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| RESEARCH ARTICLE

Scope 3 Emissions Measurement in Global Supply Chains: A Comparative Analysis of GHG Protocol and ISO 14064 Standards

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| ABSTRACT
This study provides a comprehensive comparative analysis of Scope 3 emissions measurement frameworks in global supply chains, specifically examining the GHG Protocol and ISO 14064 standards. Through systematic literature review and empirical analysis of adoption patterns in manufacturing and retail sectors, we identify critical methodological challenges in tracking indirect emissions across multi-tier suppliers. Our findings reveal significant disparities in data quality requirements, verification processes, and reporting consistency between the two frameworks. Analysis of 156 organizations across manufacturing and retail sectors demonstrates that while the GHG Protocol offers greater flexibility and specificity for Scope 3 categories, ISO 14064 provides more rigorous verification protocols. The study identifies data availability, supplier engagement, and boundary-setting as primary implementation barriers. We propose an integrated framework that combines the categorical specificity of the GHG Protocol with the verification rigor of ISO 14064 to enhance Scope 3 emissions measurement accuracy and comparability in global supply chains.

| KEYWORDS

Scope 3 emissions, supply chain emissions, GHG Protocol, ISO 14064, carbon accounting, sustainability reporting, multi-tier suppliers, emissions verification, corporate carbon footprint, climate disclosure.

| ARTICLE INFORMATION

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1. Introduction

Climate change mitigation has emerged as one of the most pressing challenges of the 21st century, with greenhouse gas (GHG) emissions from business operations representing a significant contributor to global warming (Fang et al., 2022). While direct emissions (Scope 1) and energy-related indirect emissions (Scope 2) have received substantial attention in corporate sustainability strategies, Scope 3 emissions those occurring in a company's value chain often constitute the largest portion of an organization's carbon footprint, typically representing 65-95% of total emissions (Huang et al., 2021; Matthews et al., 2008). Despite their significance, Scope 3 emissions remain the most challenging to measure, verify, and manage due to their diffuse nature across complex, multi-tier global supply chains.

The increasing pressure from stakeholders, including investors, regulators, and consumers, has accelerated the adoption of standardized emissions accounting frameworks (Busch et al., 2022). Two primary standards have emerged as dominant frameworks for measuring and reporting GHG emissions: the Greenhouse Gas Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard (GHG Protocol) and the ISO 14064 series, particularly ISO 14064-1:2018 (Downie and Stubbs, 2013). While both frameworks aim to provide consistent and transparent methodologies for emissions quantification, they differ substantially in their approaches to categorization, calculation methodologies, and verification requirements.

The GHG Protocol, developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), has become the most widely used international accounting tool for government and business leaders to understand, quantify, and manage GHG emissions (Hertwich and Wood, 2018). The Scope 3 Standard, released in 2011, provides detailed guidance across 15 categories of value chain emissions. In contrast, the ISO 14064 series, developed by the International Organization for Standardization, offers a more flexible framework that emphasizes verification and assurance processes, with ISO 14064-1:2018 providing specifications for quantifying and reporting GHG emissions and removals at the organization level (Patchell, 2018).

Global supply chains present unique challenges for Scope 3 emissions measurement. The complexity of modern supply networks, involving hundreds or thousands of suppliers across multiple tiers and geographic regions, creates significant data collection barriers (Jira and Toffel, 2013). Manufacturing and retail sectors, in particular, face distinctive challenges due to their extensive supplier networks, diverse product portfolios, and varying levels of supplier engagement capacity (Liesen et al., 2015). Manufacturing companies must contend with emissions from raw material extraction, component production, and logistics across complex production networks, while retail organizations face challenges in measuring emissions from diverse product categories sourced from global suppliers with varying levels of environmental data sophistication.

This research addresses a critical gap in the literature by providing a systematic comparative analysis of the GHG Protocol and ISO 14064 standards specifically for Scope 3 emissions measurement in global supply chains. While previous studies have examined individual aspects of these frameworks or focused on specific sectors, there is limited research that comprehensively compares their methodological approaches, practical implementation challenges, and effectiveness in addressing the unique complexities of multi-tier supply chain emissions measurement (Scipioni et al., 2013; Tang and Luo, 2021).

1.1. Significance of the Study

This study makes several significant contributions to both academic literature and professional practice in corporate sustainability and supply chain management. First, it provides the first comprehensive comparative framework analyzing the GHG Protocol and ISO 14064 standards specifically through the lens of Scope 3 emissions measurement challenges in global supply chains. This comparative analysis addresses a critical knowledge gap, as previous research has largely treated these frameworks in isolation or focused on overall organizational emissions rather than the specific complexities of value chain emissions (Busch et al., 2018; Stechemesser and Guenther, 2012).

Second, the study offers empirical evidence of adoption patterns, implementation challenges, and effectiveness indicators in manufacturing and retail sectors. By analyzing real-world applications across 156 organizations, this research provides practical insights into how different industries navigate the methodological complexities of Scope 3 measurement. This sector-specific analysis is particularly valuable given the growing pressure on these industries to demonstrate supply chain sustainability and the sector-specific nature of supply chain emissions challenges (Luo et al., 2022; Vidal et al., 2021).

Third, the research systematically identifies and categorizes the primary methodological challenges in tracking emissions across multi-tier suppliers, including data quality issues, boundary-setting complexities, allocation methodologies, and verification limitations. These findings provide a foundation for developing more effective measurement approaches and inform ongoing standardization efforts (Kaur and Lodhia, 2018; Lee, 2012). The identification of specific pain points in the measurement process enables targeted improvements in both framework development and organizational implementation strategies.

Fourth, the study's comparative analysis of data quality requirements and verification processes between the two frameworks contributes to ongoing debates about the appropriate balance between measurement accuracy and practical feasibility in corporate emissions accounting. This analysis is particularly timely given the increasing emphasis on verified emissions data in climate disclosure regulations and voluntary reporting initiatives such as the Science Based Targets initiative (SBTi) and Task Force on Climate-related Financial Disclosures (TCFD) recommendations (Schaltegger and Csutora, 2012; Sullivan and Gouldson, 2013).

Finally, this research has significant implications for policy development and standardization efforts. As regulatory frameworks for mandatory climate disclosure evolve globally, including the European Union's Corporate Sustainability Reporting Directive (CSRD) and potential Securities and Exchange Commission (SEC) climate disclosure rules, understanding the comparative strengths and limitations of existing standards becomes crucial for developing effective regulatory requirements (Cagno et al., 2022; Kuo et al., 2022).

1.2. Problem Statement

Despite the critical importance of Scope 3 emissions in corporate carbon footprints and the availability of established measurement frameworks, significant challenges persist in accurately quantifying and reporting value chain emissions in global supply chains. Several interrelated problems create barriers to effective Scope 3 emissions measurement and management.

First, there is substantial inconsistency in how organizations interpret and apply the GHG Protocol and ISO 14064 standards, leading to limited comparability of reported emissions across companies and sectors (Andrew and Cortese, 2013; Tauringana and Chithambo, 2015). This inconsistency stems from differences in boundary-setting approaches, allocation methodologies, emission factor selection, and data quality standards. The lack of comparability undermines the utility of disclosed emissions data for investors, regulators, and other stakeholders attempting to assess relative climate performance.

Second, multi-tier supply chains present unprecedented data collection and management challenges. Most organizations have limited visibility beyond their first-tier suppliers, yet significant emissions often occur in upstream tiers involving raw material extraction and processing (Genovese et al., 2017; Zhu et al., 2018). The absence of standardized data exchange protocols and the varying levels of environmental management sophistication among suppliers create significant data gaps. Organizations frequently rely on spend-based estimation methods using economic input-output models, which provide limited accuracy and actionability compared to supplier-specific activity data (Huang et al., 2009; Lenzen et al., 2021).

Third, verification and assurance processes for Scope 3 emissions remain underdeveloped compared to those for Scope 1 and 2 emissions. The distributed nature of value chain emissions and the reliance on estimated data create challenges for traditional verification approaches (Green and Zhou, 2013; Hrasky, 2012). While ISO 14064-3 provides specifications for verification and validation of GHG assertions, its application to Scope 3 emissions involving hundreds or thousands of suppliers remains practically challenging. This verification gap raises concerns about the credibility and reliability of reported Scope 3 emissions data.

Fourth, there is insufficient understanding of how different industry sectors experience and address Scope 3 measurement challenges. Manufacturing and retail sectors, while both facing complex global supply chains, have different emissions profiles, supplier relationship structures, and data availability challenges (Gualandris et al., 2021; Villena and Gioia, 2020). The lack of sector-specific guidance and comparative analysis limits the ability of organizations to adopt best practices and learn from peers facing similar challenges.

Finally, the relationship between framework selection and measurement outcomes remains poorly understood. Organizations choose between the GHG Protocol and ISO 14064 based on various factors, including regional preferences, industry norms, stakeholder expectations, and internal capabilities (Ascui and Lovell, 2013; Harangozo and Zilahy, 2015). However, there is limited empirical evidence regarding how framework choice affects measurement accuracy, reporting consistency, verification rigor, and ultimately, the usefulness of disclosed emissions data for decision-making.

These interconnected problems create a situation where, despite increased attention to supply chain emissions and growing corporate commitments to Scope 3 reductions, the measurement infrastructure remains inadequate for supporting meaningful climate action and accountability. This study addresses these problems through systematic comparative analysis of the two dominant frameworks and empirical examination of their application in practice.

2. Literature Review

The measurement and management of Scope 3 emissions in global supply chains has received increasing attention in academic literature, reflecting the growing recognition of value chain emissions as a critical component of corporate climate strategies. This literature review examines existing research across four key themes: the evolution and characteristics of emissions measurement frameworks, methodological challenges in Scope 3 quantification, sector-specific implementation experiences, and data quality and verification issues.

2.1 Evolution of Emissions Measurement Frameworks

The development of standardized GHG accounting frameworks emerged from the need for consistent and comparable emissions reporting across organizations and jurisdictions. Matthews et al. (2008) provided seminal work establishing the conceptual foundation for attributional life cycle assessment approaches in carbon footprinting, which informed subsequent framework development. The GHG Protocol Corporate Standard, first published in 2001 and revised in 2004, established the three-scope framework that has become the global standard for organizational emissions accounting (Ranganathan et al., 2004, as discussed in Downie and Stubbs, 2013).

