Systematic Underreporting in Corporate Scope 3 Disclosure

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Abstract

Scope 3 emissions, which encompass both direct emissions and induced emissions along upstream supply chains, have emerged as an important metric for evaluating corporate responsibility toward climate change. Scope 3 targets are being evaluated as a core element of decarbonization plans in many economically important jurisdictions. Yet robust Scope 3 reporting has been challenging due to varying system boundaries, diverging emission factors used for estimation, and the general absence of compliance audits. To overcome these limitations, and understand the efficacy of voluntary reporting, here we establish a consistent, independent estimate of Scope 3 emissions at the firm level using a new enterprise-level global supply chain database. We find that, collectively, company self-reported Scope 3 emissions may be underestimated by nearly 50%, or 0.75 Gt C, compared to our estimate using a harmonized approach.

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1 Introduction

Accurately assessing corporate carbon footprints is essential, and this is especially true for the Scope 3 emissions which encompass indirect emissions within a company's value chain. These emissions are crucial for a comprehensive view of corporate climate responsibility. Thus, a precise and transparent quantification method is vital for robust corporate carbon reporting and effective climate mitigation.

Existing studies, often reliant on Multi-Regional Input-Output (MRIO) databases, primarily estimate carbon emissions at national and sector levels, lacking granular detail (Davis and Caldeira, 2010; Hertwich and Peters, 2009; Wiedmann et al., 2010; Peters et al., 2011; Feng et al., 2013; Kanemoto et al., 2014, 2016; Friedlingstein et al., 2022). Here, we quantify Scope 3 emissions of companies using an enterprise-level multi-regional input-output (EMRIO) table (Katafuchi et al., 2024) with the company reporting direct (Scope 1 and 2) emissions of companies. Using a systematic top-down approach considers corporations as portions of the complete global economy and avoids the issue of incomparable Scope 3 emissions, which can arise when different companies use different inventory data and models as is often the case in conventional bottom-up life-cycle estimates and prior MRIO-based estimates. This study provides two main results: A new assessment and comparison to CDP Scope 3 for ˜500 companies, and new Scope 3 results for ˜1,500 companies.

The GHG Protocol and Scope 3 Emission Reporting

The Greenhouse Gas (GHG) Protocol established by the World Resources Institute and the World Business Council for Sustainable Development sets the international framework for classifying emissions into three distinct scopes. These are: Scope 1 for direct emissions, Scope 2 for indirect emissions from purchased energy, and Scope 3, which encompasses all other indirect emissions within the value chain of a company. Within Scope 3, the Protocol identifies 15 categories, further organized into "Upstream" and "Downstream" activities.

There exists a notable difference in the quality of monitoring, reporting, and verification between the Scope 1 and Scope 3 emissions of companies. For Scope 1 emissions there are now advanced initiatives such as Climate TRACE (Tracking Real-Time Atmospheric Carbon Emissions) and Carbon Mapper which use innovative technologies and satellite data for accurate

verification (Gore, 2022; Duren and Gordon, 2022) These advancements enable more accurate and transparent reporting of direct emissions. In contrast, Scope 3 emissions are primarily reliant on self-reported data by companies.

While the Scope 3 concept provides a clear framework for emissions reporting, there remain substantial differences in how companies execute Scope 3 reporting. The flexibility allowed in companies' actual reporting is a considerable problem. Specifically, disparities arise from the selection of different calculation methodologies, such as MRIO and Life Cycle Assessment (LCA), and the variability in defining reporting system boundaries (Suh et al., 2004) and categories of emissions further exacerbates the inconsistencies.

Moreover, the issues of incomplete data, incomplete elaboration of complex upstream supply chains, the diversity in business operations, and varying interpretations of the guidelines all exacerbate inconsistencies. Finally, as GHG accounting today still lacks the rigor of financial accounting as provided by institutions such the Global Accounting Standards Board, companies may engage in "gaming" of Scope 3 inventories (e.g. shifting burdens to other years or external parties) to improve their perceived performance. In sum, the voluntary nature of corporate GHG reporting results in varied degrees of detail and accuracy, leaving investors and policymakers with potentially untrustworthy results. Independent estimates can help reporters and auditors achieve more consistent and reliable results.

