Supply Chain Emission Hotspot and Allocation Method Analysis

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SUBMITTED TO THE PROGRAM IN SUPPLY CHAIN MANAGEMENT
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE IN SUPPLY CHAIN MANAGEMENT
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

May 2024

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Submitted to the Program in Supply Chain Management
on May 10th, 2024 in Partial Fulfillment of the
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ABSTRACT

This capstone project, "Supply Chain Emission Hotspot and Allocation Method Analysis," delves into the complex interplay between green house gas (GHG) emissions reporting and the allocation of emissions within a global supply chain, with a focus on Dell Technologies as a case study. The research addresses key challenges in accurately calculating and managing scope 3 emissions, which encompass all indirect emissions within a company's value chain. Our study highlights the nuanced relationships between suppliers' emission data, the methodologies used to calculate emissions, and the reliability of reported emissions.

Initially, the project identifies inconsistencies in emissions data reported by suppliers, suggesting that variations in measurement techniques, reporting standards, and operational processes contribute to these discrepancies. The study then analyzes the spend-based methodology for calculating scope 3 emissions, demonstrating its inadequacy in accurately reflecting the true carbon footprint due to its overreliance on financial metrics.

To enhance the accuracy of emissions reporting, the project proposes a comprehensive approach, including:

- Outlier Detection: Implementing algorithms to identify anomalies in supplier data, ensuring integrity in emissions reporting.
- Product-Specific Carbon Footprint: Encouraging the use of granular, product-specific emission factors to provide a more accurate understanding of a company's environmental impact.

The research underscores the importance of integrating robust data management practices and refined methodologies to guide strategic decision-making, enabling companies to align their operations with their sustainability goals and reduce their environmental impact.

Capstone Advisor: Dr. Josué C. Velázquez Martínez
Director, MIT Sustainable Supply Chain Lab

ACKNOWLEDGMENTS

We would like to express our deepest gratitude to a number of people and organizations whose support was invaluable during the course of my capstone project.

First and foremost, we extend our heartfelt thanks to the Kosolpatanadurong family and the Gupta family, who have provided unwavering support and encouragement throughout our academic journey. Their constant belief in our abilities has been a foundational pillar of our success. We are equally grateful to our partners, and close friends both from the Supply Chain Management program and our communities back home for their companionship and moral support. Their presence and encouragement have made our journey at MIT not only bearable but also enjoyable, helping us to stay balanced and focused.

Special thanks are due to our advisor, Prof. Josué C. Velázquez Martínez, for his expert guidance and valuable insights. His mentorship was crucial in shaping both the direction and execution of our project. We would also like to thank Dr. Sreedevi Rajagopalan and Maria Jose Chiang Rebatta, for their contributions and for sharing their expertise, which significantly enriched our research experience.

Appreciation is also extended to our gracious sponsor company, Dell Technologies, and the team including Alena (AB) Turner, Madeline Schell, and Macani Toungara. Their collaboration and input were instrumental in providing real-world perspectives that greatly enhanced the quality and applicability of our work.

Furthermore, we acknowledge the support of the MIT Center for Transportation and Logistics (CTL) and the MIT Supply Chain Management Program. The resources and opportunities provided by these bodies were crucial in the completion of this capstone project.

Thank you all for your support, guidance, and encouragement, which have been vital to our academic and personal growth.

Sincerely,

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TABLE OF CONTENTS

1. INTRODUCTION

1.1 Motivation

Environmental sustainability is essential for harmonizing human development with the ecological boundaries of our planet. It is crucial for preserving our natural resources and ensuring the health of our environment for future generations. Industries worldwide recognize their role in this balance and are increasingly committing to climate pledges to reduce green house gas (GHG) emissions. These commitments align with the GHG Protocol, a structured tool that helps organizations systematically measure and manage their emissions.

The GHG Protocol categorizes emissions into three scopes: scope 1 and 2 encompasses the direct emissions that a company has authority over, while scope 3 represent indirect emissions resulting from the company's activities but originating from sources outside its ownership or control. Measuring emissions for scopes 1 and 2 is relatively more straightforward. For instance, when it comes to energy consumption, companies can readily obtain the necessary data to calculate the green house gas emissions linked to their direct procurement of gas and electricity (National Grid, 2023)

However, scope 3 emissions, often constituting more than 79% of a company's total emissions, are typically the most difficult to reduce. One strategy a company can employ to diminish these emissions is to collaborate with their current suppliers and customers in devising solutions for emission reduction. Accurately estimating these emissions is a complex but vital step toward genuine environmental sustainability, emphasizing the interconnectedness of our actions and their broader impact on the world. (Green House Gas Protocol, 2011.)

1.2 Problem Statement & Research Questions

To better support the supply chain assurance team in understanding the nature of their suppliers' green house gas emissions and the reported emission data, this capstone focuses on exploring the relationships among the emission data, the emission calculation methodology and its impact on the allocated emissions. This insight enables the team to more effectively study and validate the data integrity of the emissions reported by their suppliers.

In this context, our capstone project focuses on the following research question:

“ How does the reporting of emissions by suppliers impact the precision and reliability of a firm's carbon emissions calculations and reporting, and what consequences does this have for the overall emissions target?”

To answer the research question, we present the following guiding questions:

- How can a model or program be developed to determine the accuracy of emissions reported by each supplier?
- What are the calculation methodologies to determine scope 3 emissions? What are the assumptions and implications?
- How can the calculation methodologies and their impact on the accuracy of emission calculations best be explained to a business audience?

1.3 Case Study Company

As a leading technology provider operating globally with an extensive supply chain and customer base, Dell Technologies (referred to as 'Dell' moving forward in the report) faces an increasingly acute and long-term risk stemming from climate change.

Dell is committed to achieving net zero green house gas (GHG) emissions across scopes 1, 2, and 3 by 2050 (Dell, n.d.). A large portion of their client systems' carbon footprint, such as notebooks and servers, primarily originates in the supply chain. Dell is actively working to decrease this footprint through design choices, material selection, and collaboration with suppliers, with a focus on reducing operational energy use and transitioning to cleaner energy sources.

Dell has set an ambitious target to reduce absolute emissions from its purchased goods and services by 45% by 2030 (Dell, n.d.) To facilitate this reduction, they have launched the Emissions Supplier Engagement Program, which seeks to involve their supply chain partners in lowering their carbon emissions. This initiative entails gaining a comprehensive understanding of the supplier's supply chain and emissions data. This data serves as a vital reflection of Dell's knowledge and the support the suppliers require on their journey to reduce GHG emissions. With this information in hand, Dell aims to take a strategic and collaborative approach to aid their suppliers in collectively striving to meet GHG reduction goals and expectations.

1.4 Project Goals and Expected Outcomes

The main goals of the project are to verify the green house gas emissions data received from Dell's suppliers within two commodities with the estimates from the model and to identify incongruous data and calculation assumptions. The results can lead to future decisions on the management of their supply chain network. The model helps them achieve their sustainability targets if applied to other commodities within their portfolio.

Deliverables to the company includes:

1. A model to flag incongruent data from suppliers for two commodities

2. A report highlighting the analysis of the methodology options to calculate scope 3 emissions and the degree of the impact of each variable associated in the calculation

3. A set of policy suggestions on how the social and environmental responsibility team at Dell can use the model and analysis to identify data integrity challenges and potential impactful approaches toward Dell's emission target in the future

2. STATE OF THE PRACTICE

In order to analyze the emissions data from any organization, we researched and understood the current industry standard procedures. These protocols include the carbon footprint mapping and the definition of the different scopes of emissions.

2.1 Carbon Footprint Mapping

A company's green house gas emissions are categorized into three scopes:

Scope 1 refers to direct emissions stemming from resources owned and controlled by the company. These emissions result directly from specific activities conducted at the firm level, including stationary combustion, such as fuels and heating sources.

Scope 2 emissions, on the other hand, represent the indirect emissions arising from purchased energy generated by an external utility provider. These emissions include GHG emissions released into the atmosphere due to the consumption of purchased electricity, steam, heat, and cooling (Plan A, n.d.)

Scope 3 emissions encompass all indirect emissions not covered within scope 2, which includes both upstream and downstream emissions in the reporting company's value chain (see Figure 2). For most enterprises and public entities, the majority of their GHG emissions exist beyond their direct operations. Addressing scope 3 emissions can significantly propel an organization's journey towards decarbonization and sustainability (Oliver Wyman Forum, n.d.)

