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Development of an Integrated Double-Materiality and Operational Risk Assessment Framework for Industrial Organizations

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ABSTRACT

Industrial organizations face sustainability issues that affect the environment, society, operations and finances, yet conventional materiality assessments identify significant ESG topics without translating them into operational risk. GRI 3: Material Topics 2021 notes that the severity-and-likelihood assessment of an impact can be understood as risk, but it offers no quantitative model linking that assessment to enterprise risk management. This paper proposes such a model and demonstrates its behaviour on an illustrative set of eight industrial ESG topics. Impact materiality is scored from GRI 3 severity (scale, scope, irremediable character) and likelihood; financial materiality follows the effect-on-enterprise-value definition used in IFRS S1 and the European Sustainability Reporting Standards (ESRS); Double Materiality is the maximum of the two, mirroring the ESRS either-lens-applies logic. An Operational Risk Score combines operational exposure, financial consequence and control effectiveness, with a residual-risk floor so that strong controls reduce risk without eliminating it. A four-quadrant matrix combines the two scores. In the illustration, business conduct and governance ranks joint-third on Double Materiality but lowest on Operational Risk, whereas supply chain disruption ranks highest on Operational Risk and joint-highest on Double Materiality. Sensitivity analysis shows that climate change and supply chain disruption stay in the Act Now quadrant under every variation tested, while the placement of borderline topics depends on the weights, control assumptions and cut-offs chosen. The scores are illustrative and not empirically validated; a reproducible scoring protocol and a Delphi validation protocol are provided for application to real organizational data.

Keywords: Double materiality; operational risk; GRI 3; enterprise risk management; impact materiality; financial materiality; industrial organizations; prioritisation matrix; India.

INTRODUCTION

A material ESG topic, once identified, does not automatically become a managed risk. An industrial company can run a thorough stakeholder engagement exercise, score water stress or supply chain disruption as highly material, publish the result in a sustainability statement, and still leave the topic sitting outside its enterprise risk register, untouched by the control environment, incident reporting and financial contingency planning that actually determine how the organization responds when the risk materialises. This is not a hypothetical failure mode. Panfilo, Scarpa and Canestraro (2025), examining 442 companies for the 2022 financial year, find that the adoption of double materiality for sustainability reporting is not significantly associated with the quality of ESG risk management, attributing the gap to symbolic reporting practices, pre-existing risk frameworks that double materiality simply documents rather than changes, or the early stage of adoption. Whatever the specific cause, the empirical result is the same: identifying what is material and managing the resulting risk are, in practice, two separate exercises that current reporting frameworks do not reliably connect.

The standard-setters' own texts point toward a connection without fully building it. GRI 3: Material Topics 2021 states that the significance of a potential negative impact is determined by its severity and its likelihood, and adds directly that "the combination of the severity and the likelihood of a negative impact can be referred to as 'risk,'" noting that this assessment "can be included within broader enterprise risk

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management systems" (Global Reporting Initiative, 2021). This is, in effect, an invitation: GRI is telling preparers that impact materiality and operational risk share a common mathematical structure, severity multiplied by likelihood, without itself supplying the operational-risk half of that structure or showing how to combine it with financial materiality under the European Sustainability Reporting Standards' double-materiality architecture. This paper takes up that invitation directly, building a scoring model that carries GRI 3's own severity-and-likelihood logic through to operational exposure, control effectiveness and financial consequence, and combining the result with financial materiality into a single, reproducible prioritisation tool.

LITERATURE REVIEW

GRI 3: Material Topics 2021 provides this paper's foundational methodology. It sets out a four-step process, understanding organizational context, identifying actual and potential impacts, assessing the significance of those impacts, and prioritising the most significant for reporting, and within the significance-assessment step defines the severity of a negative impact through three named characteristics: scale, how grave the impact is; scope, how widespread it is; and irremediable character, how hard it is to counteract (Global Reporting Initiative, 2021). ESRS 1 supplies this paper's financial-materiality and double-materiality logic, defining double materiality as having two dimensions, impact materiality and financial materiality, and stating that the terms "material" and "materiality" throughout ESRS refer to double materiality unless specified otherwise (European Commission, 2023, ESRS 1, Section 3.1). IFRS S1 contributes the financial-materiality definition this paper applies, information that "could reasonably be expected to affect" an entity's cash flows, cost of capital or access to finance (IFRS Foundation, 2023).

On the empirical side, Panfilo, Scarpa and Canestraro (2025)'s finding that double materiality adoption does not significantly improve ESG risk management is this paper's central motivating evidence, examined in depth in Section IV. Their explanation that the null result may reflect symbolic rather than substantive implementation frames this paper's contribution precisely: a quantitative scoring model that forces the translation from material topic to operational risk to be made explicit, auditable and reproducible is one concrete way to move from symbolic toward substantive integration. Guruprasad et al. (2024), analysing the sustainability disclosures of the 150 largest BSE-listed companies, document trends and gaps in Indian BRSR reporting, which is the setting in which a transparent prioritisation method is most needed.

ESG–enterprise risk integration. Enterprise risk management (ERM) guidance now addresses sustainability explicitly. The COSO and WBCSD (2018) guidance applies the COSO ERM framework to ESG-related risks, treating them as risks to be identified, assessed, prioritised, responded to and monitored within the existing ERM process and not as a separate reporting stream, and ISO 31000 supplies the generic process of risk identification, analysis, evaluation and treatment (International Organization for Standardization, 2018). Reviews of the ERM literature caution that its conceptual definition and empirical support remain contested (Bromiley et al., 2015), and Stasytytė and Shahid (2026) map the overlap between ESG and ERM in the literature and identify risk identification and internal controls as core points of convergence.

Materiality assessment methods. Materiality assessment has been operationalised through stakeholder engagement and content analysis of sustainability reports (Torelli et al., 2020) and through multi-criteria approaches to materiality analysis (Calabrese et al., 2019), and the double-materiality concept introduced by European sustainability reporting has been reviewed as a significant shift from earlier non-financial reporting (Baumüller and Sopp, 2022). These approaches rank topics for reporting; they do not assess how well each topic is currently controlled, which is the dimension this paper adds.

Operational risk assessment models. In operational risk practice, risks are commonly assessed on exposure, consequence and control dimensions; the Basel Committee's sound-practice principles, for example, list risk and control self-assessment among the tools for identifying and assessing operational risk (Basel Committee on Banking Supervision, 2011). Qualitative scoring matrices are widely used but have documented weaknesses: because they combine ordinal ratings, they can misrank risks and give poor resolution (Cox, 2008), and arithmetic on ordinal ratings assumes equal steps between scale points (Stevens, 1946). Risk

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remaining after treatment is conventionally recognised as residual risk (International Organization for Standardization, 2018), which motivates the residual-risk floor in Section II-E.

Research Gaps

1. Existing materiality studies (Panfilo et al., 2025) examine whether double materiality adoption correlates with risk management quality at the company level, but do not provide a topic-level scoring model showing how the translation from material topic to operational risk should actually be made.
2. GRI 3's own severity-and-likelihood significance framework is not extended, within the Standard itself, to the operational-risk dimensions, exposure, control effectiveness, financial consequence, that enterprise risk management requires.
3. Limited empirical research integrates impact materiality, financial materiality, operational exposure, control effectiveness and financial consequence within a single scoring framework applied to industrial ESG topics.
4. Limited studies quantify how materiality rankings change when operational-risk characteristics are introduced, leaving open whether a topic's reporting priority and its risk-management priority are the same thing or can diverge.

