and every proxy is flagged in the workbook.

Harmonization rule for the Medco case. To keep the four-case replication internally consistent, the study applies the same three environmental ratios and two safety ratios to every case, then estimates the exploratory weights from the four-company dataset. Under this controlling specification, Medco records a 38.7% decline in the primary equal-weight scenario (GRAPI-N = 0.3067) and a 45.4% decline in the CRITIC/entropy sensitivity scenario. All Medco results reported in this article follow this harmonized specification.

Weighting and Sensitivity Analysis

Equal intra-domain weights are the primary results because they are transparent and do not overfit a four-case dataset. Exploratory environmental weights are obtained using CRITIC on the 2025-to-2024 environmental ratios; exploratory safety weights use entropy on the two safety ratios. Recalculation across all four cases gives environmental weights of 0.2150 for energy, 0.2867 for GHG emissions, and 0.4983 for hazardous waste, and safety weights of 0.8816 for the first injury-rate indicator and 0.1184 for the second. These values are sample-dependent stress-test parameters, not stable stakeholder preferences or materiality judgements.

The objective weights were independently recomputed from the disclosed ratios. Sample standard deviations and the CRITIC information terms yielded environmental weights of 0.2149699, 0.2867279, and 0.4983022; Shannon entropy yielded safety weights of 0.8815958 and 0.1184042. Rounded values in the manuscript reproduce the workbook outputs, both weight vectors sum to 1.0000, and all four 2024 GRAPI-N baselines reconstruct to 0.5000.

Two top-level scenarios retain equal intra-domain weights but vary the relative coefficients while keeping their sum equal

to two: Environment 60% sets $\gamma^E = 1.2$ and $\gamma^S = 0.8$; Safety 60% sets $\gamma^E = 0.8$ and $\gamma^S = 1.2$. Because the sum remains two, the 2024 baseline remains 0.5000. Robustness is assessed by the range and sign of change across equal, CRITIC/entropy, Environment 60%, and Safety 60% scenarios. A sign change is treated as a weight-sensitive result.

Analytical Interpretation and Validity Safeguards

For descriptive communication, a GRAPI-N score of 0.45 to below 0.55 is labelled near baseline, 0.35 to below 0.45 deteriorated, and below 0.35 severely deteriorated; a score at or above 0.55 indicates improvement. These bands are analytical conventions introduced for this study, not regulatory, assurance, or investment thresholds. An organization adopting the index should calibrate thresholds to its risk appetite, incident severity, legal obligations, and historical volatility.

Construct safeguards include direction checks, unit documentation, within-entity baselines, decomposed component disclosure, and sensitivity analysis. Internal-validity threats include changes in reporting methods and consolidation scope; the Medco proxy boundary adds a specific measurement

limitation. External validity is limited by purposive selection, four heterogeneous cases, and two observations per case. Statistical significance is neither estimated nor implied. The paper uses the term “test” to mean a transparent empirical application and robustness check of the proposed formula.

RESULTS AND DISCUSSION

Input Ratios and Component Diagnostics

Table 2 reports the dimensionless 2025-to-2024 ratios used by GRAPI-N. A ratio above one is favourable only for economic productivity; for environmental and safety burdens, it indicates deterioration. Vale improved energy and waste intensity but contractor LTIFR rose to 4.75 times baseline. Pertamina’s productivity weakened while both safety rates approximately doubled. Astra combines improvements in energy and pooled lost-time rate with deterioration in GHG, waste, and recordable injury. Medco’s economic, energy, and GHG ratios improve modestly, but its B3-waste ratio rises to 3.0413, contractor LTIFR to 1.5000, and combined TRIR to 1.3750. The disaggregation shows why no total score should be interpreted without its components.

Table 2. Dimensionless 2025-to-2024 ratios used in GRAPI-N

Company	Economic productivity	Energy	GHG	B3/waste	LTIFR/LTIR	TRIFR/recordable rate
PT Vale Indonesia Tbk	0.9915	0.9839	1.0014	0.8641	4.7500	1.5641
PT Pertamina (Persero)	0.9229	1.0198	1.0450	0.9610	2.0000	2.2000
PT Astra International Tbk	0.9148	0.9906	1.0066	1.0509	0.6693	1.1497
PT Medco E&P Indonesia	0.9532	0.9930	0.9783	3.0413	1.5000	1.3750

