

A Triangulated Audit Framework for Auditing Scope 3 Supply Chain Disclosures in Capital Markets

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Abstract

Scope 3 greenhouse gas (GHG) emissions represent 87% of total corporate emissions yet remain systematically unaudited in capital markets, creating an assurance gap that undermines investor decision-making and enables greenwashing. This study addresses the absence of a validated audit framework specifically designed for Scope 3 supply chain disclosures by developing and testing a triangulated audit model that integrates data-source verification, methodological coherence assessment, and greenwashing detection. Drawing on a sample of 1,247 firm-year observations from CDP Climate Change respondents (2018–2024), we validate the framework through comparative analysis against traditional limited-assurance approaches. Results demonstrate that the triangulated framework achieves 89.4% detection accuracy for material misstatement, outperforming conventional verification methods by 23.7 percentage points. The framework's three components—supplier data lineage tracing, GHG Protocol alignment scoring, and greenwashing risk indexing—collectively explain 78.2% of variance in assurance outcomes. Findings indicate that firms with weak governance characteristics exhibit significantly higher greenwashing probability ($\beta = 0.412$, $p < 0.001$), confirming assurance exploitation risks. The study contributes a replicable, audit-ready framework that extends beyond financial materiality

to incorporate impact materiality, offering practical guidance for auditors, standard setters, and capital market participants navigating fragmented global disclosure regimes.

Keywords: Scope 3 assurance, supply chain auditing, greenwashing detection, triangulated audit framework, GHG Protocol

1. Introduction

1.1 Background

The global regulatory landscape for climate-related financial disclosure has undergone significant transformation, yet Scope 3 greenhouse gas emissions—those indirect emissions occurring across a company's upstream and downstream value chain—remain the most material and least assured category of corporate environmental reporting . Scope 3 emissions account for approximately 87% of total emissions for carbon-intensive companies, a figure that underscores their systemic importance to capital market participants assessing climate transition risk . Despite this materiality, the disclosure and assurance infrastructure for Scope 3 data lags substantially behind that for Scope 1 and Scope 2 emissions, creating what regulators and investors increasingly identify as an assurance deficit in sustainability reporting.

The regulatory environment has evolved unevenly across jurisdictions. The European Union's Corporate Sustainability Reporting Directive (CSRD), operationalized through European Sustainability Reporting Standards (ESRS), mandates Scope 3 disclosure with limited assurance from the first reporting year for in-scope entities . The International Sustainability Standards Board (ISSB) issued IFRS S2 in 2023, requiring entities to consider all fifteen Scope 3 categories, though recent targeted amendments in 2025 introduced relief provisions for Category 15 financed emissions . In contrast, the U.S. Securities and Exchange Commission adopted climate disclosure rules in 2024 that notably excluded Scope 3 requirements, and as of 2026, the SEC has formally initiated rescission proceedings . This regulatory fragmentation creates a patchwork of disclosure obligations that complicates cross-jurisdictional comparability and assurance convergence.

The voluntary disclosure landscape presents analogous challenges. In 2024, 76% of companies representing 88% of global market capitalization disclosed at least one category of Scope 3 emissions, yet only 42% obtained external assurance of sustainability information, with the vast majority relying on limited rather than reasonable assurance . This assurance gap is particularly acute for Scope 3 data, which typically relies on supplier-provided information, spend-based estimation methodologies, and environmentally extended input-output models—all of which introduce measurement uncertainty that limited assurance procedures are poorly designed to address .

1.2 Problem Statement

The fundamental problem addressed by this research is the absence of a validated, replicable audit framework specifically designed for Scope 3 supply chain disclosures in capital market contexts. While substantial literature addresses greenwashing measurement and assurance effectiveness generally, and regulatory bodies have developed limited assurance guidelines for sustainability information, no comprehensive framework integrates the distinctive challenges of Scope 3 auditing into a coherent, testable methodology. Existing assurance approaches were largely designed for financial statement auditing or adapted from limited assurance protocols for sustainability information, neither of which adequately addresses the multi-tier data provenance, methodological heterogeneity, and estimation uncertainty inherent in Scope 3 supply chain disclosures.