Contributions

This paper makes five contributions. First, it identifies eight ESG materiality issues relevant to industrial organizations and scores each using GRI 3's own severity and likelihood framework rather than an independently constructed set of criteria. Second, it distinguishes impact and financial materiality dimensions explicitly and combines them into a Double Materiality score using ESRS 1's own either-lens-applies logic. Third, it develops an ESG-to-operational-risk scoring model that extends GRI 3's severity-times-likelihood structure into the operational domain, substituting a residual-control factor for likelihood, and illustrates, with values computed from illustrative inputs, that materiality priority and operational-risk priority can diverge sharply for the same topic. Fourth, it develops a four-quadrant prioritisation matrix combining both scores into a decision-support tool addressing the research gap Panfilo et al. (2025) identify between double-materiality reporting and substantive risk management action, and tests the stability of its assignments to weights, functional forms, control assumptions and cut-offs. Fifth, it specifies a reproducible scoring protocol and an expert-validation (Delphi) protocol that organizations and researchers can apply to real data.

Status of the evidence. The input scores in this paper are illustrative: they were assigned by the author to exercise the model and were not drawn from any organization's risk register or audited records. Every derived value (Severity, Impact Materiality, Double Materiality, Operational Risk Score and quadrant) is computed exactly from those inputs, so the results show how the model behaves and what it would reveal; they do not establish that it measures operational risk accurately in any organization. No expert validation has yet been carried out; the Delphi procedure in Section II-I is a protocol for future work.

METHODOLOGY

The framework proceeds in five stages: identifying ESG topics, scoring impact materiality, scoring financial materiality, combining both into Double Materiality and extending the same underlying logic into an Operational Risk Score, and finally plotting both scores on an integrated prioritisation matrix. Figure 1 sets out this workflow. Sections II-G to II-I add a scoring protocol, the design of the sensitivity analysis and a protocol for expert validation that has been specified but not yet carried out.

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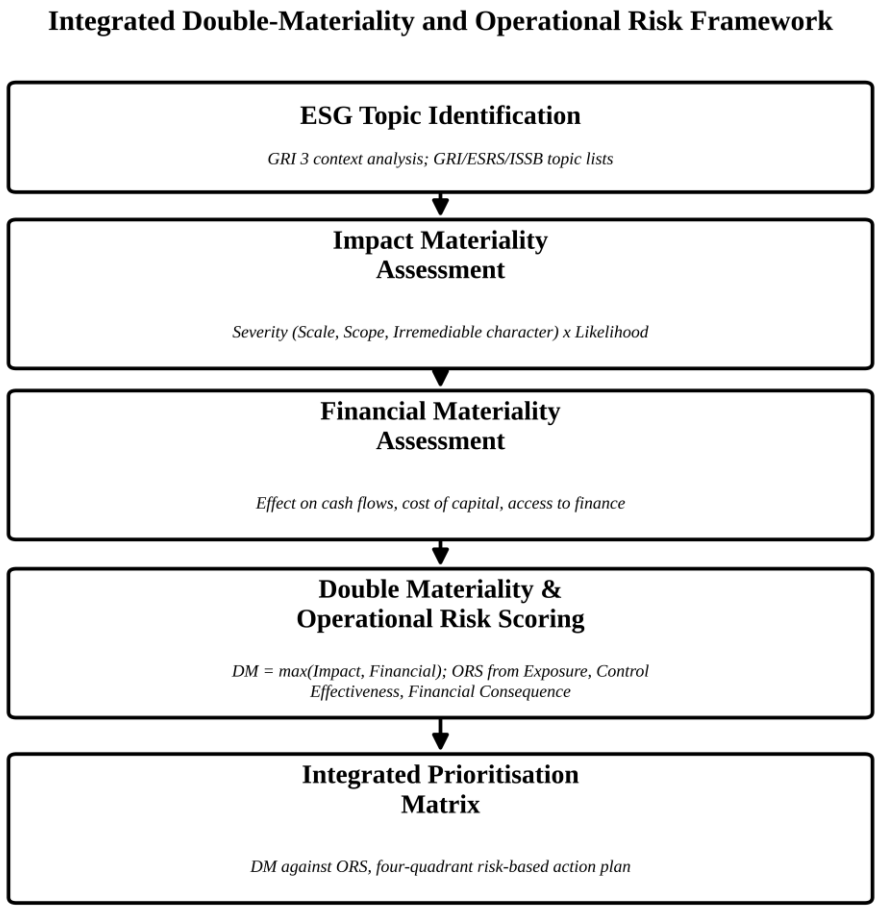


Fig. 1. Integrated double-materiality and operational risk framework

ESG Topic Identification

Eight ESG topics relevant to industrial organizations were identified following GRI 3's Step 1, understanding organizational context, and cross-checked against the topic lists in GRI's topic-specific standards, ESRS's environmental and social standards, and IFRS S2's climate-related disclosure requirements: climate change and GHG emissions; water stress and management; occupational health and safety; pollution of air, water and soil; resource scarcity and circular economy; supply chain disruption; business conduct and governance; and community and human rights. These eight were selected as representative topics, not as an exhaustive list and not as the outcome of a systematic survey of company disclosures; they span environmental, social and governance dimensions and include both stakeholder-impact-heavy topics, such as community and human rights, and financial-risk-heavy topics, such as supply chain disruption.

Impact Materiality Scoring

GRI 3 states that the significance of an actual negative impact is determined by its severity, and the significance of a potential negative impact by its severity and likelihood, with severity itself determined by three characteristics: scale, how grave the impact is; scope, how widespread it is; and irremediable character, how hard it is to counteract (Global Reporting Initiative, 2021). This paper scores each of the three severity characteristics on a five-point scale (1 = minimal, 5 = severe) and takes Severity as their unweighted mean:

$$\mathrm{Sev_i} = \frac{\mathrm{Scale_i} + \mathrm{Scope_i} + \mathrm{Irrem_i}}{3} \quad (1)$$

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Likelihood is scored separately on a five-point scale (1 = rare, 5 = near-certain), following GRI 3's guidance that likelihood can be expressed qualitatively or as a probability. Impact Materiality combines the two exactly as GRI 3's own severity-times-likelihood significance logic specifies, normalised to keep the result on the same 0-5 scale as the two inputs:

$$\mathrm{ImpM_i} = \frac{\mathrm{Sev_i} \times \mathrm{Like_i}}{5} \tag{2}$$

Financial Materiality Scoring

Financial Materiality was scored directly on a five-point scale following IFRS S1's definition of information that "could reasonably be expected to affect" an entity's cash flows, cost of capital or access to finance (IFRS Foundation, 2023), a definition with which the financial-materiality dimension of ESRS 1's double-materiality architecture is closely aligned (European Commission, 2023). No further decomposition into sub-characteristics was applied at this stage, since, unlike GRI 3's impact-severity guidance, neither IFRS S1 nor ESRS 1 specifies named financial-materiality sub-components in the way GRI 3 specifies scale, scope and irremediable character for impact severity.

Double Materiality

ESRS 1 states that double materiality has two dimensions, impact materiality and financial materiality, and that a topic is material under ESRS if either dimension applies (European Commission, 2023, ESRS 1, Section 3.1). This paper translates that either-lens-applies logic directly into a maximum function rather than an average, since averaging would understate a topic that is severely impact-material but only moderately financially material, or vice versa, in a way the Standard's own wording does not support:

$$\mathrm{DM_i} = \max(\mathrm{ImpM_i}, \mathrm{FM_i}) \tag{3}$$

The maximum function is a normative modelling choice: it follows the either-lens-applies wording of ESRS 1, but it makes Double Materiality insensitive to whichever dimension scores lower. Weighted averages are therefore tested as alternatives in Section III-G.