Source notes. Vale: unit production cost, production, energy, GHG, B3 waste, and Sorowako contractor safety data are drawn from its Sustainability Report 2025, printed pp. 5–7, 132, and 185 (PT Vale Indonesia Tbk, 2026). Pertamina: revenue/assets and environmental/safety data are drawn from its Sustainability Report 2025, printed pp. 44, 105, 110, 127, and 160 (PT Pertamina (Persero), 2026). Astra: revenue/assets, environmental intensity, hours, and cases are drawn from its Sustainability Report 2025, printed pp. 11, 124, 131, 135, and 179–180 (PT Astra International Tbk, 2026). Medco: oil-and-gas productivity and public environmental/safety disclosures are reconciled from MedcoEnergi’s Sustainability Report 2025 and the case documentation (PT Medco Energi Internasional Tbk, 2026; Panjaitan et al., 2026, pp. 18–20). Exact values, scope flags, formulas, and source links are preserved in the audit workbook.

Raw GRAPI versus Normalized GRAPI-N

Table 3 provides the central comparison. Raw GRAPI appears to improve for Vale by 0.5%, although GRAPI-N falls by 51.7%. The difference is not a rounding issue: energy intensity measured in hundreds of GJ per tonne numerically dominates injury rates measured in fractions per million hours. Medco’s raw decline is only 3.6%, while GRAPI-N falls 38.7% after dimensionless ratios expose the tripling of waste intensity and higher safety rates. Pertamina and Astra agree in direction under the primary weights, but their normalized magnitudes remain more interpretable. These results support P1 and demonstrate why raw GRAPI should be retained only as a diagnostic comparator, not a stand-alone KRI.

Table 3. Primary equal-weight results

Company	Raw GRAPI 2024	Raw GRAPI 2025	Raw change	GRAPI-N 2024	GRAPI-N 2025	GRAPI-N change	Primary interpretation
PT Vale Indonesia Tbk	0.000666	0.000670	+0.5%	0.5000	0.2414	–51.7%	Severe deterioration
PT Pertamina (Persero)	0.007311	0.006460	–11.6%	0.5000	0.2969	–40.6%	Severe deterioration
PT Astra International Tbk	0.006802	0.006266	–7.9%	0.5000	0.4751	–5.0%	Near baseline
PT Medco E&P Indonesia	0.006272	0.006048	–3.6%	0.5000	0.3067	–38.7%	Severe deterioration

Raw GRAPI levels are presented only to reproduce the original formula.

They are unit-dependent and must not be compared across companies. GRAPI-N levels share a mathematical baseline but still do not establish that underlying absolute sustainability performance is comparable, because case boundaries and indicator definitions differ.

Pertamina's raw and normalized measures agree on direction but not on magnitude. Revenue-to-assets productivity declined by 7.7%; energy and GHG intensity increased; hazardous-waste intensity improved modestly; and LTIR and TRIR rose to approximately two and 2.2 times their baselines. The equal-weight GRAPI-N score falls to 0.2969. The result is broad enough that shifting the relative importance of environmental and safety domains does not reverse its sign.

Astra's equal-weight GRAPI-N remains close to baseline at 0.4751. Its economic productivity declined by 8.5% and its waste and recordable-injury rates deteriorated, while energy intensity and the pooled lost-time rate improved. This mixed profile is precisely the condition in which aggregation assumptions matter. The objective-weight scenario places substantial safety weight on the first rate, which improved, and changes the aggregate sign. The appropriate managerial conclusion is not that Astra

definitively improved or deteriorated, but that the aggregate is inconclusive without an explicit materiality judgement and component review.

Medco's equal-weight GRAPI-N is 0.3067, a 38.7% decline from baseline, compared with a 3.6% decline in raw GRAPI. The economic-productivity ratio (0.9532), energy ratio (0.9930), and GHG ratio (0.9783) indicate modest improvement or near-stability, but the waste ratio (3.0413), contractor LTIFR ratio (1.5000), and combined TRIR ratio (1.3750) materially expand the normalized denominator. Because these data use an oil-and-gas segment and combined safety proxy, the result is a bounded case-study signal, not a legal-entity performance rating.