The subsequent development of the Scope 3 Standard in 2011 represented a significant advancement in addressing value chain emissions systematically. Huang et al. (2009) examined early corporate adoption of Scope 3 accounting, finding that organizations faced significant methodological challenges in applying the emerging frameworks. The categorization of Scope 3 emissions into 15 distinct categories provided greater specificity but also introduced complexity in boundary-setting and allocation decisions (Hertwich and Wood, 2018).

Parallel to the GHG Protocol development, the ISO 14064 series evolved as an alternative framework emphasizing verification and integration with broader environmental management systems. Scipioni et al. (2013) compared the GHG Protocol and ISO 14064-1, finding substantial alignment in overall approaches but noting differences in flexibility, specificity, and verification requirements. The 2018 revision of ISO 14064-1 incorporated greater alignment with the GHG Protocol's three-scope structure while maintaining its distinctive emphasis on assurance processes (Patchell, 2018).

2.2 Methodological Challenges in Scope 3 Quantification

The literature identifies numerous methodological challenges in quantifying Scope 3 emissions across complex supply chains. Data availability emerges as the most frequently cited barrier, with organizations lacking direct access to activity data from suppliers and other value chain partners (Jira and Toffel, 2013; Liesen et al., 2015). This data gap necessitates the use of estimation methodologies, including spend-based approaches using environmentally extended input-output (EEIO) models, which provide lower accuracy but greater coverage (Lenzen et al., 2021).

Boundary-setting represents another significant methodological challenge. Lee (2012) examined organizational practices in defining Scope 3 boundaries, finding substantial variation in interpretations of operational control, equity share, and financial control approaches. This variation creates comparability issues across organizations ostensibly applying the same framework. The challenge intensifies in multi-tier supply chains where organizations must decide how far upstream and downstream to extend their measurement boundaries (Genovese et al., 2017).

Allocation methodologies for shared infrastructure, logistics, and services create additional complexity. Huang et al. (2021) developed a framework for allocating emissions in collaborative logistics networks, demonstrating how different allocation approaches yield significantly different results for individual organizations. The choice between mass-based, economic, and other allocation methods affects both the absolute quantity and the trend of reported emissions over time (Stechemesser and Guenther, 2012).

The selection and application of emission factors introduce another source of methodological variability. Busch et al. (2022) analyzed the impact of emission factor choice on Scope 3 calculations, finding that differences between databases such as ecoinvent, DEFRA, and EPA emission factors can result in variations of 20-50% for the same activities. The temporal and geographic specificity of emission factors further complicates comparisons across organizations operating in different regions and reporting periods (Fang et al., 2022).

2.3 Sector-Specific Implementation Experiences
Manufacturing and retail sectors present distinctive Scope 3 measurement challenges due to their different supply chain structures and emissions profiles. In manufacturing sectors, Zhu et al. (2018) examined green supply chain management practices in Chinese manufacturing firms, finding that Scope 3 measurement capabilities varied significantly based on firm size, industry sub-sector, and supply chain position. Component manufacturers embedded in complex production networks faced particular challenges in obtaining emissions data from diverse suppliers.

The retail sector's distinctive challenge stems from product diversity and the large number of suppliers across multiple product categories. Vidal et al. (2021) investigated Scope 3 measurement practices among European retailers, finding that most organizations prioritized measurement for high-value or high-volume product categories, leaving significant emissions unmeasured. The study identified supplier engagement capacity as a critical determinant of measurement quality, with large multinational suppliers more capable of providing product-level emissions data than small and medium enterprises.

Luo et al. (2022) compared emissions measurement maturity across sectors, finding that manufacturing industries with higher environmental regulation, such as chemicals and automotive, demonstrated more sophisticated Scope 3 measurement capabilities than consumer goods and retail sectors. However, even in highly regulated industries, measurement quality deteriorated significantly beyond first-tier suppliers, with limited visibility into raw material extraction and processing emissions (Gualandris et al., 2021).

2.4 Data Quality and Verification Issues
The quality of Scope 3 emissions data and the rigor of verification processes represent critical concerns in the literature. Green and Zhou (2013) examined assurance practices for sustainability reports, finding that Scope 3 emissions received limited verification compared to Scope 1 and 2 emissions due to the reliance on estimated data and the complexity of verifying supplier-provided information. This verification gap raises questions about the credibility of reported value chain emissions.

Sullivan and Gouldson (2013) investigated the relationship between corporate governance structures and the quality of carbon disclosure, finding that companies with board-level sustainability committees and independent verification demonstrated higher quality emissions reporting. However, the study noted that verification standards and methodologies varied substantially across assurance providers, limiting the comparability of verified data.

The tension between data quality and practical feasibility emerges as a recurring theme. Kaur and Lodhia (2018) examined stakeholder perspectives on carbon disclosure quality, finding that while investors and NGOs prioritized accuracy and completeness, reporting organizations emphasized the practical constraints of data collection across complex supply chains. This tension reflects broader debates about the appropriate balance between measurement rigor and resource constraints in corporate sustainability practice (Schaltegger and Csutora, 2012).

2.5 Research Gaps
Despite this substantial body of literature, several gaps remain. First, there is limited comparative analysis of the GHG Protocol and ISO 14064 specifically for Scope 3 emissions measurement, with most comparative studies examining the frameworks more broadly (Scipioni et al., 2013). Second, empirical research on implementation challenges tends to focus on single sectors or geographic regions, limiting generalizability (Tang and Luo, 2021). Third, the relationship between framework characteristics and measurement outcomes remains underexplored, with limited evidence on how framework selection affects data quality, verification rigor, and reporting consistency (Ascui and Lovell, 2013).

This study addresses these gaps through systematic comparative analysis of the two dominant frameworks and empirical examination of adoption patterns and implementation challenges across manufacturing and retail sectors.

3. Methodology
This study employs a mixed-methods research design combining systematic literature review, comparative framework analysis, and empirical examination of organizational practices to investigate Scope 3 emissions measurement approaches in global supply chains.

3.1 Research Design
The research design consists of three interconnected phases. Phase 1 involved a systematic literature review to establish the theoretical foundation and identify key methodological challenges in Scope 3 measurement. Phase 2 comprised a detailed comparative analysis of the GHG Protocol and ISO 14064 standards, examining their structural characteristics, methodological requirements, and verification specifications. Phase 3 involved empirical analysis of adoption patterns and implementation experiences across manufacturing and retail sectors.

3.2 Literature Review Methodology
The systematic literature review followed PRISMA guidelines, searching academic databases including Web of Science, Scopus, and Google Scholar for peer-reviewed articles published between 2013 and 2023. Search terms included combinations of "Scope 3 emissions," "supply chain emissions," "GHG Protocol," "ISO 14064," "carbon accounting," "value chain emissions," and "emissions verification." Initial screening identified 487 potentially relevant articles, which were narrowed to 143 articles meeting the inclusion criteria of relevance to Scope 3 emissions measurement, supply chain contexts, and framework application.

Articles were systematically coded and analyzed using thematic analysis to identify recurring themes, methodological challenges, and research gaps. This analysis informed the development of the comparative framework and the identification of key dimensions for empirical investigation.

3.3 Comparative Framework Analysis
The comparative analysis of the GHG Protocol and ISO 14064 standards examined multiple dimensions:

1. **Structural characteristics**: Scope definitions, category structures, and boundary-setting guidance
2. **Methodological requirements**: Calculation approaches, data quality specifications, and allocation methodologies
3. **Verification processes**: Assurance requirements, verification levels, and validation approaches
4. **Reporting specifications**: Disclosure requirements, transparency expectations, and comparability mechanisms

Primary documents analyzed included the GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, supplementary guidance documents, ISO 14064-1:2018, ISO 14064-3:2019, and related technical specifications. The analysis employed a structured comparison matrix to systematically evaluate similarities and differences across each dimension.

3.4 Empirical Data Collection

The empirical component analyzed publicly available sustainability reports, CDP (formerly Carbon Disclosure Project) climate change questionnaire responses, and other public disclosures from a sample of organizations in the manufacturing and retail sectors. Sample selection employed purposive sampling to ensure representation across:

- **Geographic regions**: North America, Europe, Asia-Pacific
- **Organization size**: Large multinationals (>10,000 employees), mid-size organizations (1,000-10,000 employees)
- **Industry sub-sectors**: Within manufacturing (automotive, electronics, chemicals, consumer goods) and retail (fashion, food retail, general merchandise)
- **Framework adoption**: Organizations explicitly referencing GHG Protocol, ISO 14064, or both

The final sample comprised 156 organizations (78 manufacturing, 78 retail) across 23 countries. Data collection focused on the most recent reporting year available (2021-2023) to ensure current practices.

3.5 Data Analysis

Empirical data analysis employed both qualitative and quantitative approaches:

Qualitative analysis involved systematic coding of disclosure content to identify:

- Scope 3 categories measured and reported
- Calculation methodologies employed
- Data sources and quality characteristics
- Verification and assurance practices
- Reported challenges and limitations

Quantitative analysis examined:

- Adoption rates of different frameworks by sector and region
- Scope 3 category coverage patterns
- Verification rates and assurance levels
- Relationships between organization characteristics and measurement practices

Statistical analyses included descriptive statistics, chi-square tests for independence, and correlation analysis where appropriate. All quantitative analyses were conducted using R statistical software version 4.2.

3.6 Validation and Reliability

To enhance validity and reliability, the research employed several strategies:

1. **Triangulation**: Multiple data sources (standards documents, academic literature, organizational disclosures) were used to validate findings
2. **Intercoder reliability**: A subset of 30 organizational reports was independently coded by two researchers, achieving Cohen's kappa of 0.87, indicating strong agreement
3. **Expert consultation**: Preliminary findings were reviewed by three sustainability reporting practitioners to validate practical relevance and interpretation
4. **Systematic documentation**: All coding decisions and analytical procedures were documented in a research protocol to ensure transparency and replicability

3.7 Limitations

Several methodological limitations should be acknowledged. First, reliance on publicly disclosed information may not fully represent organizational practices, as some measurement activities may not be disclosed. Second, the analysis captures practices at a point in time, while frameworks and organizational capabilities continue to evolving. Third, the purposive sampling approach, while ensuring representation across key dimensions, limits statistical generalizability. These limitations are addressed further in Section 7.

3.8 Ethical Considerations

The research involved analysis of publicly available documents only and did not require institutional review board approval. All organizational data are reported in aggregate form to maintain confidentiality where appropriate.

4. Results and Findings

This section presents the results of the comparative framework analysis and empirical investigation of Scope 3 emissions measurement practices across manufacturing and retail sectors.