Operational Risk Score

To extend GRI 3's severity-times-likelihood structure into the operational domain, this paper defines three operational-risk inputs, each scored on a five-point scale: Operational Exposure (OE), the degree to which core operations are exposed to the topic; Control Effectiveness (CE), how effective current internal controls are at preventing or mitigating the topic's negative consequences (5 = highly effective); and Financial Consequence (FC), the potential financial impact should the risk materialise. Mirroring GRI 3's structure, in which likelihood scales up significance, the average of exposure and consequence is multiplied by a control factor that rises as control effectiveness falls, since weak controls increase the likelihood that exposure and consequence translate into actual harm. The factor is bounded below by a residual-risk floor φ, because no control is perfectly effective: controls can fail, be circumvented or become outdated, and risk-management guidance treats the risk remaining after treatment as residual risk that must itself be recorded and monitored (International Organization for Standardization, 2018). A form without a floor, in which the factor is (5 − CE)/5, returns exactly zero for CE = 5 whatever the exposure and financial consequence; the floor removes that artefact, and the gap form is retained only as a sensitivity variant (Section III-G):

$$\mathrm{ORS_i} = \frac{\mathrm{OE_i} + \mathrm{FC_i}}{2} \times \left[\varphi + (1 - \varphi)\,\frac{5 - \mathrm{CE_i}}{4}\right] \tag{4}$$

where φ = 0.20 is the residual-risk floor, so that the control factor runs linearly from 1.00 when controls are absent (CE = 1) to 0.20 when they are fully effective (CE = 5), and OE, CE and FC are the integer scores defined in Table I. A topic with strong controls therefore returns a low but non-zero Operational Risk Score that remains proportional to its exposure and financial consequence, while a topic with minimal control returns the full average of exposure and consequence. The value of φ is a modelling assumption, not an

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empirical estimate; Section III-G tests values from 0 to 0.40, and organizations should calibrate it to their own control-failure experience.

Integrated Prioritisation Matrix

Double Materiality and the Operational Risk Score are plotted together on a two-axis matrix, divided into four quadrants at the sample mean of each axis, which addresses Research Gap 4. A topic is classed as high on an axis if its score is at or above the cut-off. Topics combining high Double Materiality with high Operational Risk fall into an Act Now quadrant warranting immediate attention; high Double Materiality with low Operational Risk falls into a Disclose and Govern quadrant, where reporting and governance oversight are appropriate but urgent operational intervention is not; low Double Materiality with high Operational Risk falls into a Monitor Closely quadrant; and low Double Materiality with low Operational Risk falls into Routine Monitoring. Sample means are used as default cut-offs because they need no external calibration and express priority relative to the organization's own topic list. They have two drawbacks: they move when topics are added or removed, and with only eight topics a borderline topic can cross a boundary on a small change. Section III-H therefore tests the sample median, fixed scale-based cut-offs and shifted means, and an organization applying the framework should replace the sample mean with fixed cut-offs tied to its own risk appetite once its scores have been calibrated against real data.

Scoring Protocol and Assessor Procedure

Table I defines every rating level for the eight inputs and the evidence required to assign it. Likelihood levels follow the qualitative-or-probabilistic expression GRI 3 permits; the percentage bands for the financial inputs are expressed against annual operating profit (EBITDA) as a reference and should be recalibrated to the organization's own materiality threshold. For an actual, already occurring negative impact, Likelihood is scored 5.

Table I. Scoring Protocol: Rating Levels and Required Evidence

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Input (what is scored)	**1**	**2**	**3**	**4**	**5**	**Evidence required**
Scale (gravity of the impact)	Negligible; no discernible harm	Minor harm, quickly reversed	Moderate harm; contained and remediable	Serious harm to health, livelihoods or ecosystems	Severe harm: loss of life, irreversible damage or gross rights violation	Incident and injury records, environmental monitoring, regulator notices, impact assessments
Scope (breadth of the impact)	One workstation or small team	One facility	Several sites or one local community	Several regions, communities or a major value-chain tier	Organization-wide, value-chain-wide or global	Site and value-chain maps; workforce and community exposure data
Irremediable character (difficulty of reversal)	Fully reversible at once	Reversible within months at low cost	Reversible within years with substantial effort	Only partly reversible	Not reversible (fatality, species loss, permanent contamination)	Remediation case histories; restoration cost and time estimates
Likelihood (over a three-	Rare (< 5%)	Unlikely (5–20%)	Possible (20–50%)	Likely (50–80%)	Near-certain (> 80%) or already	Incident frequency, near-

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year horizon)					occurring	miss data, sector loss data, scenario analysis
Financial materiality, FM (effect on cash flows, cost of capital or access to finance, with likelihood)	< 1% of annual EBITDA	1–3%	3–10%	10–25%	> 25%, or threat to financing or continuity	Financial-model sensitivities; carbon-price and liability scenarios; lender and investor feedback
Operational Exposure, OE (share of operations, assets or workforce affected)	< 5%	5–15%	15–35%	35–60%	> 60%, or a core process	Asset register; process maps; revenue and headcount by process
Control Effectiveness, CE	No control, or untested	Informal, undocumented controls	Documented controls, partly tested, known gaps	Documented, tested and monitored; minor gaps	Mature controls independently tested or assured; no significant gaps in last audit cycle	Internal audit findings; control-test results; management-system audits; incident trends
Financial Consequence, FC (direct loss if the risk materialises)	< 1% of annual EBITDA	1–3%	3–10%	10–25%	> 25%, or threat to financing or continuity	Loss history; insurance claims; penalty schedules; remediation and replacement cost estimates

Each topic should be scored independently by at least two assessors drawn from different functions, for example sustainability reporting, enterprise risk or internal audit, environment-health-safety or operations, and finance, each recording the evidence behind every score. Where two assessors differ by two or more points on any input, the evidence is reviewed jointly and, if disagreement persists, a third assessor adjudicates; agreement before reconciliation (for example, weighted Cohen's kappa for two assessors or an intraclass correlation for more) is reported alongside the final scores. Scores are re-assessed at least annually and whenever an incident, audit finding or regulatory change alters the evidence.

The scores in Tables II to IV are illustrative inputs assigned by the author, acting as the single assessor, from the industrial-sector patterns documented in the standards and disclosures consulted. No second assessor was used, so no disagreement-resolution procedure was applied and no inter-assessor agreement can be reported, and the scores were not derived from any organization's risk register. They have been checked for consistency with the rating levels in Table I and are best read as plausible values for a generic heavy-industry organization, chosen to exercise the model.

Sensitivity Analysis Design

Because the scores and several structural choices are assumptions, the analysis tests whether rankings and quadrant assignments survive reasonable alternatives. The variations are: (i) alternative Severity weights; (ii) alternative functional forms for Impact Materiality, the geometric mean $\sqrt{(Sev \times Lik)}$ and the arithmetic mean $(Sev + Lik)/2$; (iii) alternative Double Materiality rules, the arithmetic mean and two weighted averages in place of the maximum; (iv) alternative control assumptions, namely floors φ of 0, 0.10, 0.30 and 0.40, the gap form without a floor, a one-point reduction of every Control Effectiveness score to represent optimism in self-assessed controls, unequal weights on OE and FC, and a geometric-mean form for the

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exposure-consequence term; and (v) alternative quadrant cut-offs, the sample median, fixed scale-based values and sample means shifted by 10%. For each variation the Spearman rank correlation ρ_s between the varied and baseline scores (Double Materiality for variations (i) to (iii), Operational Risk Score for (iv)) and the topics that change quadrant are reported. To represent scoring uncertainty directly, each of the 64 input scores (eight inputs for each of eight topics) is also perturbed independently by −1, 0 or +1 with probabilities 0.25, 0.50 and 0.25 (limited to the 1–5 range) in 10,000 random draws, with cut-offs recomputed at the sample means in every draw, and the share of draws in which each topic keeps its baseline quadrant is reported. The random seed and code are provided with the paper (see Data Availability).

Proposed Expert Validation (Delphi Protocol)

This step has not been carried out, and no Delphi results are reported in this paper. It is specified so that it can be conducted and reported reproducibly. A three-round Delphi procedure is proposed (Dalkey and Helmer, 1963; Hasson et al., 2000), in which specialists revise their judgments after anonymised, controlled feedback (Rowe and Wright, 1999). Fifteen practitioners would be recruited purposively in three groups of five (enterprise risk managers at industrial companies, sustainability and materiality-assessment specialists, and academic researchers in ESG disclosure and corporate risk governance), a size within the range commonly used for Delphi panels (Okoli and Pawlowski, 2004). Recruitment criteria (for example, at least five years of relevant experience and no involvement in scoring the topics), the numbers invited, accepted and retained in each round, and reasons for withdrawal would be recorded.