Sensitivity and Robustness

Table 4. GRAPI-N results across weighting scenarios

Company	Equal score / change	CRITIC –entropy score / change	Environment 60% score / change	Safety 60% score / change	Scenario range	Robustness conclusion
PT Vale Indonesia Tbk	0.2414 / -51.7%	0.1870 / -62.6%	0.2705 / -45.9%	0.2180 / -56.4%	0.1870–0.2705	Robust decline
PT Pertamina (Persero)	0.2969 / -40.6%	0.3054 / -38.9%	0.3193 / -36.1%	0.2774 / -44.5%	0.2774–0.3193	Robust decline
PT Astra International Tbk	0.4751 / -5.0%	0.5223 / +4.5%	0.4699 / -6.0%	0.4804 / -3.9%	0.4699–0.5223	Sensitive; sign changes
PT Medco E&P Indonesia	0.3067 / -38.7%	0.2728 / -45.4%	0.3021 / -39.6%	0.3113 / -37.7%	0.2728–0.3113	Robust decline

Vale, Pertamina, and Medco remain below 0.5000 in every scenario,

supporting P2. Their scenario ranges do not touch the baseline, although estimated severity changes. Astra crosses 0.5000 only in the CRITIC/entropy scenario and therefore supports P3: a near-baseline, internally mixed signal is more sensitive to weighting. With $n = 4$, a single case still strongly affects CRITIC dispersion, correlation, and entropy. Objective weights are therefore interpreted only as a stress test, not an optimal or final weighting system.

Numerical verification. Thirty-two source rows carry evidence status, printed-page trace, unit, boundary, and an official source URL or document identifier. Formula checks confirm the primary environmental and safety weight sums, the top-level coefficient sum of two, every baseline reconstruction, every 2025-to-2024 ratio, and all sixteen sensitivity-scenario outputs. The companion workbook's final audit status is PASS with zero spreadsheet error values. This is an internal computational validation; it does not replace assurance of the companies' source disclosures.

The analysis illustrates two kinds of robustness. Directional robustness asks whether the score remains above or below baseline; magnitude robustness asks whether the estimated change is stable. Vale, Pertamina, and Medco are

directionally robust but vary in magnitude. Astra is neither directionally invariant nor suitable for a categorical conclusion without approved materiality weights. In governance terms, direction can trigger review, whereas magnitude should inform priority only after data quality, severity, scope, and materiality have been checked.

Case Interpretation: PT Vale Indonesia Tbk

Vale's economic ratio is close to one because Sorowako unit production cost increased slightly from USD 9,479 to USD 9,560 per tonne. Energy intensity improved from 445.73 to 438.57 GJ per tonne matte, GHG intensity was nearly flat at 28.76 to 28.80 tCO₂e per tonne, and calculated B3-waste intensity improved. Against those gains, Sorowako contractor LTIFR rose from 0.04 to 0.19 and TRIFR from 0.39 to 0.61. The normalized safety sub-index therefore expands markedly and dominates the equal-weight risk denominator. The finding is not a judgement on all Vale operations; it is a boundary-specific warning that the productivity–environment story should not obscure contractor safety.

For ERM use, Vale's result points to three controls: formally reconcile contractor safety definitions and hours

across periods; establish a non-compensable escalation rule for serious injury events; and report the environmental and safety sub-indices beside the total score. A site should not be labelled “green productive” on the basis of environmental efficiency if a material safety deterioration is being averaged away.

Case Interpretation: PT Pertamina (Persero)

Pertamina’s consolidated revenue declined from USD 75,327 million to USD 70,894 million while assets increased from USD 89,850 million to USD 91,630 million, lowering the economic-productivity ratio. Energy intensity increased from 2.53 to 2.58 TJ per USD million and GHG intensity from 338.26 to 353.49 tCO_{2e} per USD million. Calculated B3-waste intensity improved because waste tonnage fell relative to revenue. LTIR rose from 0.02 to 0.04 and TRIR from 0.05 to 0.11 per million work hours. The common direction of weaker productivity and higher energy, emissions, and injury burdens explains the robust decline across scenarios.

For ERM use, Pertamina could decompose the consolidated score by subholding and major operation, provided denominator and incident definitions

remain consistent. This would reveal whether the consolidated decline is broad or concentrated. Management should also test whether changes in revenue caused by commodity prices alter an intensity denominator even when physical operating efficiency is unchanged. A supplementary physical-output productivity numerator would help distinguish market effects from operational effects.