This gap has practical consequences. Carbon Tracker's analysis found that over 70% of carbon-intensive companies ignored material climate issues in their 2020 financial statements, while 80% of their auditors did not flag these omissions. The New Climate Institute similarly documented that companies were not disclosing Scope 3 emissions with transparency and integrity despite these emissions representing the majority of their carbon footprint. Empirical research on Japanese listed companies demonstrates that assurance itself can be exploited by firms engaged in greenwashing to increase the degree of their overstatement, suggesting that current assurance models may paradoxically legitimize rather than deter misrepresentation.

The unsolved issue is therefore not whether assurance is valuable—the evidence strongly supports investor demand for verified sustainability information—but rather how to design an audit framework that can effectively verify Scope 3 disclosures given their distinctive characteristics: dependence on external value chain actors, reliance on estimation methodologies with wide uncertainty ranges, and the inherent potential for strategic misrepresentation in contexts of weak enforcement.

1.3 Objectives of the Study

General Objective:

To develop and validate a triangulated audit framework for assessing the reliability and integrity of Scope 3 supply chain disclosures in capital market contexts.

Specific Objectives:

1. To identify the key methodological, data-source, and governance factors that predict material misstatement in Scope 3 supply chain disclosures.
2. To design a triangulated audit framework integrating data lineage verification, GHG Protocol alignment scoring, and greenwashing risk indexing that addresses the limitations of conventional limited assurance approaches.
3. To validate the framework's detection accuracy against established assurance benchmarks using CDP Climate Change data and regulatory filing samples.

1.4 Research Questions

1. What combination of data-source, methodological, and governance variables most accurately predicts material misstatement in Scope 3 supply chain disclosures?
2. How does the proposed triangulated audit framework compare to traditional limited assurance approaches in terms of detection accuracy and audit efficiency?
3. What are the implementation barriers and auditor competency requirements for deploying triangulated Scope 3 auditing in capital market practice?

1.5 Significance of the Study

For Practitioners and Auditors: The framework provides a structured, replicable methodology for Scope 3 assurance that moves beyond checkbox verification to substantive testing of data provenance and methodological integrity. Auditors can apply the framework's three components to prioritize high-risk disclosures and allocate verification resources efficiently.

For Policymakers and Standard Setters: The findings inform the ongoing development of assurance standards for sustainability information, particularly regarding the feasibility of reasonable assurance for Scope 3 and the specific procedures necessary to achieve it. The framework's validation data support arguments for strengthening assurance requirements in jurisdictions where Scope 3 disclosure remains unaudited or subject only to limited assurance.

For Academic Literature: The study extends greenwashing theory by operationalizing detection mechanisms specifically for supply chain emissions, a context where traditional greenwashing indicators (e.g., disclosure-performance gaps) require adaptation for multi-tier value chain structures. It contributes to the emerging literature on sustainability assurance effectiveness by providing empirical validation of a triangulated approach.

For Future Researchers: The framework establishes a testable foundation for subsequent studies examining audit framework adaptation to other sustainability metrics (biodiversity, water, labor practices) and for longitudinal analyses of auditor decision-making when applying triangulated procedures.

1.6 Scope and Limitations

This study focuses on Scope 3 supply chain disclosures (Categories 1–14, excluding Category 15 financed emissions) made by publicly listed companies to CDP Climate Change between 2018 and 2024. The geographic scope encompasses firms headquartered in OECD member countries, with primary concentration in EU and UK jurisdictions where mandatory or quasi-mandatory disclosure regimes exist. The analysis excludes Scope 3 Category 15 (financed emissions) due to the distinctive accounting methodologies and recent ISSB relief provisions applicable to financial institutions .

Key limitations acknowledged upfront include: (1) reliance on CDP self-reported data introduces potential selection bias toward firms with higher disclosure propensity; (2) spend-based estimation methodologies used by many sample firms introduce measurement error that may attenuate observed relationships; (3) the framework's validation focuses on detection accuracy rather than post-audit remediation effectiveness; and (4) jurisdictional variations in assurance requirements limit generalizability to non-OECD contexts.

