The Impact of Logistics Provider Data Maturity in Defining Scope 3 Transportation Emissions

by
Jessica Yao Xiong

Bachelor of Science in Business Administration (University of North Carolina at Chapel Hill)

and
Nora Lestari
Bachelor of Engineering in Industrial Engineering (Universitas Kristen Maranatha)

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 2022

Signature of Author: ____
Department of Supply Chain Management
May 6, 2022

Signature of Author: ____
Department of Supply Chain Management
May 6, 2022

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

Accepted by: ____
Prof. Yossi Sheffi
Director, Center for Transportation and Logistics
Elisha Gray II Professor of Engineering Systems
Professor, Civil and Environmental Engineering

The Impact of Logistics Provider Data Maturity in Defining Scope 3 Transportation Emissions

by

Jessica Yao Xiong

and

Nora Lestari

Submitted to the Program in Supply Chain Management
on May 6, 2022 in Partial Fulfillment of the
Requirements for the Degree of Master of Applied Science in Supply Chain Management

ABSTRACT

Global warming is a reality. According to the UN's Intergovernmental Panel on Climate Change, the Earth's average temperature may increase by another 1.5°C to 2.0°C in the next thirty years, causing extreme weather, deteriorating air quality, depleting resources, and disrupting economies. By 2025, an estimated 1.8 billion people worldwide may suffer absolute water scarcity. Xylem Inc. is among the companies aiming to reduce its carbon footprint to offset this trajectory. Xylem aims to reduce its supply chain carbon footprint by 2.8 million metric tons by 2025. Among supply chain activities, transportation and logistics remains one of the greatest contributors to carbon emissions. To help the company take swift climate action, our capstone helps Xylem understand emissions hotspots along its inbound transportation network and identify emissions reduction initiatives by way of establishing an accurate and reliable Scope 3 emissions baseline. By developing a hybrid activity-based emissions calculation tool, we assessed the data maturity of Xylem's top ten logistics suppliers, added supplier evaluation criteria, and provided means to overcome data limitations. We quantified trade-offs between emissions and commercial levers (e.g., cost, customer service level, etc.) and estimated the emissions effects of supply chain decisions using scenario, comparative, and regression analysis. The results show that shipment mode selection, shipment weight, shipment type, and shipment transit time have a meaningful impact. The combined effects of these variables, coupled with supplier selection, may help Xylem reduce up to 50% of its inbound transportation carbon footprint. The outputs of our study include a set of tailored demand and production planning, sourcing and procurement, inventory management, and customer relationship management recommendations and a prioritized implementation roadmap to support Xylem in its pledge towards net zero operations.

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

ACKNOWLEDGMENTS

The enclosed capstone report spanned the course of nine months with the involvement of several individuals who guided, supported, and facilitated our research and our efforts. Without these key contributors, this study would not have been possible.

We would like to begin by thanking our capstone advisor, **Dr. Josué C. Velázquez Martinez**, for his continuous support, guidance, and humor throughout this process. His passion for sustainable supply chain management, his expertise and experience in the domain, and his valuable feedback enabled us to complete this body of research and contribute thought leadership to the sustainable supply chain field.

We would like to thank our writing coach, **Pamela Siska**, for her tremendous patience, attention to detail, and critique in helping us capture our thoughts in writing and in editing our numerous drafts.

We would like to thank our sponsoring company, **Xylem Inc.**, for the ongoing partnership and the chance to collaborate on addressing one of the world's most pressing issues: greenhouse gas emissions. In addition, we thank you for the opportunity to make our impact in the race against climate change and global warming and to provide innovative solutions to a complex supply chain problem. We would like to extend a special thank you especially to our Xylem sponsors, Valtteri Koponen, Andrea Montuori, Krista Thompson, and Tony Oteka.

In addition, we would like to thank our families and friends for their unwavering support, emotional, morale, and physical, in our pursuits of continuous learning. Thank you for keeping us grounded throughout our time at MIT and for helping us overcome challenges and obstacles.

Last but not least, we would like to thank our classmates, the staff and faculty at the Center for Transportation and Logistics, and the entire MIT community for the learnings and an unforgettable graduate school experience.

Jessica Yao Xiong and Nora Lestari

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

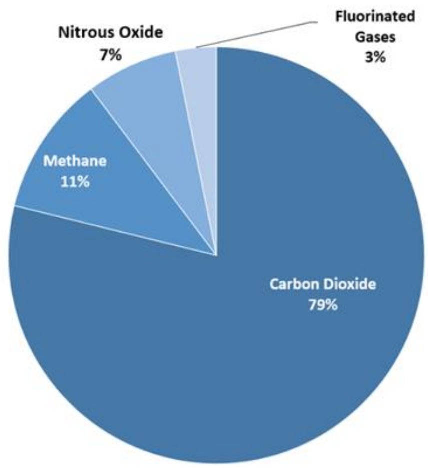
Climate change is an undeniable and inevitable reality in today's world. Characterized by increasing global temperatures, rising sea levels, and changing weather patterns, climate change prevails as a growing geopolitical, socioeconomic, and humanitarian concern (American Museum of Natural History, 2022). Historically, climate change occurs naturally due to shifts in the Earth's orbit or atmosphere (Dunbar, 2015). More recently, however, another major driver emerges: human activities. Inducing approximately 1.0°C of global warming in the past century, human activities may cause another 1.5°C to 2.0°C surge in temperatures worldwide by 2052 if left unchecked (Masson-Delmotte et al., 2019).

The main reasons for these rising temperatures are carbon dioxide and other "greenhouse" gases (GHG) emitted from human-driven industrial operations that trap heat in the Earth's atmosphere (Environmental Protection Agency, 2021). *Figure 1* displays a sample breakdown of greenhouse gases in the United States (Environmental Protection Agency, 2022). Since carbon dioxide (CO_2) contributes the most to total GHG emissions, GHG emissions are commonly expressed as carbon emissions or carbon dioxide-equivalent emissions.

The consequences of this global warming exist in the forms of extreme weather events, wildlife extinctions, poor air quality, public health issues, and declining natural resources, disrupting societies and economies worldwide (Shaftel, 2021). To prevent worsening conditions and further disruptions, businesses play an obligatory and vital part in leading climate action by reducing their carbon footprints. The first step on this journey requires a thorough understanding of the environmental impacts of their value or supply chains.

Figure 1

Overview of Greenhouse Gas Emissions in 2020 (Environmental Protection Agency, 2020)



In this capstone, we study the significance of understanding, quantifying, and analyzing value chain carbon emissions via a Scope 3 emissions calculation tool for our sponsoring company, Xylem Inc. (Xylem). We uncover major challenges in the Scope 3 emissions baselining process and establish a comprehensive, step-by-step methodology to develop a robust and flexible calculation tool that surmounts these obstacles. We conduct analysis to identify emissions hotspots, pinpoint emissions drivers, and ascertain emissions trade-offs. To help companies set and achieve their carbon emissions reduction targets, we synthesize and interpret our findings, generate insights, formulate recommendations, and develop a high-level initiatives roadmap.

To provide context for this study, this chapter consists of three sections. *Section 1.1* discusses the motivation and relevance of our research and specifies the scope of this study. *Section 1.2* explains Xylem's business and the challenges in establishing its Scope 3 emissions baseline. Finally, *Section 1.3* discusses our key research questions and outlines the remaining topics covered in this report.

1.1 Motivation Statement and Relevance

The water and wastewater management industry faces a period of unprecedented disruption. Studies predict that an estimated 1.8 billion people worldwide may suffer absolute water scarcity by 2025 (United Nations, 2014). While harrowing for communities across the globe, these statistics also imply a significant decline in the future water and wastewater management business. To combat this trajectory, water and wastewater management companies seek means to expand and to prolong the global water supply. Recently, Water UK, a United Kingdoms-based water industry trade association, launches the Water Pavilion conference to highlight the role of water in achieving net zero and to garner pledges from more than 20% of global water companies to deliver net zero water supplies by 2030 (Water UK, 2021). Despite their best efforts, however, climate change and global warming remain the biggest deterrents to achieving their objectives. With record numbers of droughts, storms, floods, and other natural disasters directly threatening the quality, availability, and affordability of water globally, water and wastewater management companies have vested interests in minimizing climate change and its catastrophic effects on their financials and the communities they serve (Environmental Protection Agency, 2021a).

Furthermore, mounting political and societal pressures provide more incentive now than ever before for companies to manage and to reduce their carbon footprints (Environmental Protection Agency, 2021b). In conjunction with increasing regulatory stringency and a rising number of “green” programs worldwide, changing investor, supplier, employee, and consumer expectations in favor of sustainable products and services prove to be a major impetus for companies to rethink their business practices (Farsan et al., 2018). Internal and external stakeholders alike demand better transparency in reporting, and companies across all industries have fewer reasons to “opt out” (Greene & Lewis, 2019). Not surprisingly, a growing number of companies and sectors, including the water and wastewater management industry, need to adopt science-based targets to give credence to their sustainability initiatives (*How To Guide*, 2021).

As both victims of and contributors to climate change, water and wastewater management companies play an indispensable role in worldwide decarbonization (International Water Association, 2021). Carbon emissions comprise three types: Scope 1 emissions, Scope 2 emissions, and Scope 3 emissions (Greenhouse Gas Protocol, 2015). Scope 1 indicates direct emissions from owned or controlled sources, Scope 2 indicates indirect emissions from purchased energy, and Scope 3 indicates indirect emissions from the corporate value or supply chain (Greenhouse Gas Protocol, 2015). Although many companies participate in setting their science-based targets and demonstrate concerted efforts to govern Scope 1 and

Scope 2 emissions, their Scope 3 emissions remain largely unchecked. As Velázquez et al. (2013) implies the difficulty in Scope 3 emissions management primarily lies in a lack of visibility into supplier operations, prohibitive supplier data limitations, and uncertainties around emissions trade-offs. Coincidentally, business operations and external ecosystem partners along the supply chain often produce the majority (potentially up to 90%), of a company's overall emissions (Greenhouse Gas Protocol, 2021). Among the numerous supply chain activities, transportation and logistics stands as one of the main contributors to greenhouse gases, accounting for 15% to 20% of the world's collective emissions (National Geographic Society, 2020). Since 1990, year-over-year emissions from transportation and logistics also increase more rapidly than any other sector (Environmental Protection Agency, 2021c). To decarbonize, water and wastewater management companies now recognize the need to identify opportunities to reduce the emissions impact not only in their internal logistics operations but also in those of their logistics suppliers. In the following section, we introduce our sponsoring company, Xylem, its sustainability ambitions, and the challenges surrounding its Scope 3 emissions.

1.2 Xylem Inc.'s Business and Problem Statement

Xylem Inc. (Xylem) is a water technology company specializing in developing innovative solutions and in producing industrial equipment to support the collection, treatment, distribution, and return of water and wastewater (Xylem Inc., 2021a). With $4.9 billion in revenues in 2020, the company serves utilities, industrial, commercial, and residential customers in 150 countries across the United States, Western Europe, emerging markets, and the rest of the world (Xylem Inc., 2021b).

Similar to its industry peers, Xylem commits to its customers, investors, and communities to reduce the environmental impact of its inbound logistics activities, particularly those originating from its inbound logistics suppliers. To avoid further strain on the global water supply that drives its business, prevent disruptions to its supply chain, and alleviate the shrinking carbon budget, the company strives to identify swift and deliberate actions to help these suppliers decarbonize (Farsan et al., 2018).

As part of its 2025 Sustainability Goals, Xylem aims to reduce its carbon footprint (measured in carbon dioxide-equivalents or CO_2eq) by 2.8 million metric tons (tonnes), develop a science-based target for

Scope 1, 2, and 3 greenhouse gas emissions, and engage suppliers in sustainability initiatives (Xylem Inc., 2021c). While it has existing baselines for Scope 1 and Scope 2 emissions, the company currently lacks a Scope 3 emissions baseline due to a lack of visibility into its upstream logistics suppliers' operations. Heavy reliance on supplier data for Scope 3 reporting further exacerbates the problem, as supplier data limitations and omissions jeopardize the integrity and accuracy of its emissions baseline.

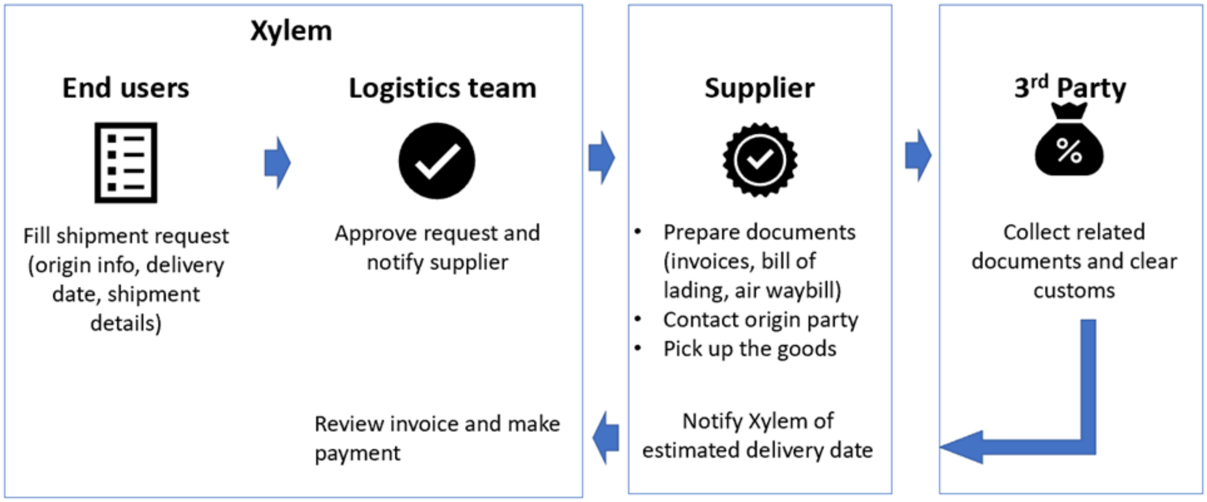
Together with Xylem, we address these challenges, profile its inbound transportation activities, and create an accurate Scope 3 emissions baseline in our capstone. The main contributions of our capstone are the insights, evidence, and ammunition to pinpoint emissions hotspots, identify improvement levers, and formulate strategies to help influence and develop its inbound logistics suppliers. Moreover, we provide insights to help Xylem balance sustainability targets with business imperatives while enhancing its ability to maintain customer service levels and cost-effectiveness. The next section dives into the key research questions we answer throughout our research.

1.3 Key Research Questions

The data collected from Xylem's top ten inbound transportation suppliers consists of more than 500K lines of shipment data, with more than 85% requiring data verification and normalization. Data collection for emission calculation becomes challenging when the suppliers are not required by any contractual agreement to provide their data, especially the fuel consumption data, to Xylem. Besides the data challenge, Xylem's inbound transportation activities are complex, involving external suppliers and third parties to handle the shipments and customs clearance. To illustrate Xylem's inbound transportation operations and its inherent complexities, we provide a simplified view of its upstream supply chain network in *Figure 2* below.

Figure 2

Xylem's Inbound Transportation Activities



This capstone report addresses the following key research questions to help Xylem understand and improve the environmental impact of its inbound logistics operations:

- How can Xylem estimate its current Scope 3 inbound transportation emissions?
- What data is required to enable Xylem to establish its emissions baseline?
- What are the emissions hotspots and drivers across Xylem's inbound transportation network?
- How can Xylem monitor data from suppliers and identify CO_2eq emissions improvements?
- What are the emissions trade-offs and impacts of Xylem's supply chain decisions?
- How can Xylem minimize these inbound transportation emissions?

The following chapters of this report provide the methodology, results, and findings from our research. In *Chapter 2*, we present the observations from our literature review and the limitations in existing studies. *Chapter 3* describes our approach to understanding Xylem's current state, developing an emissions calculation tool, establishing the inbound transportation emissions baseline, and performing trade-off and scenario analyses. In *Chapter 4*, we discuss the findings and results from these analyses. *Chapter 5* interprets these results to reveal key takeaways, management implications, future state recommendations, a high-level roadmap to achieve emissions reductions, and potential next steps for Xylem to consider. We conclude our capstone research in *Chapter 6*.

2. LITERATURE REVIEW

The purpose of this capstone is to identify impactful emissions reduction initiatives in partnership with Xylem through the development of a robust and flexible calculation tool that establishes a reliable Scope 3 emissions baseline. In developing this calculation tool, we review several existing calculation methods, primarily the Greenhouse Gas (GHG) Protocol, the Global Logistics Emissions Council (GLEC) Framework, and the Network for Transport Measures (NTM) Methodology. These methods offer us a perspective into current schools of thought and allow us to assess their appropriateness and efficacy in a real-world application given current business challenges.

This chapter consists of four sections. *Section 2.1* highlights the common themes and considerations in Scope 3 emissions calculations across people, process, technology, data, and metrics dimensions. *Section 2.2* discusses emerging trends in the market impacting businesses and efforts underway to estimate Scope 3 emissions. *Section 2.3* explains the existing GHG, GLEC, and NTM calculation methodologies and their limitations. Lastly, *Section 2.4* concludes the chapter with a summary of our literature review.

2.1 Common Themes and Considerations in Scope 3 Emissions Calculations

Throughout our literature review, we discover five recurring themes to guide our Scope 3 emissions baselining and opportunities identification in Xylem's upstream transportation activities. The first theme is ensuring clear people, organization, and policy alignment. To produce accurate, relevant, and reliable reports, organizational alignment is crucial in setting and in adopting standard organizational and operational boundaries through all levels of the reporting company (Greenhouse Gas Protocol, 2015). Executive buy-in and stakeholder engagement across the supply chain with suppliers, employees, and customers alike are paramount in identifying impactful reduction levers and in driving transformational change (Farsan et al., 2018).

The second theme is enabling impact sizing and decarbonization through formal processes. Coupled with knowledge of the emissions factors, a thorough understanding of current process information and detailed mapping of inbound logistics activities are essential in quantifying emissions (Greenhouse Gas Protocol, 2013). Emissions reductions also hinge upon the reporting company's ability to improve its process efficiencies, optimize its upstream transportation network, and embed decarbonization and sustainability principles into its procurement practices (Greene & Lewis, 2019).

The third theme is leveraging technology to share information and to enforce accountability. Technologies such as cloud, platforms, electronic data interchange (EDI), and application programming interface (API) facilitate information sharing and transparency across a company's external ecosystem. These technologies also allow for more timely and more accurate data collection for baselining purposes (Greene & Lewis, 2019). The same tools play a key role in fostering cross-company partnerships with logistics suppliers and other third parties while promoting innovative joint solutions and collaborative execution (Farsan et al., 2018).

The fourth theme is collecting and synthesizing high-quality data. Since data forms the foundation of emissions quantification and analysis, the more complete, comprehensive, timely, and accurate the data is, the better the baseline is (Greenhouse Gas Protocol, 2013). High-quality data and sound methods to conduct analysis similarly help to pinpoint emissions hotspots, identify the most impactful improvement levers, determine focus areas, and allocate emissions fairly among upstream logistics suppliers to help prioritize and shape supplier engagement and development (Farsan et al., 2018).

The last theme is activating decarbonization through ongoing target tracking, monitoring, and reporting. Similar to baselining Scope 1 and Scope 2 emissions, baselining Scope 3 emissions is a prerequisite to a company's commitment to driving sustainability. Setting both absolute emissions targets and emissions intensity targets in the baselining process is necessary to demonstrate a company's ambition and to hold it accountable on concrete, quantifiable terms (*How To Guide*, 2019). In execution, measuring and monitoring impact provides the company assurance and credibility while delivering actionable insights to its leadership to drive intended outcomes (Farsan et al., 2018).

To establish an accurate Scope 3 emissions baseline, companies need to establish clear boundaries, garner buy-in from internal and external stakeholders, establish and standardize processes, leverage technology to collaborate, ensure data quality, and enable visibility and accountability through ongoing reporting. Vertical alignment throughout the organization and horizontal alignment across the supply chain are essential, and the absence of the aforementioned underlying components hinders progress. In the next section, we discuss emerging trends and existing progress in Scope 3 emissions baselining.

2.2 Emerging Trends in the Market and Efforts Underway

As discussed in *Chapter 1 Section 1.1*, markets and business communities around the world recognize the growing importance and relevance of Scope 3 emissions to their overall carbon inventory reporting and management (Greenhouse Gas Protocol, 2013). To engrain sustainability and decarbonization into the fabric of their businesses, companies are undergoing transformative changes. Across industries, business leaders are acknowledging sustainability as a top priority, embedding emissions reduction targets into their corporate objectives, and tying environmental improvements to traditional business incentives (Farsan et al., 2018). These incentives exist as financial gains (such as cost reduction and revenue growth through market differentiation), improved efficiency, better brand equity, and deeper supplier relationships (Greenhouse Gas Protocol, 2013).

Companies are also unlocking innovation throughout the supply chain, from product development to distribution, to accelerate progress. For example, the water and wastewater management industry enacts circular design concepts to alleviate the growing scarcity in natural resources and to actively develop new treatments to reuse and to recycle wastewater (Wenneburg, 2021). Disruptive technologies grow in importance due to their abilities to facilitate new ways of working and to deliver new products and services. Internet of Things (IoT), artificial intelligence (AI), blockchain, and data analytics allow for connected, distributed, and secure collection of Scope 3 emissions and transportation data, real-time routing optimization, and actionable insights to drive improvements. Companies in the water and wastewater management industry, in particular, use these digital capabilities to create modeling technologies that forecast and predict risks and vulnerabilities in their end-to-end supply chains (Wenneburg, 2021).

While they help companies build a sustainability-focused mindset and enable mechanisms to manage and execute reduction initiatives, these advancements do little in baselining current Scope 3 emissions and influencing supply chain decisions. With little to no access to information outside their organizations, most companies rely solely on their suppliers and other external partners to report Scope 3 emissions. Although exceptions exist, the majority of suppliers hesitate to share detailed shipment and emissions data due to trade secrets and other propriety information, reporting only aggregate numbers. In other instances, suppliers retain disparate, incomplete data and provide rough emissions estimates derived from "one-size-fits-all" third-party tools. As a result, companies contend with potentially inaccurate views of their Scope 3 emissions and no way to validate them. In addition to the dangers, an inaccurate baseline poses to setting absolute and intensity targets, these limitations conceal insights into emissions drivers and impacts, impeding businesses' abilities to ideate improvements. The following section dives into current calculation methods and tools, along with their limitations.

2.3 Calculating or Estimating Carbon Emissions

Carbon emissions come from industrial operations, with Scope 3 emissions being the byproducts of supplier and other ecosystem partner activities in serving the reporting company's business needs. The Greenhouse Gas (GHG) Protocol specifies Scope 3 inbound transportation emissions as a function of the distance, the weight or volume, the transportation mode, and the fuel consumed in a shipment that the reporting company requests from its logistics supplier (Greenhouse Gas Protocol, 2013). Calculating Scope 3 emissions is challenging, primarily due to limited shipment-level data, such as activities and fuel consumption data, available from suppliers. Currently, suppliers have no incentive or enforcement to submit this detailed data to their customers (Velazquez et al., 2013). In the following sub-sections, we describe the prevailing Scope 3 emissions calculation methodologies (e.g., the GHG Protocol, the GLEC Framework, and the NTM Methodology) and the impact supplier data limitations have on their applicability and effectiveness.

2.3.1 Greenhouse Gas (GHG) Protocol

The GHG Protocol is a collection of global standards and frameworks to guide private and public entities in measuring and in managing their greenhouse gas emissions. The protocol provides an activity-based Scope 3 emissions calculation method for upstream logistics that hinges upon the distance of a shipment, the mass or volume of the products shipped, and a mass-distance emissions factor based on the transportation mode (Greenhouse Gas Protocol, 2013). *Chapter 3 Section 3.2.1* describes the detailed formulations. As the name suggests, an activity-based calculation method allows reporting companies to pinpoint and to understand emissions drivers based on upstream logistics activities that manifest as shipment levers (i.e., distance, mass or weight, and volume).

The benefits of the GHG method rest in its simplicity and its ability to quantify Scope 3 emissions with minimal shipment-level data from inbound logistics suppliers. This method is particularly effective in the absence of fuel consumption data, which may expose fuel surcharge and other sensitive supplier information. Since it allocates emissions based on the actual distance traveled and the actual mass or volume of the products by shipment, the GHG method also effectively allocates Scope 3 emissions when a shipment is not exclusive to the reporting company.

Conversely, the GHG method has its disadvantages. With its simplified model, the method neglects emissions variations between different fuel types, vessels or vehicles used, elevations and topographical conditions, and utilization levels in a shipment load that may affect its accuracy. Furthermore, the GHG method fails to accommodate gaps in shipment-level distance, mass, or transport mode data. As seen in the case with Xylem, inbound logistics suppliers do not consistently capture or provide this information. This method thus lacks the robustness needed for more in-depth emissions analysis and the adaptability necessary to overcome potential supplier data challenges.

2.3.2 Global Logistics Emissions Council (GLEC) Framework

The GLEC Framework is a globally-recognized methodology that standardizes and harmonizes emissions calculations across various modes and geographies for the transportation and logistics sector. Derived from the GHG Protocol, the framework provides both activity-based and fuel-based Scope 3 emissions calculation methods for upstream logistics. The GLEC method provides two types of emissions factors: mass-distance CO_2eq intensity factors and mass-distance fuel efficiency factors (Greene & Lewis, 2019). When only shipment distance, mass, and transport mode data are available, the reporting company can apply the CO_2eq intensity factor to estimate emissions similar to the GHG method (Greene &

Lewis, 2019). When more detailed fuel type and fuel consumption data are available, the GLEC method allows the reporting company to apply the fuel efficiency factor for a more accurate calculation (Greene & Lewis, 2019). *Chapter 3 Section 3.2.1* depicts the detailed formulations.