In each round panelists would rate the four framework elements (the impact-materiality severity scoring, the operational risk scoring, the integrated prioritisation matrix and the overall framework) for Clarity, Feasibility and Utility on a five-point Likert scale, with free-text comments, and would rank the eight topics by priority. From round 2, each panelist would see the panel median, interquartile range (IQR) and rating distribution for every item and the anonymised comments. Consensus on an element would be defined in advance as at least 80% of retained panelists rating it 4 or above in the final round with an IQR of 1 or less, combining a percentage-agreement criterion with a dispersion measure (von der Gracht, 2012); the process would stop after round 3 or earlier if agreement changes little between rounds. Agreement on the topic rankings would be summarised with Kendall's coefficient of concordance (Kendall, 1948), computed separately for each round:

$$W = \frac{12S}{m^2(n^3 - n)} \tag{5}$$

where m is the number of panelists, n = 8 is the number of topics ranked, and S is the sum of squared deviations of each topic's rank-sum from the mean rank-sum, $m(n + 1)/2$. Where panelists tie topics, the denominator is reduced by $m\Sigma T$, with $T = \Sigma(t^3 - t)$ over each panelist's groups of t tied ranks. For $n > 7$ the statistic $m(n - 1)W$ is referred to a chi-square distribution with $n - 1$ degrees of freedom to test the null hypothesis of no agreement (Siegel and Castellan, 1988); $W \geq 0.70$ is conventionally read as strong agreement (Schmidt, 1997). W applies to rankings, not to Likert ratings, so ratings are summarised by medians, IQRs and percentages instead. The panel's consensus ranking would also be compared with the framework's ranking by Spearman's ρ_s. The reporting package would comprise round-by-round response and retention counts, full rating distributions, medians and IQRs, the consensus classification of each element, W with its test statistic and p value for each round, and the anonymised comments, with raw ratings archived in de-identified form.

RESULTS

This section reports the model's outputs for the illustrative inputs described in Section II-G. The values are computed exactly from those inputs; they show how the model behaves, not the operational risk of any organization.

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Impact Severity Components by Topic

Table II reports the three GRI 3 severity components, Scale, Scope and Irremediable character, for each of the eight topics, together with the resulting Severity score from Equation (1); Fig. 2 plots them.

TABLE II. Impact Severity Components by ESG Topic

ESG Topic	Scale	Scope	Irremediable	Severity
Climate Change & GHG Emissions	5	5	4	4.67
Water Stress & Management	4	4	3	3.67
Occupational Health & Safety	5	3	5	4.33
Pollution (Air, Water, Soil)	4	4	4	4.00
Resource Scarcity & Circular Economy	3	3	3	3.00
Supply Chain Disruption	3	4	2	3.00
Business Conduct & Governance	3	2	3	2.67
Community & Human Rights	4	3	4	3.67

Reading Table II by column rather than by row shows that no single severity characteristic dominates the ranking on its own: the two highest-Severity topics lead on different characteristics, climate change on Scale and Scope, occupational health and safety on Irremediable character, which is itself a useful check on Equation (1)'s averaging approach, since a formula that only ever rewarded one characteristic would risk systematically underweighting topics like occupational health and safety whose severity is driven by finality rather than breadth.

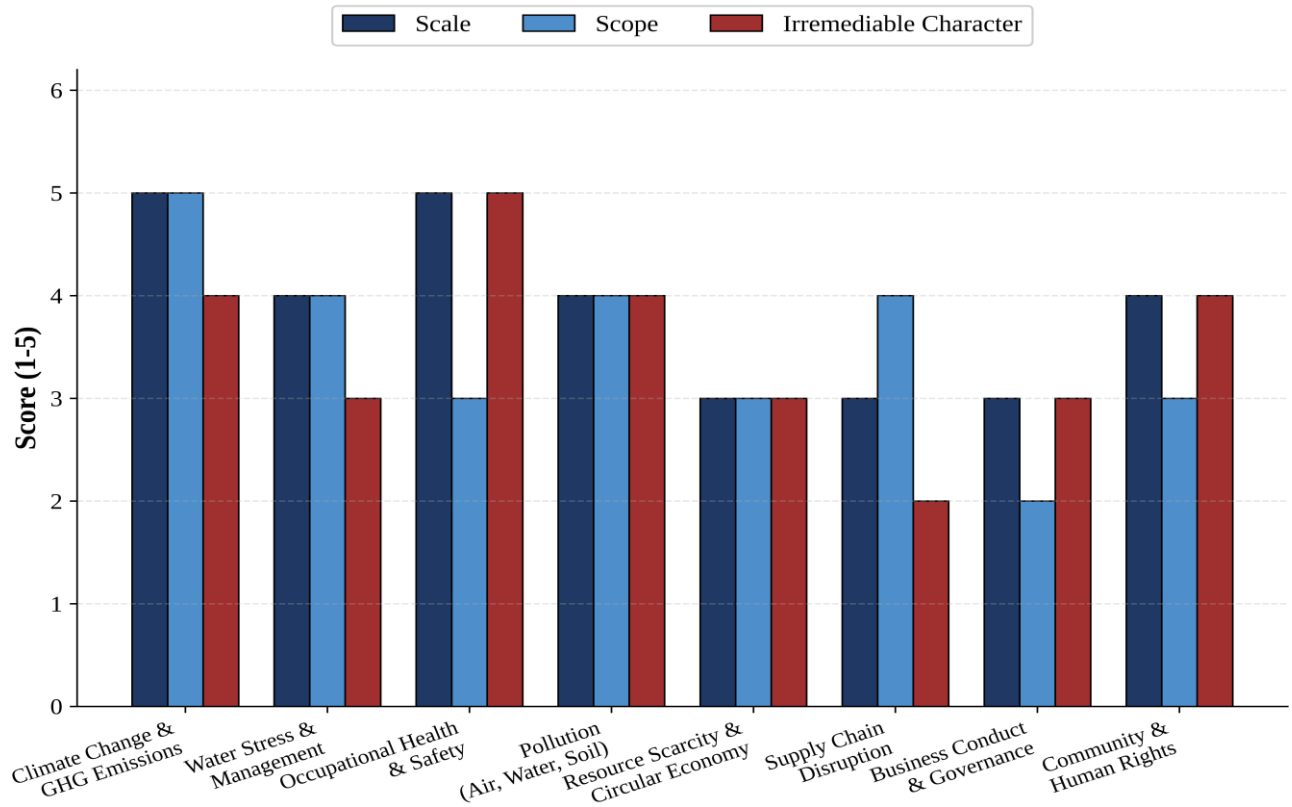


Fig. 2. Impact severity components by ESG topic

Climate change and occupational health and safety return the two highest Severity scores (4.67 and 4.33), but for different reasons: climate change scores maximally on Scale and Scope, reflecting its global reach, while occupational health and safety scores maximally on Irremediable character specifically, reflecting that a workplace fatality or serious injury cannot be undone regardless of how localised the incident is. Business conduct and governance returns the lowest Severity (2.67), consistent with governance lapses typically

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being correctable, through board changes, policy revision or remediation payments, in a way environmental and safety harms often are not.

Impact, Financial and Double Materiality

Table III reports Likelihood, Impact Materiality from Equation (2), Financial Materiality, and the resulting Double Materiality from Equation (3) for all eight topics; Fig. 3 plots the three materiality scores.