Climate-Related Disclosures and Corporate Emission Reporting

In the current landscape of climate-related disclosures a growing number of enterprises across the globe are, or will soon be, mandated to report emissions. Recent legislation in California (California Legislative Information, 2023), the United States (Securities and Exchange Commission, 2022), Canada (Canadian Securities Administrators, 2022), Singapore (Government of Singapore, 2023), the European Union (Aligned Incentives, 2023), and Australia's AASB S1 and S2 standards (Australian Accounting Standards Board, 2024) aim to aim to mandate major corporations to disclose their Scope 3 emissions within the coming years.

The growing focus on Scope 3 emission reporting highlights its importance for investors, regulatory authorities, and the public in comprehending the extensive environmental impact of corporate operations. These

measures are indicative of a global shift towards increased scrutiny of corporate emissions and underscore the necessity for comprehensive and accurate carbon reporting frameworks.

2 Data and Methods

2.1 Data Sources

We sourced company-level Scope 1 and 2 emission data from three reputable inventories: the Carbon Disclosure Project (CDP), the United States Environmental Protection Agency (U.S. EPA), and Ministry of the Environment Government of Japan. Specifically, for 2015, these databases provide emissions data for 3,079 companies, 9,875 U.S. facilities, and 12,432 Japanese companies across 73 countries. The economic MRIO model underlying this study details 78,676 subsegments (see next section) but to estimate reliable Scope 3 results this study is limited to those 3,079 firms which report Scope 1 emissions. Combining company-level data with a global input-output dataset implies that that small and medium size enterprises which do not report Scope 1 emissions are not omitted but instead merged together into sectors. While these merged sectors have only an average national emissions intensity rather than a per-firm emissions intensity, we argue merging is preferable to omitting them entirely as is often implicitly done in bottom-up company-prepared Scope 3 footprints. Issues of potential sample bias in the are discussed below in Methods. In the analysis companies' self-reported Scope 3 emissions from CDP were also used for comparison.

Sector-level emission data was derived the International Energy Agency (IEA)'s energy balance database and Emissions Database for Global Atmospheric Research (EDGAR).

2.2 Model Description

In this study we aggregate the EMRIO table, a global enterprise-level global supply chain database from the sister paper (Katafuchi et al., 2024) to include only companies with reported direct carbon emissions. The EMRIO model uses company data where available to separate individual companies out from sectors within an MRIO table, then breaks those companies further into their operational segments and subsegments. For in-

stance, the EMRIO model deconstructs Toyota Motor Corporation into 'Automotive' and 'Financial Services' segments according to its annual security report; then, 'Automotive' segment into more detailed subsegments: 'Automobile Manufacturing', 'Truck Manufacturing', 'Automobile Engine Manufacturing', 'Automobile Parts Manufacturing', and 'Wholesale operations'. These subsegments are meticulously aligned with the corresponding sectors in the relevant national industrial output tables (IOTs), according to the annual security report of the corporation. This approach combines the best of both worlds: company-level operation and emissions data and a balanced official national input-output table which captures residual flows.

The current version of the EMRIO framework covers 121 countries, 17,322 sectors, 9,466 companies, 20,795 primary segments, 86,305 subsegments in 2015. By aligning the company carbon emission datasets with the EMRIO framework, we are able to quantify supply chain carbon for the intersection of two databases, encompassing 2,026 companies across 36 countries, which includes 5,095 segments and 12,226 subsegments.

2.3 Scope N Emissions Estimation Process

Scope 1 Emissions

In alignment with the EMRIO framework we disaggregate the Scope 1 emission of a company to the subsegment level by applying sector-specific emission intensities to the financial data. Consistency with the EMRIO database is maintained as the subsegment is disaggregated on an unconsolidated basis, referring to economic activities generated solely from the parent company's primary operations and excluding those of its subsidiaries. This approach ensures that subsegment data accurately reflect the core business performance unaffected by subsidiary activities.