The advantages of the GLEC method lie in its flexibility and adaptability to varying levels of available data from inbound logistics suppliers. Without fuel type or consumption data, this method simplifies emissions calculations by leveraging only basic shipment-level information (i.e., the distance and mass). As such, the GLEC method effectively allocates emissions when a shipment is not exclusive to the reporting company like the GHG method. Moreover, as a transportation and logistics sector-specific methodology, the GLEC method offers emissions intensity and fuel efficiency factors that pertain to the various shipment modes deployed in a supply chain. In essence, this method produces arguably more accurate Scope 3 transportation emissions estimates than its GHG counterpart.

Despite these benefits, the GLEC method also possesses several shortfalls. While considering emissions variations in different fuel types and vessels, the method neglects elevations and topographical conditions and assumes standard load utilizations by shipment mode that may not reflect reality. Similar to the GHG method, the GLEC method also lacks the ability to fill gaps in shipment-level distance, mass, or transport mode data from suppliers. On the other hand, its emissions factors are extensive and require a certain level of knowledge and familiarity with transportation and logistics operations to determine the right ones to use when suppliers fail to provide specific line-level vessel and fuel details. Lastly, when detailed shipment activity and fuel consumption data are both available, the GLEC method's optionality presents a challenge in selecting the appropriate calculation approach.

2.3.3 Network For Transport Measures (NTM) Methodology

NTM is a non-profit organization that consolidates and recommends standardized approaches and data to calculate transportation-specific emissions. The methodology provides a detailed fuel-based method to calculate Scope 3 emissions across four transport modes: air, road (including trucks and vans), railway, and ocean. Air transport emissions depend on the total flight emissions and emissions allocations based on the shipment weight (Network for Transport Measures, 2015). Required shipment information includes distance, aircraft model, fuel type, load factor or utilization, and shipment weight. For road freight, emissions are a function of the shipment weight or volume, vehicle type and load capacity utilization, distance, fuel consumption, and relevant emission factors (Network for Transport Measures, 2015). Railway transport emissions behave like road transport and depend on the same shipment levers (Network for Transport Measures, 2015). Finally, ocean freight assumes fuel consumption to be a function of the shipment load and vessel type. Required shipment information to calculate emissions include shipment distance, weight or volume, load factor or utilization, vessel type, and fuel type (Network for Transport Measures, 2015). *Chapter 3 Section 3.2.1* depicts the detailed formulations.

As a fuel-based calculation method, the NTM method relies on fuel consumption data and affords more precision and accuracy than the GHG and GLEC methods. The specificity it provides by shipment mode yields results suitable for further in-depth analysis. When considered with elevation and topographical data, these results are as close to direct measurements as possible for Scope 3 emissions. While comprehensive, NTM emissions factors are manageable, with generalized factors by transport mode in case of fuel type information from suppliers is sparse. Additionally, in the absence of actual distance data, NTM offers a distance calculator between origin and destination countries, assuming major ports of departure and arrival (Network for Transport Measures, 2015). Coupled with its average load factors by vessel or vehicle type, the NTM method provides assumptions to help supplement potential gaps in supplier shipment data.

Like the other methods, the NTM method also exhibits shortcomings. As the most complex method among the three reviewed, this method requires some understanding of and experience with transportation and logistics activities. With more robust formulations come additional and more stringent data requirements. Aside from shipment distance, mass or volume, and mode, the NTM method requires vessel or vehicle information, fuel consumption data, elevations, and topographical details, and load factors. When inbound logistics suppliers struggle to provide even basic shipment-level data, as seen with Xylem, this method loses its effectiveness and impact. Additionally, the NTM method bases its distance and load factor assumptions on average shipments reported within the transportation and logistics sector. These assumptions may not apply to the reporting company and may compromise the accuracy of the emissions calculations in lieu of company-specific shipment data.

Existing Scope 3 emissions calculation methods all carry certain benefits and limitations. Simple methods run the risk of inaccuracy, while more robust methods require a level of supplier data maturity that may not be presently possible. Across the board, these methods lack the flexibility necessary to adapt to varying levels of data available to companies utilizing multiple logistics suppliers. In the subsequent section, we summarize our observations from the literature review and offer the path forward for developing a new and improved emissions calculation tool.

2.4 Literature Review Summary

In recent years, businesses across industries are taking climate action by embedding sustainability goals into their corporate mandates, aligning internal and external stakeholder motivations, and establishing mechanisms to execute emissions reduction initiatives across their supply chains. Although progressing towards environmentally-conscious operations, companies remain ill-equipped to take the initial step of quantifying their current Scope 3 emissions due to supplier data limitations. We built our research and calculation tool on the multiple methods, such as the GHG Protocol, the GLEC Framework, and the NTM Methodology, exist for calculating inbound logistics emissions, while taking into consideration the data availability and quality. This sweeping approach may overgeneralize shipment conditions, overlook the context and nuances in which a company operates, and inhibit the company's ability to identify meaningful and applicable improvements.

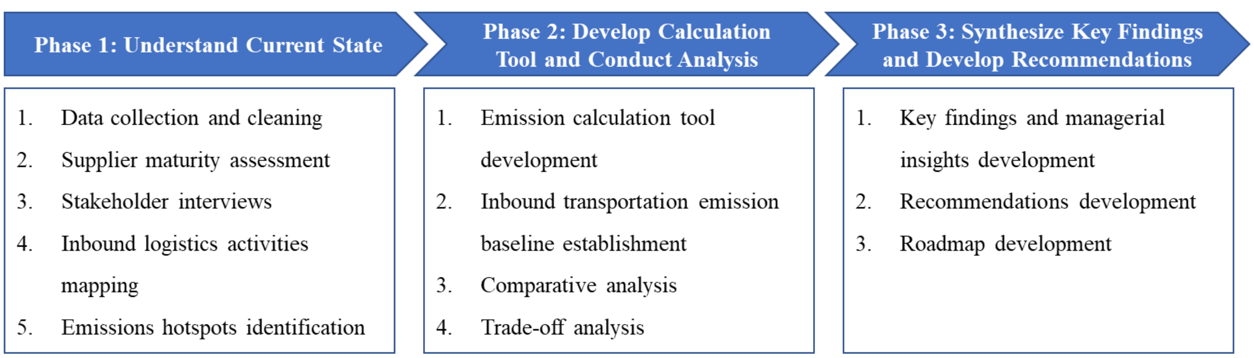
To help companies like Xylem accurately baseline their Scope 3 inbound logistics emissions in light of data challenges, our capstone expands upon existing methods to construct a hybrid emissions calculation tool. Merging GHG, GLEC, and NTM methods, our tool capitalizes on the benefits of each approach and possesses the flexibility to adapt emissions calculations depending on the supplier shipment-level data available. Our calculation tool further incorporates internal shipment order details, logistics spend data, industry-specific assumptions, company-specific context, and supplier-specific information to fill data gaps, enhance established methods, and facilitate additional analysis. Combined with transportation network maps, our innovative tool and analytical models generate tailored managerial insights to define opportunities to minimize emissions and to shape a company's transformation roadmap. The subsequent chapter describes the comprehensive approach and the step-by-step methodology employed in our study.

3. METHODOLOGY

In the literature review, we examined the rigidity and drawbacks in existing Scope 3 emissions calculation methodologies in the face of limited and poor-quality supplier shipment-level data. We alluded to a versatile hybrid emissions calculation tool that we cultivated through our research. This chapter elaborates on the comprehensive methodology we developed and the detailed data sets we used to establish a Scope 3 carbon emissions baseline for Xylem. Along the way, we identified emissions hotspots, analyzed impacts from emissions drivers, and quantified trade-offs to shape emissions reduction initiatives. Our approach consisted of three phases to understand Xylem's current state of inbound transportation activities, configure the Scope 3 emissions calculation tool, and develop future state recommendations (see *Figure 3* for details).

Figure 3

Research Methodology



The following sections discuss our capstone methodology in detail. Aligned to *Figure 3* above, *Section 3.1* describes the initial steps we took to understand Xylem's current state of inbound logistics operations and to map its upstream transportation network. *Section 3.2* explains our approach to developing our calculation tool, establishing Xylem's inbound logistics emissions baseline, and conducting a trade-off analysis. *Section 3.3* discusses our activities in distilling key analysis findings, uncovering insights, and creating an executable and customized initiatives roadmap for Xylem to implement. Finally, *Section 3.4* concludes the chapter with a summary of our methodology.

3.1 Phase 1: Understand the Current State

The first phase in the journey involved understanding Xylem's current state of inbound logistics operations to establish a solid foundation for developing the emissions calculation tool and performing subsequent analysis. This initial phase consisted of five steps: 1) data collection and cleansing, 2) supplier data maturity assessment, 3) quantitative information gathering, 4) inbound transportation activities mapping, and 5) emissions hotspot identification. The sub-sections below describe these steps in detail.

3.1.1 Step 1: Data Collection and Cleansing

Since Scope 3 emissions depend on certain shipment data more than others, data collection and cleansing began with developing an extensive data collection template to gather data from Xylem's upstream transportation suppliers. This template segmented the requested data elements into three different categories based on their priority to emissions calculations:

- **High-Priority Shipment Data** included year, departure and arrival dates, pick-up and delivery times, shipment identifiers (i.e., shipment number and house bill number), origin and destination coordinates (e.g., port names, port codes, latitudes, and longitudes), carriage type, vehicle type, container type, fuel consumption, distance, and weight.
- **Medium-Priority Shipment Data** included contract and part numbers, supplemental origin and destination information (i.e., country, address, postal codes), shipment cost, shipment or purchase order number and date, volume, packaging type and weight, and emissions data (e.g., CO_2eq, CO_2, NOX, CH_4, among others).
- **Low-Priority Shipment Data** included vehicle identifiers, vehicle descriptions, and auxiliary energy consumption data for hybrid or electric fleets.

Upon finalizing an agreed-upon scope, Xylem leadership distributed the template and collected the above data by shipment lane, shipment leg, and transportation mode from its top ten inbound logistics suppliers worldwide. These suppliers represented approximately 65% of Xylem's total upstream transportation spend, and the company believed them to comprise a commensurate proportion of total upstream transportation emissions. The focused date range was from January 2019 to October 2021, where 2019 served as the base year for emissions estimations. For data collection and cleansing steps, see *Figure 21* in Appendix C.

A thorough data screening and review followed data collection activities and uncovered a series of data limitations. Most of the top ten logistics suppliers failed to provide shipment-level distance, weight, fuel, or energy consumption data at the requested levels of granularity. Furthermore, inconsistent fields, irregular formats, and incomplete or inaccurate values appeared in the data received. Although these limitations affected the accuracy of our calculations and analyses, we foresaw data gathering at this granular level to be problematic. As a mitigation tactic, the data collection template requested more fields than were necessary. In lieu of actual distances, origin and destination coordinates and addresses functioned as an alternative way to estimate distances. In lieu of actual weights and volumes, Xylem's internal shipment order information and logistics spend data typically carried similar shipment-level details. In lieu of load capacity utilization and fuel consumption data, shipment lanes, supplier-reported emissions, and Xylem submissions to the Carbon Disclosure Project (CDP) informed regional averages and standards through reverse-engineering and extrapolation. These supplemental data sets helped overcome supplier data limitations, add complementary variables, and strengthen emissions calculations.

Aligning on a set of guiding principles with the sponsoring company under which to drive data preparation activities and to continue the study was paramount. The first principle was to perform any required adjustments and translations to make the given supplier shipment data readable for subsequent data wrangling and processing. The second principle was to homogenize and normalize data where possible, to leverage industry estimates and standards, and to accept reasonable margins of error previously aligned with Xylem. The last principle was to simplify the calculation approach to require only the fundamental data elements and to use generalized assumptions and the aforementioned internal Xylem data to supplement supplier data, where necessary. These principles afforded an opportunity to evaluate data maturities to advise Xylem's contract management activities and to guide its logistics procurement policies. The next sub-section explains our approach to the supplier data maturity assessment.

3.1.2 Step 2: Supplier Data Maturity Assessment

The conclusion of the data collection and review led to a detailed assessment of the logistics supplier data. We developed a supplier data maturity assessment framework based on the two criteria of data availability and data quality. Data availability meant being provided the critical data fields (i.e., origin-destination pairs, distance, weight, volume, and fuel consumption) necessary to complete Scope 3 emissions calculations. Data quality meant being provided complete, unitized, labeled, consistent, and accurate data.

The results of the data maturity assessment influenced subsequent data preparation activities (see *Chapter 4, Sections 4.1 and 4.2* for details). Data wrangling began with data aggregation, data designation by the supplier, and data field standardization. Of the data fields given, we narrowed the mandatory data fields list down to the year, departure date, arrival date, shipment mode, shipment leg, origin country and city, destination country and city, distance, weight, volume, cost, vehicle type, and container information. Combined, these fields provided critical year-over-year trends, enabled emissions calculations, helped distinguish between expedited and regular shipments, and supplemented missing data with assumptions and estimates. Standardizing the data required conversion of all available quantitative data to metric units (ex. kilometer, kilogram, cubic meter, and tonne), costs to the United States dollar (USD), shipment modes to five major types (i.e., air, ocean, rail, truck, and van), and origins and destinations to International Standards Organization (ISO) naming conventions.

Additionally, data formats went through harmonization, while data values went through scaling to minimize the effects of outliers. To compare the relative environmental impact of each supplier, each data set underwent normalization over its mean and standard deviation to calculate efficiency measures such as CO2eq per shipment, CO2eq per kilometer traveled, and CO2eq per kilogram shipped. These preparatory activities ensured fair and accurate comparisons of the performances across the top logistics suppliers in later analyses. To augment emissions estimation methods with critical qualitative and contextual information on the Xylem company, we discuss our qualitative information gathering efforts in the following sub-section.

3.1.3 Step 3: Qualitative Information Gathering

Qualitative and contextual information gathering took the form of interviews with key stakeholders, site leaders, and process owners across Xylem's logistics organization. These interviews served a critical role in providing company-specific and supplier-specific intel to refine and to adjust our calculation formulas and modeling algorithms. The first step involved jointly identifying the following transportations and logistics stakeholders to engage across regions with Xylem leadership: the North America Logistics Analyst, the North America Logistics Category Manager, the North America Logistics Manager, the EMEA Transportation and Logistics Manager, and the APAC Logistics Category Manager.

With gaps in the supplier shipment data, stakeholder interviews fostered a better understanding of Xylem's inbound transportation and logistics landscape, clarified pain points and improvement areas, and shed light on any ongoing initiatives and desired future states from Xylem's perspective. The accompanying set of interview questions was both comprehensive and targeted to achieve these outcomes. After confirmation from Xylem leadership, the questions centered around three main categories of people and strategy, process and related capabilities, and technology. Each category contained questions to clarify the upstream and downstream supply chain, drivers in the inbound logistics decision-making process, and relationships between decisions and shipment levers (ex, shipment lane and shipment weight).

From the people and strategy perspective, interview questions focused on Xylem's logistics function, operating model, and role in shaping critical shipment decisions such as shipment type (i.e., expedited, return, or regular shipment). For process, questions investigated the direct and indirect contributors of Scope 3 emissions in the upstream and downstream supply chain, such as forecasting and planning, inventory management, logistic network, and supplier relationship management. On the technology side, questions concentrated on the shipment monitoring and tracking system, data quality standards, and causes of and mitigations for supplier transportation and Xylem shipment order data variations. These findings refined inbound transportation activities maps, unearthed emissions hotspots, provided assumptions for the calculation tool, and guided roadmap recommendations. We discuss the results of the interviews in *Chapter 4 Section 4.3*. The next sub-section summarizes the steps in our key inbound logistics activities mapping exercise.

3.1.4 Step 4: Inbound Transportation Activities Mapping

Inbound transportation activities or network maps consisted of process flows that illustrated the end-to-end upstream shipment process from shipment booking to delivery and produced important insights into emission hotspots and drivers. This step in the methodology began with a collection of sample standard operating procedures (SOPs), or step-by-step process instructions, to complement the process information obtained from key stakeholder interviews. As agreed upon with Xylem leadership, the scope of the activities maps included five major sites dispersed geographically: Auburn (in New York, United States), Aguascalientes (Mexico), Emmaboda (Sweden), Montecchio (Italy), and Greater China.

Upon our review of the SOPs and our realization that Auburn provided the most representative process steps, the site emerged as our sample or “model” site upon which to base our activities maps. Auburn also exhibited criticality to Xylem’s operations due to its strategic placement in the United States market and sizeable shipment volumes. The activities mapping exercise included identifying key steps in the inbound transportation process, the classification of these steps into process segments from shipment book to delivery, and the plotting of these steps along with their process owners. In the following sub-section, we discuss our steps in identifying emissions hotspots using these activities maps.

3.1.5 Step 5: Emissions Hotspots Identification

Emissions hotspots are drivers of emissions in the inbound transportation network. As a derivative of the inbound transportation activities maps, the identification of these hotspots began by highlighting the discrepancies between actual and documented practices for the major sites in scope. The exercise continued with documenting process nuances among logistics suppliers managed by the same site. Contextualizing and connecting each step in the activities maps to the pain points, observations, and other findings from the stakeholder interviews illuminated areas for emissions improvement and process-related opportunities in the booking, shipment, and delivery sub-processes from shipment origin to destination.

Findings from these activities formed the basis of the emissions hotspots and leading indicators while underscoring low-efficiency sites.

From data collection and cleansing to emissions hotspot identification, we gained a comprehensive and in-depth understanding of Xylem's current state inbound logistics network and its daily operations. This understanding offered guidance and direction for the hybrid emissions calculation tool and subsequent analysis. In *Section 3.2*, we explain the methods we leveraged and the activities we completed to execute the quantitative portion of our study.

3.2 Phase 2: Develop the Calculation Tool and Conduct Analysis

Development of a robust and flexible Scope 3 emissions calculation tool and relevant emissions reduction initiatives began with deciding on the appropriate type of formulations, fuel-based or activity-based, to use. This decision depended on the purpose of the calculation tool and the way in which Xylem intended to use its results. Since the tool focused on aiding Xylem in making inbound logistics decisions based on key shipment levers, the final decision was to build a hybrid activity-based model that considered fuel consumption and vehicle type information only when these data points were available.

This phase of the capstone consisted of four steps: 1) emissions calculation tool development, 2) inbound transportation emissions baselining, 3) comparative analysis by the supplier, and 4) scenario-based and regression-based trade-off analysis. The sub-sections below describe these steps in detail.

3.2.1 Step 1: Emission Calculation Tool Development

As discussed in *Chapter 2 Section 2.3*, our Scope 3 emissions calculation tool merges and expands upon the GHG, GLEC, and NTM methods to adapt to the extent of the supplier shipment-level data available. The calculation tool also integrates internal shipment order details, logistics spend data, industry-specific assumptions, company-specific context, and supplier-specific information to fill data gaps. Ultimately, this enhanced tool allows Xylem to ingest data from its inbound logistics suppliers and to identify, evaluate, and monitor their emissions improvements continuously.

The development process started with creating an emissions factor library that accumulated emissions factors from the GHG Protocol, fuel efficiency, emissions intensity, and scaling factors from the GLEC

Framework, and emissions, fuel consumption, and load factors from the NTM Methodology. The process continued with a collection of assumptions that functioned as additional calculation inputs and supplemented missing supplier data. The first part of this collection was a master list of distances by transport mode (i.e., air, road for truck and van, rail, and ocean) for every Xylem shipment lane between 2019 and 2021 using the NTM Calculator. This information provided assumed distances when actual distance data was unavailable. The second piece comprised transport mode assumptions that contained average speed, daily working hours, average transit time, maximum allowable distance, maximum payload, average carrier dimensions, average load utilizations, typical container type, typical vehicle type, and typical fuel type by mode. This information offered assumed weights, volumes, and fuel consumptions in the absence of actuals. The third part of this collection consisted of shipment lane assumptions that covered major ports for origin-destination pairs, estimated time of departure (e.g., morning, afternoon, or evening) by origin country, and the estimated time of arrival by the destination country. This information formed assumptions of transit time, shipment type, and delivery time to determine whether traffic congestion and expedited shipment emissions multipliers were applicable for a particular shipment. The last component included aggregated Xylem purchase order data from 2019 to 2021 that highlighted origin country, origin city, destination country, destination city, and total shipping cost for each origin-destination pair by the supplier and by shipment mode. This data filled gaps in actual origin and destination information to determine geographic coordinates and distances.

The factors and assumptions libraries supported the creation of three calculated input tabs that fed into the emissions formulas: Calculated Distance (in kilometers), Calculated Weight (in kilograms and in tonnes), and Calculated Volume (in cubic meters). The Calculated Distance tab captured supplier names, shipment identifiers, shipment counts, shipment legs, actual distances, origin information, and destination information from the supplier data given. Additionally, the tab deduced shipment lanes using origin and destination data or assumptions, designated shipment lane types (i.e., domestic vs. international), and estimated transit times and shipment types given comparisons against regular transit times. Final distances derived on this tab came from actual distance data, calculated distances using geographic coordinates, or assumed NTM distances depending on the data provided. The Calculated Weight tab captured supplier names, purchase or shipment order numbers, shipment modes, actual weights, and any vehicle information (e.g., vehicle type, vehicle age, contain type, load type, and fuel type) provided. The tab also deduced remaining vehicle information, fuel types, and load types (i.e., full container load vs. less than container load) using transport mode assumptions. Final weights derived on this tab came from actual weight data or calculated weights based on available or assumed load factors, vehicle information, and container information. The last tab, Calculated Volume, followed a similar structure to the Calculated Weight tab. The main difference occurred in the final volumes, which came from actual volume data or volume estimates based on load factors, container type, and average container dimensions and payloads. *Formula 1* shows the formulas we used in developing these input tabs.

Formula 1: Input Calculation Formulas

- **Distance Calculations by Shipment:**

$$D_c = R \times \cos^{-1}\{\cos[radians(90° - LAT_i)] \times \cos[radians(90° - LAT_j)] + \sin[radians(90° - LAT_i)] \times \sin[radians(90° - LAT_j)] \times \cos[radians(LONG_i - LONG_j)]\}$$

Where:

D_c = Coordinate distance (kilometer, or km)

R = Earth's radius (km)

LAT_i = Origin latitude

LAT_j = Destination latitude

$LONG_i$ = Origin longitude

$LONG_j$ = Destination longitude

- **Weight Calculations by Shipment:**

$$W_c = minimum(L\ or\ C) \times LCU_a$$

$$LCU_w = W_a \div minimum(L\ or\ C)$$

Where:

W_c = Calculated weight (kilogram, or kg)

W_a = Actual weight (kg)

L = Maximum payload by weight (kg)

C = Container capacity (kg)

LCU_a = Average load capacity utilization (%)

LCU_w = Load capacity utilization by weight (%)

- **Volume Calculations by Shipment:**

$$V_c = minimum[C \text{ } or \text{ } (l \times w \times h)] \times LCU_a$$

$$LCU_v = V_a \div minimum[C \text{ } or \text{ } (l \times w \times h)]$$

Where:

V_c = Calculated volume (cubic meter, or m^3)

V_a = Actual volume (m^3)

l = Container length (m)

w = Container width (m)

h = Container height (m)

C = Container capacity (m^3)

LCU_a = Average load capacity utilization (%)

LCU_v = Load capacity utilization by volume (%)

Depending on the availability and quality of shipment-level data from suppliers, our calculation tool applied the most appropriate one among the following emissions formulations. In each application, assumed data deduced in the above input tabs (e.g., distance, weight, and volume) supplemented any missing supplier data. The subsequent sections start with recaps of the calculation methods, share their applications, and conclude with detailed formulations or models.

The GHG Protocol and Emissions Formulas

The GHG Protocol provides an activity-based Scope 3 emissions calculation method for upstream logistics that hinges upon the shipment distance, the mass or volume of the products shipped, and a mass-distance emissions factor based on the transportation mode (Greenhouse Gas Protocol, 2013). This activity-based calculation method allows reporting companies to pinpoint emissions drivers based on upstream logistics activities, manifested as shipment levers (i.e., distance, mass or weight, and volume). The calculation tool built in the models depicted in *Formula 2* below. Where actual shipment data was lacking, the tool leveraged calculated and assumed data from the Calculated Distance, Calculated Weight, and Calculated Volume input tabs as needed.

The following formulas are taken from GHG Protocol:

Formula 2: Total CO_2eq Emissions across Transport Modes and Vehicle Types

$$E = \sum D \ x \ W \ x \ EF$$

Where:

E = Total emissions (kg CO_2eq)

D = Distance, actual or calculated (km)

W = Weight or mass, actual or calculated (metric ton, or tonnes)

EF = Emissions factor of mode or vehicle type (kg CO_2eq per tonne-kilometer, or kg CO_2eq/tkm)

The GLEC Framework and Emissions Formulas

The GLEC Framework provides both activity-based and fuel-based Scope 3 emissions calculation methods for upstream logistics. The GLEC method provides mass-distance CO2eq intensity factors and mass-distance fuel efficiency factors (Greene & Lewis, 2019). This method allows companies to apply the CO2eq intensity factor to estimate emissions when only shipment distance, mass, and transport mode data are available (Greene & Lewis, 2019). When more detailed fuel data are available, the GLEC method allows companies to apply the fuel efficiency factor for a more accurate calculation (Greene & Lewis, 2019). Incorporating GLEC formulations improved emissions calculations by combining fuel or emissions data with the logistics activities performed to transport Xylem's products.

The calculation tool built in the algorithms displayed in *Formulas 3 through 7* below. Where actual shipment data was lacking, the tool leveraged calculated and assumed data from the Calculated Distance, Calculated Weight, and Calculated Volume input tabs as needed.