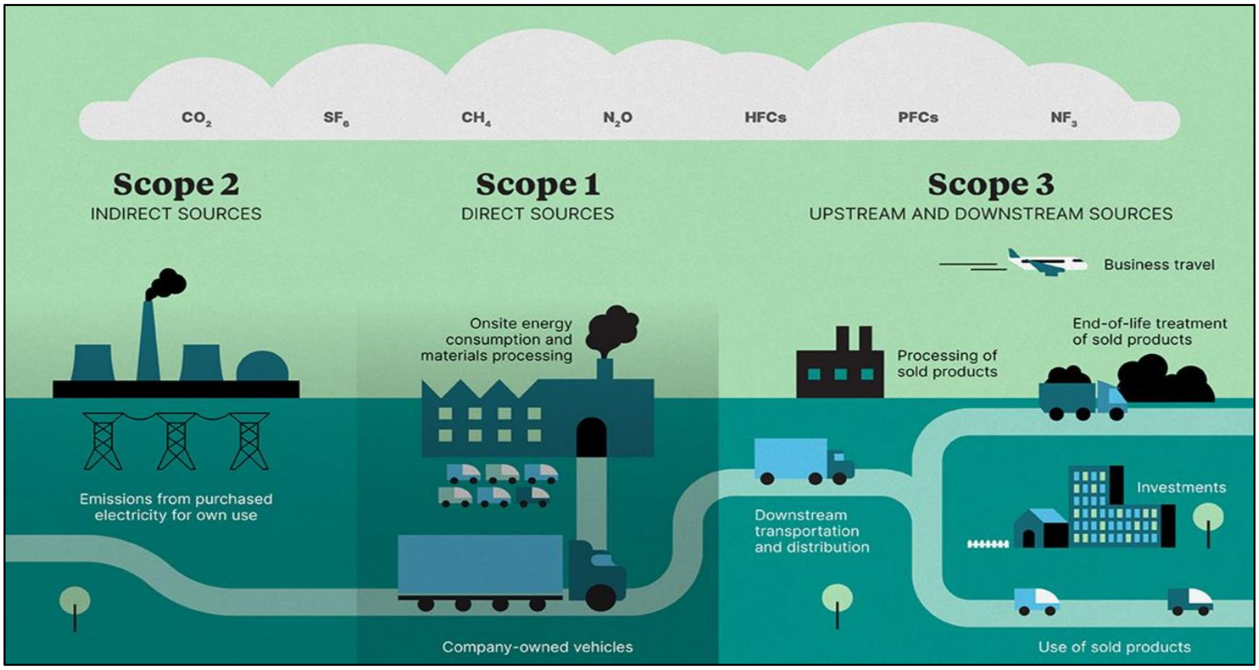

Figure 1: Scope 1, 2 and 3 emissions (Oliver Wyman Forum. (n.d.)

Beyond meeting evolving regulatory demands, quantifying scope 3 emissions empowers businesses to:

- Evaluate key emission hotspots along the value chain for prioritization of reduction strategies
- Identify leading and lagging sustainability performers among their suppliers
- Guide decision-making across procurement, product development, and logistics teams by highlighting interventions capable of delivering substantial emission reductions
- Stimulate product innovation to create more sustainable and energy-efficient products
- Advance their climate strategy by effecting genuine and measurable changes (Carbon Trust, n.d.)

Scope 3 emissions cover a wide range of indirect emissions not included in scopes 1 or 2, encompassing emissions from purchased goods and services, capital goods, fuel- and energy-related activities, upstream and downstream transportation and distribution, waste disposal, business travel, employee commuting, upstream and downstream leased assets, processing and use of sold products, end-of-life treatment of products, franchises, and investments (Thinkstep ANZ, n.d.) According to the project's scope, we delve deep into the scope 3 Category 1 emissions, which constitute a major proportion of Dell's emissions footprint.

2.2 Scope 3 Category 1:

These emissions are generated upstream in the supply chain during the production, extraction, or procurement of goods and services that the organization acquires. They account for the entire life cycle of the purchased items, including raw material extraction, manufacturing, and distribution until they reach the organization (Green House Gas Protocol, 2011.)

Assessing emissions in this category helps organizations understand the environmental impact of their supply chain. It allows for identifying hotspots in the value chain where emissions are significant, providing opportunities for reduction strategies and supplier engagement (Green House Gas Protocol, 2011.)

Quantifying these emissions can be complex due to the extensive nature of supply chains, especially for multinational companies with diverse suppliers across various regions and industries. Limited data availability and transparency from suppliers can also pose challenges in accurately measuring these emissions (Green House Gas Protocol, 2011.)

Organizations use four main approaches to compute scope 3 emissions from purchased goods and services. The supplier-specific and hybrid methods necessitate data collection directly from suppliers, while the average-data and spend-based methods rely on industry-average secondary data. These methods are sequenced by their specificity to individual suppliers, but it is not mandatory to prioritize the most detailed method initially (see Figure 3).

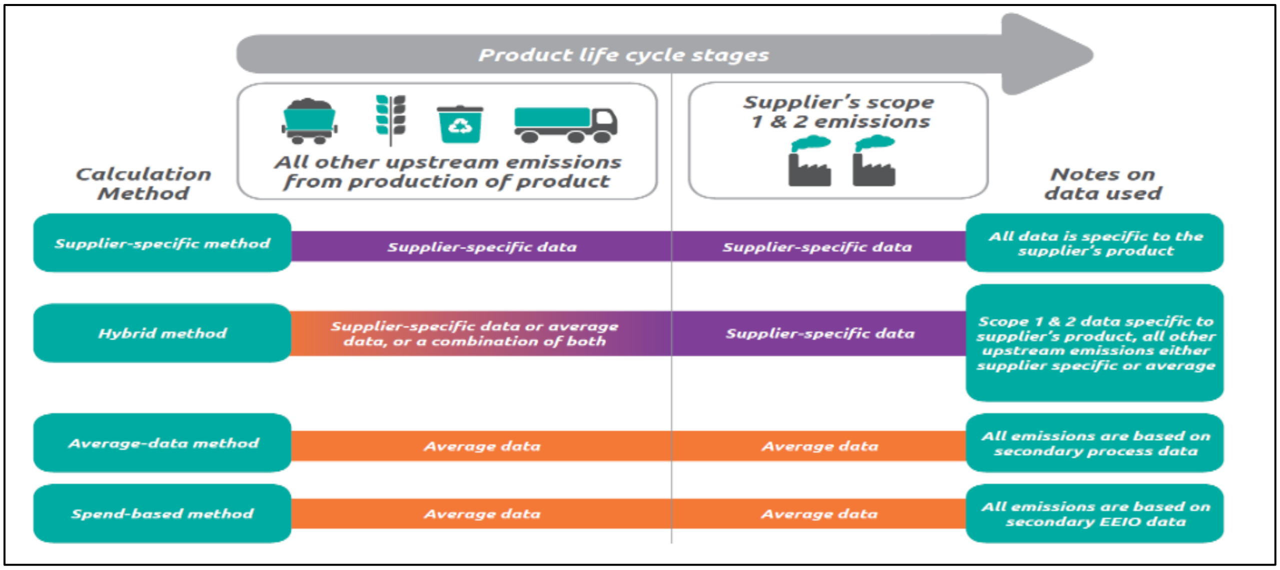

Figure 2: Scope 3 emissions Calculation methodologies (Green House Gas Protocol, 2011.)

1. **Supplier-specific method:** Gathers comprehensive product-level green house gas (GHG) inventory data from goods or service suppliers.

2. **Hybrid method:** Blends supplier-specific activity data and secondary data to address data gaps. It entails collecting supplier-allocated scope 1 & 2 emission data, computing upstream emissions based on supplier activity metrics (materials, fuel, electricity usage, transportation, waste generated, or revenue), and applying suitable emission factors. Secondary data fills gaps where supplier-specific information is lacking.

3. **Average-data method:** Approximates emissions by acquiring data on purchased goods or services in mass or relevant units and multiplying by industry-average emission factors.

4**. Spend-based method:** Estimates emissions by utilizing economic value data of purchased goods or services multiplied by industry-average emission factors related to their monetary value. This method is often used when direct emissions data from suppliers are not available or when the procurement data are more readily accessible (Green House Gas Protocol, 2011.)

Each of these methods has its advantages and limitations, with varying degrees of accuracy. Dell uses the hybrid method implemented from the reported emission data from their suppliers' CDP reports and Dell's database of their commodity spending with each of the companies (Dell, n.d.) to calculate supplier's specific emission intensity and allocate the carbon emissions accordingly. In other words, Dell calculates the supplier's specific emission intensity to replace the industrial average emission factors when it is possible, so the allocated emissions would be more accurate.