Let $c'p'q'$ represent the subsegment q' which belongs to segment p' within company c', classified under the j "customer sector" of country s. The "customer sector" (industry sector in SUT) is the sector that demands goods or services from a supplier sector (commodity sector in SUT). The unconsolidated sales are denoted by SALES°, where the superscript $\circ$ designates an unconsolidated basis, which is further detailed in Katafuchi et al. (2024). To compute the Scope 1 (S1) emissions for subsegment $c'p'q'$ in country s, denoted as $g^{s,\text{S1}}_{c'p'q'}$, we allocate the unconsolidated company-wide emissions $g^{s,\text{S1},\circ}_{c'}$ proportionally, based on each subsegment's uncon-

solidated sales concerning the emission intensity of their respective sectors. The estimation proceeds as follows:

$$g^{s,\mathrm{S1}}_{c'p'q'} = g^{s,\mathrm{S1},\circ}_{c'} \frac{\mathrm{SALES}^{s,\circ}_{c'p'q'}\, g^{s,\mathrm{S1}}_{j} / x^{s}_{j}}{\sum_{p',q'} \mathrm{SALES}^{s,\circ}_{c'p'q'}\, g^{s,\mathrm{S1}}_{j} / x^{s}_{j}}\,, \tag{1}$$

where $g^{s,\mathrm{S1}}_{j}$ represents the total Scope 1 emissions of the customer sector j, and x^{s}_{j} denotes its gross output. The ratio $g^{s,\mathrm{S1}}_{j} / x^{s}_{j}$ is defined as the emission intensity for the customer sector, indicative of the average emissions per unit of output.

Following the EMRIO framework, each customer sector is categorized into two types of subsegments: the not-other subsegments (NOS), derived from companies that provide emission data, and the other subsegment (OS), which aggregates all remaining subsegments in that sector. Notably, for subsegments belonging to companies lacking emission data, their financial information sourced from EMRIO is collectively assigned to the respective OS category. Then, the emissions for OS of customer sector j is then given as

$$g^{s,\mathrm{S1}}_{\mathrm{OS}_j} = g^{s,\mathrm{S1}}_{j} - \sum_{\{c'p'q' \in j\}} g^{s,\mathrm{S1}}_{c'p'q'}. \tag{2}$$

Detailed calculations are available in Section S2 of the SI Appendix.

Scope 2 and 3 Emissions

Scope 2 and 3 emissions can be computed following the classical Leontief demand-pull model, which functions identically no matter how sectors or regions are defined. The EMRIO transaction matrix,

$$\mathbf{T} = \begin{bmatrix} T^{11}_{cpq,c'p'q'} & T^{11}_{cpq,\mathrm{OS}_j} & T^{12}_{cpq,c'p'q'} & T^{12}_{cpq,\mathrm{OS}_j} & \cdots \\ T^{11}_{\mathrm{OS}_i,c'p'q'} & T^{11}_{\mathrm{OS}_i,\mathrm{OS}_j} & T^{12}_{\mathrm{OS}_i,c'p'q'} & T^{12}_{\mathrm{OS}_i,\mathrm{OS}_j} & \cdots \\ T^{21}_{cpq,c'p'q'} & T^{21}_{cpq,\mathrm{OS}_j} & T^{22}_{cpq,c'p'q'} & T^{22}_{cpq,\mathrm{OS}_j} & \cdots \\ T^{21}_{\mathrm{OS}_i,c'p'q'} & T^{21}_{\mathrm{OS}_i,\mathrm{OS}_j} & T^{22}_{\mathrm{OS}_i,c'p'q'} & T^{22}_{\mathrm{OS}_i,\mathrm{OS}_j} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{bmatrix}, \tag{3}$$

where the elements denote the transaction values from the supplier subsegment, cpq or OS_i to the demanding subsegment, $c'p'q'$ or OS_j, with

the superscripts indicating the exporting and importing countries. The EMRIO transaction matrix is derived by disaggregating sector-level MRIO transaction matrix into subsegment-level according to sector-segment mapping using various company-level transaction and financial data (see the sister paper Katafuchi et al. (2024) for more detail).

The matrix $\mathbf{A}$, contains technical coefficients, calculated by dividing each element of $\mathbf{T}$ by the corresponding output of the demanding subsegment, either $\text{SALES}^{s}_{\text{OS}_j}$ or $\text{SALES}^{s,\circ}_{c'p'q'}$. This matrix indicates the inputs required by each subsegment to produce one unit of output. Let $\mathbf{f}$ represent the vector of direct emission intensities,

$$\mathbf{f} = \left[\frac{g^{1,\text{S1}}_{c'p'q'}}{\text{SALES}^{1,\circ}_{c'p'q'}} \quad \frac{g^{1,\text{S1}}_{\text{OS}_j}}{\text{SALES}^{1}_{\text{OS}_j}} \quad \cdots \quad \frac{g^{s,\text{S1}}_{c'p'q'}}{\text{SALES}^{s,\circ}_{c'p'q'}} \quad \frac{g^{s,\text{S1}}_{\text{OS}_j}}{\text{SALES}^{s}_{\text{OS}_j}} \quad \cdots \right] \tag{4}$$