The following formulas are taken from GLEC Framework:

Formula 3: Scope 3 Fuel Efficiency, Fuel Emissions, and CO_2eq Intensity Factors

$$FE = \frac{\sum_1^n (FC)}{\sum_1^n (tkm)}$$

$$FEF = \frac{\sum_1^n (E_i)}{\sum_1^n (FC)}$$

$$EIF = \frac{\sum_1^n (E_i)}{\sum_1^n (tkm)}$$

Where:

FE = Fuel efficiency factor (kg fuel/tkm)

FC = Fuel consumed (kg)

FEF = Fuel emissions factor (kg CO_2eq/kg fuel)

EIF = Emissions intensity factor (kg CO_2eq/tkm)

E_i = Emissions for mode, vehicle, and fuel type (kg CO_2eq)

tkm = Tonne-kilometer (tkm)

Formula 4: Tonne-Kilometers (tkm)

$$tkm = W \; x \; D$$

Where:

tkm = Tonne-kilometer (tkm)

W = Weight or mass (tonnes)

D = Distance (km)

Formula 5: Total Tonne-Kilometers for Multiple Shipments

$$TKM = \sum_{t=1}^{n} W_t \times D_t$$

Where:

TKM = Total tonne-kilometers (tkm)

W_t = Weight or mass per trip (tonnes)

D_t = Distance per trip (km)

$t=1$ = Initial trip

n = Final trip

Formula 6: Total CO_2eq Emissions using Fuel Efficiency Factors

$$E = \sum_{t=1}^{n} TKM_t \times FE_t \times FEF_t$$

Where:

E = Total emissions (kg CO_2eq)

TKM_t = Total tonne-kilometers per trip (tkm)

FE_t = Fuel efficiency factor per trip (kg fuel/tkm)

FEF_t = Fuel emissions factor per trip (kg CO_2eq/kg fuel)

$t=1$ = Initial trip

n = Final trip

Formula 7: Total CO_2eq Emissions using Emissions Intensity Factors

$$E = \sum_{t=1}^{n} TKM_t \times EIF_t$$

Where:

E = Total emissions (kg CO_2eq)

TKM_t = Total tonne-kilometers per trip (tkm)

EIF_t = Emissions intensity factor (kg CO_2eq/tkm)

$t=1$ = Initial trip

n = Final trip

The NTM Methodology and Emissions Formulas

NTM provides a fuel-based method to calculate Scope 3 emissions across four transport modes: air, road (including trucks and vans), railway, and ocean. Air transport emissions depend on the total flight emissions and emissions allocations based on the shipment weight (Network for Transport Measures, 2015). Road transport emissions depend on the shipment weight or volume, vehicle type and load capacity utilization, distance, and fuel consumption (Network for Transport Measures, 2015). Railway transport emissions depend on the same shipment levers as road transport (Network for Transport Measures, 2015). Finally, ocean transport emissions depend on the shipment distance, weight or volume, load factor or utilization, vessel type, and fuel type (Network for Transport Measures, 2015).

The third and final set of calculations built into the tool included the NTM formulas shown in *Formulas 8 through 11* below. Where actual data was lacking, the calculation tool embedded calculated and assumed data from the Calculated Distance, Calculated Weight, and Calculated Volume input tabs as needed.

The following formulas are taken from NTM Methodology:

Formula 8: Total CO_2eq Emissions for Air Transports (NTM)

$$E = \sum CEF_{(i,cu)} + (VEF_{(i,cu)} \times D)$$

$TE_i[kg] = CEF_{(i,cu)}[kg] + VEF_{(i,cu)}[kg/km] \; x \; D[km]$

Where:

E = Total emissions (kg CO_2eq)

$CEF_{(i,cu)}$ = Constant emissions factor for substance *i* at capacity utilization *cu* (kg CO_2eq)

$VEF_{(i,cu)}$ = Variable emissions factor for substance *i* at capacity utilization *cu* (kg CO_2eq/km)

D = Great Circle Distance (GCD) between airports (km)

Based on the International Civil Aviation Organization, the calculation tool corrected GCD calculations in the following manner (see *Table 1* below):

Table 1

Great Circle Distance Corrections for Air Transport (Network for Transport Measures, 2015)

GCD Estimations	Corrections to GCD Estimations
Less than 550 km	+ 50 km
Between 550 km and 5500 km	+ 100 km
Above 5500 km	+ 125 km

Formula 9: Total CO_2eq Emissions for Road (Truck or Van) Transports (NTM)

$$E = \sum CE \times D \times [FC_{empty} + \left(FC_{full} - FC_{empty}\right) \times LF]$$

$$LF = W \div C$$

Where:

E = Total emissions (kg CO_2eq)

CEF = Constant emissions factor, 2.61 grams CO_2eq/liter (g CO_2eq/l)

D = Distance (km)

FC_{full} = Fuel consumption for full load (liter/kilometer, or l/km)

FC_{empty} = Fuel consumption for empty load (l/km)

LF = Load factor or load capacity utilization (%)

W = Weight of cargo (kg or tonne)

C = Total Weight Capacity (kg or tonne)

Formula 10: Total CO_2eq Emissions for Railway Transports (NTM)

$$E = \sum EF \times D \times LF$$

Where:

E = Total emissions (kg CO_2eq)

EF = Emissions factor (kg CO_2eq/km)

D = Distance (km)

LF = Load factor or load capacity utilization (%)

Formula 11: Total CO_2eq Emissions for Ocean Transports (NTM)

There are a few steps in calculating emissions of sea transports based on NTM as follows:

$$E = \sum EIF \times W \times D$$

$$EIF = \frac{[a \times dwt^{-c} \times F(LCU)]}{(PDR_{ship} \times LCU)}$$

$$F(LCU) = (d + e \times LCU)^{2/3}$$

Where:

E = Total emissions (kg CO_2eq)

EIF = Emissions intensity factor by ship type (kg CO_2eq/tkm)

W = Weight or mass of cargo (tonne)

D = Distance (km)

F(LCU) = Fuel consumption as a function of load (kg fuel)

PDR_{ship} = Payload to deadweight ratio by ship type

a, c, d, e = Parameter constants by ship type (see *Table 18 and 21* in the Appendix B for details)

Additional Multipliers for Scope 3 Emissions Calculations

To convert non-carbon dioxide (CO_2) greenhouse gas emissions and to account for traffic congestion and shipment type, the hybrid calculation tool embedded and applied the following emissions multipliers:

- **Non-CO_2 Greenhouse Gas Emissions:** The tool converted non-CO_2 greenhouse gas emissions to CO_2eq emissions based on the Global Warming Potential (GWP) of each gas against CO_2 over a 100-year time horizon (Greenhouse Gas Protocol, 2014). *Table 2* displays the specific multipliers.

Table 2

Global Warming Potential by Greenhouse Gas (Greenhouse Gas Protocol, 2014)

Compound	Chemical Formula	CO_2eq Factor as of ARS5 (Relative to CO_2)
Carbon dioxide	CO2	1.00
Methane	CH4	28.00
Nitrous oxide	N2O	265.00
Nitrous oxides	NOX	10.00
Hydrocarbons	HC	1.00

Carbon monoxide	CO	2.00

- **Traffic Congestion Emissions Multiplier, *t* = 1.53** (Transportation Research Procedia)**:** The tool applied this multiplier to emissions estimates for cases where the estimated shipment pick-up and delivery times coincided with peak travel hours (Bharadwaj et al., 2017). These peak hours typically fell in between 8:00AM to 10:00AM in the morning or 4:00PM to 6:00PM in the afternoon. Since traffic congestion mainly plagued pre-carriage and post-carriage shipment legs, the tool applied this multiplier to the applicable truck and van shipments.
- **Expedited Shipment Emissions Multiplier, *s* = 4.18** (GLEC Framework)**:** Expedited shipments via trucks produced more emissions than regular shipments (Greene & Lewis, 2019). This increase resulted from the increased speed or velocity, a potentially sub-optimal route to adjust distance, vehicle types and fuel consumption changes, and varying topographical conditions. The calculation tool designated shipments as "expedited" when the calculated transit time was lower than the average transit time for the same distance and mode. Derived from the expedited truck and regular truck shipment emissions factors from the GLEC framework, this multiplier applied to only expedited truck shipments.

With embedded formulaic capabilities across every input and output component, the hybrid calculation tool auto-generated inbound logistics emissions using Xylem's supplier shipment data. These results formed the basis of the company's Scope 3 emissions baseline. While this research focused on the inbound transportation network and associated activities, this tool enables Xylem to leverage it independently beyond the scope of this research. For example, due to similar input data requirements in the outbound or downstream transportation network, Xylem may use this tool to calculate Scope 3 emissions for shipments to customer sites. The next sub-section discusses our steps in establishing Xylem's inbound transportation emissions baseline.

3.2.2 Step 2: Inbound Transportation Emissions Baselining

Once finalizing the emissions calculation tool, we deployed the tool on the cleansed and normalized supplier shipment data. The emissions baselining exercise comprised two parts: 1) calculation and summary of inbound transportation emissions for Xylem's top ten logistics suppliers and 2) descriptive shipment and emissions data analysis. The two components combined generated an interactive Power BI dashboard for management use. *Chapter 4* discusses the results of the dashboard in detail.

Xylem's Scope 3 emissions baseline was an aggregation of emissions estimates across all shipments in-scope. To yield managerial insights, the calculation tool and dashboard isolated and consolidated by-shipment emissions results by year, by shipment mode, by shipment lane, by major site, and by the supplier. Similar summarization of shipment-specific data, such as total shipments, total distance traveled, total weight shipped, total volume shipped, and total logistics spend, accompanied these baselines. Descriptive shipment and emissions analysis took calculation tool results further by generating averages and efficiency measures, year-over-year trends, and distributions across suppliers and modes. Key insights from the baselining exercise included total shipments and emissions by year, average emissions per shipment, average emissions per kilometer traveled, average emissions per tonne shipped, average emissions per USD spent, and average emissions per tonne-kilometer, among others. In the next sub-section, we discuss the relevance of these key insights to the comparative analysis we conducted by the supplier to inform logistics and sourcing decisions.

3.2.3 Step 3: Comparative Analysis by Supplier

The shipment and emissions averages, efficiency measures, trends year-over-year, and distributions above directly impacted the by-supplier comparative performance analysis. Understanding that each supplier included in the analysis varied by size, scale, volume, and scope, these insights effectively "scaled" and "normalized" their emissions against one another to allow for fair and accurate comparisons. Using the above insights as inspiration, the comparative analysis initiated with the development of a set of key supplier performance metrics. These metrics included the following:

- **Shipment Performance Metrics** included average distance per shipment, average weight or volume per shipment, average spend per shipment, and percentage of shipments by mode. These metrics also encompassed variability metrics, such as the coefficient of variance (CoV = Standard Deviation ÷ Mean) for shipment distance and shipment weight by the supplier.
- **Emissions Performance Metrics** included average CO_2eq emissions per shipment, average CO_2eq emissions per kilometer traveled, average CO_2eq emissions per tonne or cubic meter shipped, average CO_2eq emissions per USD spent, average CO_2eq emissions per tonne-kilometer, and year-over-year percent change in emissions.

Upon calculating these metrics and deriving supplier-specific insights, the comparative analysis continued with a systematic ranking of the suppliers by performance. Finally, for logistics suppliers that provided their own shipment level or aggregate CO_2eq emissions numbers, the comparative analysis measured any underestimations and overestimations between their estimates and those produced by our calculation tool. The following sub-section highlights the final step in our analysis, the trade-off analysis, and our rationale for the various models and techniques applied.

3.2.4 Step 4: Scenario-Based and Regression-Based Trade-off Analysis

Beyond the supplier data maturity assessment, an accurate and reliable Scope 3 emissions baseline, and supplier emissions performance measurements, the arguably most powerful insights from our capstone rested in the trade-off analysis. Previous studies remained an uncharted territory for connecting important upstream and downstream supply chain decisions to inbound logistics emissions and quantifying the inherent impacts. The trade-off analysis focused on answering these lingering questions and providing a perspective into the potential effects of key supply chain decisions on transportation emissions.

The trade-off analysis began with developing a multi-variable regression model using emissions as the target or dependent variable and shipment features as the independent variables. As a function of distance, weight, and fuel consumption, CO_2eq emissions possessed an overall linear relationship with these variables. As such, the multi-variable regression model employed linear regression techniques. The resulting R^2 value, coefficients, p-values, and upper and lower bounds indicated the model's overall fit, the statistical significance of each variable in influencing emissions, and the impact a per unit change in a shipment feature had on emissions. These insights offered high-level, quantified trade-offs for Xylem's overall Scope 3 inbound logistics emissions.

We then organized the trade-off analysis into four parts aligned to the key upstream and downstream supply chain processes we examined: 1) demand and production planning, 2) sourcing and procurement, 3) inventory management, and 4) customer relationship management. Drawing connections between these supply chain processes and inbound logistics emissions required forming preliminary hypotheses for the relationships between the relevant supply chain decisions and shipment characteristics. For demand and production planning, we hypothesized that better forecast accuracy resulted in fewer expedited shipments and greater regular shipments. For sourcing and procurement, we theorized that improved purchasing compliance, a preferred logistics supplier program, and more beneficial supplier contracts impacted supplier data quality, supplier selection, and transport mode selection. For inventory management, we hypothesized that incremental changes to safety and cycle stock policies affected shipment distance, weight, and load type. Finally, we theorized that better customer relationship management manifested as increased customer service levels (CSL), or the percentage of times a company delivers orders to its customers as-promised and under agreed-upon conditions, using transit time as a proxy (ERP Information, 2022).

After ideating the above hypotheses, we assessed and selected the most appropriate analysis technique for each part of the trade-off analysis. We then log-transformed, scaled, and analyzed the following variables as necessary to quantify impacts and to understand trade-offs between these drivers and emissions:

- **Demand & Production Planning – Shipment Type Trade-off Analysis:** Designated as either expedited shipment or regular shipment, shipment type served as a proxy for demand and production planning capabilities, as forecast inaccuracies triggered reactive shipments and rush orders. Regular shipments arrived at the expected, average shipment lead times by mode, while expedited shipments indicated those delivered ahead of expected lead times. Given the expedited shipment multiplier (see *Section 3.2.1*) in effect, shipment type exhibited a possible linear relationship with emissions, although the exact impact was unknown. Trade-off analysis for this variable therefore consisted of a combined correlation and ordinary least-squared (OLS) linear regression model.

- **Sourcing & Procurement – Supplier & Shipment Mode Selection Trade-off Analysis:** Suppliers consisted of the ten in-scope logistics suppliers, while shipment mode consisted of air, ocean, rail, truck, van, and intermodal (represented as "other"). These two variables served as proxies for sourcing and procurement capabilities and policies. Supplier selection's impact on emissions depended on the relative emissions performance of each supplier against the others and the "opportunity cost" of selecting one supplier versus another. While the effect shipment mode had on emissions was widely established as emissions factors, the more interesting trade-offs lied in the effect per dollar spent on a particular mode had on Xylem's emissions. Since the relationship between these variables and emissions was not straightforward, this trade-off analysis used both scenario analysis and OLS regression.
- **Inventory Management – Shipment Distance, Weight, and Load Type Trade-off Analysis:** Shipment distance and weight were scaler, numerical variables, while load type comprised of either full container load (FCL) or less than container load (FCL). These variables combined served as a proxy for inventory management policies. Reallocation of products across the inbound transportation network and increases in safety and cycle stock levels potentially induced shorter distances travelled, lower weight per shipment, but greater frequencies in FCL shipments. Based on the results from numerous trials, distance and weight directly and proportionally correlated with emissions. To avoid multicollinearity, this trade-off analysis involved scenario analysis to quantify impacts.
- **Customer Relationship Management – Transit Time Trade-off Analysis:** Measured in days, transit time was a feature we engineered based on data provided, assumptions, and industry averages. Values represented the estimated time elapsed between arrival date and departure date and indicated the estimated travel time while a shipment was in transit. Without the exact CSL percentages per shipment, transit time became the proxy for customer relationship management decisions. With no changes in shipment modes or types, net decreases in transit times potentially

boosted CSLs and reduced emissions by theory of network optimization, vehicle routing, and shipment consolidation. Similar to that for shipment type, trade-off analysis for this variable consisted of a combined correlation and OLS linear regression model.

At Xylem leadership's request, we concluded our trade-off analysis with the testing and quantification of the effect of logistics spend on emissions, as spend served as a high-level proxy and driver of emissions for several established calculation methods. We used correlation analysis as our primary technique, plotting aggregated logistics spend against aggregated logistics emissions and testing multiple regression models to determine the best fit. The results provided important insights into the relationship between spend and Scope 3 emissions, identified local spend maximums and thresholds, and quantified the effect per dollar increase in inbound logistics spend had on emissions by mode. In the last phase of our research, detailed in Section 3.3 below, we discuss our steps in synthesizing findings, interpreting results, generating insights, and developing recommendations for the initiatives roadmap.

3.3 Phase 3: Synthesize Key Findings and Develop Recommendations

Based on the various activities, deep-dives, and analyses we conducted, we synthesized the key findings and developed the recommendations for carbon emissions reduction initiatives to enable Xylem to achieve its sustainability goals. The first step in this phase involved understanding the results, drawing key findings, and synthesizing important managerial implications and insights. The next activity included discussions and alignments with Xylem sponsors and key stakeholders to ideate and to determine feasible improvement opportunities, reduction initiatives, and the desired future state inbound logistics strategy. These discussions also revolved around important emissions levers and key performance indicators, major takeaways and implications, and analysis results and insights. Decisions and alignments from these conversations helped develop recommendations and prioritize emissions reduction initiatives. Finally, the capstone concluded with the development of an implementation roadmap that categorized improvements and initiatives into quick wins, short-term, and long-term horizons to enable Xylem to achieve its emissions reduction targets and ambitions.

3.4 Methodology Summary

The approaches and methods leveraged in our study included both quantitative and qualitative models and techniques. Activities and results spanned Xylem's top ten inbound logistics suppliers, 79 sites worldwide, and more than 4,300 unique origin-destination shipment lanes between January 2019 and October 2021. In the course of our capstone, we analyzed 539K+ line items of shipment-level data, processed 410K+ lines of logistics spend and shipment order data, and conducted more than ten stakeholder and supplier interviews. Deep-dives and qualitative insights centered on five major sites across North America, Europe, and Asia to enhance our findings. While our research had a finite scope, the frameworks, tools, models, and insights from our study are replicable. In addition to enabling Xylem to leverage these assets to accelerate Scope 3 emissions baselines and reductions for other sites, suppliers, and processes, our goal is to propagate them across other companies, categories and industries. Detailed results from our analyses and in-depth recommendations are available in *Chapter 4 Results and Analysis* and *Chapter 5 Discussion*, respectively.

4. RESULTS AND ANALYSIS

The three-part methodology discussed in *Chapter 3 Methodology* generated a substantial amount of results and insights. As a continuation, this chapter presents these qualitative and quantitative results and insights in detail. Due to supplier data limitations, assumptions play an essential role in enabling and supplementing our analysis and provide context to elucidate our results. This chapter thus begins with a discussion of our key assumptions in *Section 4.1*. *Section 4.2* shares the results from the supplier data maturity assessment, and *Section 4.3* describes key findings from stakeholder interviews. In *Section 4.4*, we elaborate on the inbound transportation network activities and emissions hotspots. *Section 4.5* shares the final Scope 3 inbound logistics emissions baseline and emissions efficiency metrics. The chapter concludes with results of the comparative analysis by supplier in *Section 4.6*, outcomes of the trade-off analyses in *Section 4.7*, and a summary of key findings in *Section 4.8*. For confidentiality purposes, supplier names are sanitized and concealed.

4.1 Assumptions

As discussed above and in *Chapter 3 Methodology*, assumptions filled critical gaps in the supplier shipment-level data and enabled us to build our models and to perform our analyses. These assumptions comprise two kinds: data assumptions and emissions calculation assumptions:

- **Data Assumptions:** Data assumptions provide a perspective and a direction for handling missing data values for fields outside those directly needed in Scope 3 emissions formulations.
    - Departure dates are assumed to be the first of a month if a specific date is not given
    - Arrival dates are assumed to be the summation of the departure date and the estimated transit time needed based on the origin-destination pair and the transport mode
    - Estimated transit times (in days) are assumed to be a function of average speed and average working hours per day by mode, divided by total distance traveled
    - Estimated departure and arrival times are assumed to be similar to the typical flight departure and arrival times between origin and destination sites unless specified otherwise
    - Shipment mode is assumed to be intermodal unless specified otherwise

- Road transport for in-scope shipments is assumed to comprise only trucks and vans
- Inland waterways are assumed to be out of scope for the stipulated shipments
- Shipment legs are assumed to cover all legs (i.e., pre-carriage, main haul, post-carriage) unless specified otherwise
- Shipment count is assumed to be one shipment per line item unless otherwise specified
- Shipment lanes with missing origins or destinations are assumed to have estimated distances that equal the average distances across all lanes for the known origin or destination
- Twenty-foot Equivalent Unit (TEU) containers are assumed to be used for lightweight, small, or average-weight cargo shipments
- Forty-foot Equivalent Unit (FEU) containers are assumed to be used for heavyweight and big cargo shipments
- Vehicle or vessel types, unless otherwise specified, are assumed to be the most frequently used vehicle for a given transport mode
- Fuel types are assumed to be the most frequently used fuel for a given mode and vehicle type
- Origin and destination cities are assumed to be based on the most frequently visited Xylem sites by the supplier, mode, origin and destination country-pairing in the logistics spend data
- Suppliers included in the study comprise 65% of total inbound logistics spent between January 2019 and October 2021.

* **Emissions Calculation Assumptions:** Emissions calculation assumptions provide a perspective and a direction for handling missing data values for fields that feed Scope 3 emissions formulations.
  - GHG emissions without emissions factors are assumed to be negligible under the GHG method
  - Total GLEC emissions estimates are assumed to be Well-to-Wheel (WTW) figures, although both Well-to-Tank (WTT) and Tank-to-Wheel (TTW) numbers are provided
  - Non-CO_2 GHG emissions are assumed to be negligible for non-air transports under NTM due to a lack of applicable emissions factors

- For vehicles and fuel types that lack fuel efficiency, load, or emissions factors under any of the three studied methods, their fuel efficiency, load, and emissions factors are assumed to be averages of the factors available for all vehicles and fuel types under the same shipment mode
- In the absence of actual distance data, the distance is assumed to be the NTM-calculated distance between major ports in the origin and destination countries based on the mode
- In the absence of actual weight data, the weight is assumed to be a function of the maximum payload and the average load factor for the specified mode, vehicle, and container type
- In the absence of actual volume data, the volume is assumed to be a function of the maximum volume capacity and the average volume load factor for the mode, vehicle, and container type
- FCL loads are assumed to be used for shipments with a container utilization of more than 85%
- LCL loads are assumed to be used for shipments with a container utilization of less than 85%

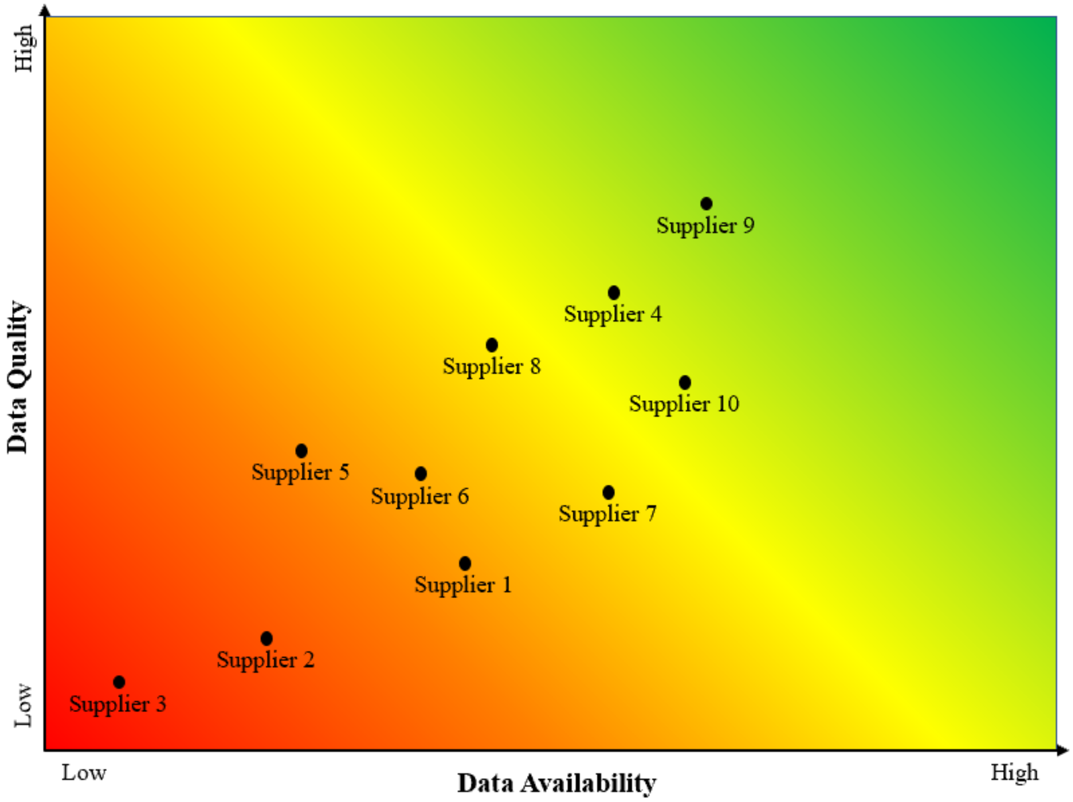
Each of the above assumptions influenced our data models and analysis. In the following sections, we revisit the various qualitative and quantitative analysis in our study and share their results.

4.2 Supplier Data Maturity Assessment Results

The supplier data maturity assessment shows that when assessed on the dimensions of data availability and data quality, some logistics suppliers have more robust and mature data than others. The availability and quality of shipment-level data impact the accuracy of the emissions calculations. As defined in *Section 3.1.2*, the better the shipment-level data availability and quality, the more reliable the data, and the fewer the assumptions needed to calculate emissions. *Figure 4* shows the results of our assessment on a heatmap.