3. DATA & METHODOLOGY

Dell has given the carbon emission data for all the purchased goods and services (PG&S) from all suppliers from FY 2021 to FY 2023 for analysis. The dataset includes the list of the purchased goods and services, the suppliers' data that are reported to the CDP, the spending on each supplier, and some other relevant information. Since the allocation of the carbon emissions is dependent on both the data quality and the allocation method, the project explores two main topics: 1) Outlier Detection of the data, and 2) the sensitivity analyses of the emission allocation method.

3.1 Outlier Detection Methodology

3.1.1. Potential Outlier Detection Techniques

Outlier detection is a fundamental aspect of data analysis, impacting various fields from finance to healthcare. An outlier is an observation that deviates markedly from other observations, potentially indicating variability in measurement, experimental errors, or novelty. Effective outlier detection techniques are crucial for accurate data analysis (see Table 1). Several outlier identification methods are widely used in the industries: Z-score, Isolation Forest, DBSCAN, and the Interquartile Range (IQR) method on a boxplot.

Each outlier detection method has strengths and limitations, influenced by factors such as dataset size, distribution, and the specific requirements of the analysis. Z-score is best suited for large, normally distributed datasets, while Isolation Forest excels in high-dimensional spaces. DBSCAN is effective in spatial data but sensitive to parameter settings. The IQR method on a boxplot provides a straightforward approach for datasets with a median-focused distribution. The choice of method should be guided by the nature of the dataset and the specific goals of the analysis.

In our analysis, we encountered many small datasets that deviate from the assumption of normality and present a natural lower bound at zero. To address the deviation issue, we have adopted a two-pronged approach: implementing the Truncated Normal Distribution (TND) with a minimum limit of zero and employing the Box Plot with the Interquartile Range (IQR) method for outlier detection. This section explains our methodology, considering the specific characteristics of our dataset.

3.1.2 Implementing Truncated Normal Distribution

Our datasets from Dell lack normality and include a logical lower bound (zero), making standard normal distribution models inappropriate. Values in the dataset cannot fall below zero, indicative of scenarios like time durations, concentrations, or non-negative measurements like emission intensity distribution. The TND would accommodate these datasets with natural bounds (Fisher, 1931.) By truncating the normal distribution at zero, we can model our data more accurately, ensuring that the distribution reflects the actual constraints of the dataset as it provides a realistic and statistically sound representation of the underlying data distribution.

3.1.3 Applying Box Plot with IQR Method for Outlier Detection

While TND effectively models our bounded data, outlier detection remains crucial. Outliers can significantly skew results and lead to erroneous interpretations, especially in datasets with inherent constraints. Hence, the box plot would offer a visual representation of the distribution, particularly the spread and central tendency, which is now modeled by the TND. This visualization aids in initially identifying potential outliers, especially those that are extreme compared to the bulk of the data. In addition, the IQR method, a robust statistical technique, is used to quantitatively identify outliers. By calculating the

IQR (the range between the 25th and 75th percentiles) and defining outliers as data points lying outside 1.5 times the IQR from the quartiles, we ensure a consistent and objective approach to outlier detection (The Pennsylvania State University, n.d.) Employing the IQR method on a dataset modeled by TND is particularly effective as it accounts for the skewness and bounds inherent in the data. The IQR method does not assume normality, making it a fitting choice for our truncated dataset.

3.2. Emission Allocation Method

Ideally, the allocated emission of the purchased goods and services should be equal to the actual emissions incurred by these particular purchased goods and services. However, the current emission allocation methods utilized various variables to calculate the allocated emission. This study explores the effects of relevant variables and the accuracy of the emission allocation method with two approaches.

3.2.1. Hypothetical Case Studies and Sensitivity Analysis

The hybrid methodology employed by Dell to estimate scope 3 emissions, assumes that a supplier's carbon emissions are proportional to their revenue. Simulating different scenarios and using sensitivity analysis helps to pinpoint critical areas within the supply chain that could benefit from focused interventions, underscoring the nuanced management of supply chain emissions and the importance of leveraging financial data to inform and refine environmental strategies.

3.2.2. Analytical and Numerical method for mathematical analysis

The emission allocation method can be written as a mathematical equation with all the relevant variables such as the price of the product, the emission intensity of the product, the revenue of the supplier, etc. This study manipulates the mathematical formula to solve for the simplified equation that can be used for the consequent numerical method. The numerical method explores the effects of some important variables that might influence the value of the allocated emissions.

4. RESULTS

4.1. Outlier Identification Method

After implementing the outlier identification method and analyzing the emission data from Dell's suppliers for two commodities in Python, we plotted the emission intensity data for each of the commodities in a box & whisker plot and truncated normal distribution (see Figures 4, 5, 6, and 7). This distribution helped us flag the suppliers whose data was incongruent with the average supplier data in their commodity from the data that fell outside of the interquartile range. The results helped set a starting point to narrow down these suppliers for Dell to further investigate whether there are errors in the suppliers' reporting data or not.

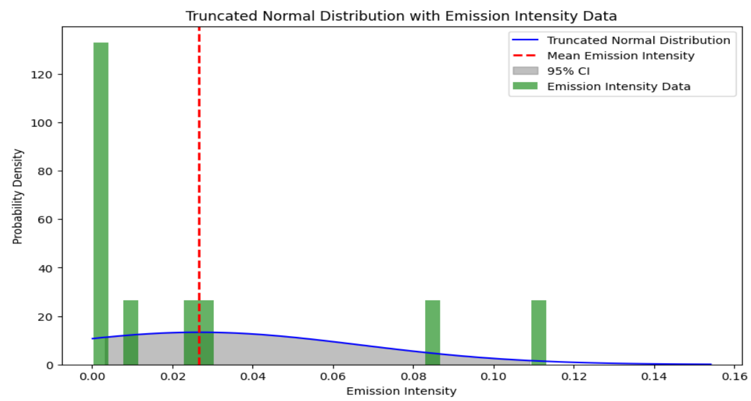

Figure 3: The truncated normal distribution with Emission Intensity Data for Commodity 1

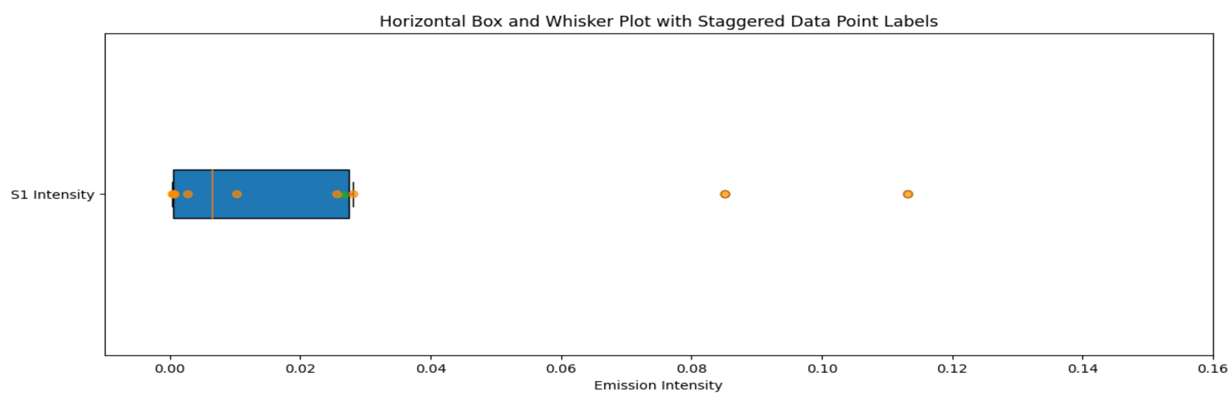

Figure 4: The box and whisker plot with IQR range from emission Intensity Data for Commodity 1

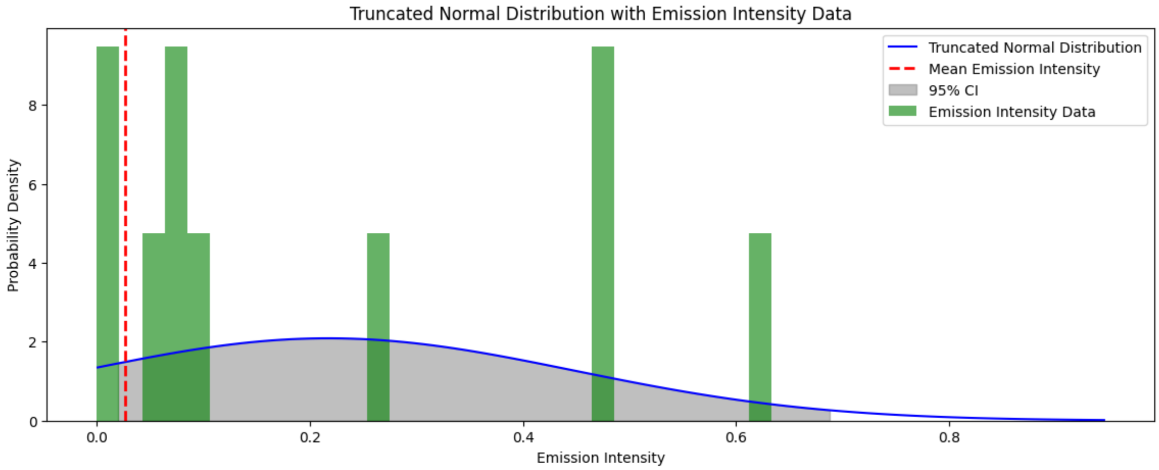

Figure 5: The truncated normal distribution with Emission Intensity Data for Commodity 2