Then, the vector of upstream emission coefficients is thus given by:

$$\mathbf{e}^{\text{S2+S3}} = \mathbf{f}(I - \mathbf{A})^{-1}, \tag{5}$$

where I is the identity matrix. This formulation calculates the vector of upstream emission coefficients, integrating both Scope 2 and Scope 3 emissions, accounting for the indirect emission intensities of each subsegment. We compute Scope 2 emissions following the GHG Protocol definition. Where in a pure classical Leontief approach, Scope 2 would refer to inputs from all tier 2 suppliers, we follow the GHG Protocol definition whereby Scope 2 emissions refers to emissions from electricity generation into the company under study.

In this analysis, we focus exclusively on upstream emissions. As a result, the Scope 2 and 3 emissions for country s and subsegment $c'p'q'$ are computed as follows:

$$g^{s,\text{S2+S3}}_{c'p'q'} = \mathbf{e}^{\text{S2+S3}} T^{s}_{\cdot,c'p'q'}. \tag{6}$$

Here, $T^{s}_{\cdot,c'p'q'}$ signifies the column of $\mathbf{T}$ that corresponds to the transaction values from all subsegments to subsegment $c'p'q'$ in country s. Specifically, Scope 2 emission of country s and subsegment $c'p'q'$ is given by:

$$g^{s,\text{S2}}_{c'p'q'} = \sum_{cpq \in \{\text{electricity,steam,}\atop \text{heat,cooling}\}} f_{cpq} T^{s}_{cpq,c'p'q'}. \tag{7}$$

Further details can be found in the SI Appendix, Section S4. Then, we derive Scope 3 emissions at the subsegment level as:

$$g^{s,\mathrm{S3}}_{c'p'q'} = g^{s,\mathrm{S2+S3}}_{c'p'q'} - g^{s,\mathrm{S2}}_{c'p'q'}. \tag{8}$$

The analysis is subject to a number of sources of uncertainty. These include: uncertainty in the initial MRIO model; uncertainty in cross-segment and cross-subsegment sales; biases in the sample of surveyed companies; mis-estimates of the Scope 1 emissions; and manual errors matching subsegments to sectors. In this study we have not attempted to quantify reliability due to the fact that there is little to no quantitative information available about reliability of primary data. Regarding sample bias, the data collection process has focused on the largest global corporations but relatively less data is available for small and mid-sized enterprises, companies operating primarily in the Global South (including regions such as Africa, Latin America, and parts of Asia), and the sample may potentially be biased by the omission of state-owned enterprises which do not participate in standard disclosure processes of the financial markets. These omissions are offset to a degree due to the method which blends corporate and national input-output data. When working with an individual company, when supply chain detail diminishes deeper in the supply chain the system boundary will be drawn closed where information stops, whereas in a blended model as company-level data decreases it will be replaced with the typical national or global supply chain(s) supplying that input. This blended approach presented in this study will lead to a systematically larger system boundary and thus Scope 3 emissions account for each entity but also more accurately reflects the concept of Scope 3 as defined in the GHG Protocol and provides results which more fully allocate emissions among culpable companies.

3 Results

Leveraging estimates derived from the EMRIO model we estimate the Scope 3 emissions for comparative analysis for 2,026 companies with 12,226 subsegments across 36 countries, which is the intersection of the EMRIO framework and the company carbon emission datasets.

In Figure 1 and Table 1, we present a comparative analysis of upstream Scope 3 emissions, contrasting company self-reported Scope 3 emissions