Figure 4

Supplier Data Maturity Assessment Heatmap



The desired quadrant is the upper right-hand corner, known as the "green" zone, where both data availability and data quality are high. Suppliers located in or near the "green" zone showcase better data quality and availability in their shipment-level details, allowing for greater accuracy in their emission calculations. On the other hand, suppliers located at or near the bottom left-hand corner fail to provide the required data, especially the high-priority data elements discussed in *Section 3.1.1*. For these suppliers, assumptions apply in lieu of actual data, making the accuracy of their emission estimates questionable. To help distinguish these suppliers in the figure, *Section 4.6* shares insights into the size, scale, and scope of each supplier relative to its impact on Xylem inbound transportation shipments.

In short, no supplier included in the assessment provided data mature enough to be in the "green" zone. Large suppliers, defined as suppliers with whom Xylem has a long-term relationship, logistics spend over $100 million since 2019, and significant shipment volumes, tend to have lower data availability and quality. Smaller suppliers, defined as suppliers with whom Xylem has logistics spend less than $100 million since 2019 and lower shipment volumes, tend to trend higher across both evaluation criteria. Results from the above heatmap offer Xylem guidance on the actions needed during the next tender or contract negotiation to incentivize suppliers to disclose the information the company needs for future Scope 3 emission baselining. In particular, Xylem may consider setting new data-related service level agreements (SLAs) for quarterly supplier performance reviews or including data-related clauses in their supplier contracts. Furthermore, Xylem may consider defining the carbon disclosure requirements in their Requests For Proposal (RFPs) and documenting them in its procurement policies and procedures.

4.3 Stakeholder Interviews and Qualitative Findings

The stakeholder interviews produced key findings across three main dimensions: people, processes, and technology. As mentioned in *Section 3.1.3*, these findings provide company-specific and supplier-specific qualitative context to refine and to adjust our algorithms and models. Additionally, they enhance our understanding of Xylem's existing inbound transportation operations and steer the development of emissions reduction initiatives. *Figure 5* provides an infographic summarizing these findings.

Figure 5

Key Findings from Stakeholder Interviews

People and Organization

Xylem currently operates with a decentralized operating model across its supply chain and logistics organization. Each operational site has the autonomy to determine its shipment processes, often deviating from existing SOPs in place. Processes are therefore unstandardized across sites and geographies. For example, Auburn, Aguascalientes, Emmaboda, Montecchio, and Greater China operational sites all possessed their own set of standards and procedures that are often undocumented. As a result, Xylem has limited visibility into the efficiency and effectiveness of its inbound logistics operations and potentially operates with a sub-optimal network.

Processes (Operations and Shipments)

The rise in volume and frequency of emergency shipments drives an increased usage of air and LCL truck freight. We observe a 20% to 30% uptick in air freight shipments shifted from traditional ocean freight, coupled with a 10% to 20% movement from FCL shipments to LCL shipments via trucks. Lack of container availability and constraints in truckload volume lead to stockpiling and congestion at both ports of loading and ports of discharge. Moreover, talent shortages and skill gaps within logistics supplier organization result in increasing damages, losses, and re-shipments and decreasing reliability (from historical 80% to 90% on-time in-full to only 30% to 35% in recent years). Rising fuel and transportation costs create incentives to decrease shipments and switch transportation modes**.** RFPs, RFQs (i.e., Requests for Quotation), and tender awards completed by separate, siloed teams further exacerbate the situation by preventing process standardization due to the differing knowledge and misaligned objectives.

Technology and Data

Currently, Xylem lacks an integrated Enterprise Resources Planning (ERP) system or a consolidated transportation tracking and monitoring system across its global operations. The use of different systems across sites creates challenges in maintaining transparency and visibility for internal and supplier logistics operations, especially for a company like Xylem that operates in 40 countries. To collect inbound logistics process and spend information, Xylem must contact each region and site separately for assistance. These circumstances prevent real-time operational and data visibility, complicate spend and emissions analyses at the corporate level, and delay decision-making.

The following section, we explore the results of our activities mapping and the emissions hotspots we discovered throughout inbound transportation processes.

4.4 Emissions Hotspots in the Inbound Transportation Network

Inbound transportation activities maps shed light into Xylem's upstream business operations and provided the foundation needed to pinpoint emissions hotpots in the network. Xylem's inbound logistics activities involve shipments from materials suppliers to Xylem sites and shipments between Xylem sites. The inbound logistics process, for both raw materials and finished goods, starts with supplier or Xylem bookings that provide shipment instructions and cargo ready dates to logistics suppliers for shipment planning. Based on the required arrival dates, logistics suppliers assign shipment routes, modes, and schedules for the linehaul, arrange for pre-carriage transportation from supplier or Xylem sites to loading ports with inland carriers at origin countries, and organize inland carriers to pick-up cargo at discharge ports for delivery to receiving Xylem sites at destination countries a few days before vessel arrival. Receiving Xylem sites are typically manufacturing plants, warehouses, and distribution centers. Fourth-party logistics suppliers (e.g., 4PLs) complete documentations and security filings and receive, store, and manage information from third-party logistics suppliers (e.g., 3PLs), materials suppliers, and Xylem. The nodes in this physical network include supplier sites, ports of loading at origin countries, ports of discharge at destination countries, and Xylem sites (either manufacturing plants, warehouses, or distribution centers). These nodes construct the following arcs:

- Supplier or Xylem sites to ports of loading
- Ports of loading to ports of discharge
- Ports of discharge to Xylem sites

The inbound transportation process consists of three main parts: booking, shipment, and delivery. Within booking, the materials supplier or originating Xylem site initiates shipment requests with a logistics supplier, while the logistics supplier submits import filings, determines shipment routes, and coordinates shipment and delivery activities. Within shipment, the logistics supplier checks port availability, solidifies an inland carrier for pickup upon arrival at the port, ships the cargo, sends the delivery order, and schedules a delivery appointment with the receiving Xylem site. Finally, within delivery, the inland carrier collects the cargo at the port, delivers it to the destination site, obtains a proof of delivery, and submits it to the logistic supplier. Inland carriers may be entities within the logistics supplier itself or independent sub-contractors.

From these activities maps, we uncover the following emissions hotspots:

Booking Sub-Process Emissions Hotspots

- **Origin Site:** No known efforts to strategically design warehouse layouts to place outgoing Xylem products close to shipment docks to minimize emissions from shipping and handling.
- **Shipment Planning:** Ripe with opportunities to anticipate delays from planning and inventory activities, reduce expedited shipments, elongate buffers for customs filings, and optimize routing.
- **Customs Filing and Approval:** Usually within 24 to 48 hours before departure. A delay may cause cargo to sit idle at the port of loading or prevent it from entering the port of discharge.

Shipment Sub-Process Emissions Hotspots

- **Shipment Coordination:** Multiple information handoffs among logistics suppliers, including freight forwarders, inland carriers, etc., that may cause cargo collection delays or rush deliveries.
- **Cargo Arrival:** Potential idle time for cargo mid-transit due to port unavailability and ripe with opportunities for logistics suppliers to nominate “greener” inland carriers for delivery.

Delivery Sub-Process Emissions Hotspots

- **Cargo Collection:** Potential idle time or cargo shipment delays at the port of discharge due to labor and container unavailability with opportunities to influence inland carrier routing.
- **Destination Site:** No known efforts to strategically optimize warehouse layouts to receive Xylem shipments quickly and to minimize emissions from receiving and warehousing.

- **Delivery Proof and Tracking:** Usually required by 8:15 AM after delivery but not always enforced or captured, inducing repeat deliveries and missing routing improvement opportunities.

4.5 Inbound Transportation Emissions Baseline

As discussed throughout this report and in detail in *Section 3.2*, our hybrid activity-based emissions calculation tool served as the conduit to baselining Scope 3 emissions. Combining available supplier shipment data and assumptions, the tool supplied three sets of emissions estimates: a GHG method-based estimate, a GLEC method-based estimate, and a NTM method-based estimate. Using an average among the three, we estimate Xylem's total in-scope CO_2eq emissions to be approximately 767K tonnes between January 2019 and October 2021. Average CO_2eq efficiency for this period is roughly 10.68K kg CO_2eq/tkm. These figures spanned 1.42M shipments, 1.56B km travelled, and 1.14M tonnes of products shipped. With an estimated $481.90M USD in inbound logistics spend covering these operations, the estimated cost per tonne CO_2eq is around $628.18 USD. Annual emissions comparisons portray an increasing trend year-over-year, with a significant upsurge between 2019 and 2020 (see *Table 3*). Findings from stakeholder interviews suggest pandemic-induced labor, resource, and supply chain disruptions to be the primary cause. The following sub-sections detail results for each calculation method. *Tables 22 and 22* in Appendix B show the side-by-side results from all three methods.

Table 3

Inbound Transportation CO_2eq Emissions 2019 – 2021 (All Methods)

Total CO_2eq Emissions (tonnes)	**2019**	**2020**	**2021 YTD**	**2021 Full (est.)**
Logistics Spend Covered: 65%	83.32K	331.72K	349.08K	465.44K
Logistics Spend Covered: 100% (est.)	128.18K	510.34K	537.05K	716.06K

4.5.1 GHG Method-based Emissions Baseline and Efficiency Metrics

Based on the GHG calculation method, we estimate Xylem's total in-scope CO_2eq emissions to be approximately 1.14M tonnes between January 2019 and October 2021. The average CO_2eq efficiency for this period is roughly 16.44K kg CO_2eq/tkm. Average CO_2eq per shipment is 800.52 kg, average CO_2eq per kilometer travelled is 0.78 kg/km, and average CO_2eq per kilogram shipped is around 1.00 kg/kg. Using the same total logistics cost of $481.90M USD, the estimated cost per tonne CO_2eq emitted is around $422.72 USD. Annual emissions comparisons portray an increasing trend year-over-year. See *Table 4* for details.

Table 4

Inbound Transportation CO_2eq Emissions 2019 – 2021 (GHG Method)

Total CO_2eq Emissions (tonnes)	**2019**	**2020**	**2021 YTD**	**2021 Full (est.)**
Logistics Spend Covered: 65%	89.08K	512.39K	539.02K	718.69K
Logistics Spend Covered: 100% (est.)	137.05K	788.29K	892.26K	1,105.68K

4.5.2 GLEC Method-based Emissions Baseline and Efficiency Metrics

Using the GLEC calculation method, we estimate Xylem's total in-scope CO_2eq emissions to be approximately 608K tonnes between January 2019 and October 2021. The average CO_2eq efficiency for this period is roughly 8.92K kg CO_2eq/tkm. Average CO_2eq per shipment is 426.81 kg, average CO_2eq per kilometer travelled is 0.42 kg/km, and average CO_2eq per kilogram shipped is around 0.53 kg/kg. Using the same total logistics cost of $481.90M USD, the estimated cost per tonne CO_2eq emitted is around $792.60 USD. Annual emissions comparisons portray an increasing trend year-over-year (see *Table 5* for details).

Table 5

Inbound Transportation CO_2eq Emissions 2019 – 2021 (GLEC Method)

Total CO_2eq Emissions (tonnes)	**2019**	**2020**	**2021 YTD**	**2021 Full (est.)**
Logistics Spend Covered: 65%	91.66K	268.48K	247.93K	330.57K
Logistics Spend Covered: 100% (est.)	141.02K	413.05K	381.43K	508.57K

4.5.3 NTM Method-based Emissions Baseline and Efficiency Metrics

Based on the NTM calculation method, we estimate Xylem's total in-scope CO_2eq emissions to be approximately 553K tonnes between January 2019 and October 2021. The average CO_2eq efficiency for this period is roughly 6.69K kg CO_2eq/tkm. Average CO_2eq per shipment is 388.02 kg, average CO_2eq per kilometer travelled is 0.38 kg/km, and average CO_2eq per kilogram shipped is around 0.48 kg/kg. Using the same total logistics cost of $481.90M USD, the estimated cost per tonne CO_2eq emitted is around $871.43 USD. Annual emissions comparisons portray an increasing trend year-over-year (see *Table 6 for details*).

Table 6

Inbound Transportation CO_2eq Emissions 2019 – 2021 (NTM Method)

Total CO_2eq Emissions (tonnes)	**2019**	**2020**	**2021 YTD**	**2021 Full (est.)**
Logistics Spend Covered: 65%	78.21K	214.29K	260.30K	347.07K
Logistics Spend Covered: 100% (est.)	120.32K	329.68K	400.46K	533.95K

As seen above, the results from each calculation method differ, with GHG-driven calculations providing the highest emissions baselines and NTM-driven calculations providing the lowest emissions baselines. The variations are the product of supplier data integrity at the shipment-level. For suppliers with higher scores in the supplier data maturity assessment (see *Section 4.2*), differences in emissions estimates among the three methods are minimal. For suppliers with lower scores in the maturity assessment, however, differences in emissions estimates across the three methods are amplified due to the margin of error inherent in using assumptions in lieu of actual shipment data. While we assert that Xylem's actual inbound logistics emissions baseline is likely an average of the three estimates, we recommend the use of the most conservative (i.e., the largest) estimate for external reporting purposes prior to conducting detailed data validations and resolutions. This conservative baseline eases emissions reduction sizing by providing more buffer for adjustments and more opportunities for improvement. For these reasons, all measures reported in subsequent sections of this report use results from the GHG method as basis, unless otherwise specified. The sub-section below shares additional results from deep-dives into shipment and emissions performances from critical Xylem sites and from various suppliers.

4.5.4 Shipment and Emissions Performance Deep-Dive Results

Following an in-depth examination of the baseline results, we discovered that the nine origin-destination pairs from Germany (DE), Sweden (SE), and the United States (US) to Australia (AU), Germany (DE) and the United States (US) encompass a majority of the shipments and carbon emissions for all origins and destinations. This finding is consistent with the site-specific insights from the stakeholder interviews highlighted in *Section 4.3*. *Table 7* offers summary statistics that compare and contrast these shipment lanes against all others.

Table 7

Summary Statistics for High Volume Shipment Lanes

Statistic	DE, SE, US to All Destinations	DE, SE, US to AU, DE, US	All Origins to AU, DE, US
Average distance per shipment (km)	2,719.13	2,898.45	888.00
Average weight per shipment (tonne)	1.91	1.90	0.54
Average CO2eq per shipment (kg)	1,470.00	526.80	273.57
Average CO2eq per distance (kg/km)	0.54	0.18	0.30
Average CO2eq per weight (kg/tonne)	0.77	0.28	0.49
Average CO2eq efficiency (tkm)	11,460.00	2,730.00	7,140.00

In addition, we observe the following insights:

- On average, shipments originating from Sweden, the United States, and Germany are heavier in weight and longer in the distance traveled than those from other origins

- Emissions per shipment and average emissions efficiency in tonne-kilometers from these three origins are significantly higher than those originating from other countries
- On average, shipments to the United States, Germany, and Australia emit lower emissions per shipment than those to other destinations
- Shipment weights and distances are heavily leftward-skewed in general, implying greater numbers of smaller shipments across shorter distances
- Across the board, variability (measured as CoV) is significantly lower for shipment distances than for shipment weights
- Smaller logistics suppliers show lower variability in the distance traveled (CoV between 0.19 and 0.66) than large suppliers (CoV greater than 0.87)
- Large suppliers show manageable variability in the distance travelled (CoV between 0.75 and 1.33) but extremely high variability in weight shipped (CoV up to 80.0+)
- Although not always the case, variability may be used to evaluate the ease of planning and forecasting shipments by supplier
- A further point of exploration is lead time variability (where data is available), which may be an indicator of supplier reliability to support inventory policy

Further analysis of the emissions baseline and accompanying shipment data reveals strong fluctuations in distances and cargo weights across shipments that contribute to higher emissions overall. This finding is especially true for shipments with large logistics suppliers with whom Xylem has sizeable business. Shipments originating from Germany, Sweden, and the United States exhibit particular high emissions likely due to greater shipment volumes, globally-dispersed distributions to other sites, increased usage of air and truck shipment modes, and a rise in expedited shipments. Shipments to Australia, Germany, and the United States, on the other hand, emit lower emissions on average. Given Xylem's current logistics operations, high variability in shipment operations suggest opportunities for networking and routing optimization, demand planning, inventory policy, and supply allocation to minimize emissions. In the section to follow, we dive into similar results and findings by supplier.

4.6 Supplier Performance Results and Comparisons

Taking the emissions baselining results further, we performed a comparative analysis to reveal insights on the shipment and emissions performance for each of the top ten logistics suppliers studied. The analysis follows the key performance indicators highlighted in *Section 3.2.3*, examining magnitudes of shipment levers (i.e., weight, distance, volume, etc.), emissions intensities, and variability among emissions drivers. For each supplier below, we begin with descriptions of its size, scale, and scope relative to Xylem inbound logistics operations to provide distinguishing characteristics. We then continue with the quantification of key shipment and emissions metrics and conclude with the identification of any underestimations or overestimations between the suppliers' self-reported emissions and our baseline. See *Figures 6 to 15,* Appendix B *Tables 16 to 21,* and Appendix B *Tables 24 to 27* for additional details.

- **Supplier 1:** Supplier 1 is a global logistics supplier with whom Xylem has $100M+ USD in transportation spend and the greatest volume of shipments over the past few years. Although most shipments rely on road freight (i.e., trucks) for delivery, average emissions per shipment remains relatively low at 216.72 kg CO_2eq. Average CO_2eq emissions per kilometer travelled is manageable at 0.84 kg/km, and the CoV across shipment distances is low at 0.17. Average CO_2eq emissions per kilogram shipped is also manageable at 1.5 kg/kg, while the CoV across shipment weights is a comparatively low 3.49.
- **Supplier 2:** Supplier 2 is a global logistics supplier that provides three different types of services, express, freight, and global, for Xylem. Since 2019, Xylem has around $50M USD in transportation spend with this supplier, with total shipments around 50K. Most shipments leverage either air freight or trucks for delivery, causing average emissions per shipment to significantly exceed those of all other suppliers at 79.28K kg CO_2eq. Average CO_2eq emissions per kilometer travelled is the second highest at 3.53 kg/km, although CoV across shipment distances is manageable at 0.84. Average

CO_2eq emissions per kilogram shipped is a manageable 2.30 kg/kg, while the CoV across shipment weights is 16.34.

- **Supplier 3:** Supplier 3 is a medium-sized logistics supplier with whom Xylem has around $11M USD in transportation spend and 69K shipments regionally over the past few years. Shipments rely almost exclusively on trucks, with average emissions per shipment at 669.29 kg CO_2eq. Average CO_2eq emissions per kilometer travelled is the highest among suppliers at 186.98 kg/km, although CoV across shipment distances is low at 0.19. Average CO_2eq emissions per kilogram shipped is also the highest at 6.0 kg/kg, while the CoV across shipment weights is a low 0.53.
- **Supplier 4:** Supplier 4 is a medium-sized, incumbent logistics supplier with whom Xylem has around $38M USD in transportation spend and 37K shipments over the past few years. Supplier 4 uses ocean freight more than air freight for long-haul shipments but relies heavily on trucking for shorter hauls. With high total shipment distance and weight, Supplier 4 shows average emissions per shipment at 1.36K kg CO_2eq. Average CO_2eq emissions per kilometer travelled is a low 0.30 kg/km, and CoV across shipment distances is a low 1.33. Average CO_2eq emissions per kilogram shipped is also low at 0.50 kg/kg, although CoV across shipment weights is 17.52.
- **Supplier 5:** Supplier 5 is a small, regional logistics supplier with whom Xylem has around $5M USD in transportation spend and 3K shipments over the past few years. With all-truck shipments within Europe and select Asian countries, Supplier 5 shows average emissions per shipment at a high 1.86K kg CO_2eq. Average CO_2eq emissions per kilometer travelled is 1.31 kg/km, and CoV across shipment distances is 0.66. Average CO_2eq emissions per kilogram shipped is low at 0.20 kg/kg, with CoV across shipment weights of 1.26.
- **Supplier 6:** Supplier 6 is a medium-sized logistics supplier with whom Xylem has around $11M USD in transportation spend but 101K shipments mostly within continental Europe. With heavy reliance on trucking, Supplier 6 shows average emissions per shipment at 739.44K kg CO_2eq. Average CO_2eq emissions per kilometer travelled is 0.60 kg/km, and CoV across shipment distances

is a low 0.21. Average CO_2eq emissions per kilogram shipped is 0.90 kg/kg, although CoV across shipment weights is the highest among suppliers at 125.31.

- **Supplier 7:** Supplier 7 is a large logistics supplier with whom Xylem has around $74M USD in transportation spend and 60K shipments. Shipments split between air and ocean freight, with a heavier leaning towards air, with average emissions per shipment at 1.67K kg CO_2eq. Average CO_2eq emissions per kilometer travelled is 0.22 kg/km, and CoV across shipment distances is one of the lowest at 0.18. Average CO_2eq emissions per kilogram shipped is 0.40 kg/kg, although CoV across shipment weights is 31.10.
- **Supplier 8:** Supplier 8 is a medium-sized logistics supplier with whom Xylem has only around $6M USD in transportation spend and 3K shipments. Shipments mostly originate in Europe and use air or truck for delivery. As a result, average emissions per shipment is a high 4.1K kg CO_2eq. Average CO_2eq emissions per kilometer travelled is 1.11 kg/km, and CoV across shipment distances is 1.25. Average CO_2eq emissions per kilogram shipped is 0.30 kg/kg, while CoV across shipment weights is a sizeable 18.82.
- **Supplier 9:** Supplier 9 is a medium-sized logistics supplier with whom Xylem has only around $13M USD in transportation spend but the fewest shipments at 760 over the past few years. Shipments mode distributions are arguably the best among suppliers with equal splits between air and ocean freight, with limited use of trucks. With mostly domestic shipments, Supplier 9 shows average emissions per shipment of 3.4K kg CO_2eq. Average CO_2eq emissions per kilometer travelled is 0.24 kg/km, and CoV across shipment distances is 0.52. Average CO_2eq emissions per kilogram shipped is 2.60 kg/kg, while CoV across shipment weights is a comparable 2.37.
- **Supplier 10:** Supplier 10 is a small fourth-party logistics (4PL) supplier with whom Xylem has more than approximately $150M USD in transportation spend and 65K shipments over the past few years. Shipments are almost exclusively within the continental United States, relying entirely on trucking. Average emissions per shipment is 273.61 kg CO_2eq. Average CO_2eq emissions per

kilometer travelled is 0.15 kg/km, and CoV across shipment distances is 0.75. Average CO_2eq emissions per kilogram shipped is a low 0.30 kg/kg, while CoV across shipment weights is 86.83.

Patterns and deductions for each supplier emerge based on the above results. Low CoVs across shipment levers typically imply established routes and standardized cargo types, while high CoVs suggest unexpected or emergency shipments with fluctuations in cargo. Supplier 1's low emissions intensities attribute mostly to its volume advantage and its operations across similar shipment lanes. Supplier 2 appears to be the supplier of choice for rush deliveries globally for a variety of products. Supplier 3's performance suggests its use for short shipment lanes and small cargo, while Supplier 4 seems to dominate long-haul shipments using LCL. Supplier 5 shows a propensity towards LCL shipments for small cargo, and its unexpected presence in select Asian countries points to potential purchasing non-compliance in those sites. With heavy usage of truck, Supplier 6 demonstrates more flexibility and higher shipment frequency but relies on more LCL shipments. Supplier 7 seems to dominate intercontinental shipments with one of the highest total shipment distances and weights. Supplier 8's high emissions intensities lie mainly in its choice of shipment modes, while supplier 9 shows year-over-year drops in total emissions. Finally, Supplier 10 exhibits high total shipment distances and weights shipped for established domestic routes, but activities in other countries outside the United States suggest potential non-compliance to purchasing policy.