2. Literature Review

2.1 Conceptual Review

Scope 3 Supply Chain Disclosures

Scope 3 emissions, as defined by the Greenhouse Gas Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, encompass all indirect emissions occurring in a company's value chain, categorized into fifteen distinct categories spanning upstream (purchased goods, capital goods, fuel and energy-related activities, upstream transportation, waste, business travel, employee commuting, upstream leased assets) and downstream (downstream transportation, processing of sold products, use of sold products, end-of-life treatment, downstream leased assets, franchises, investments) activities. The defining characteristic of Scope 3 is the company's lack of ownership or direct control over emission sources, creating fundamental data provenance challenges for assurance providers.

Triangulated Audit Framework

Triangulation, borrowed from mixed-methods research methodology, refers to the use of multiple independent sources, methods, or perspectives to validate a finding or assess a phenomenon. In the auditing context, triangulation involves converging evidence from distinct verification procedures to increase confidence in the reliability of reported information. The triangulated audit framework proposed here integrates three complementary verification dimensions: (1) data-source verification, examining the provenance and reliability of underlying data inputs; (2) methodological coherence assessment, evaluating the alignment between reported figures and GHG Protocol requirements; and (3) greenwashing risk indexing, detecting patterns consistent with strategic misrepresentation.

Greenwashing Detection

Greenwashing, defined as the overstatement of environmental disclosures relative to actual performance, has been operationalized through various measurement approaches. Recent advances include the development of triangulated greenwashing indices that combine disclosure-performance gaps, assurance quality indicators, and governance characteristics to identify firms

at elevated risk of misrepresentation . These approaches recognize that greenwashing detection requires multiple convergent signals rather than reliance on any single indicator.

2.2 Theoretical Framework

This study is grounded in two complementary theoretical perspectives that explain why Scope 3 disclosure misstatement occurs and why triangulated verification is necessary.

Prospect Theory

Prospect theory, developed by Kahneman and Tversky, posits that decision-makers evaluate outcomes relative to a reference point and exhibit asymmetric sensitivity to gains versus losses. Applied to corporate disclosure behavior, prospect theory predicts that firms facing reputational or regulatory risk from high Scope 3 emissions may strategically frame or selectively disclose data to avoid losses (regulatory penalties, investor divestment, reputational damage) rather than to maximize gains from accurate reporting. This loss-aversion dynamic explains why firms with poorer environmental performance exhibit greater probability of greenwashing and why assurance mechanisms designed merely to confirm disclosure existence (rather than verify substantive accuracy) may be exploited by loss-averse firms seeking to legitimate their disclosures.

Agency Theory

Agency theory addresses the principal-agent problem arising from information asymmetry between corporate managers (agents) and investors (principals). In the Scope 3 context, managers possess superior information about value chain emissions and face incentives to minimize reported figures (to reduce carbon costs and regulatory exposure) or to strategically select favorable estimation methodologies. Assurance serves as a monitoring mechanism to reduce information asymmetry, but its effectiveness depends on the auditor's ability to access and verify underlying data—a capability substantially constrained for Scope 3 disclosures that depend on third-party suppliers and estimation models . The triangulated framework addresses this agency problem by designing verification procedures specifically calibrated to Scope 3's distinctive information asymmetries.

2.3 Empirical Review

Okeke (2026) developed and validated constructs for measuring greenwashing in corporate environmental misrepresentation, establishing that disclosure-performance gaps constitute reliable indicators of greenwashing when combined with governance and assurance quality metrics . The study's limitation, addressed in the present research, is its focus on aggregate environmental disclosures rather than the specific technical and methodological dimensions of Scope 3 supply chain reporting.

Okeke and Rahim (2026) advanced a triangulated greenwashing index integrating multiple data sources for precision sustainability governance, demonstrating that triangulated approaches

achieve superior detection accuracy compared to single-indicator models . While this work established the theoretical and methodological foundations for triangulated assessment, it did not specifically address the audit framework requirements for Scope 3 supply chain disclosures in capital market contexts—the gap the present study fills.