TABLE III. Impact, Financial and Double Materiality by ESG Topic

ESG Topic	Likelihood	ImpM	FM	DM
Climate Change & GHG Emissions	4	3.73	5	5.00
Water Stress & Management	4	2.93	3	3.00
Occupational Health & Safety	3	2.60	4	4.00
Pollution (Air, Water, Soil)	3	2.40	3	3.00
Resource Scarcity & Circular Economy	3	1.80	3	3.00
Supply Chain Disruption	4	2.40	5	5.00
Business Conduct & Governance	2	1.07	4	4.00
Community & Human Rights	2	1.47	2	2.00

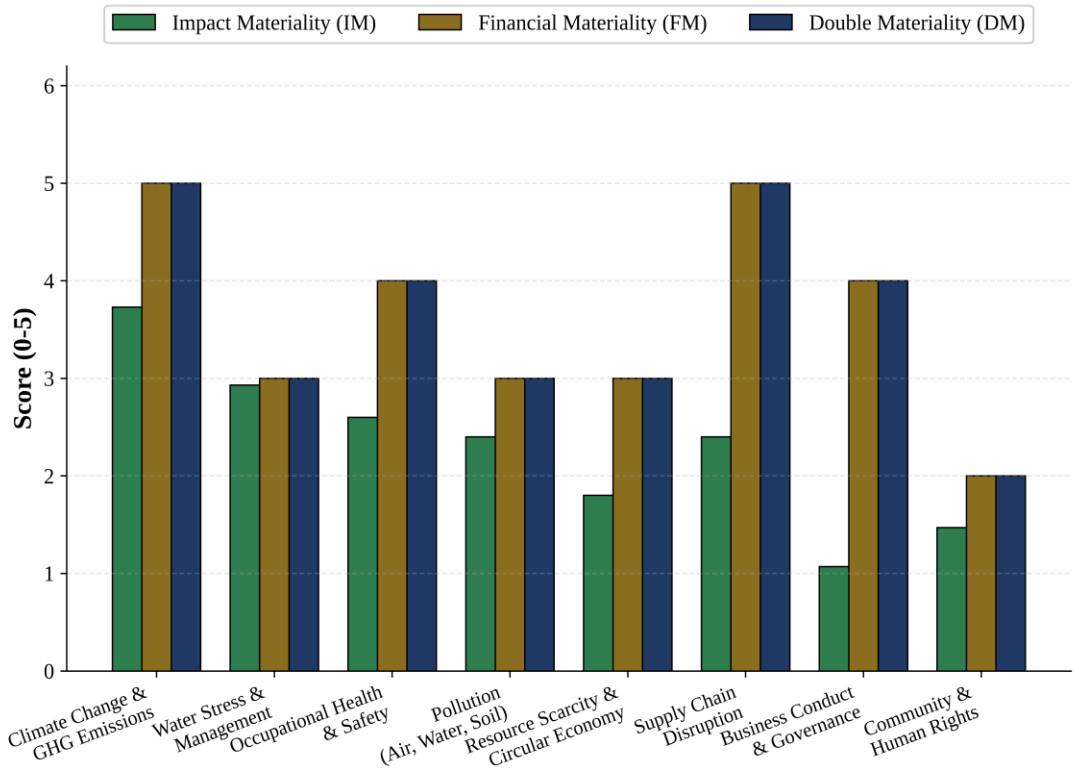


Fig. 3. Impact Materiality, Financial Materiality and Double Materiality by ESG topic

Climate change and supply chain disruption tie for the highest Double Materiality (5.00 each), but Table III shows that this tie conceals two different underlying stories. Climate change reaches 5.00 through Financial Materiality alone, since its Impact Materiality of 3.73 would not have been sufficient on its own. Supply chain disruption also reaches 5.00 through Financial Materiality, from an even lower Impact Materiality of 2.40: its moderate Severity (3.00), multiplied by a Likelihood of 4, gives only 2.40 on the 0–5 scale. In both cases, Equation (3)'s maximum function is doing exactly the work ESRS 1's either-lens-applies wording calls for: a topic reaches full Double Materiality on the strength of financial exposure alone, without requiring the impact lens to independently confirm the same severity.

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Operational Risk Components and Score

Table IV reports Operational Exposure, Control Effectiveness and Financial Consequence, and the resulting Operational Risk Score from Equation (4), for all eight topics; Fig. 4 plots the three inputs.

TABLE IV. OPERATIONAL RISK COMPONENTS AND SCORE BY ESG TOPIC

ESG Topic	Exposure	Control Eff.	Fin. Consequence	ORS
Climate Change & GHG Emissions	5	3	5	3.00
Water Stress & Management	4	3	3	2.10
Occupational Health & Safety	4	4	4	1.60
Pollution (Air, Water, Soil)	3	3	3	1.80
Resource Scarcity & Circular Economy	3	4	2	1.00
Supply Chain Disruption	4	2	5	3.60
Business Conduct & Governance	2	5	4	0.60
Community & Human Rights	2	4	2	0.80

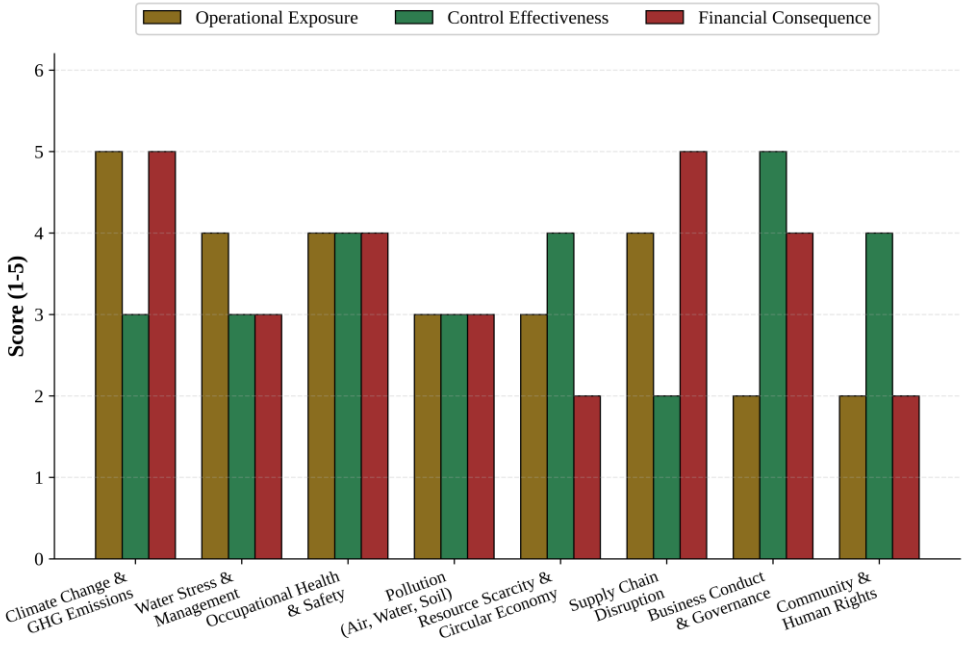


Fig. 4. Operational risk components by ESG topic

Business conduct and governance combines the joint-lowest Operational Exposure (2, shared with community and human rights) with the highest Control Effectiveness (5) of any topic, a pairing consistent with governance typically being managed through mature, board-level oversight structures that most industrial companies have operated for decades, well before ESG reporting created a separate disclosure obligation for the same topic. Supply chain disruption shows close to the opposite pattern, combining above-average Operational Exposure (4) with the lowest Control Effectiveness (2) of any topic, reflecting that supply chain risk is structurally harder to control directly, since the controls that matter most, supplier financial health, alternate sourcing capacity, logistics resilience, sit substantially outside the reporting company's own operations.

Double Materiality Against Operational Risk

Table III and Table IV each describe one half of a topic's overall risk profile, but neither, read alone, answers the question a risk committee actually needs answered: given everything this framework has scored so far, which topics deserve attention first? Figure 5 plots Double Materiality against the Operational Risk

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Score directly for all eight topics, the comparison this paper's Research Gap 4 calls for, making visible exactly where the two measures agree and where they pull apart. Across the eight topics, Double Materiality and Operational Risk Score correlate only moderately (Pearson r = 0.70; Spearman ρ_s = 0.54), confirming numerically that the two scores are measuring related but distinct things rather than one simply restating the other in different units; a correlation close to 1.0 would have meant Section II-E's additional scoring step added little beyond what Double Materiality alone already captured.