Figure 6

Shipment Variance: Distance

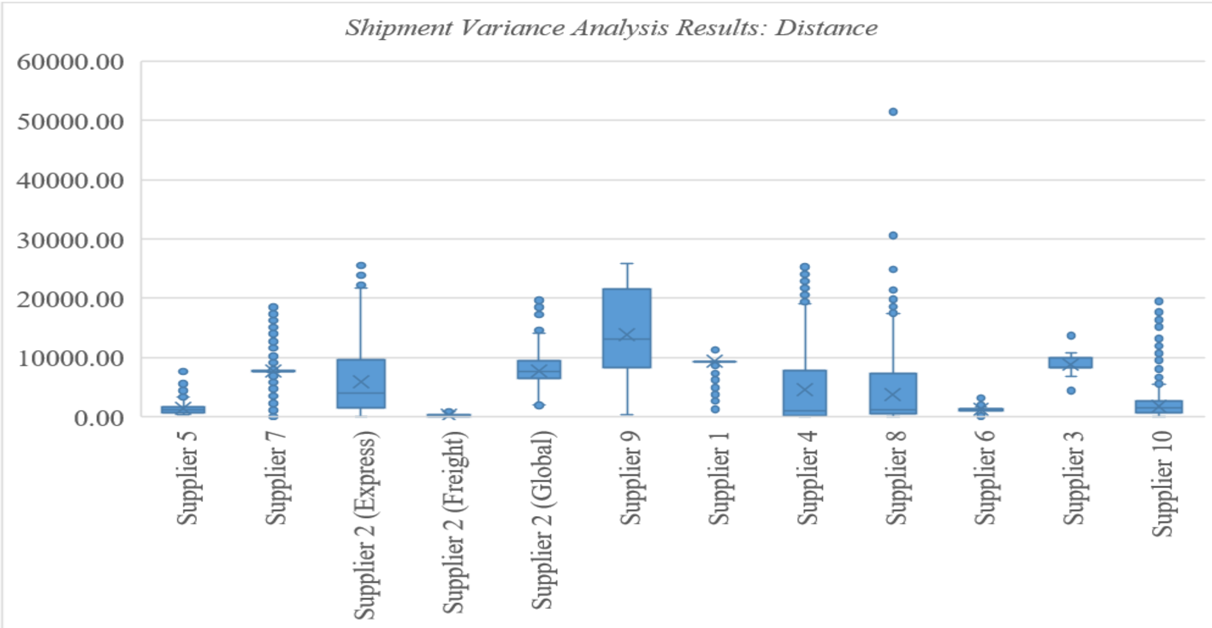


Figure 7

Shipment Variance: Weight

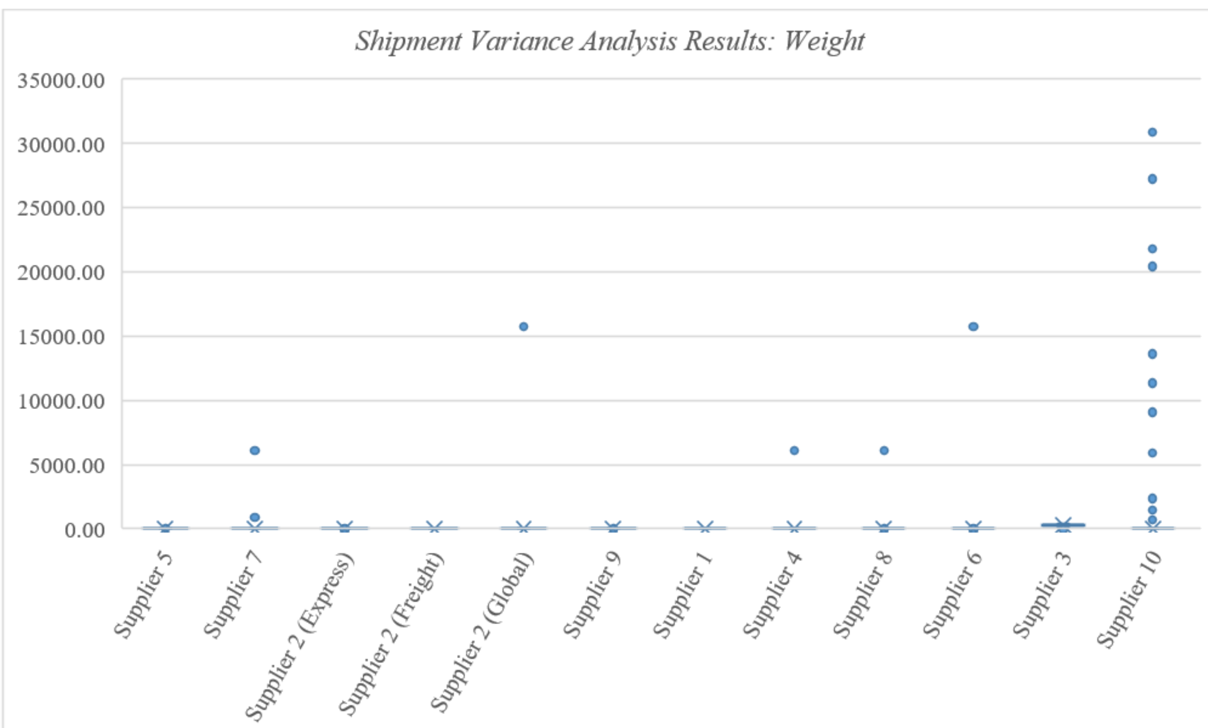


Figure 8

Carbon Emissions Trend Analysis Results (2019 – 2021)

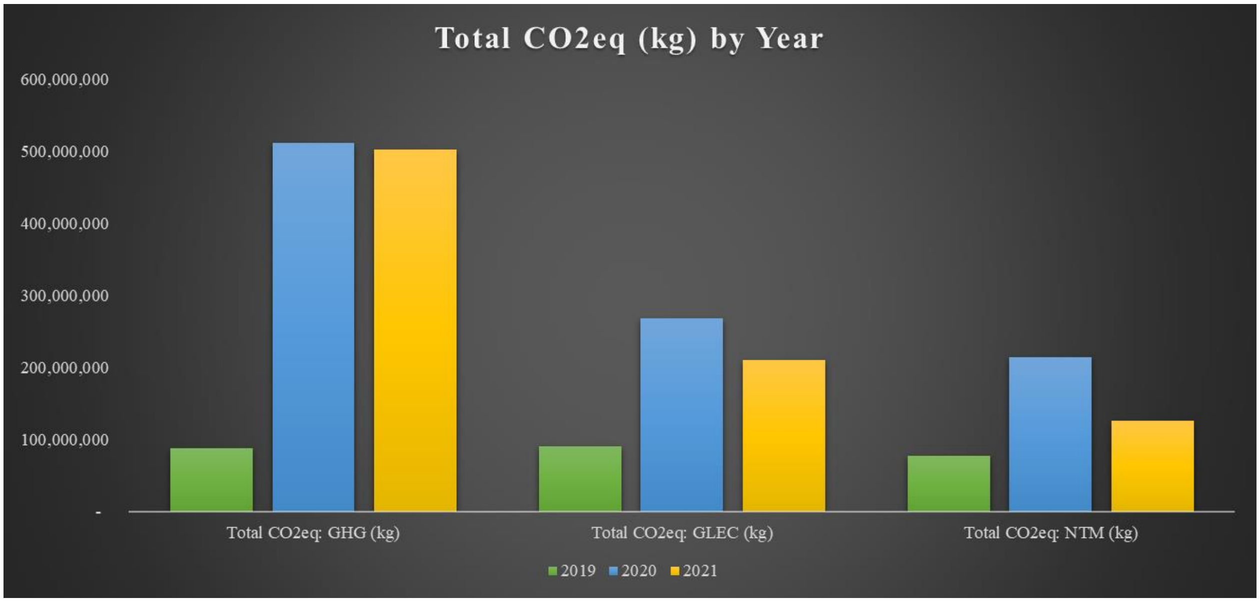


Figure 9

Carbon Emissions Intensity Comparisons by Supplier (Emissions per Spend)

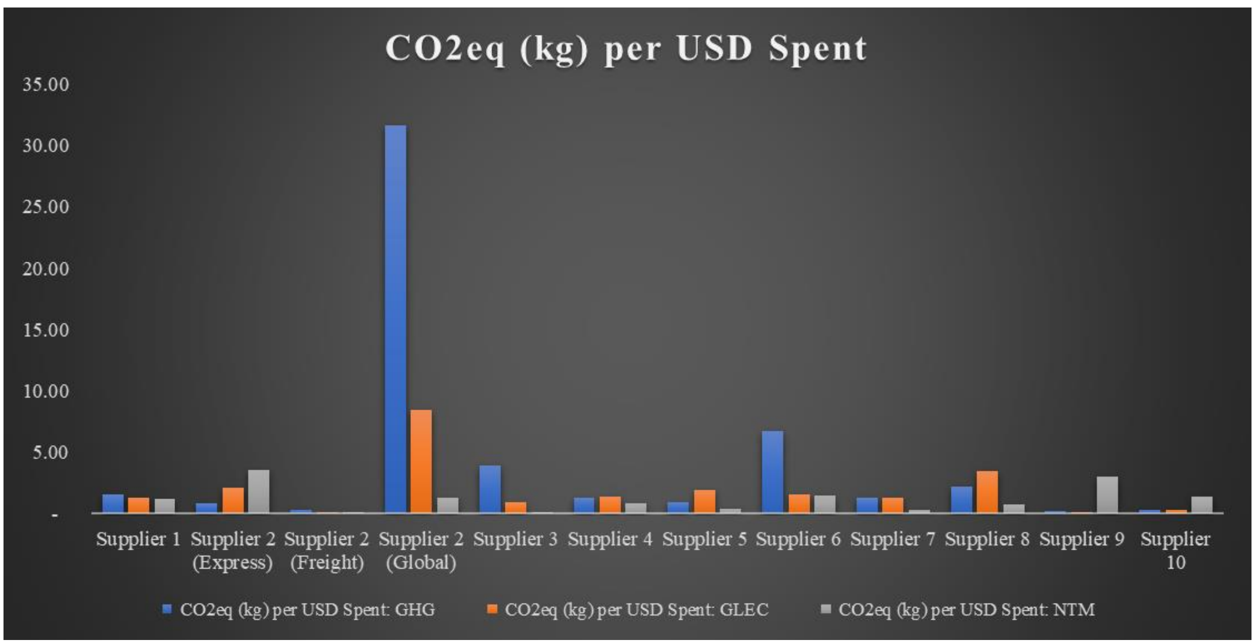


Figure 10

Carbon Emissions Intensity Comparisons by Supplier (Emissions per Shipment)

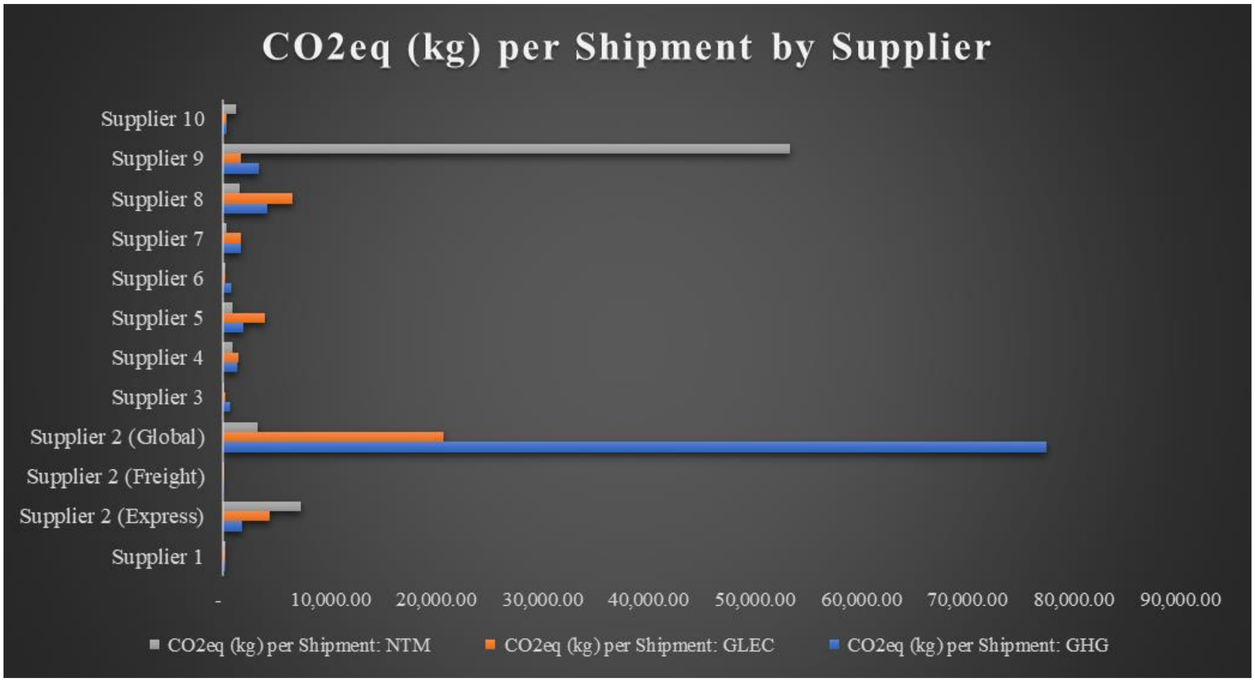


Figure 11

Carbon Emissions Intensity Comparisons by Supplier (Emissions per Distance)

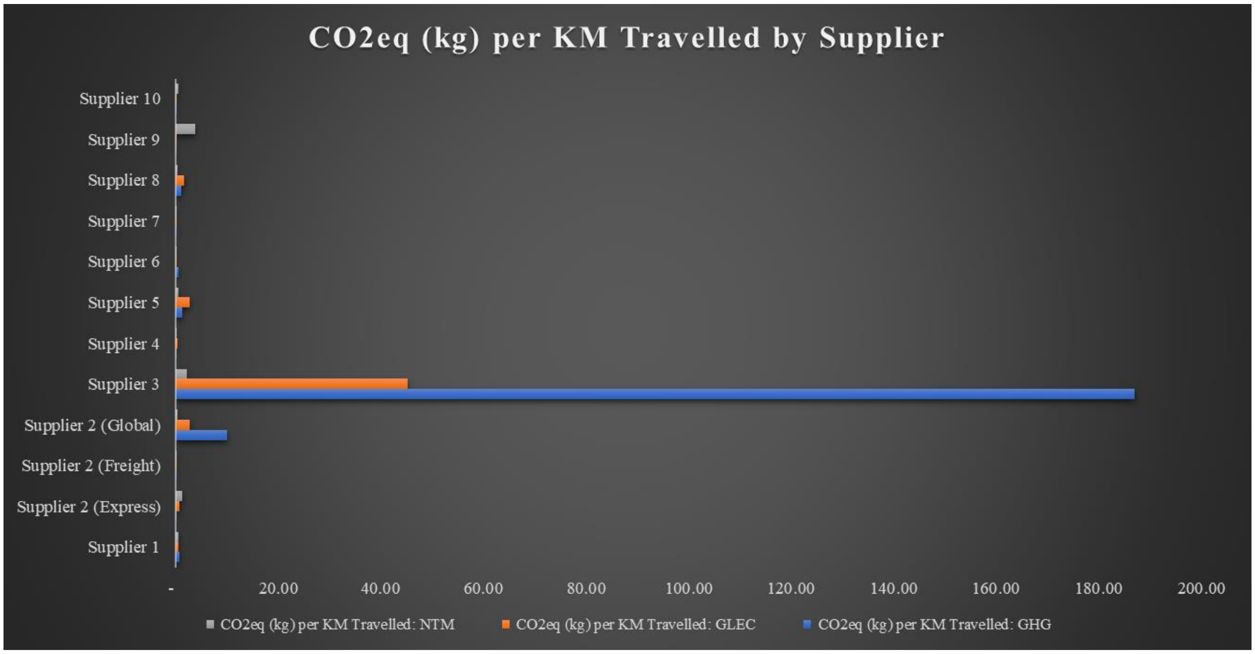


Figure 12

Carbon Emissions Intensity Comparisons by Supplier (Emissions per Weight)

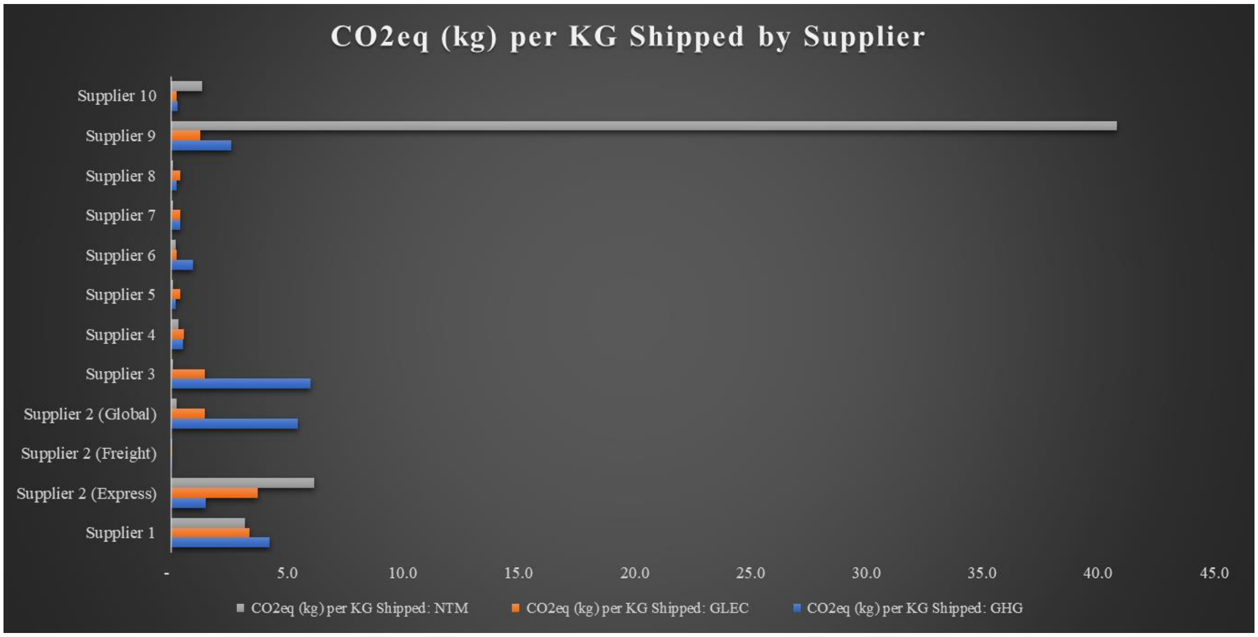


Figure 13

Carbon Emissions Intensity Trend Analysis Results (Emissions per Shipment)

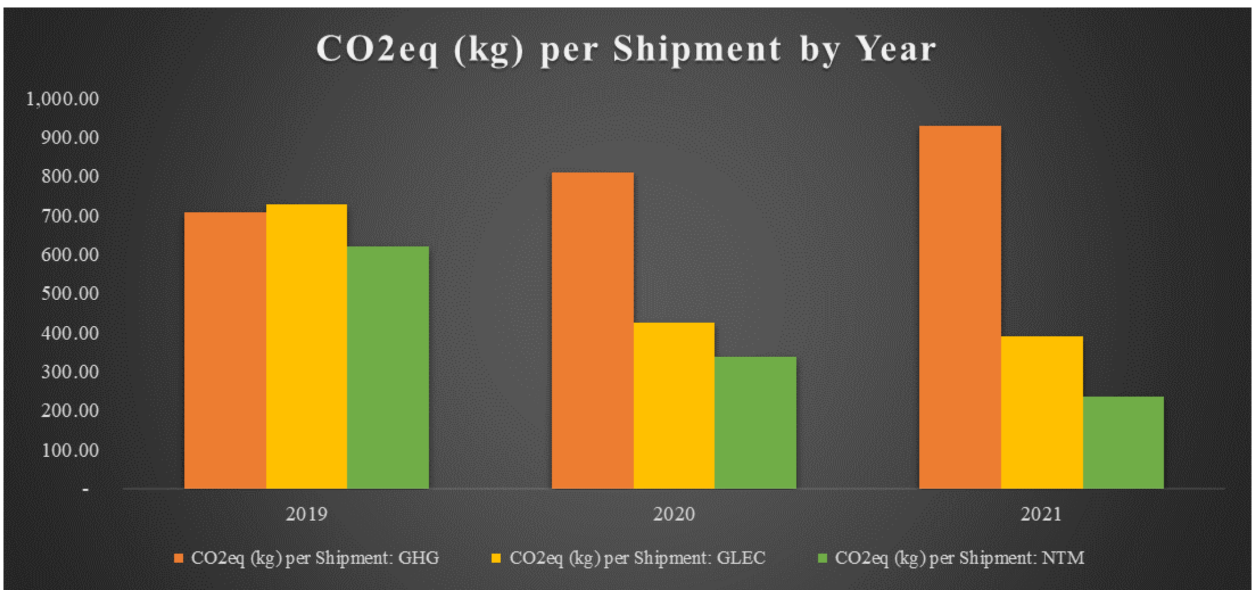


Figure 14

Carbon Emissions Intensity Trend Analysis Results (Emissions per Distance)

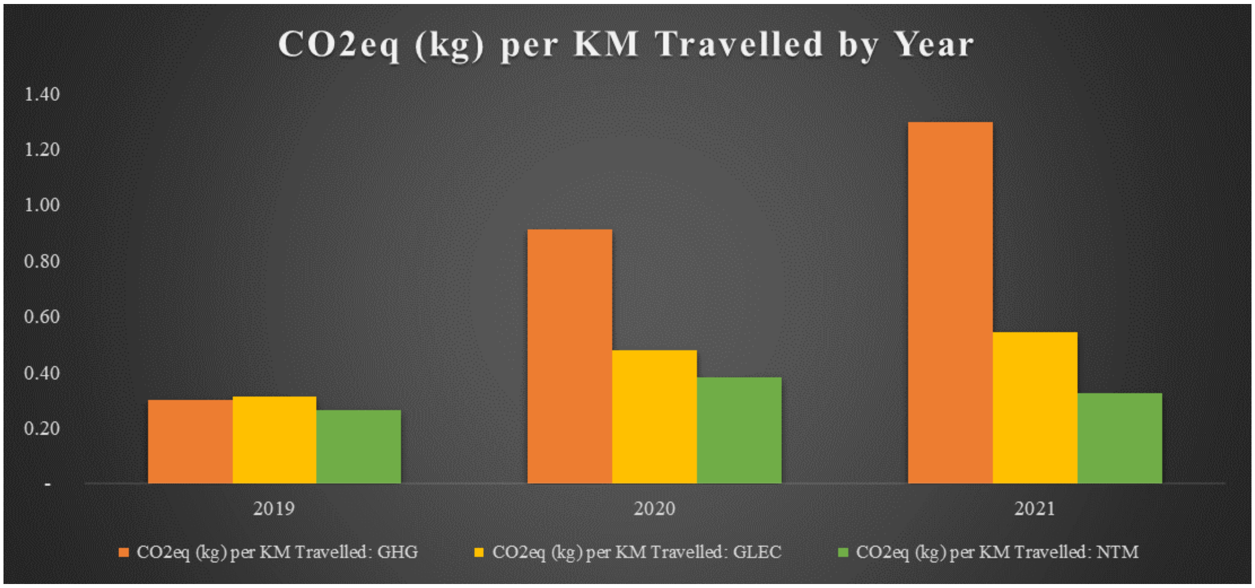
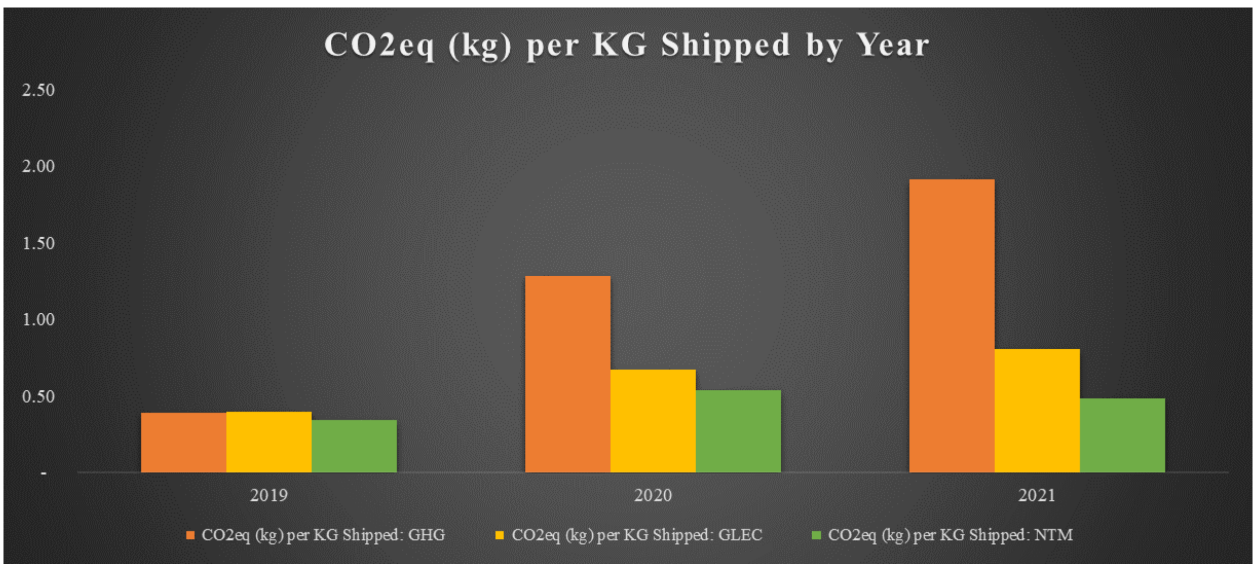


Figure 15

Carbon Emissions Intensity Trend Analysis Results (Emissions per Weight)



Across the board, suppliers who self-reported emissions show underestimations relative to our emissions calculations. This phenomenon is likely due to inaccuracies and gaps in the shipment-level and to the high probability of non-Xylem-exclusive shipments that the data fails to designate. However, assuming our estimates provide a degree of confidence due to the clear methodology and more exhaustive considerations, this finding suggests that current Scope 3 emissions may be underreported. Companies may therefore benefit from conducting detailed investigations and data validation sessions with suppliers to ensure a strong starting point.

Since Xylem mainly drives the variability in shipment weights and distances, a proper evaluation of supplier-driven performance focuses on the emissions performance metrics. In terms of emissions intensity per shipment, Supplier 1 exhibits the best performance while Supplier 2 demonstrates the worst. In terms of emissions intensity per distance travelled, Supplier 10 performs the best while Supplier 3 performs the worst. In terms of emissions intensity per weight shipped, Supplier 5 shows the best performance while Supplier 3 exhibits the worst. Furthermore, large suppliers appear to perform better for high-volume, long-haul shipments, while smaller suppliers appear to fare better for frequently-used routes and standardized cargo types. These rankings and insights help to inform future tender awards, to guide supplier selections, and to quantify net impacts on emissions. In the next section, we discuss how these findings, coupled with others from additional analyses, pinpoint inbound logistics emissions trade-offs.