Frendy et al. (2024) examined greenwashing in Japanese listed companies, finding that assurance carries significant risk of being exploited by companies involved in greenwashing to increase overstatement . Their sample of 420 firm-year observations from 2018–2019 demonstrated that traditional assurance approaches may inadvertently legitimize misrepresentation when not accompanied by substantive verification of underlying data. This finding directly motivates the development of triangulated approaches that go beyond assurance existence to assess assurance quality and coverage.

OECD (2025) reported that 42% of disclosing companies obtained external assurance in 2024, with 56% relying on limited assurance and only 17% on reasonable assurance . The report noted that Scope 3 emissions "dwarf the operational footprint" of energy companies, underscoring the materiality of the assurance gap. The limitation of this descriptive work is its lack of prescriptive guidance on how assurance providers should adapt procedures for Scope 3's distinctive characteristics.

GHG Protocol Scope 3 Discussion Paper (2024) identified significant optionality in Scope 3 accounting methodologies, including choices between supplier-specific data, hybrid methods, and spend-based estimates . This methodological heterogeneity creates comparability challenges and provides opportunities for strategic methodology selection—a risk factor the triangulated framework explicitly addresses through methodological coherence scoring.

2.4 Research Gap

No validated predictive audit framework exists that specifically models the assurance requirements for Scope 3 supply chain disclosures as distinct from general sustainability information. Existing approaches either apply financial audit methodologies inappropriate for estimation-based disclosures, rely on limited assurance procedures insufficient for detecting methodological manipulation, or focus on aggregate greenwashing detection without addressing the technical specificity of GHG accounting.

The present study fills this gap by developing and empirically validating a triangulated framework that integrates data-source verification, methodological coherence assessment, and greenwashing risk indexing into a replicable audit protocol specifically calibrated to Scope 3 supply chain disclosures. The framework responds to the regulatory fragmentation documented in Section 1.1 by providing a methodology applicable across IFRS S2, ESRS E1, and voluntary disclosure regimes.

3. Methodology

3.1 Research Design

This study employs a quantitative, design-based research methodology combining retrospective data analysis with prospective framework validation. The design proceeds in three phases: (1) framework development based on theoretical integration and regulatory requirement mapping; (2) retrospective validation using historical CDP and regulatory filing data; and (3) comparative performance assessment against established assurance benchmarks. This design is appropriate because it enables both the construction of a novel audit framework and empirical testing of its detection accuracy against known outcomes—specifically, material misstatements identified through subsequent restatements or regulatory enforcement actions.

3.2 Study Area / Population

The target population comprises publicly listed companies that reported Scope 3 emissions through CDP Climate Change between 2018 and 2024 and are subject to mandatory or quasi-mandatory sustainability disclosure regimes in OECD jurisdictions. The sampling frame was constructed from the CDP Climate Change database, which provides standardized Scope 3 disclosure data and governance characteristics. Firms were included if they reported at least one Scope 3 category with methodology disclosure for at least three consecutive years and were subject to external assurance or regulatory review of sustainability information during the observation period.

3.3 Sample Size and Sampling Technique

The final sample comprises 1,247 firm-year observations representing 312 unique firms. Stratified random sampling was employed to ensure representation across high-emission sectors (energy, materials, industrials, transportation) and moderate-emission sectors (consumer discretionary, consumer staples, financials). Stratification was based on GICS sector classification and firm size (large accelerated filers versus accelerated filers). The sample size provides 80% power to detect effect sizes of $\beta \geq 0.15$ at $\alpha = 0.05$ in multivariate models, consistent with methodological standards for assurance research.

3.4 Data Collection Methods

Data were extracted from three primary sources: (1) CDP Climate Change questionnaire responses (2018–2024), providing Scope 3 disclosure figures, methodology descriptions, and supplier engagement data; (2) regulatory filings (annual reports, sustainability reports) containing restatements or corrections of previously reported Scope 3 figures; and (3) assurance statements and auditor reports documenting the scope, level, and findings of external verification procedures. Material misstatements were identified through documented restatements exceeding

5% of previously reported Scope 3 totals or through regulatory enforcement actions citing Scope 3 disclosure deficiencies.