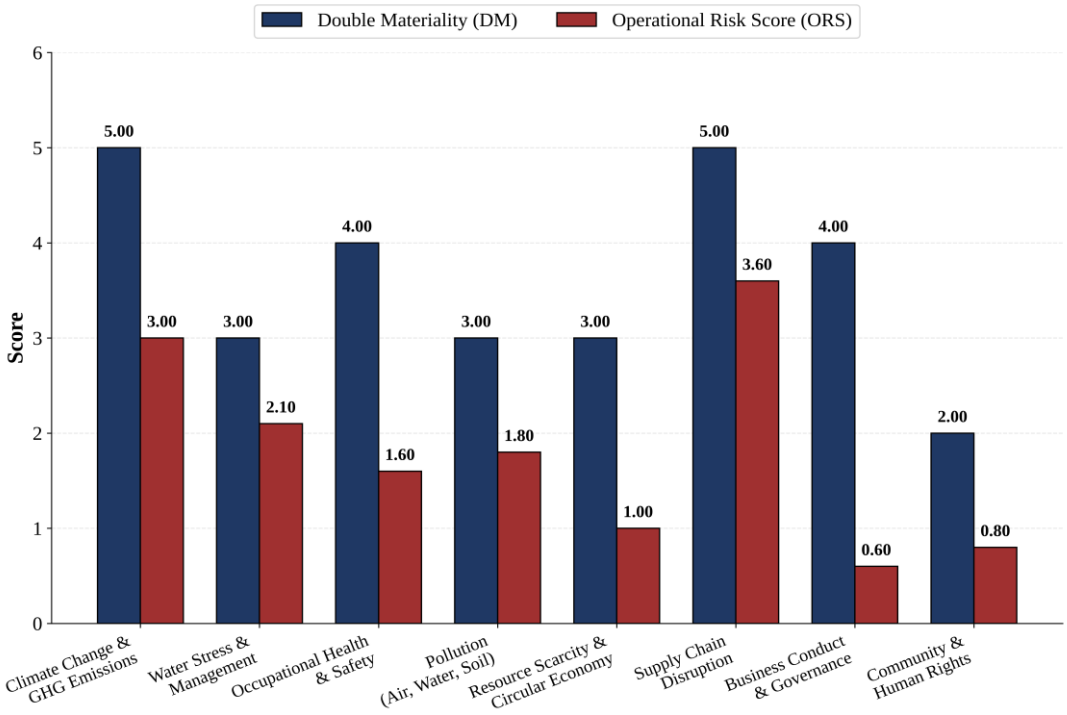


Fig. 5. Double Materiality against Operational Risk Score by ESG topic

The two rankings diverge sharply for two topics in particular. Business conduct and governance ranks joint-third on Double Materiality (4.00, tied with occupational health and safety) but returns the lowest Operational Risk Score (0.60), whereas climate change and supply chain disruption tie for the highest Double Materiality (5.00 each) but diverge on Operational Risk Score, climate change at 3.00 and supply chain disruption at 3.60, the highest of any topic studied. These divergences are examined in detail in the worked example below.

Worked Example: Governance Versus Supply Chain Disruption

Tracing the full calculation chain for these two topics shows precisely why a single materiality score cannot substitute for a separate operational-risk score. Business conduct and governance scored Scale = 3, Scope = 2 and Irremediable character = 3, giving, from Equation (1):

$$\mathrm{Sev}_{\mathrm{Gov}} = \frac{3+2+3}{3} = 2.67 \tag{6}$$

With a Likelihood of 2, Equation (2) gives an Impact Materiality of only 1.07, but a Financial Materiality of 4 reflects the real cost of governance failures through investor confidence, regulatory penalties and cost of capital, so Equation (3) gives:

$$\mathrm{DM}_{\mathrm{Gov}} = \max(1.07, 4) = 4.00 \tag{7}$$

For Operational Risk, governance scored Exposure = 2, Control Effectiveness = 5 and Financial Consequence = 4. Equation (4) gives:

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$$\mathrm{ORS}_{\mathrm{Gov}} = \frac{2+4}{2} \times \left[0.20 + 0.80 \times \frac{5-5}{4}\right] = 0.60 \quad (8)$$

Supply chain disruption, by contrast, scored Exposure = 4, Control Effectiveness = 2 and Financial Consequence = 5, giving:

$$\mathrm{ORS}_{\mathrm{SCD}} = \frac{4+5}{2} \times \left[0.20 + 0.80 \times \frac{5-2}{4}\right] = 3.60 \quad (9)$$

Both topics reach their Double Materiality through financial exposure alone, 4.00 for governance and 5.00 for supply chain disruption, but Equation (4)'s control factor produces very different Operational Risk Scores from that similar starting point: governance's Control Effectiveness of 5 reduces the control factor to its floor of 0.20, while supply chain disruption's Control Effectiveness of 2 leaves it at 0.80, so most of the exposure and consequence remain unmitigated. A company reading only its Double Materiality assessment would treat these two topics as comparably urgent; a company that also runs Equation (4) learns that one of them is largely under control, though not risk-free, with 0.60 of residual risk remaining, and the other is not.

Integrated Prioritisation Matrix

Figure 6 plots all eight topics on the integrated prioritisation matrix described in Section II-F, divided at the sample mean Double Materiality (3.63) and mean Operational Risk Score (1.81).

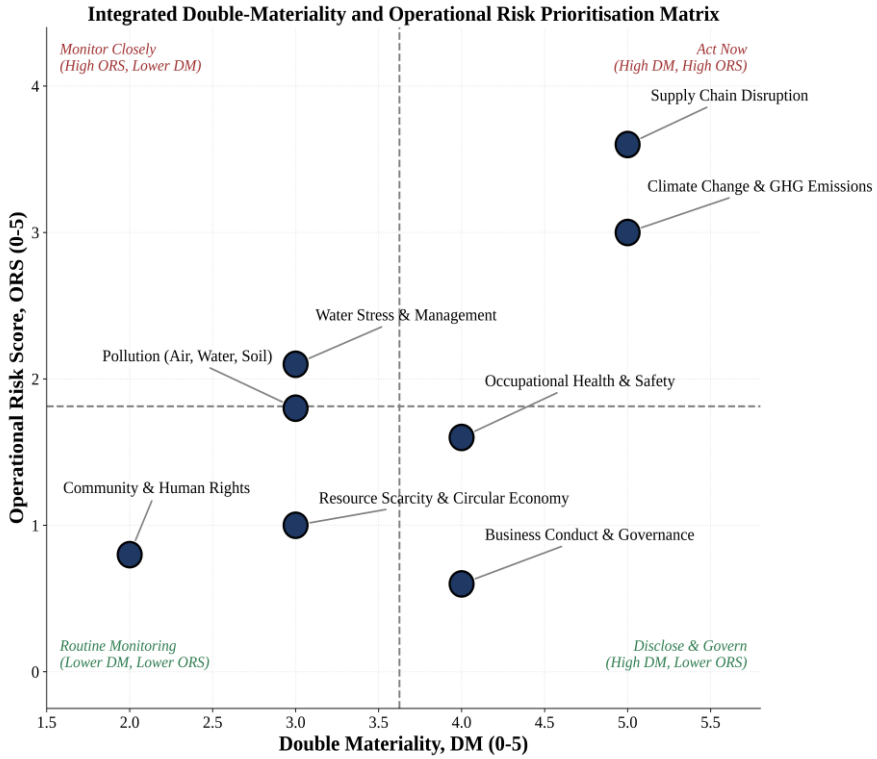


Fig. 6. Integrated double-materiality and operational risk prioritisation matrix

Supply chain disruption and climate change fall in the Act Now quadrant, combining above-average Double Materiality with above-average Operational Risk, and both the worked example in Section III-E and the underlying Control Effectiveness scores in Table IV point toward the same candidate response: these are the two topics where additional direct operational investment (supplier diversification and contingency planning for supply chain disruption; decarbonisation and physical-risk adaptation for climate change) would be considered first. Business conduct and governance and occupational health and safety fall in the Disclose and Govern quadrant, above-average Double Materiality paired with below-average Operational Risk, indicating that continued board-level and management oversight and transparent disclosure, rather than urgent new operational control investment, would be the proportionate response, since Table IV shows both

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topics' Control Effectiveness at or above the scale midpoint of 3. Water stress falls in the Monitor Closely quadrant, below-average on Double Materiality but above the mean Operational Risk Score. Pollution, resource scarcity and community and human rights fall in Routine Monitoring; pollution's Operational Risk Score (1.80) lies only 0.01 below the cut-off of 1.81, so its assignment is not robust (Section III-H).