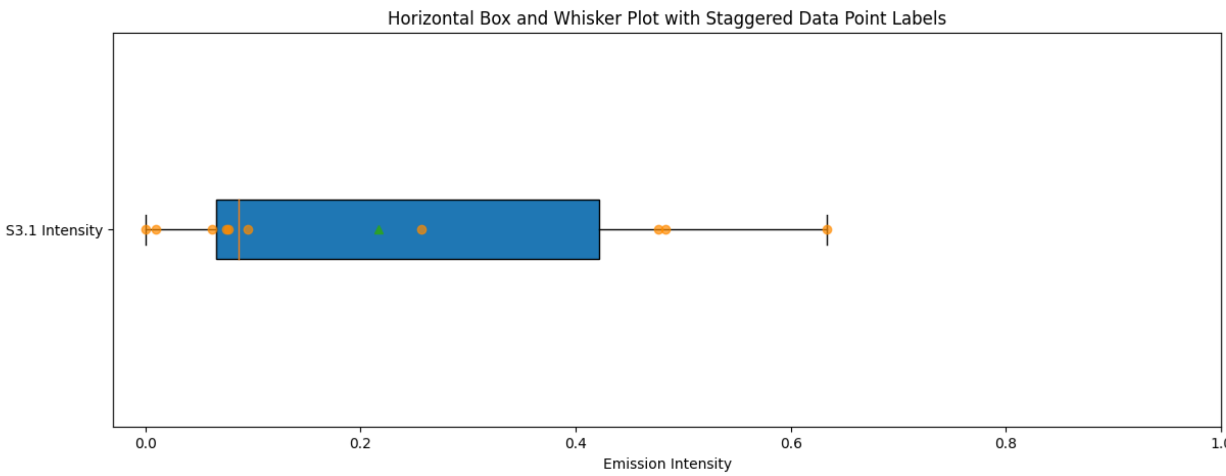

Figure 6: The box and whisker plot with IQR range from emission Intensity Data (scope 1, 2, and 3.1) for Commodity 2

4.2 Hypothetical Case Studies

A crucial part of our analysis also involves understanding the assumptions and the stakes behind the methodology used for calculating scope 3 emissions. For instance, in hybrid methodology, which is one of the methods used by Dell to calculate scope 3 emissions, it is assumed that the total carbon emissions from a supplier are proportional to their total revenue. By understanding the proportionality between revenue and emissions, we can identify high-impact areas within the supply chain and prioritize interventions. This approach underscores the complexity of supply chain emissions management and the importance of leveraging financial data to drive environmental strategies. Thus, through this methodology we first calculate the emissions intensity for each supplier, which leads to calculating the scope-3 carbon emissions by that supplier by multiplying this intensity with the respective spend. The summation of emissions by all the suppliers leads to total scope-3 category 1 carbon emissions for a firm.

For any supplier, **Intensity = Total carbon emissions / Total Revenue**

$$\textbf{Intensity} = \sum(P_i \times C_i) / \sum(P_i \times R_i)$$

$$= \sum(P_i \times C_i) / \sum(P_i \times Q_i \times \$_i)$$

P_i - Product type, where i is 0 to N for all product types

C_i - Total carbon emissions by product type i

R_i - Revenue generated by product type i

Q_i - Total quantity of product type i sold by supplier

$\$_i$ - Price at which product type i is sold by supplier

Assuming that Dell is procuring only 1 product type from that supplier,

Scope 3 carbon emissions due to supplier = Intensity * Spend by Dell

$$\textbf{Total scope 3 carbon emissions} = [\sum(P_i \times C_i) \;/\; \sum(P_i \times Q_i \times \$_i)] * (P_1 \times D \times \$_i)$$

We now look at some hypothetical cases where the hybrid methodology could fail, giving an inaccurate estimate of the emissions.

4.2.1 CASE 1: IF EACH PRODUCT TYPE DOES NOT HAVE THE SAME INTENSITY

To understand the impact of having suppliers with different product types having different emission intensities, we have created a hypothetical scenario of a supplier having 4 products with varying prices and intensities (see Table 2). The firm, which is procuring parts from this supplier, is sourcing only 1 of the 4 products that the supplier manufactures.

Note: The data below is hypothetical and has no bearing on Dell or its suppliers

	Product Types	Average Price	Total Qty sold by supplier (S)	Total Qty bought by firm (F)	Supplier's Revenue	Spend by Firm (F)	Product Intensity	Total Emissions (MT)
1	**Digital Signage**	$5,000	5	0	$25,000	$ -	0.4	10,000
2	**LED**	$30,000	10	0	$300,000	$ -	0.3	90,000
3	**Hospitality TVs**	$10,000	15	0	$150,000	$ -	0.2	30,000
4	**Laptop display**	$200	70	35	$14,000	$7,000	0.1	1,400

Table 1: Supplier S portfolio of products with different intensities

Firm (F): The company which is procuring the parts from suppliers

Supplier (S): One of the companies that is a supplier to firm (F)

Calculation 1: When only the procured part is considered for intensity calculation

Supplier (S) intensity for procured part (laptop display) = 0.1

Scope 3 emissions for Firm (F) = 700 MT

Calculation 2: When entire product range is considered and proportioned for revenue from Firm (F)

Supplier (S) overall intensity = 0.27

Scope 3 emissions for Firm (F) = 1881 MT CO_2e (referred to as 'MT' moving forward in the report)

Impact = 169% increase due to aggregated product emissions

In this hypothetical scenario, we explore the impact of product mix on a firm's scope 3 category 1 emissions calculation, considering the varying emission intensities and prices of products from a single supplier. The firm procures only one product type from the supplier, but the supplier manufactures multiple products with different emission intensities. When calculating emissions based solely on the procured product, the impact appears minimal. However, when considering the supplier's entire product range and attributing a proportion of the total emissions based on revenue from the firm, there is a significant increase in the firm's calculated scope 3 emissions.

This example illustrates the complexity of accurately assessing scope 3 emissions and the importance of considering the full scope of a supplier's product offerings, not just the products directly procured, to understand environmental impact truly.

4.2.2. CASE 2: PRICE HIKE: INVESTMENT BY SUPPLIER TO REDUCE CARBON EMISSIONS

Here we discuss the impact of price changes on emissions. Our analysis suggests that a price hike, potentially due to investments by suppliers in reducing carbon emissions, can lead to an increase in the firm’s emissions, even if the actual emissions remain the same or decrease (see Table 3). This paradoxical result underscores the complexity of managing supply chain emissions and the importance of strategic decision-making.

Note: The data below is hypothetical and has no bearing on Dell or its suppliers

Product Types	Average Price	Total Qty sold by supplier (S)	Total Qty bought by firm (F)	Supplier's Revenue	Spend by Firm (F)	Product Intensity	Total Emissions (MT)
Digital Signage	$5,000	5	0	$25,000	$ -	0.4	10,000
LED	$30,000	10	0	$300,000	$ -	0.3	90,000
Hospitality TVs	$10,000	15	0	$150,000	$ -	0.2	30,000
Laptop display	$250	70	35	$17,500	$8,750.00	0.1	1,000

Table 2: Same portfolio of products but with price hike of Laptop Display

Firm (F): The company which is procuring the parts from suppliers

Supplier (S): One of the companies that is a supplier to firm (F)

Calculation 1: Scope 3 category 1 emissions for price $200

Scope 3 emissions for Dell (@ price $200) = 1,881 MT | (Supplier (S) overall intensity = 0.266)

Calculation 2: Scope 3 category 1 emissions for price $250

Scope 3 emissions for Dell (@ price $250) = 2,327 MT | (Supplier (S) overall intensity = 0.269)

Impact = 24% increase in emissions for Dell even though actual emissions dropped

Calculation 3: Scope 3 category 1 emissions for price $250

Scope 3 emissions for Dell (@ price $250) = 500 MT | (Supplier (S) product intensity = 0.1)

Impact = 365% increase in emissions for Dell even though actual emissions dropped

Our analysis of the impact of price changes on emissions reveals a paradox where efforts to reduce emissions could inadvertently increase a company's reported emissions due to higher costs. When suppliers invest in greener technologies, their prices might rise to reflect these investments. If a company's emission calculations are partly based on the financial value of its purchases, an increase in prices—even if actual emissions are lower—could result in a higher emission footprint being attributed to the company.