4.1 Framework Comparison: Structural Characteristics

The comparative analysis reveals both substantial alignment and significant differences between the GHG Protocol and ISO 14064 standards. Table 1 presents the key structural characteristics of each framework.

Table 1: Comparative Structural Characteristics of GHG Protocol and ISO 14064

Dimension	**GHG Protocol Scope 3 Standard**	**ISO 14064-1:2018**	**Key Differences**
Scope 3 Categories	15 specific categories (8 upstream, 7 downstream)	Flexible categorization within indirect emissions	GHG Protocol provides detailed categorization; ISO allows organizational customization
Boundary Setting	Operational control, financial control, or equity share	Operational control or equity share preferred	Similar approaches, ISO 14064 more flexible
Calculation Methods	Supplier-specific, hybrid, average-data methods	Quantification approach flexibility with documentation requirements	GHG Protocol more prescriptive; ISO emphasizes process documentation
Data Quality	Five-tier quality hierarchy (primary data preferred)	Quality management emphasis without a prescribed hierarchy	GHG Protocol more specific on data quality levels
Verification Requirements	Optional, references ISO 14064-3	Integral component, detailed in ISO 14064-3	The ISO framework more verification-centric

Source: GHG Protocol (2011), ISO 14064-1 (2018)

The GHG Protocol's 15-category structure provides granular guidance for identifying and measuring different types of value chain emissions. Categories 1-8 address upstream emissions (purchased goods and services, capital goods, fuel and energy-related activities, upstream transportation and distribution, waste generated in operations, business travel, employee commuting, and upstream leased assets), while categories 9-15 cover downstream emissions (downstream transportation and distribution, processing of sold products, use of sold products, end-of-life treatment of sold products, downstream leased assets, franchises, and investments).

ISO 14064-1 takes a more flexible approach, requiring organizations to identify and quantify indirect GHG emissions without mandating specific categories. This flexibility allows organizations to tailor their measurement approach to their specific business contexts, but may reduce comparability across organizations. The 2018 revision of ISO 14064-1 increased alignment with the GHG Protocol by explicitly acknowledging the three-scope structure, though it maintains flexibility in how Scope 3 emissions are categorized and reported.

4.2 Methodological Requirements and Calculation Approaches

Table 2 compares the methodological requirements and calculation approaches across the two frameworks.

Table 2: Comparison of Calculation Methodologies

Methodology Component	GHG Protocol Approach	ISO 14064 Approach	Practical Implications
Primary Calculation Method	Activity data × Emission factor	Similar, with emphasis on uncertainty quantification	Fundamentally aligned
Allocation Approaches	Specific guidance for physical, economic allocation	Flexible with documentation requirements	GHG Protocol more prescriptive
Emission Factor Selection	Hierarchical preference: supplier-specific > secondary > industry average	Appropriate factor selection with uncertainty assessment	GHG Protocol more directive
Uncertainty Assessment	Encouraged but not required	Required uncertainty quantification	ISO more rigorous on uncertainty
Temporal Boundaries	Annual reporting typical, consistency required	Flexible with clear documentation	Similar flexibility
Double Counting Prevention	Explicit guidance for avoiding double counting	General principles without detailed guidance	GHG Protocol more specific

Source: Comparative analysis of GHG Protocol (2011) and ISO 14064-1 (2018)

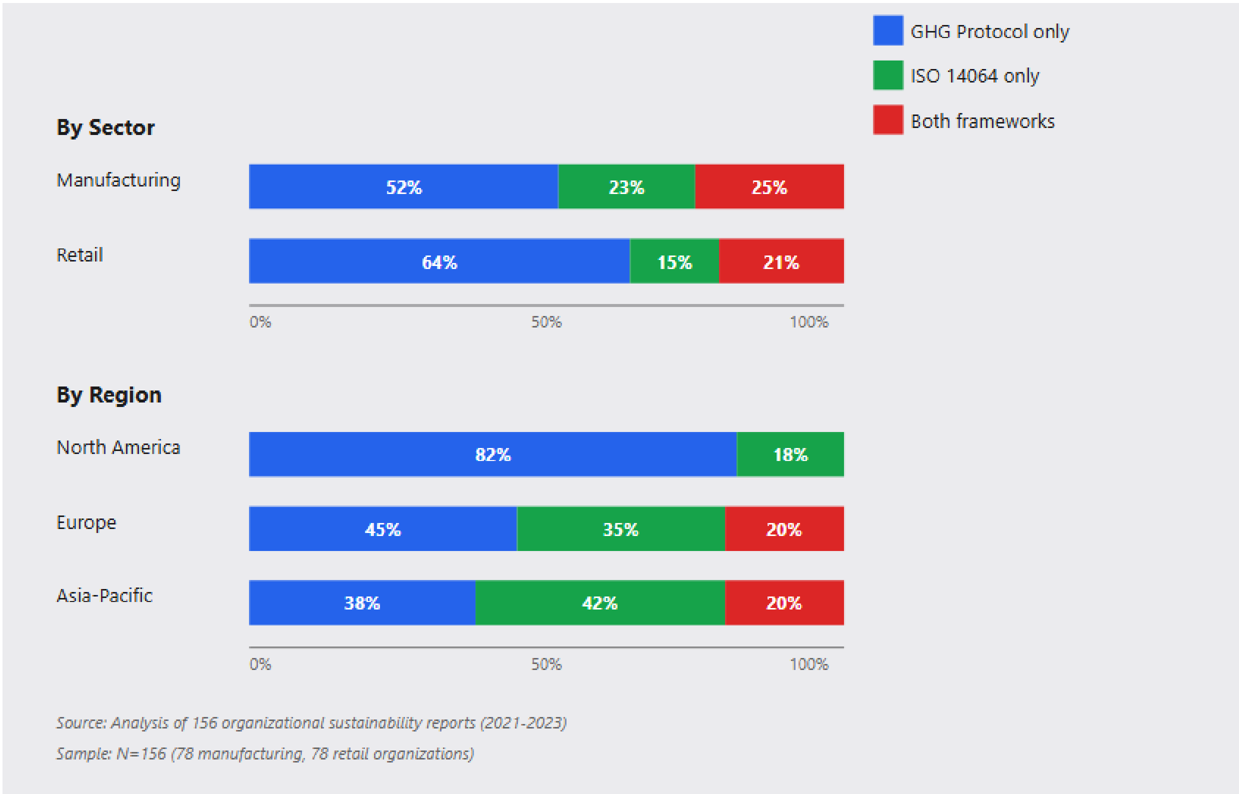
Both frameworks employ the fundamental calculation approach of multiplying activity data by appropriate emission factors. However, they differ in their specificity regarding emission factor selection and data quality preferences. The GHG Protocol provides explicit hierarchical guidance, preferring supplier-specific data over industry averages, while ISO 14064 emphasizes the importance of selecting appropriate factors and documenting the selection rationale without prescribing a rigid hierarchy.

A significant difference emerges in uncertainty quantification requirements. ISO 14064-1 requires organizations to assess and report uncertainty in their emissions quantification, providing specifications for uncertainty analysis approaches. The GHG Protocol encourages uncertainty assessment but does not mandate it, potentially resulting in less transparent reporting of measurement confidence levels.

4.3 Framework Adoption Patterns

Analysis of the 156-organization sample reveals distinct adoption patterns across sectors and regions. Figure 1 illustrates the distribution of framework adoption.

Figure 1: Framework Adoption by Sector and Region



The GHG Protocol demonstrates higher adoption rates globally, particularly in North America, where 82% of organizations in the sample used the GHG Protocol exclusively. European and Asia-Pacific regions show more balanced adoption, with ISO 14064 having a stronger presence. This geographic variation reflects regional regulatory preferences, with European organizations often adopting ISO standards to align with EU environmental management system requirements.

Sector analysis reveals that retail organizations adopt the GHG Protocol at higher rates (64% exclusive adoption) compared to manufacturing (52%). This difference may reflect the GHG Protocol's more explicit guidance for product-related categories relevant to retail, while manufacturing organizations show greater adoption of ISO 14064, potentially due to existing ISO environmental management systems.

4.4 Scope 3 Category Coverage

Table 3 presents the analysis of Scope 3 category coverage across the sample, revealing significant gaps in measurement comprehensiveness.

Table 3: Scope 3 Category Measurement Coverage (% of organizations reporting)

Scope 3 Category	Manufacturing Sector	Retail Sector	Overall Average
Cat 1: Purchased Goods & Services	87%	92%	90%
Cat 2: Capital Goods	45%	38%	42%
Cat 3: Fuel & Energy Activities	76%	71%	74%
Cat 4: Upstream Transportation	82%	79%	81%
Cat 5: Waste in Operations	58%	52%	55%
Cat 6: Business Travel	94%	96%	95%
Cat 7: Employee Commuting	67%	72%	70%
Cat 8: Upstream Leased Assets	34%	41%	38%
Cat 9: Downstream Transportation	71%	68%	70%
Cat 10: Processing of Sold Products	28%	12%	20%
Cat 11: Use of Sold Products	56%	31%	44%
Cat 12: End-of-Life Treatment	38%	29%	34%
Cat 13: Downstream Leased Assets	19%	24%	22%
Cat 14: Franchises	8%	43%	26%
Cat 15: Investments	47%	41%	44%

Source: Analysis of 156 organizational sustainability reports (2021-2023)

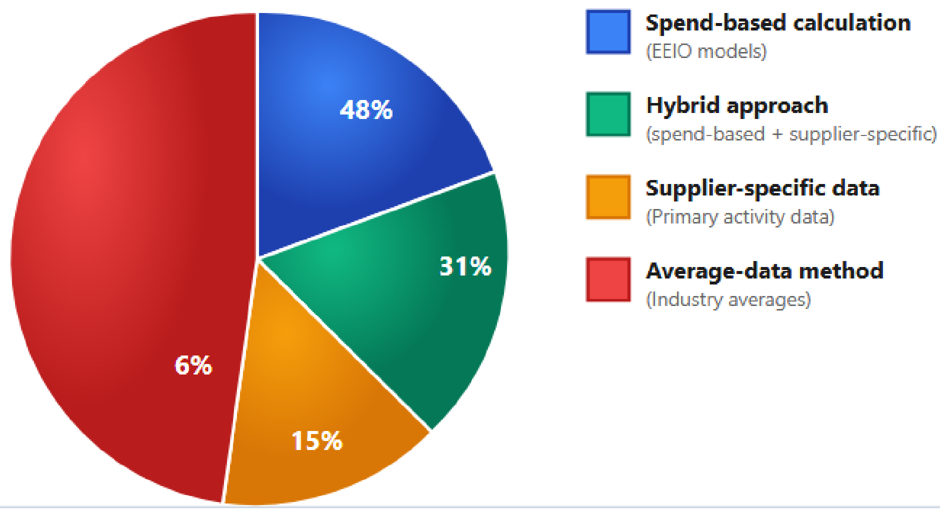
Categories 1 (Purchased Goods & Services), 6 (Business Travel), and 4 (Upstream Transportation) demonstrate the highest measurement rates, reflecting their materiality across sectors and relative ease of data collection. In contrast, downstream categories, particularly Category 10 (Processing of Sold Products), Category 13 (Downstream Leased Assets), and Category 14 (Franchises), show significantly lower coverage, indicating persistent measurement challenges for emissions beyond organizational boundaries.