Sensitivity of Rankings and Quadrants

Table V reports, for each variation described in Section II-H, the Spearman rank correlation with the baseline and the topics whose quadrant changes.

TABLE V. SENSITIVITY OF RANKINGS AND QUADRANT ASSIGNMENTS TO MODEL VARIATIONS

Variation	ρ_s vs baseline	Quadrant changes from baseline
Baseline (Equations 1–4, $\varphi = 0.20$)	1.00	—
Severity weights 0.50 / 0.25 / 0.25 (Scale / Scope / Irrem.)	1.00	—
Severity weights 0.25 / 0.25 / 0.50	1.00	—
ImpM = $\sqrt{(\text{Sev} \times \text{Lik})}$	0.98	—
ImpM = (Sev + Lik) / 2	0.98	—
DM = 0.5 ImpM + 0.5 FM (mean)	0.84	Water stress → Act Now; Governance → Routine Monitoring
DM = 0.7 ImpM + 0.3 FM	0.78	Water stress → Act Now; Governance → Routine Monitoring
DM = 0.3 ImpM + 0.7 FM	0.96	Governance → Routine Monitoring
Residual-risk floor $\varphi = 0.00$	1.00	Pollution → Monitor Closely
Residual-risk floor $\varphi = 0.10$	1.00	Pollution → Monitor Closely
Residual-risk floor $\varphi = 0.30$	1.00	—
Residual-risk floor $\varphi = 0.40$	0.95	—
Gap form (5 − CE)/5, no floor	1.00	Pollution → Monitor Closely
CE reduced by one point (min. 1)	0.99	—
ORS weights 0.7 OE / 0.3 FC	1.00	—
ORS weights 0.3 OE / 0.7 FC	1.00	—
ORS = $\sqrt{(\text{OE} \times \text{FC})} \times$ control factor	1.00	—

Rankings are highly stable: the rank correlation with the baseline is 0.95 or higher for every variation except the arithmetic-mean and impact-heavy Double Materiality rules (0.84 and 0.78). Quadrant assignments are more sensitive. Climate change and supply chain disruption remain in Act Now in every variation, and the Severity-weight and Impact Materiality variations change no assignment. The Double Materiality rule matters most: under any averaging rule governance moves from Disclose and Govern to Routine Monitoring, because its Double Materiality of 4.00 rests entirely on financial materiality and falls to 2.53 when averaged with an Impact Materiality of 1.07, and under the arithmetic-mean and impact-heavy rules water stress moves, marginally, into Act Now. The maximum function is therefore a normative choice in line with ESRS 1's either-lens-applies wording, not an empirically superior one. Among control assumptions, the floor affects only pollution, which sits within 0.01 of the Operational Risk Score cut-off in the baseline: at $\varphi \leq 0.10$, or under the gap form, it moves to Monitor Closely. The zero-risk artefact is visible in the gap form, where governance scores 0.00 against 0.60 in the baseline, but the rank order of Operational Risk Scores is unchanged ($\rho_s = 1.00$).

Alternative Cut-offs and Score Uncertainty

Table VI shows each topic's quadrant under alternative cut-offs (Double Materiality / Operational Risk Score in each column heading) and the share of the 10,000 perturbed-score draws in which it keeps its baseline quadrant. Quadrant codes are AN (Act Now), DG (Disclose and Govern), MC (Monitor Closely) and RM (Routine Monitoring).

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TABLE VI. Quadrant Assignment Under Alternative Cut-Offs And Under Score Perturbation

ESG topic	Baseline: mean (3.63 / 1.81)	Median (3.50 / 1.70)	Fixed (3.5 / 2.5)	Fixed (3.0 / 2.0)	Mean −10% (3.26 / 1.63)	Mean +10% (3.99 / 1.99)	Draws keeping baseline quadrant (%)
Climate change	AN	AN	AN	AN	AN	AN	96
Water stress	MC	MC	RM	AN	MC	MC	46
Occupational H&S	DG	DG	DG	DG	DG	DG	49
Pollution	RM	MC	RM	DG	MC	RM	39
Resource scarcity	RM	RM	RM	DG	RM	RM	74
Supply chain disruption	AN	AN	AN	AN	AN	AN	100
Governance	DG	DG	DG	DG	DG	DG	74
Community & human rights	RM	RM	RM	RM	RM	RM	100

Climate change (96%), supply chain disruption (100%) and community and human rights (100%) are stable; resource scarcity and governance keep their quadrant in 74% of draws; and occupational health and safety (49%), water stress (46%) and pollution (39%), whose scores lie close to a cut-off, keep their baseline quadrant in fewer than half of the draws. Under fixed cut-offs of 3.5 and 2.5, water stress moves to Routine Monitoring because its Operational Risk Score (2.10) is below 2.5; under the lower fixed cut-offs of 3.0 and 2.0, water stress moves to Act Now and pollution and resource scarcity move to Disclose and Govern, because the many topics with Double Materiality of 3.00 now count as high. Quadrant assignments for borderline topics should therefore be treated as provisional; only the placement of climate change and supply chain disruption in Act Now, and of community and human rights in Routine Monitoring, holds in every variation. These checks vary the model's assumptions and the scores' noise; they do not test whether the underlying scores are right.

DISCUSSION

Addressing the Symbolic-Adoption Gap

Panfilo, Scarpa and Canestraro (2025) find that double materiality adoption does not significantly improve ESG risk management, drawing on 442 companies' 2022 disclosures; this is the paper's central motivating evidence. The governance-versus-supply-chain divergence in Section III-E illustrates one mechanism that could contribute to such a null result, although the present study cannot test it. A company that stops at Double Materiality scoring would see business conduct and governance and supply chain disruption as comparably material, 4.00 and 5.00 respectively, and would have no quantitative basis within the materiality assessment itself for treating one as more operationally urgent than the other. Only by extending the assessment into the Operational Risk Score, as Equation (4) does, does the difference, 0.60 against 3.60, become visible. If, as Panfilo et al. suggest, many companies' double materiality adoption is symbolic, stopping at the disclosure-ready Double Materiality number, the framework identifies a candidate missing step and shows, for illustrative inputs, that its output is not redundant with the materiality assessment it follows ($r = 0.70$ between the two scores). Whether the step improves risk management in practice is untested.

The Maximum Function Versus Averaging for Double Materiality

Section II-D chose a maximum function over an average for combining Impact and Financial Materiality. Table III shows why the choice matters in magnitude: climate change's Impact Materiality of 3.73 and Financial Materiality of 5 would average to 4.37, understating the maximum score that ESRS 1's either-lens-applies wording entitles the topic to, and supply chain disruption's gap is larger, an Impact Materiality of 2.40 against a Financial Materiality of 5 averaging to only 3.70, nearly a full point below the 5.00 the

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maximum function assigns. Averaging would therefore lower the Double Materiality of the two topics identified as Act Now, although it would not change their quadrant (Section III-G). The choice does change other assignments: under any averaging rule governance moves from Disclose and Govern to Routine Monitoring, since its Double Materiality rests on financial exposure alone. The maximum function is therefore a normative choice that follows the standard's wording, not an empirically superior one, and organizations should report results under both rules when the placement of a financially driven topic matters.