This scenario highlights the intricate relationship between cost, investment in sustainability, and the calculation of carbon emissions, emphasizing the need for nuanced strategies that consider both financial and environmental impacts.

4.3. SENSITIVITY ANALYSIS

We now take a step further to understand the degree of impact of the supplier's decisions on the scope 3 emissions of the procuring firm F by carrying out a sensitivity analysis. To understand the impact, let us assume the same base hypothetical case where the supplier (S) is again has 4 products with varying prices and intensity (see Table 4). The firm (F), which is procuring parts from this supplier, is sourcing only 1 of the 4 products that the supplier manufactures.

Note: The data below is hypothetical and has no bearing on Dell or its suppliers

Product Types	Average Price	Total Qty sold by supplier (S)	Total Qty bought by firm (F)	Supplier (S) Revenue	Spend by Firm (F)	Product Intensity	Total Emissions (MT)
Digital Signage	$5,000	5	0	$25,000	$ -	0.4	10,000
LED	$30,000	10	0	$300,000	$ -	0.3	90,000
Hospitality TVs	$10,000	15	0	$150,000	$ -	0.2	30,000
Laptop display	$200	70	35	$14,000	$7,000	0.1	1,400

Table 3: Same base portfolio of products by Supplier S

Firm (F): The company which is procuring the parts from suppliers

Supplier (S): One of the companies that is a supplier to firm (F)

4.3.1. CASE 1: DEGREE OF IMPACT IF PRICE OF PROCURING PRODUCT VARIES

To understand the impact of the change in the price of products procured, let us assume that there is a **change in the price of the laptop display product (which firm F is procuring)**. These fluctuations can happen due to a shift in market supply-demand ratio or forex currency fluctuations.

We assume that the price adjustment ensures that the quantity of the product remains constant (see Table 5). We also assume that there is no change in the price and quantity of the remaining products.

Sensitivity	-50%	-20%	-10%	ORIGINAL	10%	20%	50%	100%
Price change for display	100	160	180	200	220	240	300	400
Supplier S total revenue	482,000	486,200	487,600	489,000	490,400	491,800	496,000	503,000
Supplier S total emissions	131,000	131,000	131,000	131,000	131,000	131,000	131,000	131,000
Supplier S Emission intensity	0.272	0.269	0.269	0.268	0.267	0.266	0.264	0.26
Firm F scope 3 emissions	951	1,509	1,693	1,875	2,057	2,237	2,773	3,646
Percentage Change	**-49%**	**-20%**	**-10%**	**0%**	**10%**	**19%**	**48%**	**94%**

Table 4: Sensitivity Analysis table for varying laptop display prices

This calculation shows that changes in prices of the product procured can impact the scope 3 emissions even though base emissions remain same when hybrid methodology is used. Therefore, even though there is no change in the quantity, or emissions of the product being procured by firm F, we see a change in emissions for firm F.

LEARNING: During price changes, investigate changes in carbon emissions to keep scope 3 in check

SAMPLE CALCULATIONS:

Original Scenario (Laptop display = $200)

Total Revenue = ∑(**Pi x $i x Qi**)

= ($5000 x 5) + ($30000 x 10) + ($10000 x 15) + ($200 x 70)

= $489,000

Total Emissions = ∑**(Pi x Ei)**

= 10,000 MT + 90,000 MT + 30,000MT + 1,400 MT

= 131,000 MT

Emission Intensity = Total Emissions/ Total Revenue = 0.268

Spend by Firm F on Laptop displays = $200 x 35 = $7,000

Scope 3 emissions for firm F = 1,875 MT

Increase by 50% in Laptop display price (Display = $300)

Total Revenue = ∑**(Pi x $i x Qi)**

= ($5000 x 5) + ($15000 x 10) + ($10000 x 15) + ($300 x 70)

= $496,000

Emission Intensity = Total Emissions (Remains same as only LED price change)/ Total Revenue = 0.264

Spend by Firm F on Laptop displays = $300 x 35 = $10,500

Scope 3 emissions for firm F = 2,773 MT

4.3.2. CASE 2: DEGREE OF IMPACT IF PRICE OF NON-PROCURING PRODUCTS VARY

Now we shift gears to understand the impact of changes in products that Firm (F) is not procuring. Even though it is not procuring them, Firm F still is impacted due to hybrid methodology. We assume that there is a **change in the price of the LED product (which firm F is not procuring)** due to shift in market supply-demand ratio for the product or forex currency fluctuations (see Table 6). Price adjustment ensures that the quantity of the Direct view LED product remains constant. We also assume that there is no change in the price and quantity of the remaining products.

Sensitivity	-50%	-20%	-10%	ORIGINAL	10%	20%	50%	100%
Price change for LED	$15,000	$24,000	$27,000	**$30,000**	$33,000	$36,000	$45,000	$60,000
Supplier S total revenue	$339,000	$429,000	$459,000	$489,000	$519,000	$549,000	$639,000	$789,000
Supplier S total emissions (MT)	131,000	131,000	131,000	131,000	131,000	131,000	131,000	131,000
Supplier S Emission intensity	0.386	0.305	0.285	0.268	0.252	0.239	0.205	0.166
Firm F scope 3 emissions (MT)	2,705	2,138	1,998	1,875	1,767	1,670	1,435	1,162
Percentage Change	**44%**	**14%**	**7%**	**0%**	**-6%**	**-11%**	**-23%**	**-38%**

Table 5: Sensitivity analysis for varying prices of LED (non-procured product)

This calculation shows that changes in prices of any of the products in a supplier's portfolio can impact the scope 3 category 1 emissions of a firm when hybrid methodology is used. Therefore, even though there is no change in the quantity, price or emissions of the product that is being procured by firm F, we see a change in emissions for firm F.

LEARNING: Monitor performance of ALL products of a supplier (even though not procuring all)

SAMPLE CALCULATIONS:

Original Scenario (LED = $30000)

Total Revenue = ∑(**Pi x $i x Qi)**

= ($5000 x 5) + ($30000 x 10) + ($10000 x 15) + ($200 x 70)

= $489,000

Total Emissions = ∑(**Pi x Ei)**

= 10,000 MT + 90,000 MT + 30,000MT + 1,400 MT

= 131,000 MT

Emission Intensity = Total Emissions/ Total Revenue = 0.268

Spend by Firm F on Laptop displays = $7,000

Scope 3 emissions for firm F = 1,875 MT

Decrease by 50% in LED price (LED = $15000)

Total Revenue = ∑(**Pi x $i x Qi)**

= ($5000 x 5) + ($15000 x 10) + ($10000 x 15) + ($200 x 70)

= $339,000

Emission Intensity = Total Emissions (Remains same as only LED price change)/ Total Revenue = 0.386

Spend by Firm F on Laptop displays = $7000 (Remains same as only LED price change)

Scope 3 emissions for firm F = 2,705 MT

Therefore, the sensitivity analysis emphasizes the importance of a diligent check on scope 3 emissions in case of price variation in both procured and non-procured products.

4.4. Analytical Method

With a financial and economic focus, the emission intensity of any product is determined by the value of carbon emission divided by the price of the product as shown in equation 1 (appendix A). The total emission from the company of interest, denoted as A, is the sum of all emissions from all products sold as shown in equation 2 (appendix A). The emission intensity of the company A is the total emission by company A divided by the total revenue of the company as shown in equation 3 (appendix A). When company B buys M products from company A, company B gets the allocated carbon emission from the company as derived in equation 4 (appendix A). In the case of one product j, the allocated emission can be calculated from equation 5 (appendix A). If there are changes in the price and the emission intensity of the product, the allocated emission can be changed as shown in equation 6 (Appendix A). After mathematical derivation resulting in equation 7 (Apprendix A), the percentage of change in allocated emission for the product j from company A to company B is dependent on four variables:

1) The change in the price of product j
2) The change in the emission intensity of product j
3) The share of the emissions from product j compared to the total emissions of company A
4) The share of the revenue from product j compared to the total revenue of company A

4.5. Numerical Analysis

To explore the effects of each variable in the equation, numerical analysis is utilized. Since there are four variables that determine the value of the change in allocated emissions, the study explores the influence of relevant variables by setting some of them as constants.