Case Interpretation: PT Astra International Tbk

Astra’s revenue-to-assets ratio declined because revenue decreased from Rp 328,480 billion to Rp 323,392 billion while assets rose from Rp 471,449 billion to Rp 507,366 billion. Energy intensity improved from 284.72 to 282.05 GJ per Rp billion revenue; GHG intensity edged up from 13.63 to 13.72 tCO_{2e} per Rp billion; and waste intensity increased from 7.46 to 7.84 tonnes per Rp billion. Pooling reported employee and contractor data yields a lower lost-time rate but a higher recordable-injury rate. These opposing movements explain both the near-baseline equal-weight result and the sign change under entropy safety weights. For ERM use, Astra should treat the consolidated index as a screening layer and preserve sector-level decomposition.

A diversified group can experience changes in business mix that alter consolidated intensity without equivalent changes in operational efficiency. Separate indicators for automotive, financial services, heavy equipment/mining/construction/energy, agribusiness, infrastructure/logistics, information technology, and property would reduce aggregation bias if consistently disclosed.

Case Interpretation: PT Medco E&P Indonesia

The Medco case examines upstream oil and gas using the same harmonized six-ratio model applied to the other cases. Annualized production per oil-and-gas capital expenditure yields an economic ratio of 0.9532. Energy and GHG ratios improve slightly to 0.9930 and 0.9783. Reported B3 waste rises from 5,125 tonnes to 15,997 tonnes; after scaling by the case production denominator, the waste-intensity ratio is 3.0413. Contractor LTIFR rises from 0.04 to 0.06 and combined TRIR from 0.16 to 0.22. The equal-weight score of 0.3067 lies within a scenario range of 0.2728–0.3113; its direction is therefore robust, although its magnitude depends on weights (PT Medco Energi Internasional Tbk, 2026; Panjaitan et al., 2026).

For ERM use, Medco should reconcile legal-entity, segment, and consolidated boundaries before operational deployment; investigate the waste increase at asset and waste-stream level; and retain contractor safety as a non-compensable escalation domain. A future calculation should replace every proxy with assured legal-entity data and disclose any restatement of production, emissions factors, waste classification, incident definitions, or working hours. Until then, the result is suitable for methodological demonstration and internal hypothesis generation, not external comparison.

Assessment of Propositions

Table 5. Proposition assessment

Proposition	Empirical evidence	Assessment
P1: Normalization reduces unit-scale dominance.	Vale raw GRAPI rises +0.5% while GRAPI-N falls −51.7%; dimensionless ratios expose contractor-safety deterioration.	Supported in this sample
P2: Vale, Pertamina, and Medco remain below baseline across reported scenarios.	All four scenario scores are below 0.5000 for each of the three cases.	Supported in this sample
P3: Near-baseline mixed results are more weight-sensitive.	Astra changes from −5.0% under equal weights to +4.5% under CRITIC/entropy.	Supported, exploratory

Implications for Theory, Method, and Practice

The theoretical implication is deliberately limited. The evidence supports GRAPI-N's dimensional

coherence relative to raw GRAPI, not the universality of a new productivity theory. A stronger theory would specify causal pathways linking prevention, environmental efficiency, productivity, and enterprise value, then test them with longitudinal operational data and external outcomes. The present index is best described as a proposed measurement model and decision-support heuristic.

Methodologically, the common baseline solves one problem and reveals another. It removes physical units but makes the result dependent on baseline selection. It also permits a transparent decomposition: economic ratio, environmental sub-index, safety sub-index, and total score. Future versions should preserve that traceability and introduce rules for baseline restatement. If a merger, divestment, methodology change, or emission-factor revision materially alters the series, the baseline should be recalculated and the reason disclosed.

Practically, an organization can integrate GRAPI-N into quarterly or annual risk review through a four-stage protocol. First, validate boundary, units, definitions, and data lineage. Second, calculate component ratios and the composite under the approved weights. Third, compare the result with risk

appetite while applying non-compensable overrides for fatalities, major process-safety events, and legal breaches. Fourth, assign actions, owners, due dates, and follow-up indicators. The audit workbook accompanying this paper implements the first two stages and documents the assumptions needed for the latter stages.

A score should never be communicated without its denominator components. A falling GRAPI-N may arise from weaker productivity, higher environmental burdens, higher safety burdens, or their combination. Conversely, an improved score may be driven by a productivity surge even if one absolute burden grows. Stakeholders should therefore receive both intensity and absolute figures where available, particularly when output or revenue changes sharply.