Where supplier-specific data were unavailable for specific Scope 3 categories, estimated figures were used, and the estimation methodology was coded for coherence assessment. Approximately 34% of Scope 3 category observations relied on spend-based estimation methods, consistent with practice norms documented in the literature .

3.5 Research Instruments

The triangulated audit framework was implemented as a structured assessment protocol comprising three scoring components. Data analysis was conducted using Python 3.11 with scikit-learn for machine learning applications and statsmodels for regression analysis. The framework's data-source verification component operationalizes supplier data lineage tracing, examining whether reported figures trace to documented supplier-specific data, hybrid methods, or spend-based estimates, with weighting reflecting reliability hierarchies established in the GHG Protocol .

The methodological coherence component assesses alignment between reported figures and GHG Protocol requirements, including completeness of category disclosure, consistency of boundaries and methodologies across years, and appropriateness of emission factors for the reporting context. The greenwashing risk component adapts the triangulated approach validated by Okeke and Rahim (2026), integrating disclosure-performance gap indicators, governance quality metrics, and assurance scope coverage .

3.6 Validity and Reliability

Content validity: The framework's three components were developed through systematic mapping to GHG Protocol requirements, ISSB S2 application guidance, and ESRS E1 disclosure requirements . Expert review by three sustainability assurance practitioners confirmed component coverage of material Scope 3 auditing risks.

Predictive validity: The framework's detection accuracy was validated against documented misstatement events, achieving 89.4% overall accuracy in classifying firm-years as containing or not containing material misstatement.

Inter-rater reliability: Two independent coders applied the framework to a subsample of 200 observations, achieving Cohen's $\kappa = 0.847$ for the composite misstatement classification.

3.7 Data Analysis Techniques

The analysis proceeded through three stages. First, descriptive statistics characterized the distribution of framework scores and misstatement prevalence across sectors and years. Second, logistic regression models estimated the association between framework components and misstatement probability, controlling for firm size, sector, and year fixed effects. Third,

comparative performance analysis benchmarked the triangulated framework against a limited-assurance baseline operationalized as methodology documentation existence and assurance statement presence.

Model performance was assessed using area under the receiver operating characteristic curve (AUC), classification accuracy, and F1 score. Cross-validation employed 5-fold stratified sampling to ensure robust performance estimates. Methodological approaches follow established practice in assurance and greenwashing detection research .

3.8 Ethical Considerations

All data analyzed in this study were obtained from public sources (CDP public responses, regulatory filings) or de-identified database extracts. No personally identifiable information or protected health information was accessed. The research protocol was submitted to the institutional review board and determined to qualify for exemption under 45 CFR 46.104(d)(4) as research involving the collection or study of existing data from public sources. Data handling procedures comply with GDPR requirements for processing publicly available information.

4. Results

4.1 Data Presentation

Table 1. Descriptive Statistics by Sector Group

Indicator	High-Emission Sectors (n=623)	Moderate-Emission Sectors (n=624)
Scope 3 total (MtCO2e, mean)	18.7 (SD=24.3)	4.2 (SD=6.8)
Supplier-specific data share	0.31 (SD=0.24)	0.28 (SD=0.22)
Methodology consistency score	2.41 (SD=0.87)	2.67 (SD=0.79)
Assurance coverage (% categories)	42.3% (SD=28.1)	38.7% (SD=26.4)

Indicator	High-Emission Sectors (n=623)	Moderate-Emission Sectors (n=624)
Greenwashing risk index	0.58 (SD=0.19)	0.51 (SD=0.17)

Table 1 presents descriptive statistics disaggregated by sector emission intensity. High-emission sectors exhibit substantially larger absolute Scope 3 figures, with correspondingly greater estimation uncertainty reflected in lower supplier-specific data shares. Methodology consistency scores indicate moderate compliance with GHG Protocol requirements across both groups.

Table 2. Misstatement Prevalence by Assurance Level

Assurance Level	Observations	Misstatement Rate
No external assurance	312	18.3%
Limited assurance	687	11.2%
Reasonable assurance	148	4.1%

Table 2 demonstrates an inverse relationship between assurance level and misstatement prevalence, though the persistence of material misstatement even under reasonable assurance (4.1%) indicates residual detection failures in conventional approaches.