4.5.1. The effects of the change in price and emission intensity on the change in allocated emissions

For this case, the numerical analysis sets the share of the emissions from product j compared to the total emissions of company A, and the share of the revenue from product j compared to the total revenue of company A as 0.1 (10%.) To see the effect of the change in price, the change in emission intensity is set as zero, and vice versa. The results are shown in Figure 8. The effects of both variables are almost linear, but the effect of the price change is stronger with steeper slope.

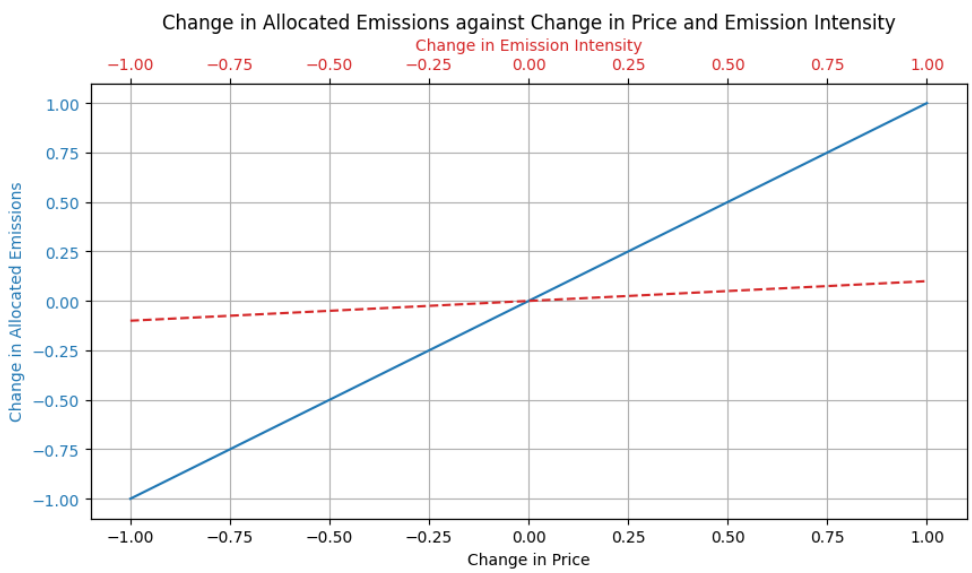

Figure 8: The change in allocated emissions against change in price and emission intensity

When the company evolves, the emission intensity of that particular product also evolved along with the processes or management of the company as well. However, the change in emission intensity is not necessarily equal to the change in the allocated emissions since it is determined by other variables as well. So, there could be some error between the expected emissions and allocated emissions as shown with a heatmap in Figure 9. The heatmap is structured with the horizontal axis representing the change in price, ranging from -1.00 to 1.00, and the vertical axis representing the change in emission intensity, also ranging from -1.00 to 1.00. Each cell within the heatmap corresponds to a specific combination of changes in price and emission intensity, with the color indicating the magnitude of the error in allocated emissions. The error between the expected and allocated emissions can be as high as 200%.

In the case where a specific commodity is responsible for 20% of the revenue and only 1% of the total emissions of the supplier (emission-light commodity, the dynamic changes as seen in Figure 10. The error range between the expected and allocated emissions is less wide and ranges from 0% to 35%.

In the case where a specific commodity is responsible for only 1% of the revenue but 20% of the total emissions of the supplier (emission-heavy commodity, the dynamic changes as seen in Figure 11. The error range between the expected and allocated emissions is more sporadic and volatile and ranges from 0% to 166%.

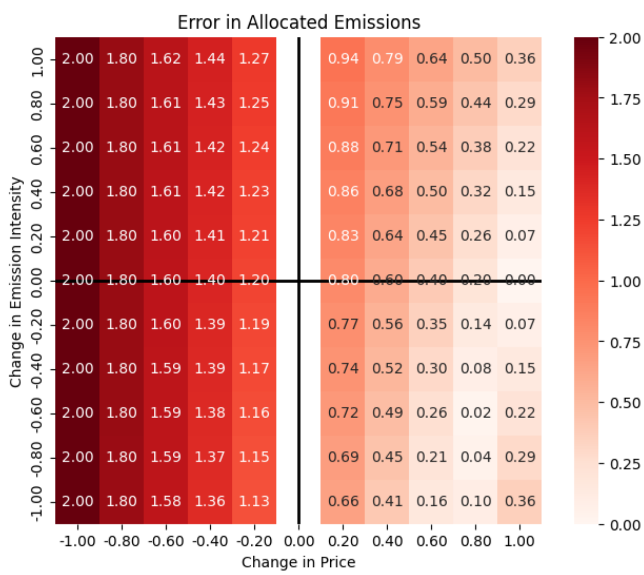

Figure 9: Heatmap of the error in allocated emissions with change in price and emission intensity

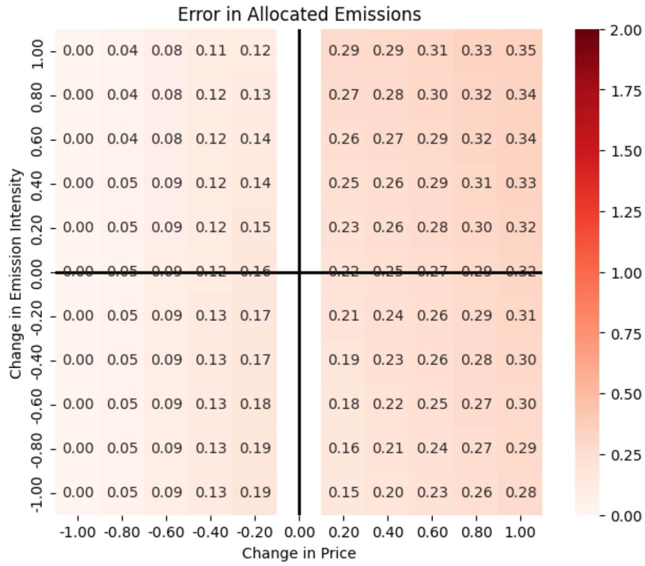

Figure 10: Heatmap of the error in allocated emissions with change in price and emission intensity when the commodity is emission-light.

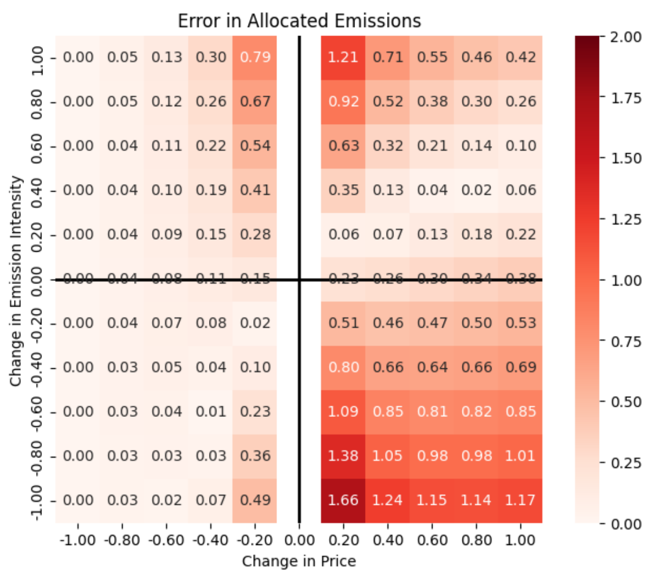

Figure 11: Heatmap of the error in allocated emissions with change in price and emission intensity when the commodity is emission heavy.

4.5.2. The effects of price increase with the reduction in carbon emission with different value of share of the commodity's revenue and emissions against total revenue and emissions

With the global trend and initiatives to reduce carbon emissions, many companies pay or invest in carbon reduction projects, whose costs are eventually passed onto the customers. However, the reduction in carbon emissions is not necessarily reflected in the allocated emissions. So, there could be some discrepancies between the expected emission and allocated emission as shown with a heatmap. The heatmap is structured with the horizontal axis representing the share of the commodity emissions against the total carbon emission of the supplier, ranging from 0 to 1.00, and the vertical axis representing the share of the company's spending on the supplier against the total revenue of the supplier, also ranging from 0 to 1.00. Again, each cell within the heatmap corresponds to a specific combination of shares, with the color indicating the magnitude of the change in allocated emissions. For this case, the numerical analysis assumes that there is a 10% price increase for the 10% reduction in the emission intensity of the commodity. In Figure 12, the change allocated emission calculated is always lower than the expected reduction of 10%. The allocated emission might reduce as low as 1% and paradoxically might increase by 10%. In the case of an efficient reduction of carbon emissions intensity of 30% with only 10% price increase, the allocated emissions might reduce by 23% but can also increase by 10% as well as seen in Figure 13. In the case where the carbon emission reduction is costly with 30% price increase with only 10% reduction in carbon emission intensity, the allocated emission only increases from 0% to 52% as shown in Figure 14.