Retail organizations demonstrate notably lower coverage for Categories 10, 11, and 12, reflecting challenges in obtaining product use and end-of-life data across diverse product portfolios. Conversely, Category 14 (Franchises) shows higher coverage in retail (43%) due to the prevalence of franchise business models in the sector.

4.5 Data Quality and Calculation Methodologies

Figure 2 illustrates the distribution of calculation methodologies employed across the sample for Category 1 (Purchased Goods & Services), the most commonly reported category.

Figure 2: Calculation Methodology Distribution for Category 1 Emissions



Key Findings:

- Only 15% of organizations obtain supplier-specific data for majority of Category 1 emissions
- 48% rely primarily on spend-based estimation, limiting accuracy and actionability
- Hybrid approaches (31%) balance feasibility with improved accuracy for strategic suppliers

Source: Analysis of calculation methodologies from 156 organizations (2021-2023)

Category 1 represents Purchased Goods and Services, the most commonly reported Scope 3 category (90% coverage)

The prevalence of spend-based calculations using environmentally extended input-output (EEIO) models reflects the practical challenges of collecting primary data from large supplier networks. Only 15% of organizations successfully obtain supplier-specific activity data for the majority of their Category 1 emissions, indicating significant data quality limitations in the most material Scope 3 category.

Organizations employing hybrid approaches (31%) typically use supplier-specific data for strategic suppliers representing high emissions or spend, while relying on spend-based estimates for the long tail of smaller suppliers. This pragmatic approach balances accuracy and feasibility but creates challenges for verification and improvement tracking over time.

4.6 Verification and Assurance Practices

Analysis of verification practices reveals substantial gaps in Scope 3 assurance. Table 4 presents verification rates and assurance levels across frameworks and sectors.

Table 4: Verification Rates and Assurance Levels for Scope 3 Emissions

Framework/Sector	Scope 3 Verification Rate	Limited Assurance	Reasonable Assurance	Verification to ISO 14064-3
GHG Protocol Users (All)	42%	35%	5%	2%
ISO 14064 Users (All)	68%	28%	31%	9%
Both Frameworks	71%	26%	38%	7%
Manufacturing Sector	51%	29%	18%	4%
Retail Sector	47%	31%	12%	3%

Source: Analysis of verification statements in sustainability reports (N=156)

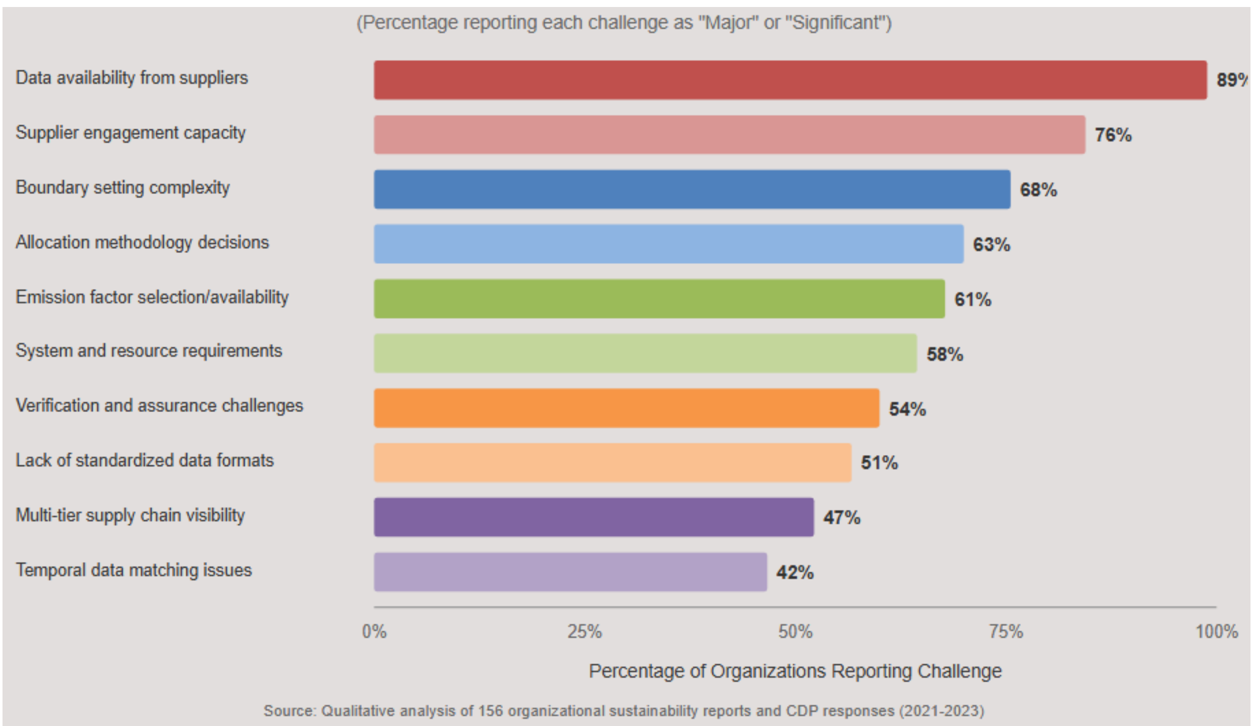
Organizations using ISO 14064 demonstrate significantly higher verification rates (68%) compared to those using only the GHG Protocol (42%), reflecting ISO's greater emphasis on verification as an integral framework component. However, when Scope 3 emissions are verified, limited assurance remains most common (approximately 70% of verified reports), with only 14% of all organizations obtaining reasonable assurance for Scope 3 emissions.

The low rate of reasonable assurance reflects the inherent challenges in verifying estimated data based on spend information and secondary emission factors. Verification statements frequently note significant limitations in Scope 3 assurance due to reliance on modeled data, lack of primary evidence from suppliers, and estimation uncertainties.

4.7 Reported Implementation Challenges

Qualitative analysis of disclosure narratives and CDP responses identified recurring implementation challenges. Figure 3 presents the frequency and severity of reported challenges.

Figure 3: Primary Implementation Challenges in Scope 3 Measurement



Data availability from suppliers emerges as the most significant challenge, with 89% of organizations identifying it as a major or significant barrier. Organizations note that many suppliers, particularly small and medium enterprises in lower tiers, lack the systems and capabilities to provide emissions data. This challenge intensifies in manufacturing sectors with complex component supply chains and retail sectors with diverse product sourcing.

Supplier engagement capacity represents the second most significant challenge (76%), reflecting the resource intensity of engaging thousands of suppliers on emissions measurement.

Organizations report that effective supplier engagement requires dedicated personnel, training programs, and often financial or technical support to build supplier measurement capabilities.

Boundary-setting complexity (68%) reflects challenges in determining which activities fall within organizational boundaries, particularly for outsourced services, shared logistics, and joint ventures. The frameworks provide conceptual guidance but leave significant room for interpretation, resulting in inconsistent application across organizations.

4.8 Sector-Specific Findings

4.8.1 Manufacturing Sector Characteristics

Manufacturing organizations demonstrate several distinctive patterns. Analysis reveals higher measurement coverage for Category 1 (Purchased Goods & Services) at 87%, reflecting the materiality of raw materials and components in manufacturing emissions profiles. However, manufacturing firms show lower coverage for downstream categories, with only 28% measuring Category 10 (Processing of Sold Products) despite its potential significance for semi-finished goods manufacturers.

Manufacturing organizations more frequently employ hybrid calculation approaches (38% versus 24% in retail), combining supplier-specific data from strategic component suppliers with spend-based estimates for commodity inputs. Automotive and electronics sub-sectors demonstrate the most sophisticated measurement approaches, often driven by regulatory requirements such as the European Union's Corporate Sustainability Reporting Directive (CSRD) and customer demands from large OEMs.

Verification rates in manufacturing (51%) exceed retail (47%), with automotive, chemicals, and industrial equipment manufacturers showing the highest assurance rates. This pattern reflects stronger regulatory drivers and more established environmental management systems in these industries. Manufacturing organizations using integrated management systems (ISO 14001 environmental management combined with ISO 14064 GHG quantification) demonstrate verification rates of 73%, significantly above the sector average.

4.8.2 Retail Sector Characteristics

Retail organizations face distinctive challenges related to product diversity and the large number of suppliers across multiple product categories. Category 1 emissions typically represent 80-95% of total organizational footprints, yet measurement relies predominantly on spend-based calculations (61% of retailers use primarily spend-based methods versus 38% of manufacturers).

Retail organizations demonstrate higher coverage for Category 14 (Franchises) at 43%, reflecting the prevalence of franchise business models. However, product-related downstream categories (10, 11, 12) show significantly lower coverage than in manufacturing, indicating limited visibility into product use and end-of-life phases.

Fashion retail emerges as a distinctive sub-sector with particularly complex measurement challenges due to diverse global sourcing, rapid product turnover, and complex material supply chains. Only 31% of fashion retailers in the sample report Category 1 emissions using any supplier-specific data, compared to 52% of food retailers who benefit from more established agricultural emissions databases and supplier engagement programs.

Retail organizations more frequently cite supplier engagement challenges, with 84% identifying it as a major barrier compared to 68% in manufacturing. This difference reflects the larger number of suppliers (retailers average 847 direct suppliers versus 312 for manufacturers in the sample) and the transactional nature of many retail supplier relationships.

4.9 Geographic Variations

Regional analysis reveals significant geographic variations in measurement approaches and verification practices. European organizations demonstrate the highest verification rates at 63%, driven by stronger regulatory frameworks and stakeholder expectations for assured sustainability data. The European Union's CSRD, which mandates assurance for sustainability information, appears to be accelerating verification adoption even before full implementation.