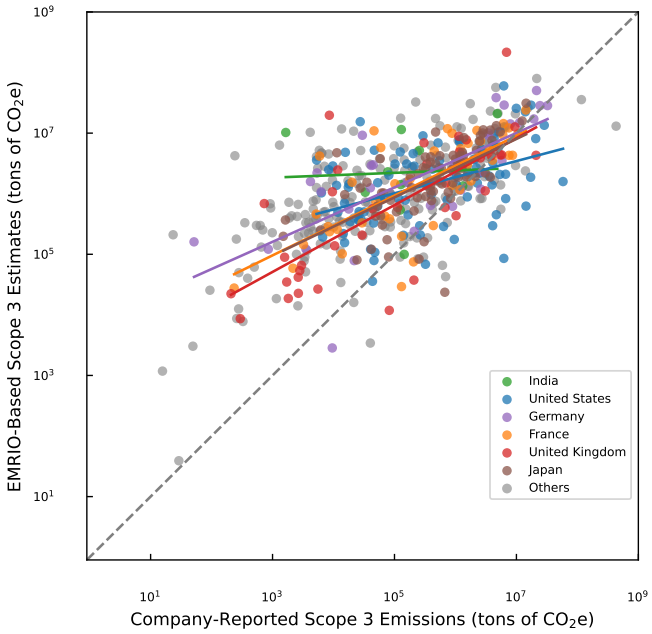

Figure 1: **Comparison of Company-Reported and EMRIO-Based Scope 3 Emissions.** Both axes log-scaled. The analysis encompasses companies that reported at least Category 1 emissions (purchased goods and services). Reported emission values aggregate all upstream categories within each company, sourced from CDP data.

with EMRIO-based estimates. This analysis includes disclosures from 507 companies across 32 countries, a subset of the 2,026 companies examined. For the average company, the EMRIO-based estimate shows a Scope 3 footprint 1.52 times greater than the company's self-reported Scope 3 footprint. Our analysis reveals that the Scope 3 emissions reported by companies are generally lower than those estimated using EMRIO. The discrepancy between self-reported and externally estimated Scope 3 emissions is even larger in some countries. For instance in India, the United Kingdom, and Japan, the EMRIO-based estimates are 7.55, 4.14, and 2.89 times greater than the reported values, respectively. The magnitude of the mismatch between company reports and whole-economy based estimates suggests there may be a systemic issue of under-reporting within corporate emissions disclosures.

The EMRIO results can also be used to investigate whether compa-

Table 1: The number of reporting companies and the ratios of total EMRIO-based company Scope 3 emissions estimates to self-reported values, summed by country in Figure 1.

	No. of Reporting Cos.	Estimate to Reported Ratio
India	10	7.55
the United States	90	1.31
the United Kingdom	36	4.14
Germany	36	1.81
France	42	2.02
Japan	78	2.89
others	215	1.01
Total	507	1.52

nies reporting to CDP have a distinct carbon intensity profile. Figure 2 illustrates Scope 3 emission intensities of the 2,026 companies segmented into three groups based on their CDP reporting status (reporters, non-disclosers, and exempt from CDP reporting). The analysis indicates that reporting companies generally have a 25% lower emission intensity compared to the average of non-reporting ones, suggesting either that intense emitters try to avoid disclosure or that disclosure is associated with lower supply-chain emissions. Additionally, companies not solicited for data by CDP questionnaires are typically smaller in scale and exhibit greater disparities in emission intensities.

We select a subset of industries classified by 4-digit Standard Industrial Classification (SIC) code (United States Census Bureau, 2023), each represented by over 20 companies distributed across a minimum of five countries, to analyze the diversity of emission intensity. Figure 3 underscores the extensive range of supply-chain emission intensities encountered. Furthermore, it also clearly demonstrates the significant disparities in emission intensities that can occur within companies sharing the same industry classification. For example, the total (ie. sum of Scope 1-3) emissions intensity of Solvay S.A. as estimated by the EMRIO is 3.3 times greater than the Plastic Material sector average.

Figure 4 and Table 2 illustrate the distribution of estimated Scope 1-3 emissions across various industries, categorized according to 1-dig SIC divisions (SIC Manual, 2023) of the subsegments. In Figure 4, each point represents a company, positioned within an equilateral triangle according to its specific balance of Scope 1, 2, and 3 emissions. It should be noted that