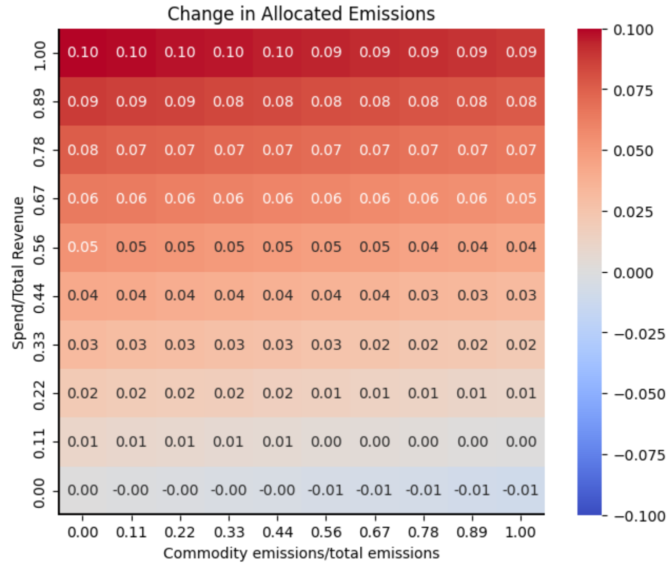

Figure 12. Heat map of the change in allocated emissions with 10% price increase and 10% reduction in emission intensity

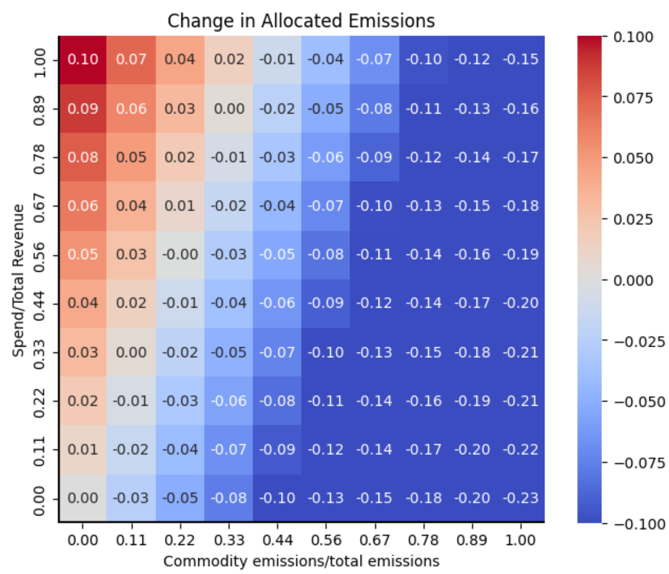

Figure 13. Heat map of the change in allocated emissions with 10% price increase and 30% reduction in emission intensity (Efficient reduction)

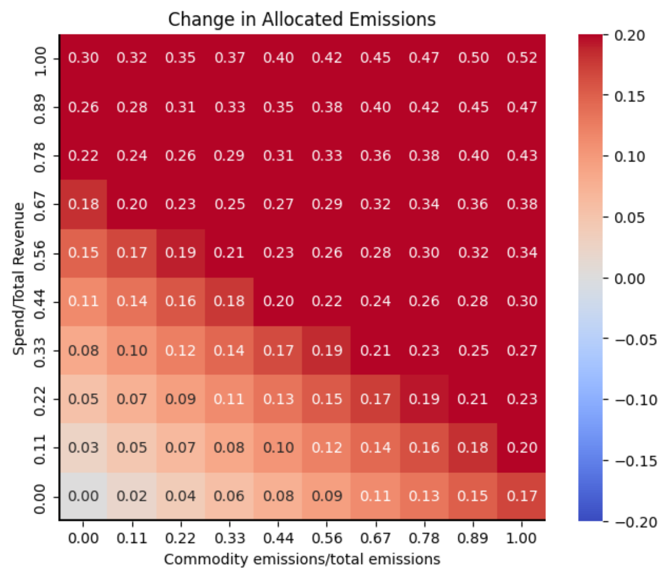

Figure 14. Heat map of the change in allocated emissions with a 30% price increase and 10% reduction in emission intensity (Costly reduction)

5. Discussion

The results of our study underscore profound challenges in accurately measuring and managing scope 3 emissions across the supply chains of global corporations like Dell. Our primary findings, derived from the outlier detection method, reveal discrepancies in carbon emissions reported by suppliers of identical commodities. Such variances are notable, not only in terms of magnitude but also in their inconsistency over time. The roots of these variations are multifaceted, potentially stemming from changes in management and operational processes, enhancements in data collection and reporting methodologies, or inconsistencies in the units of measurement used across different reports.

Further compounding the challenge, our analysis through sensitivity and analytical methods demonstrates that hybrid methodologies, though popular for their simplicity and adaptability to readily available financial data, frequently fail to accurately reflect the true carbon footprint of a company. In many instances, these allocated emissions paint a misleading picture of a company's environmental impact. This discrepancy is largely due to the undue influence that financial expenditure on goods and services exerts over the calculated emissions. Such methodologies often prioritize the price paid or the financial scale of transactions over more critical variables, like the emission intensity factor. In addition, the final equation determining the value of the allocated emission also is dependent on uncontrollable factors, which are the proportion of the carbon emission and the revenue from the particular commodity against the total carbon emissions and the total revenue of the supplier respectively. Furthermore, these variables are also dynamic changing with time and vary depending on how the company defines its fiscal year or the internal allocation methods.

This misalignment can lead to strategic missteps, as companies might allocate resources or prioritize interventions based on flawed emissions data. For instance, a supplier's low cost might mask low carbon emissions, leading to preferential selection by procurement policies that inadvertently favor cost over sustainability. On the other hand, the investment in the reduction of carbon emissions which incur additional price on the commodity also increases the allocated carbon emissions instead of reducing it. Thus, the initiatives in sustainability might get discouraged or taken down by the management team considering the failure to seize the expected outcomes. The implications of these findings are significant, suggesting a need for a paradigm shift in how companies like Dell approach the calculation and interpretation of scope 3 emissions.

5.1. Recommendations

To address these issues, we recommend an integrated and robust approach outlines as follow:

- Implementing the outlier detection algorithm

  Outlier detection is crucial in identifying anomalies that could indicate data entry errors, inconsistent reporting standards among suppliers, or even deliberate misreporting. The application of an outlier detection algorithm can significantly enhance the integrity of the data used for calculating emissions by flagging data points that deviate from established patterns. After identifying the potential outliers, the company then investigates and explores the data on a deeper level to find the root causes and potential solutions, which would vary for different cases and companies.

- Utilize product-specific carbon footprint data

  With the spend-based method or the hybrid method that operates on supplier-specific data with the financial spending, using generic emission factors or the aggregate emission factor independent of the commodity or the product can lead to significant inaccuracies in emissions calculations. By utilizing product-specific carbon footprint data (e.g. LCA of the commodity of interest), which breaks down to the most granular unit of the commodity (e.g. mass or number of units), companies can achieve a more accurate and meaningful understanding of their actual emissions, enabling better decision-making and more effective sustainability strategies. Although, there are challenges and pitfalls while shifting to this methodology. For example, suppliers typically have only industry-average LCA (Life Cycle Assessment) data available. Additionally, performing these calculations requires a large amount of information, time, and money, and there is often a lack of historical data that companies can use to report against emission reduction goals with historical baselines.

Such an approach would not only enhance the accuracy of emissions calculations but also foster a more transparent and accountable supply chain ecosystem, where sustainability metrics are as integral to supplier selection and evaluation as traditional financial metrics. This shift would enable corporations to make more informed, responsible decisions that truly reflect their environmental impact and sustainability commitments.

6. Conclusion

The research presented in this capstone project underscores the critical importance and complexity of managing scope 3 emissions within global supply chains. By conducting a thorough analysis using Dell Technologies as a case study, the project highlights the nuanced challenges and strategic considerations that companies must navigate to effectively mitigate their environmental impact.