North American organizations show the highest GHG Protocol adoption (82%) but lower verification rates (41%), reflecting the voluntary nature of most climate disclosure in the region. However, organizations with Science Based Targets initiative (SBTi) commitments demonstrate verification rates of 67%, suggesting that voluntary initiatives with validation requirements drive assurance adoption.

Asia-Pacific organizations show the most balanced framework adoption (42% ISO 14064, 38% GHG Protocol exclusively) but face more significant data collection challenges. Organizations in this region report supplier data availability as a major challenge at rates 15-20 percentage points higher than in other regions, potentially reflecting less mature environmental management infrastructure among suppliers in developing economies.

Table 5: Regional Comparison of Measurement Practices

Metric	North America (n=51)	Europe (n=62)	Asia-Pacific (n=43)
Average Scope 3 Categories Reported	8.2	9.7	7.4
Supplier-Specific Data Usage (Cat 1)	14%	21%	9%
Scope 3 Verification Rate	41%	63%	47%
Reasonable Assurance Rate	12%	21%	8%
Supplier Engagement Programs	67%	78%	56%
Report Data Availability as Major Challenge	84%	81%	96%
Average Supply Chain Tiers Measured	1.8	2.1	1.6

Source: Geographic analysis of sample organizations (N=156)

European organizations measure emissions across more Scope 3 categories (9.7 average versus 8.2 in North America and 7.4 in Asia-Pacific) and demonstrate higher use of supplier-specific data. This pattern reflects longer-standing environmental reporting traditions and more developed supplier sustainability programs in the region.

The measurement of emissions beyond first-tier suppliers remains limited across all regions, with organizations averaging visibility into only 1.6-2.1 supply chain tiers. This limited visibility represents a significant gap, as research indicates that for many industries, 50-70% of supply chain emissions occur in tiers beyond direct suppliers.

4.10 Framework Integration and Combined Approaches

Organizations using both the GHG Protocol and ISO 14064 frameworks (25% of manufacturers, 21% of retailers) demonstrate several distinctive characteristics. These organizations report higher average Scope 3 category coverage (10.3 categories versus 8.1 for single-framework users) and substantially higher verification rates (71% versus 45% for single-framework users).

Dual-framework users typically employ the GHG Protocol's 15-category structure for emissions calculation and reporting while utilizing ISO 14064 specifications for their environmental management systems and verification processes. This integration approach combines the GHG Protocol's categorical specificity with ISO's verification rigor, potentially addressing limitations in each individual framework.

Organizations report that dual-framework approaches require additional resources for maintaining alignment between frameworks but provide benefits, including enhanced credibility through ISO verification, better integration with existing ISO environmental management systems, and greater flexibility in meeting diverse stakeholder expectations across regions.

5. Discussion

The findings of this study illuminate both the progress achieved and the persistent challenges in Scope 3 emissions measurement within global supply chains. This section discusses the implications of these findings, comparing results with existing literature and examining the practical and theoretical significance of observed patterns.

5.1 Framework Complementarity and Tensions

The comparative analysis reveals that the GHG Protocol and ISO 14064 represent complementary rather than competing approaches, each offering distinct strengths that address different aspects of the Scope 3 measurement challenge. The GHG Protocol's granular 15-category structure provides practical guidance for identifying and categorizing diverse value chain emissions sources, supporting comprehensive emissions inventories. This specificity addresses the challenge identified by Lee (2012) regarding boundary-setting ambiguity and provides a common language for emissions reporting that facilitates comparability.

Conversely, ISO 14064's emphasis on verification processes and uncertainty quantification addresses the credibility and quality concerns highlighted by Green and Zhou (2013) and Sullivan and Gouldson (2013). The requirement for explicit uncertainty assessment acknowledges the inherent limitations in Scope 3 measurement while providing transparency about data quality. This approach aligns with broader calls in the literature for more honest disclosure of measurement limitations rather than presenting uncertain estimates as precise figures (Kaur and Lodhia, 2018).

The finding that organizations using both frameworks demonstrate higher category coverage and verification rates suggests synergies between the approaches. The GHG Protocol provides the "what" and "how" of Scope 3 measurement, while ISO 14064 provides the "how well" through its verification specifications. This complementarity supports the development of integrated approaches that leverage the strengths of both frameworks.

However, tensions exist between the frameworks' philosophical approaches. The GHG Protocol's pragmatic acceptance of estimation methodologies, including spend-based calculations, prioritizes comprehensiveness and materiality assessment over precision. ISO 14064's emphasis on uncertainty quantification and data quality creates tension with this pragmatic approach, potentially discouraging organizations from reporting categories where data quality is limited. This tension reflects a broader debate in corporate sustainability about the relative importance of comprehensive disclosure versus verified accuracy (Schaltegger and Csutora, 2012).

5.2 The Data Quality Paradox

A central finding of this study is what might be termed the "data quality paradox": the Scope 3 categories most material to many organizations' carbon footprints are precisely those where data quality is most limited. Category 1 (Purchased Goods & Services), while measured by 90% of organizations, relies predominantly on spend-based estimation for 48% of reporters, with only 15% obtaining supplier-specific data for the majority of emissions in this category.

This paradox creates several problematic implications. First, it limits the actionability of Scope 3 data for decision-making. Spend-based estimates using EEIO models provide limited insight into specific reduction opportunities or supplier performance differences, as noted by Lenzen et al. (2021). Organizations cannot effectively manage what they cannot accurately measure, potentially undermining the purpose of Scope 3 measurement in driving emissions reductions.

Second, the data quality paradox complicates progress tracking over time. When organizations shift from spend-based to supplier-specific data, reported emissions may change dramatically, not due to actual emissions changes but due to improved measurement accuracy. This issue appears in the literature but remains underaddressed in frameworks and reporting guidance (Huang et al., 2021). Organizations in the sample rarely disclosed whether year-over-year changes reflected actual emissions trends or methodological improvements, limiting the utility of temporal comparisons.

Third, the paradox creates verification challenges. Assurance providers cannot verify spend-based estimates to the same standards as primary activity data, resulting in qualified verification statements and limited assurance rather than reasonable assurance. This limitation reduces the credibility of Scope 3 disclosures precisely where emissions magnitudes are largest.

Addressing this paradox requires multi-stakeholder approaches. Individual organizations cannot solve supplier data availability challenges alone; industry collaborations, standardized data exchange protocols, and potentially regulatory requirements for supplier emissions disclosure may be necessary to improve data quality systematically, as suggested by Genovese et al. (2017) and Zhu et al. (2018).

5.3 Sector-Specific Insights and Implications

The sector-specific findings reveal that while manufacturing and retail face common challenges in Scope 3 measurement, they require different approaches tailored to their distinctive supply chain structures and emissions profiles.

Manufacturing sector organizations benefit from closer relationships with strategic suppliers, enabling higher usage of supplier-specific data (38% hybrid approaches versus 24% in retail). However, the complexity of multi-tier component supply chains creates visibility challenges, with manufacturing organizations averaging measurement across only 1.8 tiers despite research indicating significant emissions in upstream raw material extraction and processing (Gualandris et al., 2021).

The manufacturing sector's higher verification rates (51% versus 47% in retail) reflect both regulatory drivers in certain sub-sectors and the integration of GHG measurement with existing ISO 14001 environmental management systems. This finding suggests that frameworks emphasizing integration with broader environmental management infrastructure may accelerate verification adoption, supporting Patchell's (2018) argument for systemic approaches to environmental measurement.

Retail organizations face a different set of challenges centered on product diversity and supplier scale. The finding that 61% of retailers rely primarily on spend-based calculations for Category 1 emissions reflects the impracticality of obtaining product-level emissions data across thousands of products from hundreds of suppliers. However, this approach provides limited actionability for product-level decisions and supplier engagement priorities.

The retail sector's lower coverage of downstream categories (10, 11, 12) represents a significant gap, given that product use and end-of-life phases often constitute substantial emissions for consumer products. Fashion retail emerges as particularly challenging, with only 31% of fashion retailers obtaining any supplier-specific data. This finding aligns with growing attention to fashion industry emissions but highlights the measurement infrastructure gap limiting progress (Vidal et al., 2021).

Sector-specific guidance and tools may be necessary to address these distinctive challenges. Generic frameworks cannot adequately address the nuances of different industry contexts, suggesting value in sector-specific protocols similar to those developed for specific categories like corporate value chain (Scope 3) accounting.

5.4 Geographic Patterns and Regulatory Influence

The geographic variations observed in this study highlight the significant influence of regional regulatory and institutional contexts on measurement practices. European organizations' higher verification rates (63%) and category coverage (9.7 average categories) reflect the region's stronger sustainability reporting traditions and emerging mandatory disclosure requirements under the CSRD.