4.7 Trade-off Analysis Insights by Supply Chain Decision

In the trade-off analysis, we leveraged a combination of techniques, models, and methods to quantify the effects of various shipment levers and supply chain decisions on inbound logistics carbon emissions. *Figure 22* in Appendix C depicts the results of our high-level multi-variable regression analysis. As discussed in *Section 3.2.4*, this model offers insights into the statistically significant shipment-specific levers that truly impact emissions. While the scales of their impacts on emissions are subject to change depending on shipment data accuracy, a few truths emerge. First, every shipment carries an inherent emissions amount, as seen in the positive intercept that suggests a 472.56 kg in CO_2eq for every shipment initiated, regardless of its characteristics. Considering the preparatory activities needed from shipment booking to delivery, this finding makes sense. Second, shipment mode has the single biggest impact on overall emissions, whereby shifting a single shipment from air or road freight to ocean or rail may decrease emissions significantly (ex. up to -3864.52 kg CO_2eq for Xylem). Among the quantitative shipment levers, weight and fuel consumption have sizeable impacts on emissions, while distance has little impact. Increasing distance by 1 km results in a net 0.02 kg increase in CO_2eq. Meanwhile, increasing weight by 1 tonne results in a net 87.77 kg decrease in CO_2eq, pointing to the importance of proper demand planning, supply allocation, and shipment consolidation. Similarly, increasing fuel consumed per shipment by 1 kg results in a net 9.23 kg increase in CO_2eq, emphasizing the importance of supplier, lane, and route selection.

The remaining sub-sections in *Section 4.7* dives deeper into the emissions impacts and trade-offs across key supply chain decisions. These decisions include demand and production planning, sourcing and procurement strategy, inventory policy, and customer service levels. Each part begins with an explanation of the independent variable analyzed and its connection to the relevant supply chain decision and ends with a review of the quantitative results and their implications.

4.7.1 Demand & Production Planning: Shipment Type Analysis Results

Demand and production planning impacts logistics planning, lead time buffers, and potential shipment delays. Poor planning causes increases in expedited shipments and rush orders to meet unexpected changes in demand and to fulfill delivery timelines. Expedited shipments typically requires Xylem to use air or road freight instead of more environmentally-friendly ocean or rail freight to shorten lead times. With air freight contributing approximately 60 times more carbon emissions than ocean freight, for example, expedited shipments are detrimental to lowering a company's carbon footprint.

In this analysis, we use a combined correlation and OLS regression model to quantify effects and trade-offs. As discussed above, we select shipment type to represent the product of demand and production planning decisions. We assume that improved demand and production planning capabilities within Xylem mean more regular shipments, fewer expedited shipments, and lower CO_2eq emissions. Setting Shipment Type as the independent variable and Estimated CO_2eq as the dependent variable, our model produces a statistically significant (p-value < 0.05) coefficient of -0.05 between Estimated CO_2eq and Shipment_Type_Regular. Consistent with our earlier assumptions, these results mean that, as the number of regular shipments increase by 1, estimated CO_2eq reduces by 0.05 kg. With an adjusted R^2 of 95.50%, the model strongly explains the variances in CO_2eq driven by Shipment Type and considers the variable to be a strong predictor of emissions. See *Figure 23* in Appendix C for details.

Based on these results, Xylem has opportunities to reduce its expedited shipments and to increase its regular shipments. Given the effect strong demand forecasts, proper supply allocation, and robust production plans have on shipment type, Xylem should improve its planning capabilities to reduce its inbound logistics carbon footprint.

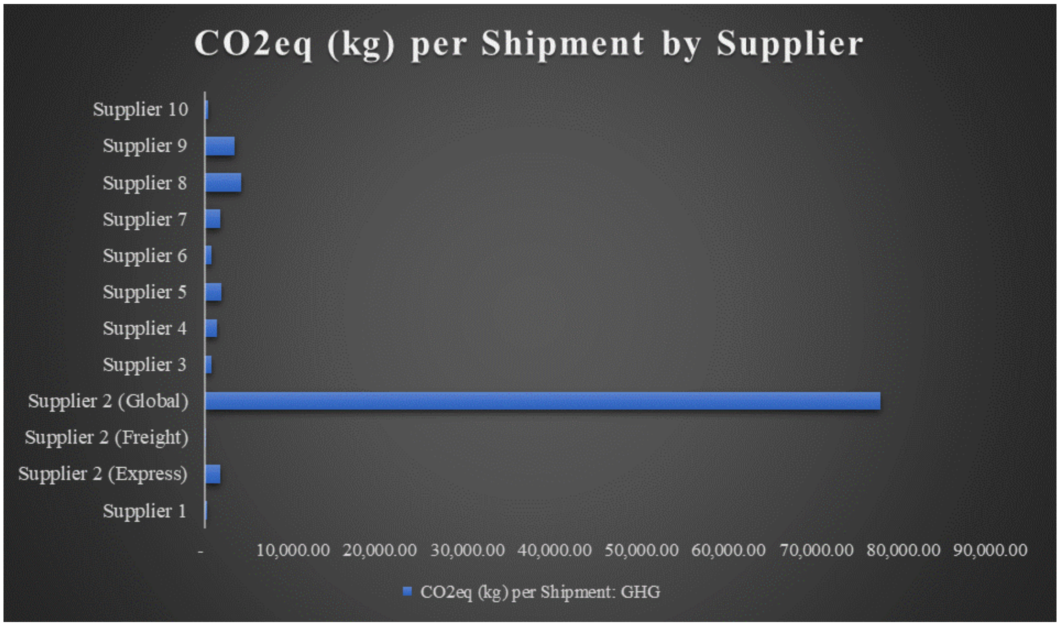
4.7.2 Sourcing & Procurement: Supplier Selection and Shipment Mode Analysis Results

Choosing the right supplier and selecting a suitable shipment mode are two important components of an organization's logistics sourcing and procurement strategy. Both of these decisions have profound impacts on carbon emissions. The supplier comparative analysis in *Section 4.6* shows the significant differences in performance among suppliers based on their emissions intensities and the sizeable impact a given supplier has on Xylem's carbon footprint. The high-level regression model in the *Section 4.7* introduction further demonstrates the substantial role a more environmentally-friendly shipment mode plays in lowering inbound logistics emissions.

In this analysis, we bifurcate our approach to address each of the decisions. For supplier selection, we leverage the supplier comparative analysis and the ensuing supplier performance evaluations to quantify effects on carbon emissions. For shipment mode selection, we revert to a OLS regression analysis. As seen in *Section 4.6*, supplier emissions performance rankings differ depending on the evaluation metric. On the whole, Supplier 1 demonstrates the best performance for emissions intensity per shipment, Supplier 10 demonstrates the best performance for emissions intensity per kilometer travelled, and Supplier 5 demonstrates the best performance for emissions intensity per kilogram shipped. By switching shipments to the best performing suppliers, Xylem may realize net decreases in emissions between 208.47K kg CO_2eq and 822.06K kg CO_2eq, or a reduction of 50% to 74%. See *Figure 16* for details.

Figure 16

Sourcing & Procurement Comparative Analysis Results



Although each supplier specializes in certain shipments and a change may not be immediately feasible, these insights provide the foundational knowledge to begin discussions with suppliers and to rationalize contract award and supplier management decisions.

Continuing with the shipment mode analysis, we augment our model by embedding cost as a secondary target variable to estimate the emissions impact of a USD spent in a particular mode. Using Estimated CO_2eq as the dependent variable and Shipment Mode and Shipment Cost as the independent variables, our model shows Truck as having the highest per-dollar emissions impact and Rail to have the lowest. Although additional fine-tuning is needed to improve the R^2 and p-values, the regression yields interesting findings (see *Figure 24* Appendix C for details). According to the model, every USD spent on air freight results in 0.08 kg CO_2eq, every USD spent on ocean freight results in 0.02 kg CO_2eq, and every USD spent on truck results in 0.13 kg CO_2eq, and every USD spent on rail has minimal emissions impact. Given these findings, Xylem should deploy efforts to maximize rail and ocean freight wherever appropriate and possible, especially for heavy, long-haul, and high-volume shipments. To do so, Xylem may need to re-evaluate its inbound transportation network and update particular shipment lanes to optimize emissions outputs.

4.7.3 Inventory Management: Combined Shipment Levers Analysis Results

Inventory management impacts shipment distance, shipment weight, and shipment load by way of its safety stock, cycle stock, and replenishment policies. The higher the safety stock and cycle stock requirements are, the more frequent and expansive the replenishments are, resulting in bulk orders on one hand and LCL shipments on the other. Inadequate inventory policies, coupled with transportation disruptions, also result in emergency shipments across sub-optimal routes and stock-piling.

To determine the combined emissions impacts of the shipment levers that inventory policies drive (i.e., distance, weight, and load type), we conduct in-depth scenario analysis and testing across ten scenarios. Each scenario in the analysis represents an incremental improvement on current shipment characteristics. A -25% improvement scenario indicates a 25% increase in distance, a 25% decrease in weight, and a 25% increase in LCL shipments. Conversely, a 25% improvement scenario indicates a 25% decrease in distance, a 25% increase in weight, and a 25% decrease in LCL shipments. The results of the scenario analysis are below in *Figures 17 and 18.* On both ends of the spectrum, the combined effects of shipment distance, weight, and load type induce exponential change in emissions. For better accuracy and to eliminate potential bias, we measure changes using the average emissions and emissions efficiencies across all three calculation methods. In the scenarios tested, worsening conditions in the shipment levers may cause an average increase of 46% in total CO_2eq emitted and nearly double the CO_2eq emitted per tonne-kilometer. On the contrary, better conditions in the shipment levers may decrease total CO_2eq emitted by 37% on average and improve CO_2eq efficiency by tonne-kilometer by 53% on average. Using the regression models derived from these scenarios, every 1% percent improvement in these shipment levers causes a 1.67% decrease in total emissions and a 2.71% enhancement in emissions efficiency per tonne-kilometer.

Figure 17

Inventory Management Scenario Analysis Results: Total CO_2eq Emissions (All Methods)

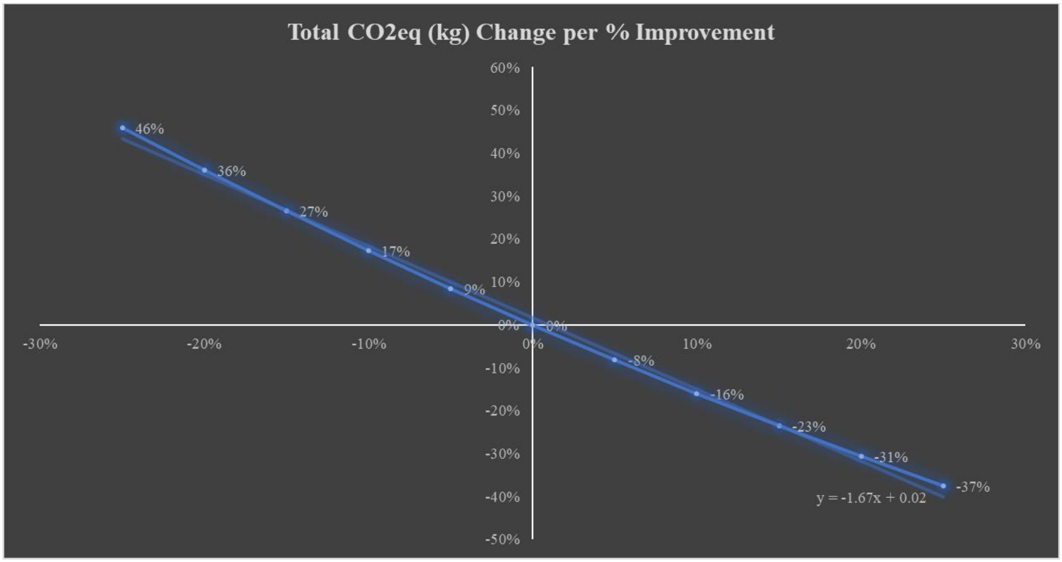
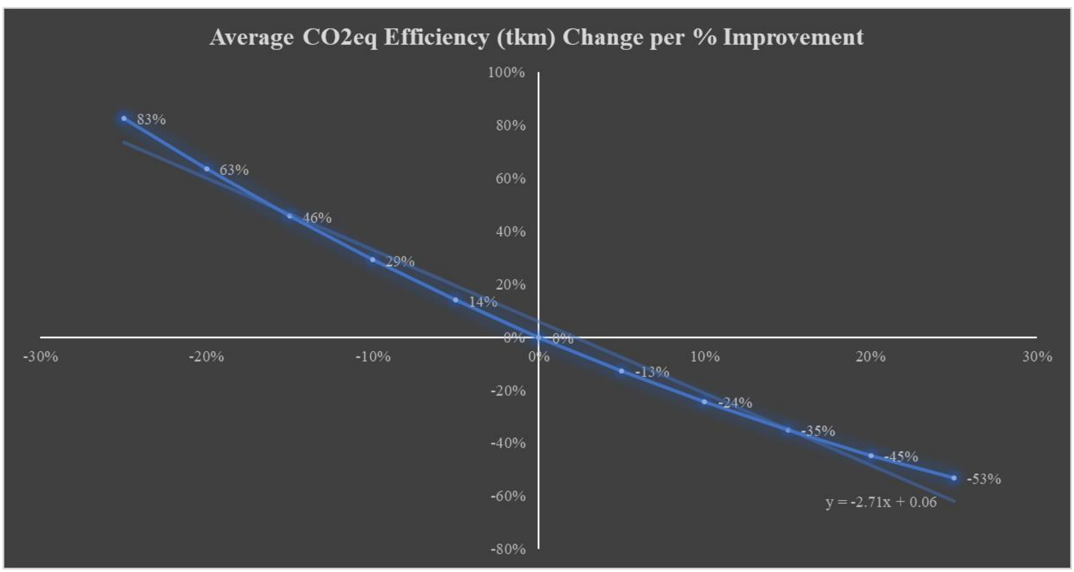


Figure 18

Inventory Management Scenario Analysis Results CO_2eq Emissions Efficiency (All Methods)



Based on these results, Xylem has opportunities decrease shipment distances per shipment, increase shipment weight per shipment, and maximize FCL shipments. Due to the impact inventory policies have on these shipment levers, Xylem should understand its current policies for major sites, discern their respective safety stock, cycle stock, and replenishment levels, and make necessary adjustments.

4.7.4 Customer Relationship Management: Transit Time Analysis Results

Customer Service Level (CSL) is a critical measure of customer relationship management performance and customer satisfaction. From the perspective of an upstream supply chain, CSL affects transit or lead times for materials and products to arrive at manufacturing plants, warehouses, and distribution centers. Higher CSLs means higher expectations for a company to deliver on-time and in-full to customers, implying a need to shorten inbound transportation lead times to allow for timely manufacturing and downstream distribution. The inverse is also true, in which a reduction in inbound transit times or a relaxing of downstream lead time requirements increases CSLs.

Without the exact CSL percentages per shipment, we choose Transit Time as a proxy to represent customer relationship management decisions. We assumed reduced transit times translate to improved CSLs for Xylem. With no change in shipment modes or shipment types, net decreases in total transit may reduce overall CO_2eq emissions by theory of network optimization, vehicle routing, and shipment consolidation. In this analysis, our regression model assumes Estimated CO_2eq as the dependent variable and Transit Time as the independent variable. The regression results show a statistically significant (p-value < 0.05) coefficient of 0.56 between Estimated CO_2eq (in kilograms) and Transit_Time (in days). In essence, these results mean that a 1-day increase in inbound transit time produces 0.56 kg more CO_2eq emissions. By the same token, decreases in inbound transit times (e.g., faster logistics supplier deliveries) reduce emissions. With an adjusted R^2 of 95.50%, the model strongly explains the variances in CO_2eq driven by Transit Time and considers the variable to be a strong predictor of emissions. See *Figure 25* in Appendix C for details.

To reduce transit times, Xylem has two options. The first option is to increase speed by switching from slower shipment modes like ocean and rail freight to faster modes like air and truck. As explained in *Section 4.7* and elaborated upon in *Section 4.7.2*, faster shipment modes greatly amplify carbon emissions, negating any emission benefits from the transit time savings. The second, and only viable, option is to decrease shipment distance travelled. As shipment distance is the product of network design decisions (i.e., which origin sites deliver to which destination sites), supply allocations, and routing, Xylem should consider optimizing these areas to reduce lead times, increase CSLs, and reduce its inbound logistics CO_2eq emissions.

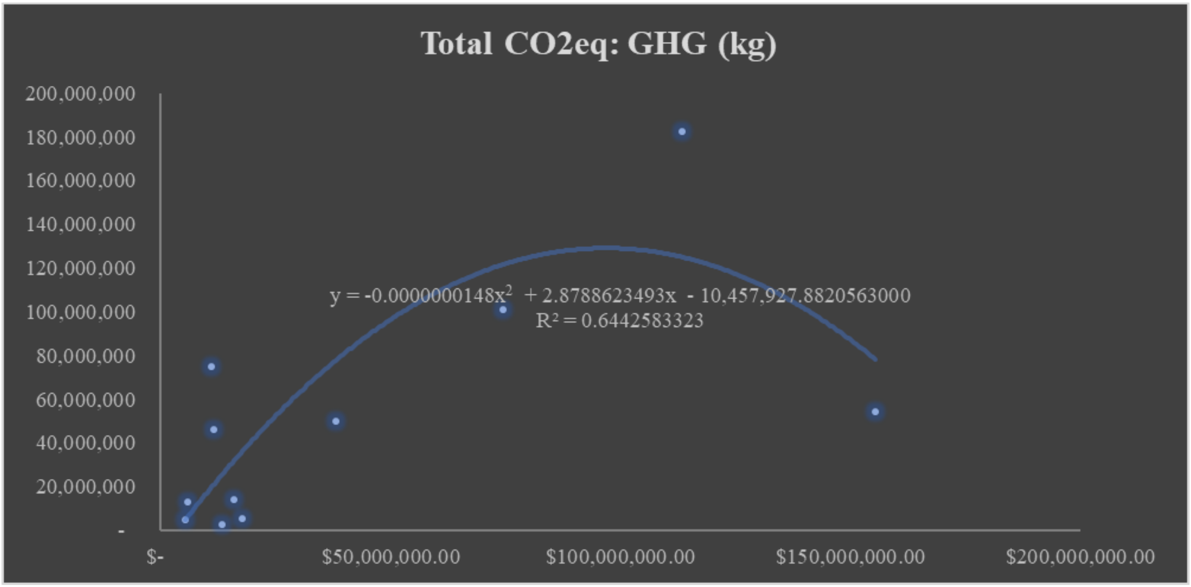
4.7.5 Shipment Cost and Emissions Analysis Results

The final component of our trade-off analysis includes a correlation analysis into the relationship between inbound logistics spend and inbound logistics emissions. As discussed in *Section 3.2.4*, established Scope 3 calculation methodologies, such as the GHG Protocol, suggest the use of spend as a high-level proxy for emissions in lieu of more granular data. The results of this analysis inspect the effectiveness of spend as a driver of Xylem's emissions and offer insights into the validity of investing in "greener," more expensive shipment options from logistics suppliers. Examples of these options include newer vehicles, alternative fuels or energy, "smart" containers, and electrical fleets.

The regression models tested through this analysis include a linear regression, logarithmic regression, and polynomial regression. Linear regression assumes CO_2eq emissions to be a linear function of spend. Logarithmic regression assumes CO_2eq emissions to be a function of the log of spend (i.e., log-linear relationship). Polynomial regression assumes CO_2eq emissions to be a function of a polynomial of spend to an nth degree. Across the board, polynomial regression produces the best fit (see *Figures 30 through 38* in Appendix C). *Figure 19* shows the approximate model to be Total CO_2eq Emissions = -0.0000000148(Total Spend)^2 + 2.8788623493(Total Spend) – 10,457,928. With an R^2 of 64.43%, the model sufficiently explains the variances in total CO^2eq driven by total logistics spend.

Figure 19

Inbound Transportation Spend Polynomial Regression Analysis Results



These results contradict current methods that assert a linear relationship between spend and emissions via a spend-based emissions factor, demonstrating that more inbound logistics spend does not automatically equate to more carbon emissions. The supporting graph further shows the existence of a global maximum or threshold for spend. Obtaining the first-degree derivative of the function yields this maximum, which is approximately $194.52M USD in total logistics spend. This finding suggests that, for spend with the in-scope logistics suppliers, CO^2eq emissions increase up to this spend threshold before decreasing as spend increases. Upon allocating this amount proportionally across suppliers based on existing spend, Xylem may make educated decisions on whether to pay more for "greener" shipment options. The next section summarizes the key takeaways from this chapter.

4.8 Results and Analysis Summary

Throughout this chapter, we reveal key results and findings from our extensive analysis. In terms of data maturity, larger suppliers exhibit lower data availability and quality, while smaller suppliers score higher on both criteria. With a decentralized organization, informal processes, and disparate systems, Xylem's inbound transportation network is ripe with emissions hotspots throughout the shipment booking to delivery process. Scope 3 inbound logistics emissions for Xylem exhibit an increasing year-over-year trend between 2019 and 2021, likely due to pandemic-induced disruptions, with high concentrations from Sweden, United States, and Germany sites. Based on emissions intensity metrics, large suppliers appear to be better-suited for high-volume, long-haul shipments, while smaller suppliers provide lower emissions on average for frequently-used routes and standardized cargo types. Among the variables affecting Xylem's inbound logistics carbon footprint, shipment mode, supplier, weight, fuel consumption, transit time, and shipment type demonstrate value in emissions reduction initiatives. Finally, logistics spend and emissions possess a non-linear relationship, allowing Xylem to identify a maximum spend threshold through which Xylem may assess the practicality of costly "greener" shipment solutions from suppliers. In *Chapter 5 Discussion*, we interpret these results into managerial insights and distill them into customized recommendations to help Xylem achieve its carbon emissions reduction targets.

5. DISCUSSION

In *Section 4.5,* our report shares the final Scope 3 inbound logistics emissions baseline and emissions efficiency metrics. The chapter concludes with results of the comparative analysis by supplier in *Section 4.6* and outcomes of the trade-off analyses in *Section 4.7*. The results and analysis in Chapter 4 generated substantial managerial insights and recommendations for this chapter. We begin this chapter with a discussion of the managerial insights in *Section 5.1*. *Section 5.2* discusses the recommendations and list of initiatives, and *Section 5.3* describes limitations and potential future research.

5.1 Managerial Insights

The following supply chain processes play a critical role in driving the inbound logistics process. Beyond the Scope 3 emissions baseline, the impact on emissions of decisions that arise from these processes is the focus of our analysis. Based on our findings, we uncover the following managerial insights.

Demand and Production Planning

Regular shipment types are negatively correlated or inversely proportional to estimated CO¬2e emissions. To reduce its Scope 3 inbound logistics carbon footprint, Xylem should explore opportunities to reduce its usage of expedited shipments. Potential strategies are the following:

- Improve demand forecasting accuracy to prevent unexpected shifts
- Enhance supply allocation to prevent production and shipment delays
- Accelerate S&OP processes to jumpstart shipment bookings and increase product cycle

Sourcing and Procurement

Shipment mode and supplier selections greatly impact carbon emissions, with per dollar spent on Truck having the greatest emissions impact and per dollar spent on Rail having the least. Emissions intensities also differ greatly among suppliers. Xylem should explore the following reduction initiatives:

- Rank and allocate 3PL/4PL carriers by shipment mode based on CO2e factors
- Establish best-performing carriers as preferred suppliers in purchasing policy
- Track, measure, and reduce the usage of non-preferred carriers by mode by lane

Inventory Management

Among the various shipment levers affected by inventory policies, distance and load type are directly correlated with carbon emissions, while weight is inversely correlated. To lower shipment emissions intensities, Xylem should consider inventory policy updates that include the following:

- Consolidate replenishment orders to maximize weight and load
- Adjust safety stock and cycle stock requirements to elongate the time between orders
- Update shipment lanes and reallocate supply to sites closer to hard-to-reach destinations

Customer Relationship Management

Improving customer service levels can have the added benefit of reducing inbound logistics carbon emissions by reducing transit time. With current CSL levels below its target of 90-95%, Xylem should explore the following strategies:

- Redesign its inbound logistics network to "move" origins closer to destinations
- Optimize delivery routing capabilities to minimize distances and topographical impacts
- Elongate delivery windows with new customers and consolidate shipments

5.2 Recommendations

With the understanding that not every opportunity highlighted in *Section 5.1* is immediately feasible for Xylem, we discuss and align with key company stakeholders on the insights derived from the analysis. The initiatives and recommendations in *Table 8* are proposed based on the insights and Xylem's desired future state for improvement and actions to achieve its carbon emissions target.

Table 8

List of Recommended Initiatives for Xylem Logistics Function

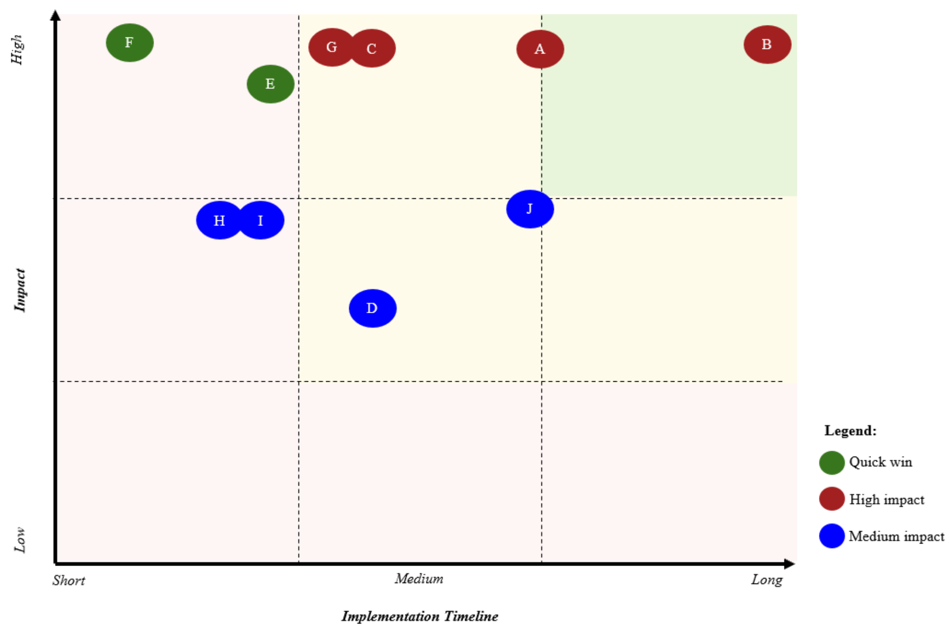
Initiatives	Description
A	Implementation of hybrid operating model
B	Integration of logistics system across Xylem global operations
C	Standardization of the shipment process
D	Performance monitoring and tracking

E	Spend analysis
F	Inclusion of emissions data requirement in RFPs
G	Optimization of the transportation network
H	Supplier rationalization and segmentation
I	Supplier relationship management
J	Customer relationship management

We segment the initiatives into quick wins (immediate), short-term implementation (implementation is feasible within 1-3 months), medium-term implementation (implementation is feasible within 3-6 months), and long-term (implementation is feasible within 6-12 months). See *Figure 20*.