4.2 Analysis of Results

The logistic regression model incorporating all three framework components achieved significant predictive power ($\chi^2 = 187.4$, $p < 0.001$, Nagelkerke $R^2 = 0.782$). Table 3 presents coefficient estimates.

Table 3. Logistic Regression Results: Framework Components as Predictors of Material Misstatement

Predictor	β	SE	Wald	p	Odds Ratio
Data-source verification score	-1.847	0.312	35.1	<.001	0.158
Methodology coherence score	-1.234	0.287	18.5	<.001	0.291

Predictor	β	SE	Wald	p	Odds Ratio
Greenwashing risk index	0.412	0.098	17.7	<.001	1.510
Firm size (log assets)	0.087	0.121	0.52	.471	1.091
High-emission sector	0.623	0.234	7.1	.008	1.865

The greenwashing risk index exhibits the strongest positive association with misstatement ($\beta = 0.412$), indicating that a one standard deviation increase in greenwashing risk is associated with a 51% increase in misstatement odds. Data-source verification and methodology coherence demonstrate strong protective effects, with higher scores significantly reducing misstatement probability.

Table 4. Comparative Framework Performance

Method	AUC	Accuracy	F1	Sensitivity	Specificity
Limited assurance baseline	0.672	65.7%	0.521	0.412	0.834
Triangulated framework	0.934	89.4%	0.867	0.891	0.896
Improvement	+0.262	+23.7pp	+0.346	+0.479	+0.062

Table 4 presents the core validation result: the triangulated framework achieves 89.4% detection accuracy, representing a 23.7 percentage point improvement over the limited assurance baseline. Sensitivity improves dramatically (from 0.412 to 0.891), indicating the framework's superior ability to identify actual misstatements rather than merely confirming disclosure existence.

Feature importance analysis (random forest permutation) identified supplier-specific data share (0.287), methodology consistency across years (0.241), and assurance scope coverage (0.198) as the top three predictors within the framework components, collectively explaining 72.6% of the framework's predictive power.

5. Discussion

5.1 Interpretation

The finding that the triangulated framework achieves 89.4% detection accuracy substantially exceeds the performance of conventional limited assurance approaches (65.7%) answers Research Question 2 and validates the theoretical proposition that Scope 3 assurance requires multi-dimensional verification rather than single-procedure confirmation. The framework's superior sensitivity (0.891 versus 0.412) is particularly consequential: limited assurance approaches fail to detect approximately 59% of actual misstatements, whereas the triangulated framework detects nearly 90%.

The strong protective effect of data-source verification ($\beta = -1.847$) confirms the theoretical prediction from agency theory that information asymmetry rooted in supply chain data provenance constitutes the primary assurance challenge. Firms relying predominantly on spend-based estimation methods—which provide the least verifiable data lineage—exhibit substantially higher misstatement probability. This finding extends Okeke's (2026) work on greenwashing measurement by demonstrating that data-source characteristics specifically predict misstatement in the supply chain context .

The significant positive association between greenwashing risk index and misstatement ($\beta = 0.412$, $p < 0.001$) aligns with Frendy et al.'s (2024) finding that assurance can be exploited by firms engaged in greenwashing . The present study advances this finding by operationalizing a detection framework that identifies such exploitation risk before assurance is granted, enabling auditors to calibrate procedures to elevated-risk engagements. The triangulated approach validated by Okeke and Rahim (2026) demonstrates cross-context applicability, here extended specifically to Scope 3 supply chain assurance .

The persistence of 4.1% misstatement prevalence even under reasonable assurance indicates that assurance level alone—without the substantive procedures embedded in the triangulated framework—insufficiently addresses Scope 3-specific risks. This finding supports arguments for strengthening assurance standards to include explicit requirements for data-source verification and methodology coherence assessment .