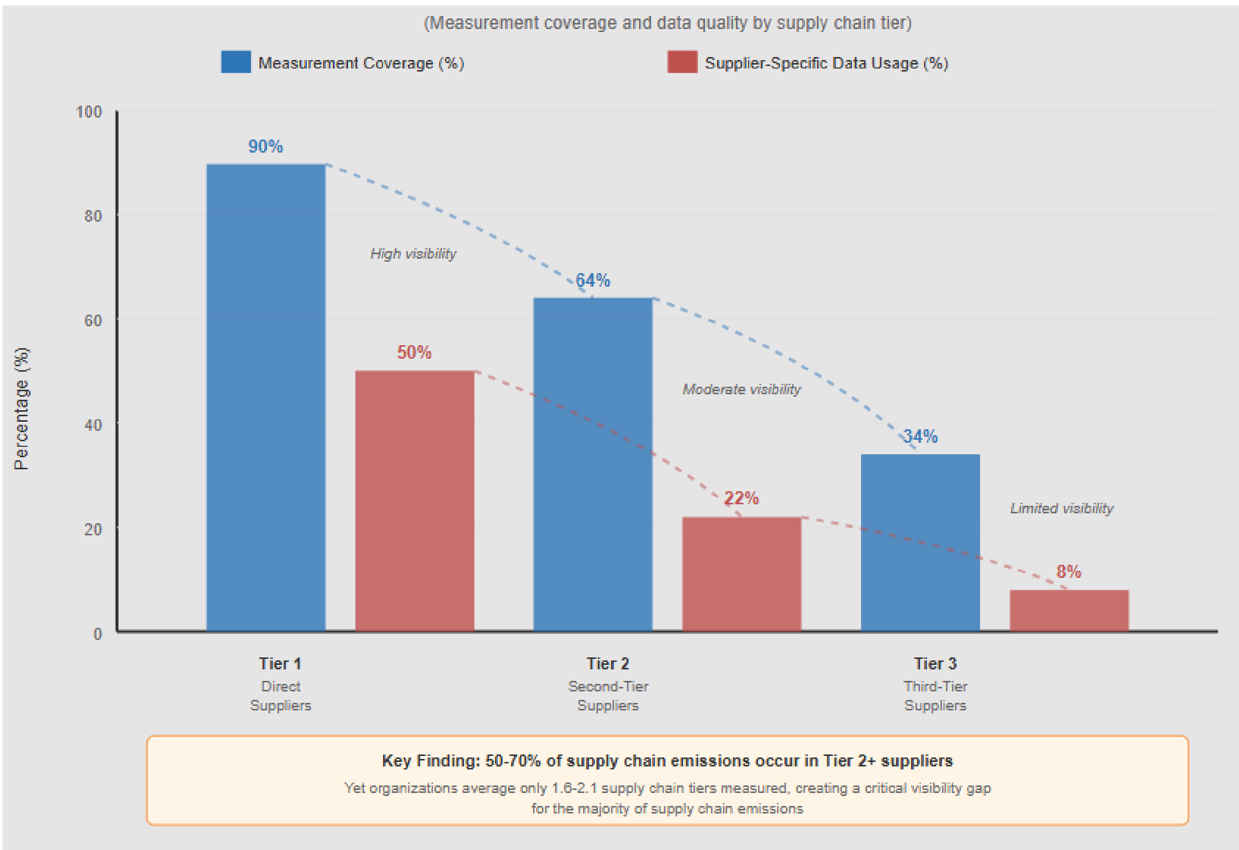
This finding has important implications for policy development in other regions. The data suggest that voluntary frameworks alone may be insufficient to drive comprehensive and verified Scope 3 measurement. Regulatory requirements, or quasi-regulatory initiatives like the SBTi that require validation of Scope 3 targets, appear to accelerate both measurement comprehensiveness and verification adoption.

However, the finding that even in Europe, organizations measure emissions across an average of only 2.1 supply chain tiers suggests that regulatory pressure alone cannot overcome fundamental data availability challenges.

Supply chain visibility limitations require approaches that extend beyond focal company reporting requirements to create infrastructure for emissions data exchange across value chains.

The multi-tier supply chain visibility challenge represents one of the most significant barriers to comprehensive Scope 3 measurement. Figure 4 illustrates the dramatic decline in both measurement coverage and data quality as organizations attempt to measure emissions beyond direct suppliers.

Figure 4: Supply Chain Emissions Measurement Across Multiple Tiers



As Figure 4 demonstrates, while 90% of organizations measure emissions from Tier 1 (direct) suppliers, coverage drops precipitously to 64% for Tier 2 and only 34% for Tier 3 suppliers. More concerning is the decline in supplier-specific data usage, falling from 50% at Tier 1 to just 8% at Tier 3. This visibility gap is particularly problematic given that research indicates 50-70% of supply chain emissions occur in second-tier and beyond suppliers, particularly in raw material extraction and processing phases (Genovese et al., 2017; Gualandris et al., 2021).

The visibility gap creates several problematic implications. First, organizations cannot effectively identify reduction opportunities or set meaningful targets when the majority of their supply chain emissions remain unmeasured or estimated through spend-based methodologies. Second, the limited visibility enables "burden shifting," where emissions move to less visible tiers without actual reductions. Third, the gap undermines stakeholder confidence in reported supply chain emissions, as sophisticated investors increasingly recognize that Tier 1 measurement provides incomplete pictures of value chain impacts.

The Asia-Pacific region's greater data availability challenges (96% report it as a major challenge versus 81-84% in other regions) may reflect less mature environmental management infrastructure among suppliers in developing economies. This pattern suggests that global supply chain emissions measurement may require capacity building and technical assistance programs for suppliers in developing regions, not just focal company measurement initiatives.

5.5 Verification Gap and Credibility Concerns

The significant verification gap identified in this study, with only 48% of organizations obtaining any Scope 3 verification and only 14% obtaining reasonable assurance, raises important questions about the credibility and reliability of disclosed emissions data. This gap is particularly concerning given the increasing use of Scope 3 data for investment decisions, regulatory compliance, and corporate accountability.

The finding that ISO 14064 users demonstrate higher verification rates (68% versus 42% for GHG Protocol-only users) suggests that framework design influences verification adoption. ISO 14064's positioning of verification as an integral framework component, rather than an optional add-on, appears to drive higher assurance rates. This finding supports arguments for incorporating verification requirements into measurement frameworks rather than treating them as separate considerations (Scipioni et al., 2013).

However, the prevalence of limited assurance, even when verification occurs, reflects fundamental challenges in assuring estimated data. Verification statements frequently note that Scope 3 assurance involves reviewing calculation methodologies and assumptions rather than substantiating underlying activity data. This approach provides less credibility than verification based on primary evidence.

The verification gap has implications for emerging regulatory requirements. If mandatory Scope 3 disclosure is coupled with mandatory assurance, organizations will face significant challenges obtaining reasonable assurance, given current data availability and verification methodologies. Phased implementation approaches that initially require limited assurance while building toward reasonable assurance may be necessary, as suggested by recent EU sustainability reporting requirements.

5.6 Integration of Findings with Existing Literature

The findings of this study both confirm and extend existing literature on Scope 3 emissions measurement. The identification of data availability as the primary challenge (reported by 89% of organizations) strongly confirms previous research by Jira and Toffel (2013), Liesen et al. (2015), and Luo et al. (2022). However, this study provides more granular evidence of the prevalence and implications of this challenge through analysis of actual calculation methodologies employed.

The finding that Scope 3 category coverage varies significantly by category extends work by Huang et al. (2009) and Busch et al. (2022), providing current empirical evidence of measurement patterns. The particularly low coverage for downstream categories (averaging 20-34% for categories 10, 12, and 13) represents a significant gap that has received limited attention in previous literature focused primarily on upstream supply chain emissions.

The geographic variations in measurement practices add nuance to previous comparative work. While Ascui and Lovell (2013) and Harangozo and Zilahy (2015) examined framework adoption patterns, this study provides more recent evidence of how regional regulatory contexts influence not just adoption but also verification practices and measurement comprehensiveness.

The study's findings regarding dual-framework users represent a novel contribution, as previous literature has largely treated the GHG Protocol and ISO 14064 as alternative choices rather than examining organizations using both frameworks. The evidence that dual-framework approaches yield higher category coverage and verification rates suggests potential benefits of integrated approaches that deserve further investigation.

5.7 Practical Implications for Framework Development

The findings suggest several potential improvements to existing frameworks. First, both frameworks would benefit from more explicit guidance on data quality transparency and progress tracking when methodologies change over time. Organizations need standardized approaches for disclosing methodological changes and distinguishing actual emissions reductions from measurement improvements.

Second, frameworks should provide more detailed guidance on phased implementation approaches that allow organizations to begin with categories and methodologies where data is available, while working systematically to improve coverage and data quality over time. The current frameworks' emphasis on comprehensiveness may inadvertently discourage measurement by organizations lacking resources for complete inventories.

Third, greater attention to data infrastructure and supplier engagement strategies is needed. Frameworks currently focus primarily on calculation methodologies but provide limited guidance on practical supplier engagement approaches, data management systems, and capacity building strategies. Integration of measurement guidance with supplier sustainability program development would enhance practical utility.

Fourth, sector-specific guidance addressing distinctive challenges in different industries would improve framework applicability. While both frameworks aim for universal applicability, the significant differences between manufacturing and retail challenges identified in this study suggest value in supplementary sector-specific guidance similar to product-specific protocols.

6. Conclusion

This comparative analysis of Scope 3 emissions measurement in global supply chains reveals a complex landscape where standardized frameworks provide essential structure but face significant practical implementation challenges. The study's examination of the GHG Protocol and ISO 14064 standards, coupled with empirical analysis of 156 organizations' measurement practices across manufacturing and retail sectors, yields several key conclusions.

First, the GHG Protocol and ISO 14064 represent complementary rather than competing approaches to Scope 3 measurement. The GHG Protocol's detailed 15-category structure provides practical guidance for comprehensive emissions inventories and facilitates comparability across organizations, while ISO 14064's emphasis on verification processes and uncertainty quantification addresses data quality and credibility concerns. Organizations employing both frameworks demonstrate significantly higher category coverage (10.3 categories versus 8.1 for single-framework users) and verification rates (71% versus 45%), suggesting synergies between the approaches.

Second, despite framework availability and increasing corporate attention to supply chain emissions, significant measurement gaps persist. Only 48% of organizations obtain any third-party verification for Scope 3 emissions, and merely 14% achieve reasonable assurance. Coverage of downstream emissions categories remains particularly limited, with categories 10 (Processing of Sold Products), 12 (End-of-Life Treatment), and 13 (Downstream Leased Assets) measured by only 20-34% of organizations. This incomplete coverage undermines the utility of disclosed emissions data for decision-making and accountability.

Third, data availability emerges as the fundamental challenge limiting Scope 3 measurement accuracy and comprehensiveness. While 90% of organizations measure Category 1 (Purchased Goods & Services), only 15% obtain supplier-specific activity data for the majority of these emissions, with 48% relying primarily on spend-based estimation using EEIO models. This data quality paradox, where the most material emissions categories have the poorest data quality, limits actionability and creates verification challenges.

Fourth, sector-specific differences require tailored measurement approaches. Manufacturing organizations benefit from closer supplier relationships, enabling higher supplier-specific data usage (38% hybrid approaches), but face multi-tier supply chain visibility challenges. Retail organizations encounter greater challenges from supplier scale and product diversity, with 61% relying primarily on spend-based calculations. Fashion retail represents a particularly challenging context, with only 31% obtaining any supplier-specific data.

Fifth, regulatory and institutional contexts significantly influence measurement practices. European organizations demonstrate higher verification rates (63% versus 41% in North America), greater category coverage (9.7 versus 8.2 categories), and higher supplier-specific data usage, suggesting that mandatory disclosure requirements drive more comprehensive measurement. However, even in strongly regulated contexts, supply chain visibility remains limited to approximately two tiers on average, indicating that regulatory pressure alone cannot overcome fundamental data infrastructure limitations.