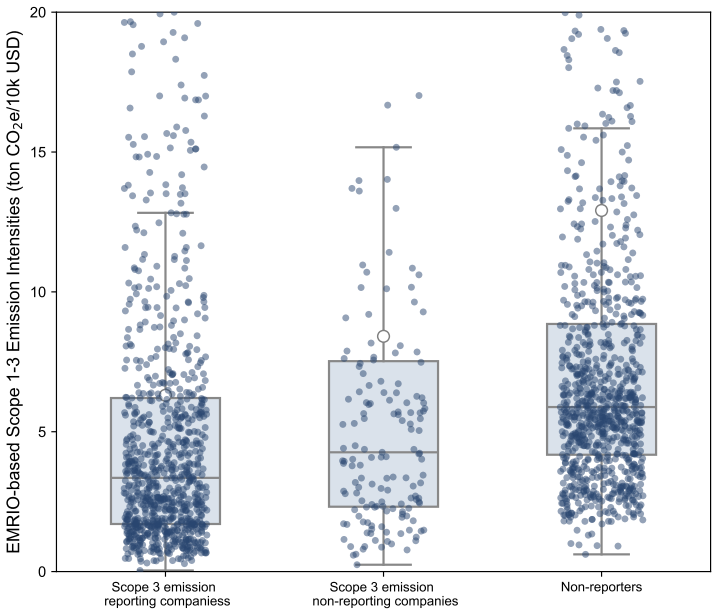

Figure 2: **EMRIO-Based Scope 1-3 Emission Intensities.** Emissions intensity is calculated as the sum of Scope 1, 2 and 3 emissions per 10k USD of company sales. "Scope 3 emission reporting companies" refers to companies reporting both Scope 1 and at least one category of Scope 3 emissions. 'Scope 3 emission non-reporting companies" are companies that report only Scope 1 emissions but no Scope 3 data. Both sets of data are acquired from the (CDP, 2015). "Non-reporters" represent companies covered in the EMRIO which are not surveyed by the CDP, with data sourced from alternative national databases. For each group, the mean and median values of emission intensities are represented in the visualizations as large circles and grey lines within each box, respectively.

each point is a business unit (subsegment) not the company as a whole. The closer a point is to a vertex, the higher the proportion of that specific type of emission in the company's overall supply chain emission.

Our analysis, as delineated in Table 2, delineates the distinct carbon footprints of segments across varied industry categories, reflecting the proportional contributions of Scope 1, 2, and 3 emissions. The concluding column tabulates the number of segments corresponding to each industry category. Predominantly, Scope 3 emissions constitute 63.5% of the total emissions, underscoring the significant reliance on indirect emission sources across the supply chains. It suggests that many companies should

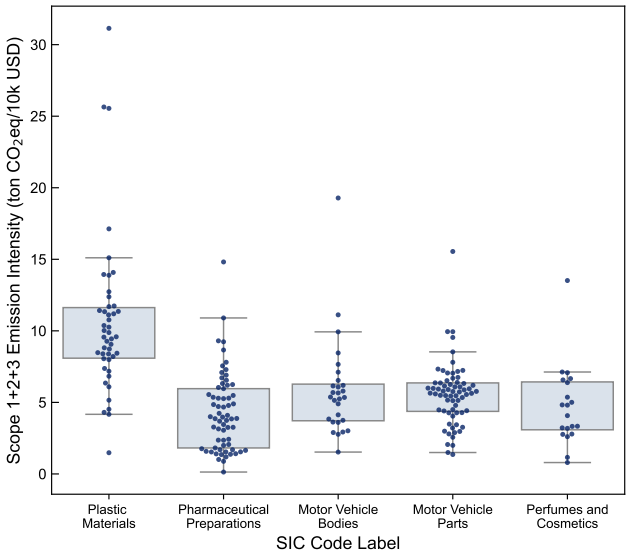

Figure 3: **Carbon Emission Intensities Across Diverse Industries.** This figure illustrates the emission intensity, calculated as the sum of segment-specific Scope 1, 2, and 3 emissions, normalized by sales amounts. The figure presents selected SIC sectors in the following order from left to right: 2821 – Plastics Materials, Synthetic Resins, and Nonvulcanizable Elastomers; 2834 – Pharmaceutical Preparations; 3711 – Motor Vehicles and Passenger Car Bodies; 3714 – Motor Vehicle Parts and Accessories; and 2844 – Perfumes, Cosmetics, and Other Toilet Preparations. The abbreviated names of these sectors are shown in the figure. The upper limit is set to 20 ton CO_2e/10k USD.

undertake the estimation of their Scope 3 emissions. Particularly, the Mining sector and the sector encompassing Transportation and Communications, Electric, Gas, and Sanitary services exhibit a considerable fraction of their direct emissions, at 48.2% and 54.7%, respectively. Furthermore, sectors typically associated with lower emission intensities, such as Services and Finance, Insurance, and Real Estate, show a significant portion of their emissions in Scope 3, accounting for 83.4% and 93.3%, respectively. This could largely be attributed to the investments and services they facilitate, which have far-reaching implications on emissions beyond their immediate operational boundaries.