CONCLUSION

This study applied raw GRAPI and GRAPI-N to four Indonesian corporate cases using 2024–2025 data. The normalized formulation establishes a common within-entity baseline and exposes the scale-dominance weakness of the raw formula. Under equal weights, Vale scored 0.2414, Pertamina 0.2969, Astra 0.4751, and Medco 0.3067 relative to a 2024 baseline of 0.5000. Vale, Pertamina,

and Medco showed robust deterioration across all four weighting scenarios. Astra remained near baseline and changed sign under objective intra-domain weights, so its aggregate signal is weight-sensitive and inconclusive without management-approved materiality weights. The Medco conclusion is explicitly conditional on the public oil-and-gas proxy boundary.

The principal conclusion is that GRAPI-N is mathematically preferable to raw GRAPI for an internal trend-monitoring KRI, but normalization does not create comparability of absolute performance, validate causal effects, or eliminate judgement. The formula is compensatory and therefore cannot replace mandatory legal limits, serious-incident escalation, or component-level assurance. Cross-company ranking is inappropriate with the present heterogeneous boundaries and definitions. The GRAPI-N framework is expected to contribute empirically as a corporate-level measurement instrument supporting Indonesia's green growth and sustainability development agenda.

Recommendations. Organizations considering adoption should use a stable and documented baseline, align reporting boundaries, retain source-level audit trails, disclose component and sub-index results, test alternative weights, and calibrate thresholds through their ERM governance

process. Equal weights are a defensible starting point when materiality preferences are not yet validated; objective statistical weights can be used as sensitivity scenarios but should not be treated as normative priorities, especially with a small sample.

Limitations. The study is limited by a two-period horizon, four purposively selected cases, heterogeneous business models, and reliance on public corporate disclosures. Vale uses a site-specific cost measure, Pertamina and Astra use consolidated accounting ratios, and Medco uses oil-and-gas segment and combined public disclosures as a proxy for PT Medco E&P Indonesia. These differences preclude cross-company ranking and limit inference to within-case change.

The ratio-to-baseline transformation is sensitive to baseline quality, restatements, and definitional change; additive aggregation is compensatory; objective weights are unstable at $n = 4$; and intensity improvements can coexist with increases in absolute burden. The analysis is descriptive and does not establish causal effects, regulatory compliance, external assurance, or predictive validity against losses, incidents, valuation, or cost of capital.

Future research. Future studies should extend the panel across at least five to ten years and a larger number of

companies within the same sector. A sector-homogeneous panel would enable stable CRITIC or entropy estimation, distributional confidence intervals, and out-of-sample validation. Researchers should test alternative economic numerators, including physical output per energy or capital input, value added, and productivity adjusted for commodity prices. Results should also be compared under ratio-to-baseline, min–max, z-score, distance-to-target, and geometric aggregation.

Criterion validity should be examined against future operational losses, environmental incidents, injury severity, downtime, insurance claims, compliance findings, and cost of capital. Convergent validity can be assessed against established eco-efficiency and safety-performance measures. A severity-adjusted safety module and non-compensatory veto thresholds warrant development. Stakeholder-derived or analytic-hierarchy weights may be compared with equal and objective weights, provided elicitation procedures and consistency checks are disclosed.

Finally, independent assurance of inputs and machine-readable sustainability data would materially strengthen the model. Replication should document restatements, acquisition and divestment

effects, calculation boundaries, and changes in GHG or incident methodologies. The companion workbook can serve as a reproducible starting point, but its assumed weights and analytical screening bands must be recalibrated before operational deployment.

DATA AVAILABILITY

All inputs used in this study are drawn from publicly available 2025 corporate sustainability disclosures and the disclosed Medco case documentation. A companion Excel workbook contains the source register, reported values, proxy and assumption flags, derived intensities, formulas, objective-weight calculations, sensitivity scenarios, dashboard, and audit checks. Calculated results are reproducible from the disclosed inputs. The workbook does not reproduce external assurance and should be read with the source reports. No confidential company data were used; the Medco case must not be interpreted as legal-entity-only assurance.

ACKNOWLEDGMENTS

The author expresses sincere appreciation to Universitas Negeri Jakarta (UNJ) for its cooperation with Leonard Tiopan Panjaitan in supporting the development and academic dissemination of this study. The author also thanks the

Regional Productivity Development Center (P3D) of the Manpower, Transmigration and Energy Office of the Jakarta Provincial Government and PT Starfin Nawasena Indonesia for the guidance-and-consultancy documentation that supports the Medco case. All interpretations, calculations, and any remaining errors are the author's responsibility.

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