Figure 20

Initiative Prioritization Matrix



Within the above initiatives, we distill final recommendations to include the emissions data as a Request for Proposal (RFP) requirement, implement a hybrid operating model, integrate a logistics system, optimize the transportation network, and manage customer relationships.

5.2.1 Emissions Data Disclosure Requirement for Requests For Proposal (RFP)

The limitations we encountered during the supplier data collection process are data unavailability and poor data quality. Although suppliers provide some requested information, they fail to follow the recommended data collection template. We develop some assumptions for the missing data in order to perform the emissions calculation. Learning from the current situation, Xylem must ensure that the data collection process in the future improves. Therefore, during logistics supplier selection, the RFP must require commitment from the suppliers to disclose accurate and reliable primary data at the shipment level for the emissions calculation. A list of primary data for emissions calculation is available in the Appendix B for reference.

5.2.2 Hybrid Operating Model and Integrated Logistics System

Xylem's logistics function operates on a decentralized model across its global operations. Due to this model, Xylem has unstandardized shipment processes, from booking to delivery. Based on our analysis of its transportation network, we find inefficiencies in the shipment lane and mode selections that subsequently increase carbon emissions. Considering that Xylem's logistics function is currently decentralized, we recommend a hybrid operating model that combines the characteristics of a centralized and of a decentralized operating model to improve governance and to maintain speed in execution.

The hybrid operating model allows Xylem to be centralized at the corporate level for the overarching logistics and transportation strategy, such as transportation network optimization and planning and strategic supplier selection. At the same time, this model allows for flexibility at the regional and site levels to make daily operational decisions, such as vehicle planning and scheduling within the regions.

Along with implementing the hybrid operating model, we recommend that Xylem integrate its logistics system across its global operations to gain real-time visibility on operations and spending and to enable shipment process standardization. The use of the integrated system enforces compliance in executing shipment booking to the completion of delivery. Tracking and monitoring may be performed on a real-time basis, and mitigating actions may be taken based on system feedback.

Simultaneously, the integrated logistics system allows Xylem to generate performance monitoring reports on metrics such as on-time delivery, customer satisfaction, and lead time between shipment delivery and invoice payment and spend analysis reports.

5.2.3 Transportation Network Optimization

Xylem does not operate in the optimized transportation network due to the current decentralized operating model and unstandardized shipment process. The analysis we performed on the distance between origin and destination of the shipment and the choice of transport mode shows some inefficiency, which subsequently causes the increase in the carbon emissions. We recommend that Xylem perform transportation network and cost optimization and the impact on the emissions reduction. The optimized transportation network design enables Xylem to perform supplier rationalization to eliminate the non-preferred suppliers by mode and lane and perform supplier segmentation. The supplier segmentation enables Xylem to identify its strategic and best-performing suppliers and to manage them through the Supplier Relationship Management (SRM) process.

5.2.4 Customer Relationship Management (CRM)

Better demand planning and forecasting impacts Xylem's ability to deliver the products on-time and maintain its CSLs. One way to enable Xylem to plan its demand and forecast more accurately is by working closely with the customers to capture the demands early on and possibly consolidate orders in bulk shipments instead of multiple smaller ones. A good CRM also enables Xylem to re-negotiate the expected arrival date and ship with ocean or road (truck) freight. All of these efforts reduce carbon emissions as discussed in *Section 4.7*.

5.3 Limitations and Future Research

Through this capstone project, we develop a calculation tool to enable Xylem to establish its carbon emissions baseline, not only for the inbound transportation network but also for the outbound transportation network from Xylem sites to the customer sites. However, we find the limitations to this study and approach to be as follows:

- Data unavailability:
  - Limited supplier and internal data at the required granular details, e.g., fuel consumption and shipment-level data, have caused some assumptions to be required in estimating the emissions.
  - Limited PO data and unavailable spend analysis prevented us from conducting a thorough scenario analysis between some operations variables and emissions
- Data inconsistency and inaccuracy
  - Inconsistency and lack of data uniformity provided by the suppliers have caused the data inaccuracy, which subsequently caused difficulties in calculating an accurate emissions baseline.
- Decentralized logistics operating model
  - The current decentralized shipment process and strategy have caused Xylem to operate without optimizing its transportation network. We found many routes that were not optimal from the distance perspective.
  - On top of the unoptimized transportation network, Xylem also did not have a centralized Enterprise Resource Planning (ERP) system to enable end-to-end visibility of its operations, data, and spending.

We propose the following next steps for Xylem and recommendations for future research:

- Optimize the transportation network, both inbound and outbound, and deep-dive into the supply chain implications of having an optimized network
- Assess and refine the logistics operating model based on the optimized transportation network, including the implementation of an integrated system across Xylem's operations
- Quantify the transportation cost and conduct a thorough scenario analysis
- Expand the emission baseline establishment beyond inbound transportation

6. CONCLUSIONS

Xylem aims to reduce its CO_2 footprint by 2.8 million metric tons by 2025, develop a science-based target for Scope 1, 2, and 3 greenhouse gas emissions, and engage suppliers in sustainability initiatives (Xylem Inc., 2021). Xylem currently establishes its emission baselines for Scope 1 and Scope 2, while aiming to set its baseline for Scope 3 emissions as part of its sustainability goal this year. Through this capstone, we provided Xylem with a calculation tool to enable Xylem to estimate its Scope 3 upstream transportation emission baseline. This comprehensive and flexible calculation tool enables Xylem to calculate emissions by adapting to one of three major methodologies, i.e., the Greenhouse Gas (GHG) Protocol, the Global Logistics Emissions Council (GLEC) Framework, and the Network for Transport Measures (NTM), depending on the quality and availability of data that Xylem collects from its suppliers in the future. Although the main focus of this capstone is the upstream transportation network, Xylem can expand the use of the calculation tool to its downstream transportation network and its Scope 1 emissions. We also buildt scenario analysis and regression models to analyze the implications key supply chain decisions via variables, such as shipment type, shipment mode, and transit time, in generating emissions. The model shows that regular shipments reduce emissions by 0.05 kg CO_2eq per shipment, while on the other hand, reduced transit times decrease emissions by 0.57 kg CO_2eq per day. The model also shows that shipment mode is the variable with the most significant impact among the other shipment levers (e.g., distance and weight) to the emissions level.

The analyses we conducted based on the models enable us to develop recommendations including the inclusion of emissions data disclose in the tender process and network optimization to enable Xylem to select the appropriate supplier, shipment lane, and shipment mode whenever possible (e.g., ocean vs. air freight). Finally, the recommendations are prioritized into quick-wins, high-impact initiatives, and medium-impact initiatives. This segmentation enables Xylem to quickly take actions in its race to reduce emissions as part of its pledge towards net zero operations.

Although this capstone study is based on Xylem's environment, the emissions calculation tool and the scenario analysis were built on the assumptions that they were are replicable across shippers and industries beyond the water and wastewater management industry. Companies across industries may refer to the research we produced through this capstone to establish their emissions baselines and reduction initiatives.

The data limitations in this research require some assumptions to complete the emission calculation. Therefore, Xylem must closely engage its top suppliers to obtain their commitment during the future bidding process in order to obtain the data necessary for accurate emissions calculations.

Beyond this capstone research, Xylem may explore opportunities to improve its shipment process efficiency and subsequently reduce its carbon emissions via optimizing its transportation network, refining and implementing new operating model, standardizing its shipment process, and conducting cost-benefit analysis against its efforts to reduce its carbon footprint. Lastly, we recommend that Xylem expands the establishment of an emissions baseline across its end-to-end transportation network to enable better Scope 3 emissions visibility.

REFERENCES

American Museum of Natural History. (2022). *Climate Change.* American Museum of Natural History. Retrieved May 2, 2022, from https://www.amnh.org/explore/science-topics/climate-change.

Bharadwaj, S., Ballare, S., Rohit, & Chandel, M. K. (2017). Impact of congestion on greenhouse gas emissions for road transport in Mumbai metropolitan region. Transportation Research Procedia, 25, 3538–3551. https://doi.org/10.1016/j.trpro.2017.05.282.

Dunbar, B. (2015, May 13). *What is Climate Change?* NASA. Retrieved May 6, 2022, from https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-is-climate-change-k4.html.

Environmental Protection Agency. (2020, March 19). *Greenhouse Gases*. EPA. Retrieved May 4, 2022, from https://www.epa.gov/report-environment/greenhouse-gases.

Environmental Protection Agency. (2021, March 18). *Addressing Climate Change in the Water Sector*. EPA. Retrieved October 8, 2021, from https://www.epa.gov/climate-change-water-sector.

Environmental Protection Agency. (2021, June 8). *Carbon Pollution from Transportation*. EPA. Retrieved October 8, 2021, from https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation.

Environmental Protection Agency. (2021, August 31). *Climate Impacts on Water Utilities*. EPA. Retrieved October 8, 2021, from https://www.epa.gov/arc-x/climate-impacts-water-utilities.

Environmental Protection Agency. (2022, April 14). *Overview of Greenhouse Gases*. EPA. Retrieved May 6, 2022, from https://www.epa.gov/ghgemissions/overview-greenhouse-gases#:~:text=Total%20U.S.%20Emissions%20in%202020,100%25%20due%20to%20independent%20rounding.&text=Gases%20that%20trap%20heat%20in%20the%20atmosphere%20are%20called%20greenhouse%20gases.

ERP Information. (2022, April 15). *What is the Customer Service Level? 5 Customer Service Standards.* ERP Information. Retrieved May 6, 2022, from https://www.erp-information.com/customer-service-level.html.

Farsan, A., Chang, A., Kerkhof, A., Cserna, B., Yan, C., Rangel Villasana, F., & Labutong, N. (2018, November). Value Change in the Value Chain: Best Practices in Scope 3 Greenhouse Gas Management. Amsterdam; Climate-KIC.

Greene, S., & Lewis, A. (2019). Smart Freight Centre. GLEC Framework for Logistics Emissions Accounting and Reporting.

Greenhouse Gas Protocol. (2013). *Scope 3 Calculation Guidance: Greenhouse Gas Protocol*. Greenhouse Gas Protocol. Retrieved October 9, 2021, from https://ghgprotocol.org/scope-3-technical-calculation-guidance.

Greenhouse Gas Protocol. (2014). *Global Warming Potential Values*. Greenhouse Gas Protocol. Retrieved May 6, 2022, from https://ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf.

Greenhouse Gas Protocol. (2015). *Corporate Standard: Greenhouse Gas Protocol*. Greenhouse Gas Protocol. Retrieved October 9, 2021, from https://ghgprotocol.org/corporate-standard.

Greenhouse Gas Protocol. (2021). Greenhouse Gas Protocol FAQ. Geneva; World Business Council for Sustainable Development.

How To Guide for Setting Science Based Targets. Sciencebasedtargets.org. (2021, April). Retrieved October 23, 2021, from https://sciencebasedtargets.org/resources/files/SBTi-How-To-Guide.pdf.

International Water Association. (2021). *Water and Wastewater Companies for Climate Mitigation*. IWA. Retrieved October 8, 2021, from https://iwa-network.org/projects/water-and-wastewater-companies-for-climate-mitigation-wacclim/.

Leenders, B. P., Velázquez-Martínez, J. C., & Fransoo, J. C. (2017). Emissions allocation in transportation routes. *Transportation Research Part D: Transport and Environment*, *57*, 39–51. https://doi.org/10.1016/j.trd.2017.08.016.

Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., & Roberts, D. (Eds.). (2019). *Global Warming of 1.5°C.* Intergovernmental Panel on Climate Change. Retrieved May 6, 2022, from https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf.

National Geographic Society. (2020, August 11). *Transportation and Climate Change*. National Geographic Society. Retrieved October 8, 2021, from https://www.nationalgeographic.org/media/transportation-and-climate-change/.

Network for Transport Measures. (2015). *Cargo Calculations*. Network for Transport Measures. Retrieved November 24, 2021, from https://www.transportmeasures.org/en/wiki/manuals/all-modes/1-2-calculations/.

Shaftel, H. (Ed.). (2021, August 26). *The Effects of Climate Change.* NASA. Retrieved May 6, 2022, from https://climate.nasa.gov/effects/.

United Nations. (2014, November 24). *International Decade for Action "Water for Life" 2005-2015.* United Nations. Retrieved May 6, 2022, from https://www.un.org/waterforlifedecade/scarcity.shtml.

United Nations. (2022). *Climate Change*. United Nations Sustainable Development Goals. Retrieved May 6, 2022, from https://www.un.org/sustainabledevelopment/climate-change/#:~:text=Climate%20change%20is%20affecting%20every,events%20are%20becoming%20more%20extreme.

United Nations. (2022). *Race to Zero Campaign*. United Nations Climate Change. Retrieved May 6, 2022, from https://unfccc.int/climate-action/race-to-zero-campaign.

Velázquez-Martínez, J. C., Fransoo, J. C., Blanco, E. E., & Mora-Vargas, J. (2013). The impact of carbon footprinting aggregation on realizing emission reduction targets. *Flexible Services and Manufacturing Journal*, *26* (1–2), 196–220. https://doi.org/10.1007/s10696-012-9170-3.

Water UK. (2021, November 20). *Water UK opens first ever Water Pavilion at COP26.* Water UK. Retrieved May 6, 2022, from https://www.water.org.uk/news-item/opening-water-pavilion-round-up/.

Water UK. (2022). *Net Zero 2030 Routemap.* Net Zero Water. Retrieved May 6, 2022, from https://www.water.org.uk/routemap2030/.

Water UK. (2022). *Water in a Net Zero World*. Net Zero Water. Retrieved May 6, 2022, from https://www.water.org.uk/netzerowater/racetozero/.

Wenneberg, C. (2021, April 22). *5 Major Trends Impacting the Water Industry in the Next Decade*. International Water Association. Retrieved October 23, 2021, from https://iwa-network.org/five-major-challenges-and-emerging-trends-impacting-the-water-industry-in-the-next-decade/#:~:text=5%20major%20trends%20impacting%20the%20Water%20industry%20in,infrastructure%20by%20collecting%20and%20analysing%20data%20more%20efficiently.

Xylem Inc. (2021). Xylem 2020 Sustainability Report: Solving Water for a Resilient World. Rye Brook, New York; Xylem Inc.

Xylem Inc. (2021). *Products & Services*. Xylem U.S. Retrieved October 8, 2021, from https://www.xylem.com/en-us/products--services/.

Xylem Inc. (2021). *Xylem at a Glance*. Xylem U.S. Retrieved October 8, 2021, from https://www.xylem.com/en-us/about-xylem/xylem-at-a-glance/.

APPENDICES

Appendix A Stakeholder Interview Questions

Target Audience: Site Leads, Logistics Managers, Other Key Stakeholders

==

Objectives of Interviews

- Understand the transportation and distribution landscape
- Capture pain points, ongoing initiatives, improvement areas, and desired future states
- Discuss any other considerations

==

<u>People and Strategy</u>

1. Please provide us an overview of the logistics function/department, your role, your team's role, the organizational structure (i.e., centralized, decentralized), and geographic areas of coverage in upstream transportation and distribution.
2. Does the logistics strategy explicitly consider the trade-offs between cost, capacity, customer/service requirements, and, most importantly, carbon emissions?
3. How is the logistics function measured in terms of performance? What are the key metrics (ex. lead times, savings)? How are these metrics measured?

==

<u>Process and Related Capabilities</u>

Overview

1. Does your organization have clearly defined and documented policies and procedures for all upstream logistics processes (e.g., SOPs, instructional manuals)? If yes, please share the documents with us. If no, how do you current manage the process?
2. Please walk us through the high-level upstream logistics process you go through to ship materials to your sites and between Xylem sites? Are there any differences in the business segments, regions served, and product types?

3. What do you see as the main pain points, challenges, and risks in this process?

Forecasting and Planning

4. Is there an annual/monthly/weekly schedule or plan for shipments? Do you collaborate with your suppliers in this planning/scheduling process?
5. What is your forecasting process and how does it relate to the S&OP process?
6. What is your forecast accuracy? Is it regularly tracked and managed?

Inventory Management

7. What is your current inventory policy (i.e., order quantity, periodic order, etc.)?
8. How do you manage the shipments to balance demand and supply? What role does data play in this process?
9. What is your item fill rate, customer service level, etc. that drive inventory policy?

Logistics Network

10. Please provide an overview your upstream distribution network. Are sites strategically placed with the right operational capacities to serve the intended customer base?
11. How often do you review your transportation network for flow optimization and efficiency? Are there opportunities or initiatives underway to improve or redesign your transportation network?
12. How resilient is your upstream logistics capability? How quickly and easily can you reallocate network capacity based on demand changes without incurring added costs?

Suppliers

13. Who are your key upstream logistics suppliers in order of spend and volume? What is their average lead time from ordering to receiving and typical transport mode?
14. Are freight rates, volumes, route distances, and shipment frequencies proactively managed to optimize freight costs and environmental impact?
15. What are the main challenges or improvement areas with these suppliers? Are there specific points in their transportation activities that consistently failed to meet expectations (ex. long lead times, failure to deliver on-time)?

Emergency/Ad-Hoc Shipments

16. What constitutes an emergency/ad-hoc shipment for and what triggers it? How do you treat these requests?
17. Are there any specific transport modes used (ex. change from ocean to air freight)?
18. How often do these happen? Are there any mitigations or ongoing initiatives to manage or minimize these requests?

===

Technology

1. How do you monitor or track the delivery/shipping status? What systems and tools are used? What other enterprise systems impact, is impacted by, or is integrated with these technologies?

===

Additional Considerations

1. Are there any other topics or considerations that we did not cover that you would like to discuss? Any past learnings in terms of change management or adoption?

Appendix B Supplemental Tables

Table 9

List of Primary Shipment Data Requirements for Emissions Calculation

No.	Description
1	Shipment year
2	Purchase Order number
3	Shipment departure date (DD/MM/YY)
4	Shipment number
5	HouseBill number
6	Shipment origin geo-code (latitude and longitude)
7	Shipment origin port (terminal, seaport, airport, rail station)
8	Shipment destination geo-code (latitude and longitude)
9	Shipment destination port (terminal, seaport, airport, rail station)
10	Shipment leg (pre-carriage, main haul, post carriage)
11	Transportation mode per shipment leg
12	Shipment exclusivity for Xylem (Yes / No)
13	Shipment distance (kilometer)
14	Pick up time (hours)
15	Delivery time (hours)
16	Type of delivery (first time delivery or re-delivery)
17	IncoTerms
18	TEUs (for ocean freight) for Xylem’s shipment
19	Volume (cbm) for Xylem’s shipment
20	Actual total weight for Xylem’s shipment

21	Vehicle information (brand, model, type, capacity – cbm/ton, type of fuel, energy consumption – kW, age, fuel efficiency – liter/kilometer)
22	Fuel consumption (liter)
23	Emission for electric vehicle (kg CO_2e/kWh)

Table 10

Example Parameters for Freight Aircraft Emissions Calculations

Aircraft	**Load factor (weight)**	**Max Distance**	**CO2**		**NOX**		**HC**		**CO**	
			CEF	VEF	CEF	VEF	CEF	VEF	CEF	VEF
	[%]	[km]	[kg]	[kg/km]	[kg]	[kg/km]	[kg]	[kg/km]	[kg]	[kg/km]
B757-200SF	50	7051	4431	15.2	26.4	0.05	1.34	0	8.85	0.01
	75	6712	4744	15.2	29.7	0.05	1.37	0	8.98	0.01
	100	5184	5073	15.3	33.3	0.05	1.41	0	9.11	0.01
A310-300 F	50	9137	5628	20.7	49.5	0.09	2.36	0	11.45	0.01
	75	9563	6159	18.3	55.2	0.07	2.41	0	11.62	0.01
	100	7955	7033	18	65.2	0.07	2.5	0	11.92	0.01

Source: Table 4-1: Example parameters for freight aircraft emission calculations (NTM, 2015)

Table 11

Vehicle Type Characteristics and Default Load Factors

NTM Nomenclature	HBEFA Nomenclature	Max gross weight tonne	Vehicle Length m	Load Capacity			Load Capacity Utilization			
				tonne	pallet	m^3	LCU w%	LCU pallet %	LCU v%	LCU dimw %
Light commercial vehicle - pick up	LCV Petrol N1-II/LCV/LCV Diesel N1-II	2.5	5	0.6	1	6	0.2	0.4	0.25	0.3
Light commercial vehicle - van	LCV Petrol N1-III/LCV/LCV Diesel N1-III	3.5	7	1.5	4	17	0.2	0.4	0.25	0.3
Rigid truck <=7.5t	RT <= 7.5t	7.5	8	5	14	0	0.4	0.6	0.4	0.5
Rigid truck 7.5-12t	RT > 7.5-12t	12	11	6	20	0	0.4	0.6	0.4	0.5
Rigid truck 12-14t	RT > 12-14t	14	11	9	24	0	0.4	0.6	0.4	0.5
Rigid truck 14-20t	RT >14-20t	20	12	12	24	0	0.4	0.6	0.4	0.5
Rigid truck 20-26t	RT > 20-26t	26	12	15	24	0	0.4	0.6	0.4	0.5
Truck with trailer 14-20t	TT/AT > 14-20t	20	12	12	20	0	0.4	0.6	0.4	0.5

Truck with trailer 20-28t	TT/AT > 20-28t	28	12	16	28	0	0.4	0.6	0.4	0.5
Truck with trailer 28-34t	TT/AT > 28-34t	34	17	22	36	0	0.5	0.7	0.5	0.6
Truck with trailer 34-40t	TT/AT > 34-40t	40	19	26	36	0	0.5	0.7	0.5	0.6
Truck with trailer 40-50t	TT/AT > 40-50t	50	16.5	33	33	110	0.5	0.7	0.5	0.6
Truck with trailer 50-60t	TT/AT > 50-60t	60	25.25	40	51	140	0.5	0.7	0.5	0.6

Source: NTM, 2015

Table 12

Function Parameter a and c for Different Ship Types

Type of Ship	**a**	**c**
Bulk carrier	0.96179	0.477
Chemical tanker, oil tanker, product tanker	1.2188	0.488
LNG tanker, LPG tanker	1.12	0.456
Container ship	0.17422	0.201
General cargo	0.10748	0.216
Reefer	0.22701	0.244
Ro-Ro ship	4.092	0.5197
Vehicle carrier	11.554	0.6565

Source: NTM Function parameter a and c for different ship types (MEPC 62/24/Add1, MEPC 59/2/23)

Table 13

Relationship between Payload and Deadweight

Type of Ship	Payload : Deadweight Ratio (PDR)
General cargo	0.9
Reefer	0.9
Bulk carrier	0.9
Oil, chemical, product, LNG, LPG tanker	0.95
Container ship	0.8
Ro-Ro ship	0.5
Vehicle carrier	0.25

Source: NTM The relationship between payload and deadweight for different ship types

Table 14

Load Capacity Utilization

Type of Ship	Size of Deadweight	Capacity Utilization
Oil tanker	all	0.48
Product tanker	20000-	0.55
Product tanker	10000-20000	0.5
Product tanker	0-10000	0.45
Chemical tanker	all	0.64
LPG tanker	all	0.48
Bulk carrier	100000-	0.5
Bulk carrier	10000-100000	0.55
Bulk carrier	0-10000	0.6
General cargo	all	0.6

Reefer	all	0.5
Container ship	all	0.7
Vehicle	all	0.7
Ro-ro	all	0.7

Source: NTM Load capacity utilization (IMO 2nd GHG study)

Table 15

Parameters of Fuel Consumption per km as a Function of Load

Type of Ship	Size of Deadweight	d	e
Oil tanker	200000+	0.637465342	0.362534658
Oil tanker	120000-200000	0.885777041	0.114222959
Oil tanker	80000-120000	0.840744641	0.159255359
Oil tanker	60000-80000	0.686941	0.313059
Oil tanker	10000-60000	0.557447532	0.442552468
Oil tanker	0-10000	0.381799381	0.618200619
Product tanker	60000+	0.835434362	0.164565638
Product tanker	20000-60000	0.328694979	0.671305021
Product tanker	10000-20000	0.505323171	0.494676829
Product tanker	5000-10000	0.7028482	0.2971518
Product tanker	0-5000	0.396342013	0.603657987
Chemical tanker	20000+	0.76655613	0.23344387
Chemical tanker	10000-20000	0.781508118	0.218491882
Chemical tanker	5000-10000	0.606501996	0.393498004
Chemical tanker	0-5000	0.076725074	0.923274926
LPG tanker	30000+ (50000+ m3)	0.533110451	0.466889549

LPG tanker	0-30000 (0-50000 m3)	0.384739394	0.615260606
LPG tanker	95000+ (200000+ m3)	0.522337205	0.477662795
LPG tanker	0-95000 (0-200000 m3)	0.527335753	0.472664247
Bulk	200000+	0.521451549	0.478548451
Bulk	10000-200000	0.521451549	0.478548451
Bulk	60000-100000	0.473917634	0.526082366
Bulk	35000-60000	0.442985473	0.557014527
Bulk	10000-35000	0.427300692	0.572699308
Bulk	0-10000	0.172969171	0.827030829
General cargo	10000+	0.776496243	0.223503757
General cargo	5000-10000	0.773371724	0.226628276
General cargo	0-5000	0.173205709	826794291