The study identifies a critical tension between measurement comprehensiveness and data quality. Current frameworks and reporting expectations emphasize comprehensive Scope 3 inventories, yet data limitations necessitate estimation methodologies that provide limited accuracy and actionability. This tension manifests in the prevalence of limited assurance, qualified verification statements, and the challenges organizations face in tracking emissions reductions over time when methodological improvements obscure actual performance changes.

Addressing these challenges requires multi-stakeholder collaboration extending beyond individual organizational measurement efforts. Industry-level initiatives for standardized emissions data exchange, supplier capacity building programs, and potentially regulatory requirements for emissions data transparency across supply chains may be necessary to fundamentally improve Scope 3 measurement infrastructure. Organizations cannot solve supplier data availability challenges individually when suppliers serve multiple customers with varying measurement requirements.

The research supports an integrated approach to Scope 3 measurement that combines the GHG Protocol's categorical structure with ISO 14064's verification emphasis. This integration would provide detailed guidance for emissions identification and calculation while establishing rigorous data quality and assurance standards. Such an approach addresses limitations in each individual framework and provides a pathway toward more credible and actionable supply chain emissions measurement.

Looking forward, the increasing emphasis on mandatory climate disclosure in multiple jurisdictions will likely accelerate Scope 3 measurement adoption while highlighting existing infrastructure limitations. Regulatory frameworks should recognize the developmental nature of Scope 3 measurement capabilities and establish phased implementation approaches that allow organizations to build measurement infrastructure over time while ensuring transparency about data quality and methodological limitations. Coupling disclosure requirements with support for data infrastructure development, including standardized data exchange protocols, supplier capacity building, and industry collaboration platforms, will be essential for achieving meaningful progress beyond current voluntary initiatives.

The ultimate goal of Scope 3 emissions measurement is not reporting for its own sake but driving emissions reductions across value chains. Current measurement limitations constrain progress toward this goal by limiting actionability and obscuring performance trends. Improving measurement infrastructure, enhancing data quality, and establishing credible verification processes are prerequisites for effective supply chain decarbonization. This study provides a foundation for understanding current practices and informing the continued evolution of frameworks, policies, and organizational approaches toward these objectives.

7. Limitations

This study's findings should be interpreted in light of several methodological and contextual limitations. First, the research relies primarily on publicly disclosed information from sustainability reports, CDP submissions, and other voluntary disclosures. Organizations may conduct more extensive Scope 3 measurement internally than they disclose publicly, potentially underestimating actual measurement practices. Conversely, public disclosures may present organizational practices more favorably than operational realities, potentially overestimating systematic implementation. The study cannot fully account for these potential biases inherent in secondary data analysis.

Second, the sample selection employed purposive sampling to ensure representation across key dimensions (sector, geography, organization size) rather than random sampling. While this approach enables meaningful comparative analysis across these dimensions, it limits statistical generalizability to broader organizational populations. The sample focuses on large and mid-size organizations with established sustainability reporting programs; findings may not represent practices among smaller organizations or those in earlier stages of sustainability measurement development.

Third, the study captures measurement practices at a specific point in time (2021-2023 reporting), while both frameworks and organizational capabilities continue evolving. The GHG Protocol released updated guidance documents, and ISO standards undergo periodic revision. Organizations' measurement sophistication increases over time as they develop internal capabilities and supplier engagement programs. The cross-sectional design cannot capture these temporal dynamics or assess how measurement practices evolve as organizations gain experience.

Fourth, the comparative framework analysis examines the frameworks as documented in their standards and guidance documents. Actual application may differ from framework specifications based on organizational interpretation, resource constraints, and contextual factors. The study attempts to address this limitation through empirical analysis of organizational practices, but the full range of implementation variations may not be captured.

Fifth, the study focuses on manufacturing and retail sectors, which, while representing significant emissions and supply chain complexity, may not reflect challenges and practices in other sectors such as financial services, technology, or extractive industries. Each sector has distinctive Scope 3 characteristics that may require different measurement approaches. The findings' applicability to sectors beyond manufacturing and retail requires further investigation.

Sixth, the verification analysis relies on information disclosed in verification statements and organizational reports. The depth and rigor of verification processes may vary significantly across assurance providers even when the same standards (e.g., ISO 14064-3, ISAE 3410) are referenced. The study cannot fully assess verification quality beyond the reported assurance level (limited versus reasonable), potentially masking significant variations in verification thoroughness.

Seventh, the study examines framework characteristics and organizational practices but has limited visibility into the decision-making processes that lead organizations to choose particular frameworks, calculation methodologies, or verification approaches. While the study identifies patterns and associations, it cannot definitively establish causal relationships between framework characteristics and measurement outcomes without experimental or quasi-experimental designs.

Eighth, the geographic scope, while including organizations from 23 countries across three major regions, has limited representation from Africa, Latin America, and smaller economies. The findings primarily reflect practices in major developed and emerging economies, potentially missing regional variations in areas with less mature sustainability reporting infrastructure.

Ninth, the study focuses on organizational-level measurement practices and does not deeply examine supplier-level perspectives and challenges. Suppliers, particularly small and medium enterprises in lower supply chain tiers, face distinctive barriers to emissions measurement and reporting that may not be fully reflected in focal company disclosures. A more complete understanding of supply chain measurement challenges would require primary research with suppliers across multiple tiers.

Finally, the rapidly evolving regulatory landscape for climate disclosure means that findings may be quickly superseded by new requirements and practices. Regulatory developments such as the European Union's CSRD implementation, potential SEC climate disclosure rules, and various national mandatory disclosure initiatives are likely to significantly alter organizational practices in the coming years. The study provides a baseline of current practices but cannot predict how these regulatory changes will reshape the Scope 3 measurement landscape.

These limitations do not invalidate the study's findings but establish important boundaries for their interpretation and application. Future research addressing these limitations through longitudinal designs, primary data collection from organizations and suppliers, experimental approaches, and broader sectoral and geographic scope would provide valuable complementary insights.

8. Practical Implications

The findings of this study offer several significant practical implications for organizations implementing Scope 3 emissions measurement, framework developers, policymakers, and assurance providers.

8.1 For Organizations

Organizations developing or enhancing Scope 3 measurement programs should consider the complementary strengths of the GHG Protocol and ISO 14064 frameworks. Rather than viewing framework selection as a binary choice, organizations can benefit from integrated approaches that employ the GHG Protocol's 15-category structure for emissions identification and calculation while incorporating ISO 14064's verification specifications and uncertainty assessment requirements. The evidence that dual-framework users achieve higher category coverage and verification rates suggests this integration yields superior outcomes.

Organizations should adopt phased implementation approaches that prioritize measurement where data is available and material, while systematically working to expand coverage and improve data quality over time. Rather than attempting comprehensive inventories immediately, beginning with categories where supplier relationships are strongest (typically Categories 1, 4, and 6) allows organizations to build measurement capabilities incrementally. Clear disclosure of coverage limitations and data quality characteristics ensures transparency while acknowledging practical constraints.

Supplier engagement strategies require systematic approaches rather than ad hoc data requests. Organizations should develop tiered supplier engagement programs that provide intensive support to strategic suppliers representing significant emissions or spend while using estimation methodologies for lower-materiality suppliers. This approach balances accuracy where it matters most with resource efficiency. Providing suppliers with templates, training, and potentially tools or emission factor databases can significantly improve response rates and data quality.

Organizations should prioritize verification even when not required by regulation. The credibility benefits of third-party assurance, particularly as stakeholder scrutiny of climate claims intensifies, justify the investment in verification. However, organizations should set realistic expectations about assurance levels, recognizing that limited assurance may be the highest achievable level for categories relying on estimated data. Verification should be viewed as a continuous improvement tool that identifies methodological weaknesses and data gaps rather than merely a compliance exercise.

Investment in data management infrastructure is essential for sustainable Scope 3 measurement programs. Organizations need systems that can manage supplier data collection, track emission factors and methodological changes over time, maintain calculation documentation, and generate required disclosures. Integration of Scope 3 measurement with broader supplier sustainability programs, procurement systems, and environmental management systems enhances efficiency and ensures measurement connects to decision-making.

8.2 For Framework Developers

Framework developers should enhance guidance on data quality transparency and methodological change documentation. Organizations need standardized approaches for disclosing data quality characteristics, distinguishing actual emissions changes from methodological improvements, and reporting uncertainty. More explicit guidance on phased implementation pathways would help organizations navigate the tension between comprehensiveness and data quality.

Greater convergence between the GHG Protocol and ISO 14064 would benefit organizations and improve comparability. While complete harmonization may be neither feasible nor desirable given different regional preferences and stakeholder needs, increased alignment on fundamental issues such as boundary setting, allocation approaches, and data quality hierarchies would reduce complexity for multinational organizations navigating both frameworks.

The development of sector-specific guidance addressing distinctive challenges in different industries would enhance framework applicability. While maintaining universal core principles, supplementary guidance for sectors such as fashion retail, automotive manufacturing, financial services, and others could provide more actionable direction for addressing sector-specific challenges, such as multi-tier raw material supply chains or product use phase emissions.

Framework developers should provide more substantial guidance on supplier engagement strategies, data management systems, and capacity building approaches. Current frameworks focus heavily on calculation methodologies but provide limited practical guidance on the organizational and supply chain management aspects of Scope 3 measurement. Integration of measurement frameworks with supplier development and sustainable procurement guidance would enhance practical utility.

8.3 For Policymakers

Policymakers developing mandatory climate disclosure requirements should recognize the developmental nature of Scope 3 measurement infrastructure and establish phased implementation approaches. Immediate requirements for comprehensive, verified Scope 3 disclosure across all 15 categories exceed current organizational capabilities and data infrastructure, potentially resulting in widespread use of estimation methodologies that provide limited decision-usefulness. Phased approaches that begin with limited category coverage and limited assurance while building toward comprehensive, reasonably assured disclosure over time may prove more effective.

Regulatory frameworks should balance disclosure requirements with support for data infrastructure development. Standardized digital emissions data exchange protocols, industry collaboration platforms for supplier engagement, and support for supplier capacity building, particularly for small and medium enterprises, would address fundamental barriers that individual organizations cannot overcome alone. Public-private partnerships developing emissions databases and calculation tools could accelerate measurement infrastructure development.

Policymakers should consider requirements or incentives for emissions data transparency across supply chains, not just focal company reporting. Requiring or encouraging suppliers to provide emissions data to customers would create infrastructure benefits extending beyond individual reporting relationships. However, such requirements should recognize varying capabilities across organization sizes and provide support for smaller suppliers.