Table 2: Proportional Contribution of Scope 1, 2, and 3 Emissions in Different Industry Categories.

Industry Categories	Scope 1 (%)	Scope 2 (%)	Scope 3 (%)	No. of Segments
Agriculture, Forestry and Fishing	17.9	9.9	72.2	13
Mining	48.2	6.6	45.1	216
Construction	4.7	1.8	93.5	113
Manufacturing	22.8	5.7	71.6	2,493
Transportation, Communications, Electric, Gas and Sanitary service	54.7	3.8	41.5	572
Wholesale Trade	16.8	5.6	77.7	180
Retail Trade	4.6	13.9	81.5	348
Finance, Insurance, and Real Estate	2.9	3.8	93.3	585
Services	7.5	9.1	83.4	528
Public Administration	26.3	3.1	70.7	46
Total	30.8	5.6	63.5	5,095

4 Discussion

Using the EMRIO table (Katafuchi et al., 2024) extended with company-level direct emissions, we first quantify the supply chain emissions of 2,000 companies. Our analysis suggests a potential underreporting of current Scope 3 emissions in corporate self-disclosures as reported values are generally lower than our independent estimates. Additionally, companies that disclose these emissions often report lower emission intensities than those that do not. This discrepancy is also evident in the considerable variations in emission intensities within the same industries. Our approach provides a nuanced and detailed assessment of companies' carbon footprints, highlighting potential discrepancies in corporate emission reporting. It underscores the importance of standardized and audited measurements for accurate and reliable corporate carbon emission mitigation.

The relative importance of Scope 3 emissions varies by industry. As shown in Figure 5, in the primary industries such as mining, the direct Scope 1 emissions comprise a relatively large share of the typical company's total Scope 1+2+3 footprint, and in the Services sector it is Scope 2 emissions (associated with electricity generation) which are relatively important. However for most firms in most sectors it is their supply chain Scope 3 emissions which comprises the largest part of their total footprint.

Consistent with our results, Berg et al. (2024) report that firms which

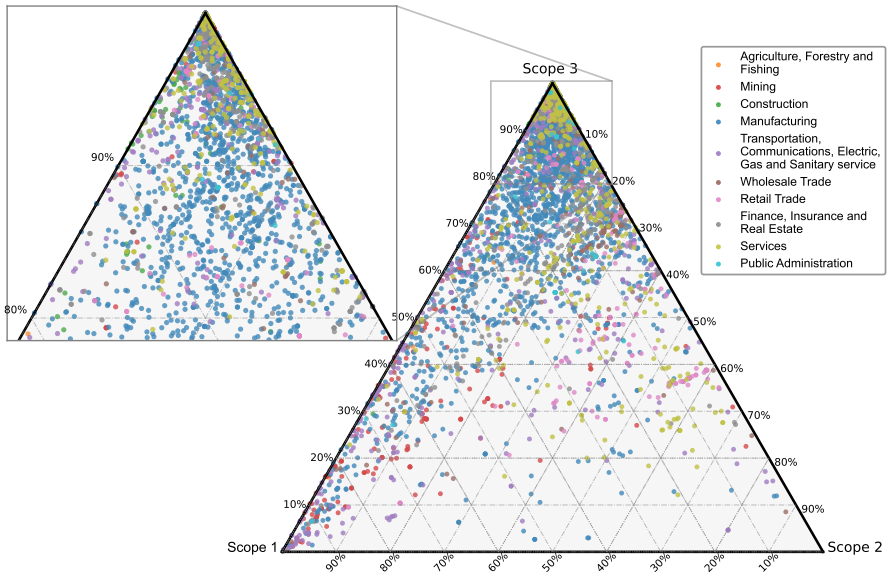

Figure 4: **Emission Proportions by Scope of Segments in Different Industries.** Points closer to the vertices correspond to higher proportions of emissions within their respective Scope categories, color-coded by SIC divisions of the segments.

obtain assurance for their GHG accounting on average see their carbon intensity rise 9% compared to peers. Even the most diligent and well-intentioned practitioners are challenged to produce accurate Scope 3 emissions inventories due to the state of available data. LCA data are available for many processes and primary and secondary inputs but are nearly nonexistent for tertiary and service inputs to companies. Best practice is to use a multinational input-output database to complement LCA results in preparing a corporate Scope 3 inventory, but the available input-output datasets have known constraints on the precision and accuracy of the results they can provide (Wood et al., 2019; Rodrigues et al., 2018; Steen-Olsen et al., 2014).