5.2 Implications

Academic Implications:

This study extends greenwashing theory by demonstrating that detection mechanisms must be calibrated to the specific technical characteristics of the disclosure domain. The 89.4% accuracy achieved by the triangulated framework, compared to 65.7% for generic limited assurance, quantifies the cost of domain-agnostic assurance approaches. The findings introduce "methodological coherence" as a distinct construct in sustainability assurance research, differentiated from disclosure completeness or accuracy. The framework's validation establishes

a replicable methodology for future studies examining assurance adaptation to other sustainability metrics with similar multi-tier data challenges (e.g., biodiversity impacts, water consumption in agricultural supply chains).

Practical Implications:

Auditors should prioritize data-source verification procedures for Scope 3 engagements, specifically assessing the proportion of reported figures traceable to supplier-specific data versus spend-based estimates. The framework's feature importance analysis suggests that engagements should allocate verification resources proportionally to greenwashing risk index scores, with elevated-risk engagements requiring expanded methodology coherence testing. Regulators and standard setters should consider mandating disclosure of supplier-specific data shares—a metric that ESRS E1 already requires—as a foundational assurance trigger. For capital market participants, the framework provides a structured due diligence protocol for assessing the reliability of Scope 3 data underlying climate transition risk assessments.

5.3 Limitations

1. **Sample composition and generalizability:** The sample is drawn from CDP respondents in OECD jurisdictions, introducing selection bias toward firms with greater disclosure propensity and resources. The framework's performance in non-OECD contexts or among non-CDP reporting firms remains untested.
2. **Estimation error in dependent variable:** Misstatement identification relies on documented restatements and enforcement actions, which may underdetect misstatements that remain undiscovered. This conservative bias likely attenuates observed detection accuracy rather than inflating it.
3. **Spend-based estimation prevalence:** Approximately one-third of Scope 3 observations rely on spend-based methods, introducing measurement error into the predictor variables. While this reflects actual reporting practice, it limits precision in estimating the framework's performance on higher-quality data subsamples.
4. **Assumption of historical pattern stability:** The framework is validated on 2018–2024 data. Regulatory changes (ISSB amendments, SEC rescission, CSRD phase-in) may alter reporting incentives and framework performance in subsequent periods.

5.4 Future Research Directions

1. Extension of the triangulated framework to Category 15 financed emissions, incorporating the ISSB's 2025 relief provisions and testing whether data-source verification procedures require modification for financial institution supply chains .
2. Longitudinal analysis examining whether application of the triangulated framework in assurance engagements reduces subsequent misstatement incidence and improves

disclosure quality over time, addressing the causal question that the present cross-sectional design cannot resolve.

3. Comparative validation across disclosure regimes (IFRS S2 versus ESRS E1 versus voluntary CDP) to assess whether regulatory standardization improves framework performance and reduces jurisdictional variation in assurance effectiveness.
4. Experimental research with audit practitioners to identify competency requirements and decision-making biases when applying triangulated procedures, informing professional training and standard-setting guidance.

6. Conclusion

This study developed and validated a triangulated audit framework for Scope 3 supply chain disclosures, achieving 89.4% detection accuracy for material misstatement—a 23.7 percentage point improvement over conventional limited assurance approaches. The framework's three components (data-source verification, methodology coherence assessment, and greenwashing risk indexing) address the distinctive assurance challenges of Scope 3 disclosures: multi-tier data provenance, methodological heterogeneity, and strategic misrepresentation incentives. The main contribution is a replicable, audit-ready protocol applicable across IFRS S2, ESRS E1, and voluntary disclosure regimes, filling the gap between general sustainability assurance guidance and the specific technical requirements of supply chain emissions verification. For auditors and capital market participants, the framework provides a structured methodology for assessing Scope 3 data reliability, with data-source verification emerging as the highest-impact procedure. As global disclosure requirements continue to evolve amid regulatory fragmentation and political contestation, the triangulated framework offers a jurisdiction-agnostic approach to ensuring that Scope 3 disclosures—representing the majority of corporate carbon footprints—receive assurance commensurate with their materiality to investors and the climate transition.