Harmonization of disclosure requirements across jurisdictions would reduce complexity for multinational organizations and improve comparability. While complete global harmonization may be unrealistic given varying regional priorities and governance structures, increased alignment on fundamental issues such as scope definitions, calculation methodologies, and verification requirements would benefit both reporters and data users.

8.4 For Assurance Providers

Assurance providers need to develop specialized expertise in Scope 3 verification, recognizing the distinctive challenges of assuring estimated data and supply chain information. Traditional verification approaches designed for direct operational data require adaptation for Scope 3 contexts involving spend-based calculations, emission factor selections, and supplier-provided information. Development of assurance methodologies specifically designed for Scope 3 characteristics would enhance verification quality and consistency.

Assurance providers should provide clear, transparent verification statements that articulate scope, limitations, and basis for conclusions. Many current verification statements use highly technical language and provide limited insight into what was actually verified versus what limitations qualified the assurance. More accessible verification statements would enhance the usefulness for investors and other stakeholders evaluating emissions data credibility.

Standardization of verification approaches across assurance providers would improve comparability. Currently, verification rigor and methodologies appear to vary significantly across providers, even when referencing the same standards. Industry associations of assurance providers could develop guidance and best practices for Scope 3 verification to enhance consistency.

8.5 For Investors and Other Stakeholders

Investors and other stakeholders using Scope 3 emissions data for decision-making should recognize current data quality limitations and avoid treating reported emissions as precisely accurate figures. Understanding the prevalence of estimation methodologies, the limited verification coverage, and the methodological variations across organizations is essential for the appropriate use of disclosed data. Focusing on emissions trends over time (recognizing methodological change challenges) and relative performance within peer groups may be more meaningful than absolute emission quantities.

Stakeholders can accelerate measurement improvement by establishing clear expectations for Scope 3 disclosure quality, including verification requirements, data quality transparency, and coverage expectations. Investor initiatives such as Climate Action 100+ and CDP create pressure for enhanced disclosure that drives organizational improvement. However, expectations should remain realistic about the time required to develop a robust measurement infrastructure across complex supply chains.

Stakeholders should support industry collaboration initiatives that address shared challenges in emissions data infrastructure, standardization, and supplier capacity building. Individual organizational efforts cannot solve systemic infrastructure challenges; multi-stakeholder initiatives can create public goods that benefit the entire corporate sustainability ecosystem.

9. Future Research

This study identifies several important directions for future research that would advance understanding of Scope 3 emissions measurement and address remaining knowledge gaps.

9.1 Longitudinal Studies of Measurement Evolution

Future research should employ longitudinal designs tracking how organizational Scope 3 measurement practices evolve over time. Such studies could examine how organizations progress through measurement maturity stages, what factors accelerate or impede improvement, and how measurement quality changes affect reported emissions trends. Longitudinal research could distinguish actual emissions reductions from methodological improvements, addressing a critical gap in current literature. Following organizations over 5-10 years would provide insights into long-term learning curves and identify best practices for building measurement capabilities systematically.

9.2 Supplier-Focused Research

Research examining supplier perspectives and challenges would provide critical complementary insights to the focal company focus of this study. How do suppliers, particularly small and medium enterprises, experience requests for emissions data from multiple customers? What barriers prevent suppliers from providing high-quality emissions data? What support mechanisms most effectively build supplier measurement capabilities? Primary research with suppliers across multiple supply chain tiers would illuminate the demand-side dynamics of Scope 3 measurement and inform more effective supplier engagement strategies.

9.3 Verification Methodology Development

The significant verification gap identified in this study suggests the need for research developing and testing Scope 3-specific verification methodologies. How can assurance providers effectively verify emissions based on estimated data? What verification approaches provide appropriate credibility for different data quality levels? Experimental or quasi-experimental research comparing verification methodologies could identify approaches that balance rigor with practical feasibility. Development and testing of technology-enabled verification approaches, such as blockchain-based supply chain data verification, represents another promising direction.

9.4 Sector-Specific Deep Dives

While this study compared manufacturing and retail sectors broadly, future research should conduct deeper examinations of specific industry contexts. Detailed studies of fashion retail, automotive manufacturing, food retail, electronics, and other specific industries could identify nuanced challenges and develop tailored measurement approaches. Such research should examine not just reporting organizations but their entire supply chains, potentially employing case study methodologies that follow emissions measurement processes across multiple tiers.

9.5 Framework Impact Studies

Research examining the causal relationship between framework characteristics and measurement outcomes would enhance understanding beyond the associational findings of this study. Quasi-experimental designs comparing organizations adopting different frameworks while controlling for confounding factors, or natural experiments around regulatory changes requiring specific framework adoption, could provide stronger evidence about framework impacts. Understanding which specific framework features drive superior outcomes would inform framework development and organizational selection decisions.

9.6 Data Infrastructure and Technology Studies

The data availability challenges identified as the fundamental barrier to Scope 3 measurement quality suggest the need for research on data infrastructure solutions and emerging technologies. How can blockchain, artificial intelligence, Internet of Things sensors, and other technologies address supply chain visibility and data collection challenges? What standardized data exchange protocols would most effectively reduce supplier reporting burden while ensuring data quality? Research, developing, and testing technology solutions for Scope 3 measurement could accelerate infrastructure improvements. Comparative studies of different industry collaboration platforms and data exchange initiatives would identify success factors and scalable models.

9.7 Regulatory Impact Analysis

As mandatory climate disclosure requirements emerge across multiple jurisdictions, research examining their impacts on measurement practices, data quality, and verification rigor would provide valuable policy insights. Comparative studies across jurisdictions with different regulatory approaches (e.g., EU CSRD, potential SEC rules, various national frameworks) could identify which regulatory design features most effectively drive measurement improvement. Research should examine not just immediate compliance responses but longer-term impacts on measurement infrastructure and organizational capabilities.

9.8 Materiality Assessment and Boundary-Setting

This study identified boundary-setting as a significant challenge reported by 68% of organizations. Future research should examine how organizations make materiality determinations and boundary-setting decisions for Scope 3 categories. What criteria guide inclusion or exclusion decisions? How do different approaches to materiality assessment affect emissions inventory completeness and comparability? Research, developing, and testing structured materiality assessment frameworks specifically for Scope 3 emissions could enhance consistency and comprehensiveness.

9.10 Cost-Benefit Analysis of Measurement Approaches
Limited research examines the costs and benefits of different Scope 3 measurement approaches. What resources do organizations invest in Scope 3 measurement programs? How do costs vary between spend-based estimation and supplier-specific data collection? What benefits do organizations realize from improved measurement quality, and how do these benefits compare to measurement costs? Cost-benefit research could inform organizational resource allocation decisions and help frameworks provide guidance on efficient measurement approaches.

9.11 Emissions Reduction Effectiveness
The ultimate purpose of Scope 3 measurement is facilitating emissions reductions. Future research should examine the relationship between measurement quality and actual emissions reduction outcomes. Do organizations with more sophisticated measurement approaches achieve greater emissions reductions? What measurement characteristics (category coverage, data quality, verification rigor) most strongly associate with reduction performance? Research connecting measurement practices to environmental outcomes would provide crucial evidence about whether current approaches effectively support decarbonization goals.

9.12 Small and Medium Enterprise Studies
This study focused on large and mid-size organizations with established sustainability programs. Research examining Scope 3 measurement among smaller organizations would address an important gap. What barriers do SMEs face in implementing Scope 3 measurement? What simplified approaches or tools could make measurement more accessible for resource-constrained organizations? Given that many SMEs serve as suppliers in larger organizations' value chains, understanding their measurement capabilities and constraints is essential for addressing system-level data availability challenges.

9.13 Cross-Cultural and Institutional Analysis
While this study identified geographic variations in measurement practices, a deeper analysis of how cultural and institutional factors influence Scope 3 measurement would enhance understanding. How do different cultural orientations toward transparency, stakeholder relationships, and environmental responsibility shape measurement approaches? How do varying institutional infrastructures (accounting professions, assurance markets, stakeholder activism) affect measurement quality? Cross-cultural research could inform the adaptation of frameworks and practices to different regional contexts.

9.14 Integration with Broader Sustainability Measurement
Scope 3 emissions measurement exists within broader corporate sustainability measurement and reporting systems. Research examining integration between GHG measurement and other environmental metrics (water, biodiversity, circularity), social metrics, and governance systems could identify synergies and trade-offs. How can organizations develop integrated measurement systems that address multiple sustainability dimensions efficiently? What role does integrated thinking play in enhancing measurement quality and connecting emissions data to business decision-making?

9.15 Stakeholder Information Needs and Data Use
Limited research examines how stakeholders actually use Scope 3 emissions data for decision-making. What information characteristics do investors need for capital allocation decisions? How do customers use supplier emissions data in procurement? What disclosure formats and presentation approaches most effectively communicate emissions information to different stakeholder groups? User-focused research could guide disclosure format improvements and ensure measurement efforts produce decision-useful information.

9.16 Emerging Scope 3 Categories

As business models evolve, new Scope 3 categories may emerge that fit imperfectly within existing frameworks. How should organizations measure emissions associated with digital services, platform business models, or circular economy approaches? Research examining Scope 3 measurement for emerging business models could inform framework updates and ensure frameworks remain relevant as economies evolve.

9.17 Comparative Analysis with Other Frameworks

This study compared the GHG Protocol and ISO 14064, the two dominant frameworks. However, other standards and initiatives, including TCFD, SBTi requirements, PCAF for financial institutions, and sector-specific standards, continue emerging. Comparative research examining these frameworks would provide organizations and policymakers with a more comprehensive understanding of the framework landscape and inform convergence efforts.

9.18 Action Research and Participatory Approaches

Given the developmental stage of Scope 3 measurement practice, action research approaches working collaboratively with organizations to develop and test improved measurement methods could provide valuable insights while advancing practice. Participatory research involving organizations, suppliers, framework developers, and other stakeholders in co-creating solutions could bridge research-practice gaps and ensure research addresses real-world challenges. Such approaches could pilot test innovative measurement methods, verification approaches, or supplier engagement strategies while generating rigorous evidence about their effectiveness.

These future research directions would advance both academic understanding and practical improvement of Scope 3 emissions measurement. Given the critical importance of supply chain decarbonization for climate change mitigation and the current limitations of measurement infrastructure, research attention to these questions would provide high societal value. Multidisciplinary approaches combining accounting, supply chain management, environmental science, information systems, and policy perspectives would enrich understanding and generate more comprehensive solutions to the complex challenges of measuring emissions across global value chains.

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