The project revealed discrepancies in carbon emissions data reported by suppliers, which are often attributed to variations in measurement techniques, reporting standards, or even operational changes within the suppliers' processes. These inconsistencies can significantly distort a company's understanding of its carbon footprint, leading to potentially misguided strategic decisions. Moreover, the sensitivity analysis conducted as part of this study exposed inherent flaws in the hybrid methodology for calculating scope 3 category 1 emissions. This approach, while popular due to its reliance on easily accessible financial data, often fails to provide an accurate representation of a company's emissions. Financial expenditure on goods and services, while readily quantifiable, does not necessarily correlate with carbon emissions, which are influenced by numerous factors including production processes, technological efficiency, and product lifecycle impacts. Additionally, the project demonstrated the potential for advanced data analysis techniques, such as outlier detection and numerical analysis, to enhance the accuracy of emissions reporting and management. By integrating these analytical tools, companies can better identify anomalies and inconsistencies in emissions data, leading to more precise and actionable insights.

To address these challenges, the project proposes a set of recommendations for Dell and similar companies. First, enhancing data integrity by implementing robust data management practices to improve the accuracy and consistency of emissions data. This includes the use of outlier detection algorithms to identify and correct anomalies in the data provided by suppliers. Secondly, refining calculation methodologies by developing more sophisticated approaches that consider specific product emissions factors and lifecycle assessments. This shift allows companies to more accurately reflect the true environmental impact of their operations and supply chains. By implementing these strategies, companies can not only improve the accuracy of their emissions calculations but also drive more effective environmental policies and practices. This proactive approach is essential for companies aiming to meet their sustainability goals and minimize their impact on the planet.

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APPENDIX A

Equation 1: the emission intensity of any product

$$I = \frac{E}{P}$$

$$I = Emission\ Intensity\ \left(\frac{kg\ of\ CO2eq}{\$}\right)$$

$$E = Carbon\ emission\ (kg\ of\ CO2eq)$$

$$P = Price\ of\ the\ product\ (\$)$$

Equation 2: The total emission from company A

$$E_A = \sum_{i=1}^{N} E_i = \sum_{i=1}^{N} (n_i \times P_i \times I_i)$$

$$E_A = Total\ emission\ from\ company\ A$$

$$n_i = number\ of\ product\ i\ sold\ by\ company\ A$$

$$P_i = Price\ of\ product\ i$$

$$I_i = Emission\ Intensity\ of\ product\ i$$

Equation 3: The emission intensity of company A

$$I_A = \frac{E_A}{R_A} = \frac{\sum_{i=1}^{N}(n_i \times P_i \times I_i)}{\sum_{i=1}^{N}(n_i \times P_i)}$$

$$R_A = Revenue\ of\ Company\ A$$

Equation 4: The allocated emission from company A to company B

$$E_{B\ from\ A} = I_A \times S_{B\ to\ A} = I_A \times \sum_{J=1}^{M}(n_j \times P_j) = \frac{\sum_{i=1}^{N}(n_i \times P_i \times I_i)}{\sum_{i=1}^{N}(n_i \times P_i)} \times \sum_{J=1}^{M}(n_j \times P_j)$$

$$E_{B\ from\ A} = Allocated\ emission\ from\ company\ A\ to\ company\ B$$

$$S_{B\ to\ A} = Spending\ from\ company\ B\ to\ company\ A$$

Equation 5: The allocated emission from company A to Company B for product j

$$E_{B\ from\ A} = \frac{n_j P_j I_j + \sum_{i=1}^{N-1}(n_i \times P_i \times I_i)}{n_j P_j + \sum_{i=1}^{N-1}(n_i \times P_i)} \times \left(n_j P_j\right)$$

Equation 6: The allocated emission from company A to company B in the case that project j has price increase

$$E'_{B\ from\ A} = \frac{n_j\left(P_j + \Delta P_j\right)\left(I_j + \Delta I_j\right) + \sum_{i=1}^{N-1}(n_i \times P_i \times I_i)}{n_j\left(P_j + \Delta P_j\right) + \sum_{i=1}^{N-1}(n_i \times P_i)} \times \left(n_j\left(P_j + \Delta P_j\right)\right)$$

Now, the mathematical derivation is performed from equation 6 to provide a final form of the change in allocated emissions from controlling factors.

$$\frac{E'}{E} = 1 + \frac{\Delta E}{E} = \frac{(P_j + \Delta P_j)}{P_j} \times \frac{\left[n_j\left(P_j + \Delta P_j\right)\left(I_j + \Delta I_j\right) + \sum_{i=1}^{N-1}(n_i \times P_i \times I_i)\right] \times \left[n_j P_j + \sum_{i=1}^{N-1}(n_i \times P_i)\right]}{\left[n_j P_j I_j + \sum_{i=1}^{N-1}(n_i \times P_i \times I_i)\right] \times \left[n_j\left(P_j + \Delta P_j\right) + \sum_{i=1}^{N-1}(n_i \times P_i)\right]}$$

$$1 + \frac{\Delta E}{E} = \left(1 + \frac{\Delta P_j}{P_j}\right) \times \left[\frac{R_A(E_A + n_j P_j \Delta I_j + n_j \Delta P_j I_j + n_j \Delta P_j \Delta I_j)}{E_A(R_A + n_j \Delta P_j)}\right]$$

$$1 + \frac{\Delta E}{E} = \left(1 + \frac{\Delta P_j}{P_j}\right) \times \left[\frac{1 + \dfrac{n_j P_j \Delta I_j + n_j \Delta P_j I_j + n_j \Delta P_j \Delta I_j}{E_A}}{1 + \dfrac{n_j \Delta P_j}{R_A}}\right]$$

$$1 + \frac{\Delta E}{E} = \left(1 + \frac{\Delta P_j}{P_j}\right) \times \left[\frac{1 + \dfrac{n_j P_j I_j \times \dfrac{\Delta I_j}{I_j} + n_j P_j I_j \times \dfrac{\Delta P_j}{P_j} + n_j P_j I_j \times \dfrac{\Delta I_j}{I_j} \times \dfrac{\Delta P_j}{P_j}}{E_A}}{1 + \dfrac{\Delta R_A}{R_A}}\right]$$

$$1 + \frac{\Delta E}{E} = \left(1 + \frac{\Delta P_j}{P_j}\right) \times \left[\frac{1 + \left(\dfrac{\Delta P_j}{P_j} + \dfrac{\Delta I_j}{I_j} + \dfrac{\Delta P_j}{P_j} \times \dfrac{\Delta I_j}{I_j}\right) \times \dfrac{E_j}{E_A}}{1 + \dfrac{\Delta R_A}{R_A}}\right]$$

$$\frac{\Delta E}{E} = \frac{\left(1 + \dfrac{\Delta P_j}{P_j}\right) + \left(\dfrac{\Delta P_j}{P_j} + \dfrac{\Delta I_j}{I_j} + \dfrac{\Delta P_j}{P_j} \times \dfrac{\Delta I_j}{I_j}\right)\dfrac{E_j}{E_A} + \left(\dfrac{\Delta P_j}{P_j}\right)\left(\dfrac{\Delta P_j}{P_j} + \dfrac{\Delta I_j}{I_j} + \dfrac{\Delta P_j}{P_j} \times \dfrac{\Delta I_j}{I_j}\right)\dfrac{E_j}{E_A} - \left(1 + \dfrac{\Delta R_A}{R_A}\right)}{1 + \dfrac{\Delta R_A}{R_A}}$$

$$\frac{\Delta E}{E} = \frac{\frac{\Delta P_j}{P_j} + \left(\frac{\Delta P_j}{P_j} + \frac{\Delta I_j}{I_j} + \frac{\Delta P_j}{P_j} \times \frac{\Delta I_j}{I_j}\right)\frac{E_j}{E_A} + \left(\frac{\Delta P_j}{P_j}\right)\left(\frac{\Delta P_j}{P_j} + \frac{\Delta I_j}{I_j} + \frac{\Delta P_j}{P_j} \times \frac{\Delta I_j}{I_j}\right)\frac{E_j}{E_A} - \frac{n_j P_j}{R_A} \times \frac{\Delta P_j}{P_j}}{1 + \frac{n_j P_j}{R_A} \times \frac{\Delta P_j}{P_j}}$$

Equation 7: The change in allocated emission in terms of the change in price, change in carbon intensity, revenue contribution and carbon emission contribution of product j

$$\frac{\Delta E}{E} = \left[\frac{1 + \left(1 + \frac{\Delta I_j}{I_j} + \frac{\frac{\Delta I_j}{I_j}}{\frac{\Delta P_j}{P_j}}\right)\left(1 + \frac{\Delta P_j}{P_j}\right)\frac{E_j}{E_A} - \frac{R_j}{R_A}}{1 + \frac{R_j}{R_A} \times \frac{\Delta P_j}{P_j}}\right] \times \frac{\Delta P_j}{P_j}$$