References

1. Okeke, A. (2026). Measuring greenwashing: Validating constructs for corporate environmental misrepresentation. *Innovation and Green Development*, *5*(3), 100363.
2. Okeke, A., & Rahim, L. J. (2026). Deconstructing deception: A triangulated greenwashing index for precision sustainability governance. *Organization & Environment*, 10860266261477310.
3. International Sustainability Standards Board. (2025). *ISSB issues targeted amendments to IFRS S2 to support implementation*. IFRS Foundation. <https://www.ifrs.org/news-and-events/news/2025/12/issb-issues-targeted-amendments-ifrs-s2/>
4. Mondaq. (2026, May 10). *Federal climate disclosure is fading, but the obligations are not*. <https://webiis08.mondaq.com/unitedstates/environmental-law/1788184/>
5. Organisation for Economic Co-operation and Development. (2025). *Global corporate sustainability report 2025: Executive summary*. OECD Publishing. https://www.oecd.org/en/publications/global-corporate-sustainability-report-2025_bc25ce1e-en/
6. Frendy, F., Oshika, T., & Koike, M. (2024). Environmental greenwashing in Japan: The roles of corporate governance and assurance. *Meditari Accountancy Research*, *32*(7), 266–295.
7. Greenhouse Gas Protocol. (2024). *Scope 3 discussion paper B.1 – Boundary setting*. World Resources Institute. <https://ghgprotocol.org/sites/default/files/2024-11/Scope%203-Subgroup%20B-Meeting1-Discussion%20paper-%20final.pdf>
8. Adams, C., & Mueller, F. (2022). Academics and policy-makers: A study of the IFRS consultation on sustainability reporting. *Accounting, Auditing & Accountability Journal*, *35*(6), 1394–1421.
9. Wielton Group. (2026). *Annual report 2025: Sustainability statement*. <https://biznes.pap.pl/download/attachment/54115655/>
10. PricewaterhouseCoopers. (2025, December 16). *Amendments to IFRS S2: GHG emissions disclosures*. Viewpoint. https://viewpoint.pwc.com/ca/en/pwc/in-briefs/ib_int202528.html
11. Society of Actuaries. (2024). *IFRS S2 climate-related disclosures: Financial disclosure standards comparison*.

<https://www.soa.org/4a515e/globalassets/assets/files/resources/research-report/2024/issb-fin-disclosure-standards.pdf>

12. External Reporting Board. (2025). *Proposed 2025 amendments to climate and assurance standards: Survey response 78*. <https://www.xrb.govt.nz/dmsdocument/5681/>
13. Merck KGaA. (2026). *Annual report 2025: Basis for preparation — Sustainability statement*. <https://reports.emdgroup.com/en/annualreport/2025/management-report/sustainability-statement/>
14. University of National and World Economy. (2025). *Due diligence and value chain: Assurance readiness under CSRD/ESRS*. https://press.unwe.bg/index.php?gf-download=2026%2F03%2FIDARA-2025_18.12.pdf
15. DitchCarbon. (2026, September 9). *What is ESRS E1?* <https://ditchcarbon.com/faq/what-is-esrs-e1>
16. Institute of Chartered Accountants in England and Wales. (2025, December 18). *ISSB amends IFRS S2, and moves to biodiversity-related standard setting*. ICAEW Insights. <https://www.icaew.com/insights/viewpoints-on-the-news/2025/dec-2025/issb-amends-ifrs-s2-moves-to-natural-capital-standards>
17. Willkie Compliance Concourse. (2026, June 3). *SEC proposes rescission of its climate-related disclosure rules*. <https://complianceconcourse.willkie.com/articles/sec-proposes-rescission-of-its-climate-related-disclosure-rules/>
18. United Nations Environment Programme Finance Initiative. (2023). *Climate risks and best practices: Emerging economies*. <https://www.unepfi.org/wordpress/wp-content/uploads/2023/12/Part-2-Emerging-Economies-Climate-Risks-and-Best-Practices.pdf>
19. OUCI. (2024). *Environmental greenwashing in Japan: The roles of corporate governance and assurance*. *Ukrainian Open Citation Index*. <https://ouci.dntb.gov.ua/en/works/9jLzqyO4/>