As the digitalization of environmental management systems (e.g. Digital Product Passports, environmental bill of health, etc.) expands and facilities for empirical and remote sensing validation of green claims mature, companies with un-audited green claims may be forced to make uncomfortable revisions to their self-assessed carbon risk exposure. The development of accounting standards and the assurance and auditing market

will be crucial for successful implementation of key supply-chain GHG abatement policies such as those presented in the introduction. We argue that the assurance gap in corporate Scope 3 results is more worrisome than the known issue of divergence across Environmental, Social, and Governance (ESG) risk assessment scores (Berg et al., 2022). Whereas ESG scores are voluntary assessments used by investors for portfolio management, Scope 3 results are increasingly asked to be empirically backed and linked to policy and regulatory consequences.

This study marks the first comprehensive, independent effort to compare Scope 3 emissions across companies. Such comparisons facilitate investment decisions, policy design and implementation, GHG account auditing, and establishing trustworthy results. Additionally, the extension of this analysis could simplify the process for companies to report their Scope 3 emissions.

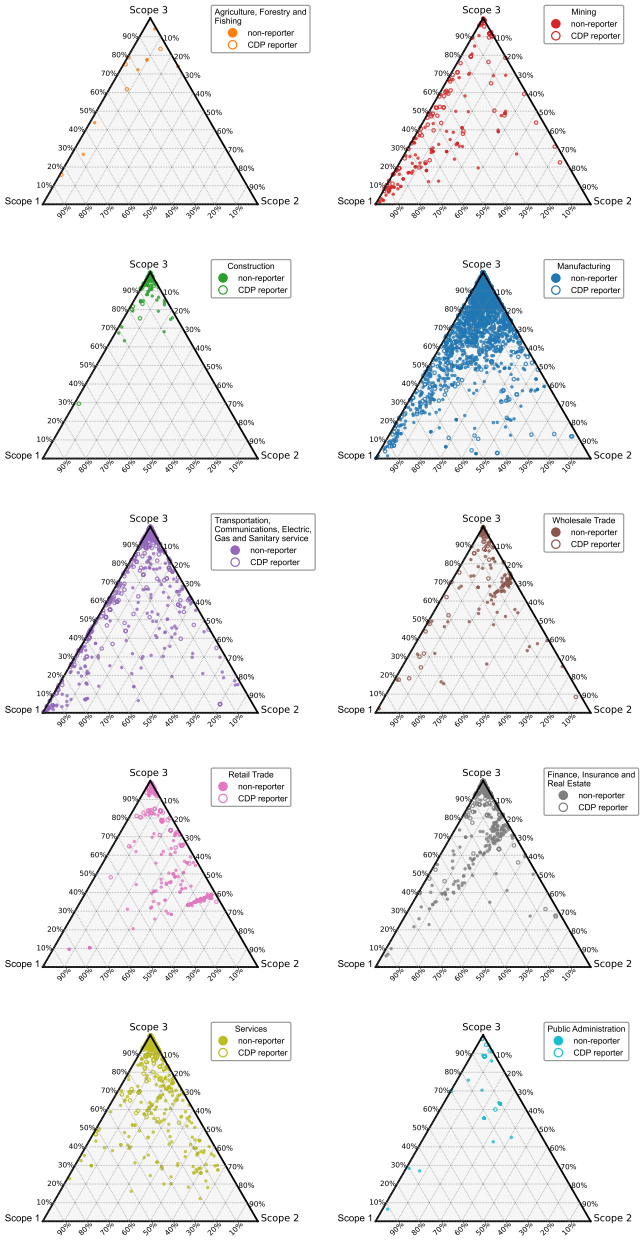

Figure 5: **Industry-specific Emission Distribution by Scope.** This figure decomposes Figure 4, presenting emission proportions and scopes across different industries. Hollow points indicate companies that report emissions to CDP, while solid points represent companies not surveyed by CDP. All values are based on EMRIO model estimates.

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Ethics Declarations

Competing Interest Statement
The authors declare no competing interests.

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