Comparison with Prior Materiality-Risk Literature

Guruprasad et al. (2024) analyse the sustainability disclosures of the 150 largest BSE-listed companies and report trends and gaps in Indian BRSR reporting. This study does not test how those disclosures relate to risk management, but the gaps they document are the setting in which a transparent, structured prioritisation step is most needed: without one, a reporting team has no systematic basis for deciding which disclosed topics warrant deeper connection to risk processes first. The ESG–ERM overlap literature's identification of risk identification and internal controls as core convergence points between ESG and enterprise risk management (Stasytytė and Shahid, 2026) maps onto this paper's Control Effectiveness input, which acts as a single quantified bridge between the two domains that the literature describes mainly qualitatively. The COSO and WBCSD (2018) guidance and the risk-matrix critique of Cox (2008) bear on the same point from opposite sides: the former supports treating ESG topics inside the ERM process, the latter cautions that coarse ordinal scoring can misrank risks, which is why this paper reports sensitivity analysis and treats borderline placements as provisional.

Demonstrated Findings and Proposed Applications

Demonstrated here, for illustrative inputs. (i) The scoring chain from GRI 3 severity components to Double Materiality and Operational Risk Score can be computed reproducibly from tabulated inputs. (ii) Double Materiality and Operational Risk Score are related but distinct (Pearson $r = 0.70$; Spearman $\rho_s = 0.54$), and governance and supply chain disruption illustrate how a topic can rank high on one and low on the other. (iii) A control-gap formula without a floor returns zero risk for fully effective controls, and a floor of 0.20 removes that artefact without altering the rank order. (iv) Climate change and supply chain disruption stay in Act Now under every variation tested, whereas the placement of water stress, occupational health and safety and pollution is sensitive to weights, cut-offs and scoring noise.

Proposed, not demonstrated. The following are applications the framework suggests, not findings. An organization's internal audit function, which already tests control effectiveness for financial and operational risks, may be the natural owner of the Control Effectiveness input, which would also ease the data-access constraint noted in the limitations. A board sustainability or risk committee reviewing a Double Materiality assessment could ask, before closing each item, not only how material the topic is but how well it is currently controlled. The four quadrants could differentiate resource allocation across a material-topic list, directing operational budget towards Act Now topics first. The Delphi and case-study steps in Sections II-I and IV-F would be needed before any of these is recommended as validated practice.

LIMITATIONS

1. The eight topics and their component scores are an illustrative scoring exercise by a single assessor, not a single named company's complete, audited risk register; a company applying this framework to its own data would obtain its own Severity, Materiality and Operational Risk values, and the results here should not be read as empirical evidence about any organization or sector.
2. Control Effectiveness scoring requires access to internal audit and control-testing information that sits outside most materiality-assessment teams' usual remit, which may limit feasibility in practice.
3. The equal weighting given to Scale, Scope and Irremediable character within Severity, and to Exposure and Financial Consequence within the Operational Risk Score, mirrors GRI 3's own unweighted presentation and was tested only against the alternatives in Section III-G.

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4. The framework was developed for industrial organizations specifically; its applicability to service-sector or financial-sector companies, where the balance between impact-heavy and financial-risk-heavy topics would likely differ, has not been tested.
5. No expert validation has been carried out. The Delphi procedure is a protocol only, so the clarity, feasibility and utility of the framework have not been assessed by practitioners.
6. The scores are ordinal judgements; averaging and multiplying them assumes equal steps between rating levels (Stevens, 1946), and coarse ordinal scoring can misrank risks (Cox, 2008). Quadrant labels should guide discussion and not replace quantitative risk analysis where data exist.
7. The residual-risk floor ($\varphi = 0.20$), the percentage bands in Table I and the quadrant cut-offs are modelling choices not calibrated to loss data; with eight topics, sample-mean cut-offs are unstable for borderline topics (Section III-H).
8. No named case study, documented risk-register evidence or independent expert assessment is included, and the literature review is targeted rather than systematic.

Future Research Directions

1. Applying the framework to a single named company's complete, audited materiality assessment and risk register, scored by independent assessors under the protocol in Table I and checked against documented risk-register evidence and independent expert assessment, would test whether the governance-versus-supply-chain divergence pattern generalises beyond the illustrative scoring used here.
2. Tracking the same company's Operational Risk Scores across successive reporting cycles would test whether Act Now topics, once targeted with the operational investment Section III-F recommends, show measurably declining scores over time.
3. Building a lightweight digital tool that draws Control Effectiveness scores directly from existing internal audit management systems would address the feasibility of obtaining those scores without a separate manual scoring exercise.
4. Extending the Operational Risk Score to incorporate formal uncertainty ranges elicited from assessors, beyond the ±1 perturbation used in Section III-H, and calibrating the residual-risk floor and the rating-level bands against incident and loss data.
5. Conducting the Delphi procedure specified in Section II-I and reporting its round-by-round results, retention, rating distributions and Kendall's W with its significance.

CONCLUSION

GRI 3 tells preparers that the significance of a negative impact is a function of severity and likelihood, and that this combination can be understood as risk, but it does not extend that logic into the operational domain or show how to combine it with financial materiality. This paper proposes a way to do so and demonstrates its behaviour on an illustrative set of eight industrial ESG topics: Impact Materiality is scored from GRI 3's scale, scope, irremediable-character and likelihood components, Impact and Financial Materiality are combined into a Double Materiality score using ESRS 1's either-lens-applies logic, and an Operational Risk Score is built from exposure, financial consequence and control effectiveness, with a residual-risk floor so that strong controls reduce risk without eliminating it. For the illustrative inputs, materiality priority and operational-risk priority are related but not the same ($r = 0.70$): business conduct and governance ranks joint-third on Double Materiality but lowest on Operational Risk (0.60), while supply chain disruption ranks highest on Operational Risk (3.60) and joint-highest on Double Materiality. Climate change and supply chain disruption remain in the Act Now quadrant under every variation of weights, functional forms, control assumptions and cut-offs tested; the placement of water stress, occupational health and safety and pollution does not, and the treatment of governance depends on the maximum rule for Double Materiality. These results show how the model behaves; they are not empirical validation. The immediate next steps are to apply the scoring protocol to a named organization's documented risk register with independent assessors and to conduct the Delphi procedure specified here. By making explicit the step that recent evidence (Panfilo et al., 2025) suggests many companies skip, the translation from material topic to quantified operational consequence, the framework offers a reproducible starting point for ensuring that double materiality disclosures inform substantive risk management rather than standing alongside it unconnected.

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Author Contributions

Chinmaya Bhat conceived the integrated framework, developed the mathematical formulation of the Severity, Impact Materiality, Double Materiality and Operational Risk Score equations, reviewed GRI 3, ESRS 1 and IFRS S1 for the severity and materiality scoring, carried out the calculations and sensitivity analysis, and prepared the figures, tables and manuscript.

Data Availability

All input scores are tabulated in Tables II to IV, which together form the complete dataset behind every reported index. A CSV file of the inputs and the Python script that reproduces every computed value, the sensitivity analyses (including the random seed) are provided as supplementary material with this submission. GRI 3, ESRS 1 and IFRS S1, the primary standard texts underlying the scoring methodology, are publicly available documents and are cited in the References. The scores are illustrative and no organizational data were used. No Delphi data exist because the Delphi procedure has not been conducted.

Ethics Statement

This study used illustrative scores and published standards only and involved no human participants, so ethical approval and participant consent were not required. The proposed Delphi procedure (Section II-I) would require ethical review or exemption and informed consent before any panelist is recruited.

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