Source: NTM Parameters of fuel consumption per km as a function of load (adapted from IMO 2nd GHG study)

Table 16

Shipment Variance Analysis Results: Distance

Shipment Distance Analysis (km)							
Supplier Name	**Minimum**	**Maximum**	**Median**	**Mean**	**Standard Deviation**	**Coefficient of Variance**	**Skew**
All Suppliers	0	51,411	1,297	2,717	3,420	1.26	Left
Supplier 1	1,270	12,167	9,288	9,378	1,637	0.17	Left
Supplier 2 (Express)	44	25,548	4,038	5,878	5,089	0.87	Left
Supplier 2 (Freight)	0	1,779	141	218	285	1.31	Left
Supplier 2 (Global)	11	19,777	7,682	7,707	2,755	0.36	Left
Supplier 3	4,390	13,668	8,288	8,784	1,653	0.19	Left
Supplier 4	0	25,547	991	4,510	5,988	1.33	Left
Supplier 5	281	8,302	1,098	1,423	936	0.66	Left
Supplier 6	78	3,137	1,297	1,223	260	0.21	Right
Supplier 7	0	18,684	7,676	7,681	1,404	0.18	Left
Supplier 8	16	51,411	1,227	3,695	4,611	1.25	Left
Supplier 9	339	25,849	13,037	13,871	7,211	0.52	Left
Supplier 10	6	19,899	1,474	1,759	1,316	0.75	Left

Table 17

Shipment Variance Analysis Results: Weight

Shipment Weight Analysis (tonne)							
Supplier Name	**Minimum**	**Maximum**	**Median**	**Mean**	**Standard Deviation**	**Coefficient of Variance**	**Skew**
All Suppliers	0	30,844	0	2	121	56.62	Left
Supplier 1	0	63	0	2	6	3.49	Left
Supplier 2 (Express)	0	560	0	1	18	14.87	Left
Supplier 2 (Freight)	0	36	0	1	5	3.08	Left
Supplier 2 (Global)	0	15,759	0	14	441	31.06	Left
Supplier 3	0	421	331	272	144	0.53	Right
Supplier 4	0	6,075	1	3	45	17.52	Left
Supplier 5	0	151	6	9	12	1.26	Left
Supplier 6	0	15,759	0	1	99	125.31	Left
Supplier 7	0	6,075	0	4	133	31.10	Left
Supplier 8	0	6,075	0	16	307	18.82	Left
Supplier 9	0	39	0	1	3	2.37	Left
Supplier 10	0	30,844	0	2	143	86.83	Left

Table 18

Comparisons of Carbon Emissions Intensity by Spend: GHG Method

Supplier Name	Total Spend (USD)	Total CO2eq: GHG (kg)	CO2eq (kg) per USD Spent: GHG
Supplier 1	113,485,327	182,647,512	1.61
Supplier 2 (Express)	15,914,023	13,842,693	0.87
Supplier 2 (Freight)	17,945,303	5,441,396	0.30
Supplier 2 (Global)	18,717,085	592,328,514	31.65
Supplier 3	11,715,327	45,988,975	3.93
Supplier 4	38,319,546	50,126,084	1.31
Supplier 5	5,438,708	4,944,901	0.91
Supplier 6	11,145,460	74,711,879	6.70
Supplier 7	74,422,633	100,755,091	1.35
Supplier 8	5,854,518	12,820,426	2.19
Supplier 9	13,475,905	2,573,722	0.19
Supplier 10	155,463,985	54,315,792	0.35

Table 19

Comparisons of Carbon Emissions Intensity by Shipment: GHG Method

Supplier Name	Shipment Count	Total CO2eq: GHG (kg)	CO2eq (kg) per Shipment: GHG
Supplier 1	842,781	182,647,512	216.72
Supplier 2 (Express)	7,856	13,842,693	1,762.05
Supplier 2 (Freight)	103,938	5,441,396	52.35
Supplier 2 (Global)	7,646	592,328,514	77,469.07
Supplier 3	68,713	45,988,975	669.29
Supplier 4	36,947	50,126,084	1,356.70
Supplier 5	2,652	4,944,901	1,864.59
Supplier 6	101,039	74,711,879	739.44
Supplier 7	60,211	100,755,091	1,673.37
Supplier 8	3,128	12,820,426	4,098.60
Supplier 9	760	2,573,722	3,386.48
Supplier 10	64,507	17,650,062	273.61

Table 20

Comparisons of Carbon Emissions Intensity by Distance: GHG Method

Supplier Name	Distance Travelled (km)	Total CO2eq: GHG (kg)	CO2eq (kg) per KM Travelled: GHG
Supplier 1	218,664,996	182,647,512	0.84
Supplier 2 (Express)	46,174,153	13,842,693	0.30
Supplier 2 (Freight)	22,613,673	5,441,396	0.24
Supplier 2 (Global)	58,928,353	592,328,514	10.05
Supplier 3	245,951	45,988,975	186.98
Supplier 4	166,612,693	50,126,084	0.30
Supplier 5	3,772,912	4,944,901	1.31
Supplier 6	123,576,541	74,711,879	0.60
Supplier 7	462,517,502	100,755,091	0.22
Supplier 8	11,558,269	12,820,426	1.11
Supplier 9	10,542,113	2,573,722	0.24
Supplier 10	119,831,767	17,650,062	0.15

Table 21

Comparisons of Carbon Emissions Intensity by Weight: GHG Method

Supplier Name	Weight Shipped (kg)	Total CO2eq: GHG (kg)	CO2eq (kg) per KG Shipped: GHG
Supplier 1	43001861.51	182,647,512	4.2
Supplier 2 (Express)	9270429.796	13,842,693	1.5
Supplier 2 (Freight)	152910317.2	5,441,396	0.0
Supplier 2 (Global)	108623975.4	592,328,514	5.5
Supplier 3	7628195	45,988,975	6.0
Supplier 4	94812201.45	50,126,084	0.5
Supplier 5	25134261.76	4,944,901	0.2
Supplier 6	79949442.92	74,711,879	0.9
Supplier 7	257855781.7	100,755,091	0.4
Supplier 8	50999251.2	12,820,426	0.3
Supplier 9	991977.069	2,573,722	2.6
Supplier 10	59462930.22	17,650,062	0.3

Table 22

Shipment Analysis Results by Mode

Supplier	(All)

Shipment Mode	Year	Sum of Shipment Count	Sum of Calc. Distance (km)	Sum of Calc. Weight (tonne)	Sum of Calc. Volume (cbm)
⊟**Air**	2019	28,080	149,379,208	9,746	653,157
Air	2020	103,766	211,389,252	17,507	2,686,927
Air	2021	111,549	192,243,400	15,860	2,326,260
⊟**N/A**	2019	46,082	11,217,376	55,331	1,573,308,195
N/A	2020	136,677	80,972,257	85,612	3,003,781,597
N/A	2021	90,931	54,246,531	99,544	1,575,721,646
⊟**Ocean**	2019	11,567	101,660,691	138,375	2,692,497
Ocean	2020	13,038	112,212,886	150,873	5,693,412
Ocean	2021	12,134	103,067,865	73,491	3,668,925
⊟**Other**	2020	65	561,756	47,322	2,262,231
Other	2021	7	62,837	47,276	243,625
⊟**Rail**	2019	150	320,534	827	3,541
Rail	2020	177	591,448	1,414	4,588
Rail	2021	188	780,630	1,545	7,190
⊟**Truck**	2019	39,368	27,682,791	24,422	226,968
Truck	2020	376,796	149,319,584	94,903	1,100,585
Truck	2021	448,176	243,857,007	276,699	2,120,477
⊟**Van**	2019	806	4,569,939	911	2,036
Van	2020	2,633	7,236,546	923	2,642
Van	2021	2,501	6,291,139	505	2,381
Grand Total		**1,424,691**	**1,457,663,680**	**1,143,086**	**6,176,508,879**

Table 23

Carbon Emissions Analysis Results by Mode

Supplier	(All)

Shipment Mode	Year	Sum of GLEC: Est. WTW CO2eq (kg	Sum of GHG: Est. CO2eq (kg	Sum of NTM: Est. CO2eq (kg)
⊟**Air**	2019	41,561,971	60,976,600	39,798,027
Air	2020	84,239,501	123,697,102	84,904,797
Air	2021	77,722,613	115,224,909	80,132,212
⊟**N/A**	2019	745,583	3,081,316	1,492,242
N/A	2020	11,736,581	48,504,442	11,042,164
N/A	2021	18,040,374	74,556,492	7,865,681
⊟**Ocean**	2019	27,288,576	15,539,399	34,026
Ocean	2020	36,644,845	20,867,298	37,149
Ocean	2021	18,434,226	10,497,315	18,951
⊟**Other**	2020	66,622,942	275,336,461	3,122,366
Other	2021	70,069,170	289,578,890	3,215,253
⊟**Rail**	2019	163,198	46,250	38,852
Rail	2020	385,374	109,214	91,744
Rail	2021	459,847	130,320	109,473
⊟**Truck**	2019	14,844,548	9,131,465	30,933,111
Truck	2020	61,884,645	43,574,149	108,353,115
Truck	2021	59,445,274	48,872,366	163,192,181
⊟**Van**	2019	7,060,191	306,985	5,916,797
Van	2020	6,961,843	302,709	6,737,170
Van	2021	3,755,676	163,301	5,768,734
Grand Total		**608,066,979**	**1,140,496,985**	**552,804,044**

Table 24

Carbon Emissions and Inbound Transportation Spend by Supplier

Supplier Name	Total Spend (USD)	Total CO2eq: GHG (kg)	Total CO2eq: GLEC (kg)	Total CO2eq: NTM (kg)
Supplier 1	$ 113,485,327	182,647,512	145,875,987	136,603,955
Supplier 2 (Express)	$ 15,914,023	13,842,693	34,517,933	57,130,384
Supplier 2 (Freight)	$ 17,945,303	5,441,396	1,316,650	3,002,413
Supplier 2 (Global)	$ 18,717,085	592,328,514	158,397,253	25,012,124
Supplier 3	$ 11,715,327	45,988,975	11,127,915	541,232
Supplier 4	$ 38,319,546	50,126,084	54,301,152	32,217,881
Supplier 5	$ 5,438,708	4,944,901	10,354,728	2,320,689
Supplier 6	$ 11,145,460	74,711,879	18,077,973	16,856,443
Supplier 7	$ 74,422,633	100,755,091	100,311,411	20,656,062
Supplier 8	$ 5,854,518	12,820,426	20,275,568	4,631,019
Supplier 9	$ 13,475,905	2,573,722	1,274,239	40,502,632
Supplier 10	$ 155,463,985	54,315,792	52,236,169	213,329,210
Total	$ 481,897,820	1,140,496,985	608,066,979	552,804,044

Table 25

Comparisons of Carbon Emissions Intensity by Shipment: GLEC and NTM Methods

Supplier Name	Shipment Count	Total CO2eq: GLEC (kg)	Total CO2eq: NTM (kg)	CO2eq (kg) per Shipment: GLEC	CO2eq (kg) per Shipment: NTM
Supplier 1	842,781	145,875,987	136,603,955	173.09	162.09
Supplier 2 (Express)	7,856	34,517,933	57,130,384	4,393.83	7,272.20
Supplier 2 (Freight)	103,938	1,316,650	3,002,413	12.67	28.89
Supplier 2 (Global)	7,646	158,397,253	25,012,124	20,716.36	3,271.27
Supplier 3	68,713	11,127,915	541,232	161.95	7.88
Supplier 4	36,947	54,301,152	32,217,881	1,469.70	872.00
Supplier 5	2,652	10,354,728	2,320,689	3,904.50	875.07
Supplier 6	101,039	18,077,973	16,856,443	178.92	166.83
Supplier 7	60,211	100,311,411	20,656,062	1,666.00	343.06
Supplier 8	3,128	20,275,568	4,631,019	6,481.96	1,480.50
Supplier 9	760	1,274,239	40,502,632	1,676.63	53,292.94
Supplier 10	64,507	15,567,038	79,732,958	241.32	1,236.04

Table 26

Comparisons of Carbon Emissions Intensity by Distance: GLEC and NTM Methods

Supplier Name	Distance Travelled (km)	Total CO2eq: GLEC (kg)	Total CO2eq: NTM (kg)	CO2eq (kg) per KM Travelled: GLEC	CO2eq (kg) per KM Travelled: NTM
Supplier 1	218,664,996	145,875,987	136,603,955	0.67	0.62
Supplier 2 (Express)	46,174,153	34,517,933	57,130,384	0.75	1.24
Supplier 2 (Freight)	22,613,673	1,316,650	3,002,413	0.06	0.13
Supplier 2 (Global)	58,928,353	158,397,253	25,012,124	2.69	0.42
Supplier 3	245,951	11,127,915	541,232	45.24	2.20
Supplier 4	166,612,693	54,301,152	32,217,881	0.33	0.19
Supplier 5	3,772,912	10,354,728	2,320,689	2.74	0.62
Supplier 6	123,576,541	18,077,973	16,856,443	0.15	0.14
Supplier 7	462,517,502	100,311,411	20,656,062	0.22	0.04
Supplier 8	11,558,269	20,275,568	4,631,019	1.75	0.40
Supplier 9	10,542,113	1,274,239	40,502,632	0.12	3.84
Supplier 10	119,831,767	15,567,038	79,732,958	0.13	0.67

Table 27

Comparisons of Carbon Emissions Intensity by Weight: GLEC and NTM Methods

Supplier Name	Weight Shipped (kg)	Total CO2eq: GLEC (kg)	Total CO2eq: NTM (kg)	CO2eq (kg) per KG Shipped: GLEC	CO2eq (kg) per KG Shipped: NTM
Supplier 1	43001861.51	145,875,987	136,603,955	3.39	3.18
Supplier 2 (Express)	9270429.796	34,517,933	57,130,384	3.72	6.16
Supplier 2 (Freight)	152910317.2	1,316,650	3,002,413	0.01	0.02
Supplier 2 (Global)	108623975.4	158,397,253	25,012,124	1.46	0.23
Supplier 3	7628195	11,127,915	541,232	1.46	0.07
Supplier 4	94812201.45	54,301,152	32,217,881	0.57	0.34
Supplier 5	25134261.76	10,354,728	2,320,689	0.41	0.09
Supplier 6	79949442.92	18,077,973	16,856,443	0.23	0.21
Supplier 7	257855781.7	100,311,411	20,656,062	0.39	0.08
Supplier 8	50999251.2	20,275,568	4,631,019	0.40	0.09
Supplier 9	991977.069	1,274,239	40,502,632	1.28	40.83
Supplier 10	59462930.22	15,567,038	79,732,958	0.26	1.34

Appendix C Supplemental Figures

Figure 21

Data Collection and Cleansing Process

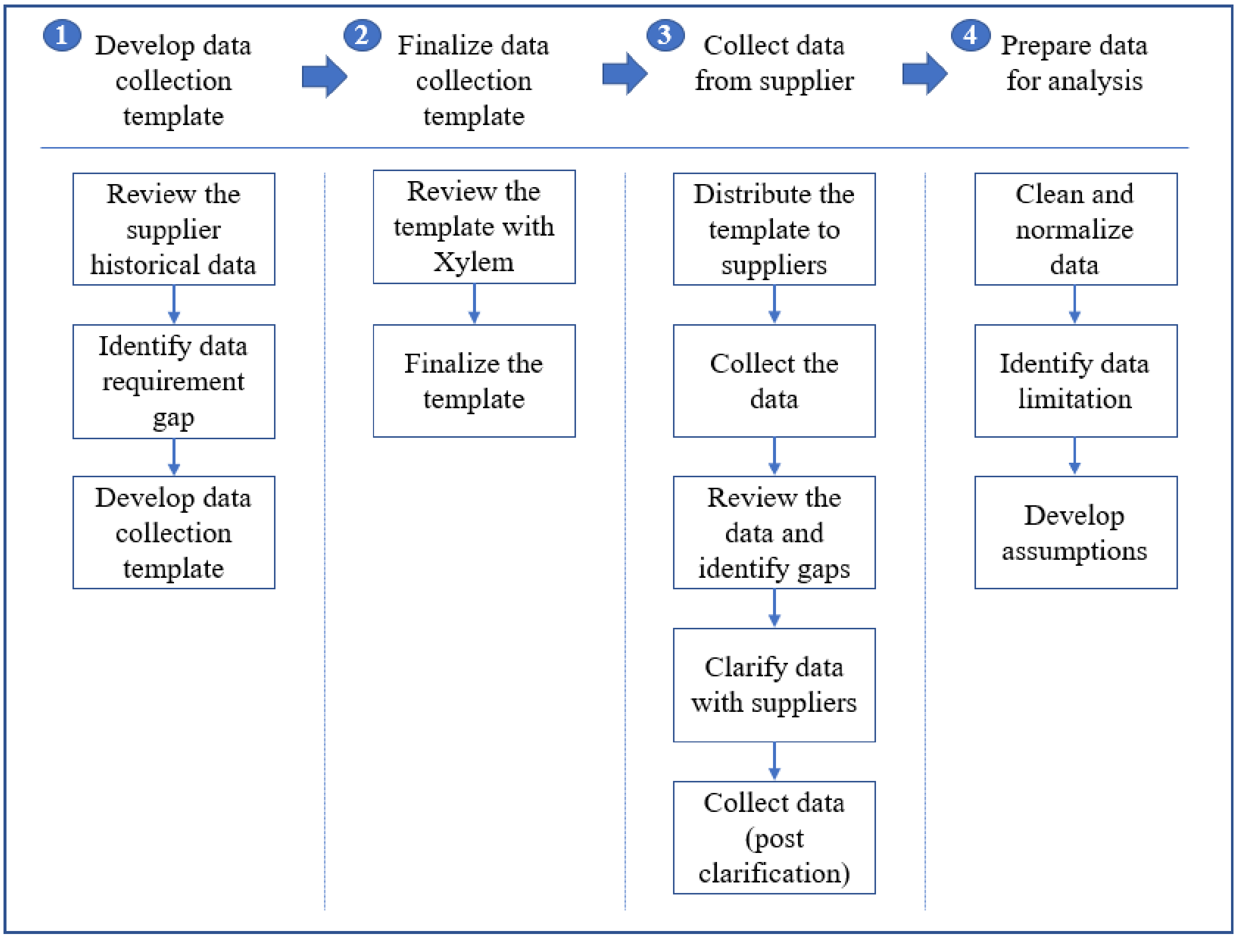


Figure 22

High-Level Linear Regression Analysis Results

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.985882078
R Square	0.971963471
Adjusted R Square	0.971963262
Standard Error	22312.15162
Observations	536556

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	9.26018E+15	2.31505E+15	4650254.44	0
Residual	536551	2.67112E+14	497832110.1		
Total	536555	9.5273E+15			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	472.5579457	39.04888072	12.10170271	1.04496E-33	396.0233732	549.0925182	396.0233732	549.0925182
Shipment Mode	-3864.522918	135.4629462	-28.52826568	7.1201E-179	-4130.026013	-3599.019824	-4130.026013	-3599.019824
Calc. Distance (km)	0.024728292	0.010069151	2.455846808	0.014055621	0.004993074	0.04446351	0.004993074	0.04446351
Calc. Weight (tonne)	-87.76522537	0.311308244	-281.923871	0	-88.37537969	-87.15507104	-88.37537969	-87.15507104
Calc. Fuel Consumption (kg)	9.233776744	0.002526819	3654.30924	0	9.228824259	9.238729229	9.228824259	9.238729229

Figure 23

Demand & Production Planning Regression Analysis Results

```
                            OLS Regression Results
=======================================================================================
Dep. Variable:          log_GHG_CO2eq   R-squared (uncentered):                   0.955
Model:                            OLS   Adj. R-squared (uncentered):              0.955
Method:                 Least Squares   F-statistic:                          2.462e+06
Date:                Sun, 01 May 2022   Prob (F-statistic):                        0.00
Time:                        00:05:51   Log-Likelihood:                      1.7090e+05
No. Observations:              232448   AIC:                                 -3.418e+05
Df Residuals:                  232446   BIC:                                 -3.418e+05
Df Model:                           2
Covariance Type:            nonrobust
=========================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
-----------------------------------------------------------------------------------------
transit_time          0.5691      0.000   1494.738      0.000       0.568       0.570
Shipment_type_Regular -0.0535     0.000   -109.980      0.000      -0.054      -0.053
==============================================================================
Omnibus:                    54755.689   Durbin-Watson:                   1.288
Prob(Omnibus):                  0.000   Jarque-Bera (JB):           386682.218
Skew:                           0.953   Prob(JB):                         0.00
Kurtosis:                       9.025   Cond. No.                         2.89
==============================================================================

Notes:
[1] R² is computed without centering (uncentered) since the model does not contain a constant.
[2] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

Figure 24

Sourcing & Procurement Regression Analysis Results

```
                            OLS Regression Results
==============================================================================
Dep. Variable:               CO2eq_GHG   R-squared:                       0.068
Model:                             OLS   Adj. R-squared:                 -0.101
Method:                  Least Squares   F-statistic:                    0.4034
Date:                 Mon, 02 May 2022   Prob (F-statistic):              0.804
Time:                         15:54:49   Log-Likelihood:                 7.3488
No. Observations:                   27   AIC:                            -4.698
Df Residuals:                       22   BIC:                             1.782
Df Model:                            4
Covariance Type:             nonrobust
=========================================================================================
                          coef    std err          t      P>|t|      [0.025      0.975]
-----------------------------------------------------------------------------------------
Shipment_Mode_Air       0.0758      0.077      0.983      0.337      -0.084       0.236
Shipment_Mode_Ocean     0.0166      0.091      0.182      0.857      -0.173       0.206
Shipment_Mode_Rail   3.828e-05      0.204      0.000      1.000      -0.423       0.423
Shipment_Mode_Truck     0.1267      0.062      2.058      0.052      -0.001       0.254
Shipment_Mode_Van       0.0038      0.118      0.032      0.975      -0.241       0.248
==============================================================================
Omnibus:                        54.673   Durbin-Watson:                   2.079
Prob(Omnibus):                   0.000   Jarque-Bera (JB):              348.307
Skew:                            3.912   Prob(JB):                     2.32e-76
Kurtosis:                       18.761   Cond. No.                         3.32
==============================================================================

Warnings:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

Figure 25

Customer Relationship Management Regression Analysis Results

```
                                 OLS Regression Results
=======================================================================================
Dep. Variable:            log_GHG_CO2eq   R-squared (uncentered):                   0.955
Model:                              OLS   Adj. R-squared (uncentered):              0.955
Method:                   Least Squares   F-statistic:                          2.462e+06
Date:                  Sun, 01 May 2022   Prob (F-statistic):                        0.00
Time:                          00:05:51   Log-Likelihood:                      1.7090e+05
No. Observations:                232448   AIC:                                 -3.418e+05
Df Residuals:                    232446   BIC:                                 -3.418e+05
Df Model:                             2
Covariance Type:              nonrobust
=========================================================================================
                           coef    std err          t      P>|t|      [0.025      0.975]
-----------------------------------------------------------------------------------------
transit_time             0.5691      0.000   1494.738      0.000       0.568       0.570
Shipment_type_Regular   -0.0535      0.000   -109.980      0.000      -0.054      -0.053
==============================================================================
Omnibus:                    54755.689   Durbin-Watson:                   1.288
Prob(Omnibus):                  0.000   Jarque-Bera (JB):           386682.218
Skew:                           0.953   Prob(JB):                         0.00
Kurtosis:                       9.025   Cond. No.                         2.89
==============================================================================

Notes:
[1] R² is computed without centering (uncentered) since the model does not contain a constant.
[2] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

Figure 26

Demand & Production Planning Regression Analysis Results (GLEC Method)

```
                            OLS Regression Results
=======================================================================================
Dep. Variable:          log_GLEC_CO2eq   R-squared (uncentered):                 0.959
Model:                             OLS   Adj. R-squared (uncentered):            0.959
Method:                  Least Squares   F-statistic:                        2.726e+06
Date:                 Sun, 01 May 2022   Prob (F-statistic):                      0.00
Time:                         00:06:24   Log-Likelihood:                    1.8549e+05
No. Observations:               232448   AIC:                               -3.710e+05
Df Residuals:                   232446   BIC:                               -3.710e+05
Df Model:                            2
Covariance Type:             nonrobust
=========================================================================================
                            coef    std err          t      P>|t|      [0.025      0.975]
-----------------------------------------------------------------------------------------
transit_time              0.5569      0.000   1557.647      0.000       0.556       0.558
Shipment_type_Regular    -0.0435      0.000    -95.369      0.000      -0.044      -0.043
==============================================================================
Omnibus:                     64292.671   Durbin-Watson:                   1.367
Prob(Omnibus):                   0.000   Jarque-Bera (JB):           621467.050
Skew:                            1.054   Prob(JB):                         0.00
Kurtosis:                       10.728   Cond. No.                         2.89
==============================================================================

Notes:
[1] R² is computed without centering (uncentered) since the model does not contain a constant.
[2] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

Figure 27

Demand & Production Planning Regression Analysis Results (NTM Method)

```
                            OLS Regression Results
=======================================================================================
Dep. Variable:           log_NTM_CO2eq   R-squared (uncentered):                 0.965
Model:                             OLS   Adj. R-squared (uncentered):            0.965
Method:                  Least Squares   F-statistic:                        3.203e+06
Date:                 Sun, 01 May 2022   Prob (F-statistic):                      0.00
Time:                         00:06:50   Log-Likelihood:                    1.2197e+05
No. Observations:               232448   AIC:                               -2.439e+05
Df Residuals:                   232446   BIC:                               -2.439e+05
Df Model:                            2
Covariance Type:             nonrobust
=========================================================================================
                            coef    std err          t      P>|t|      [0.025      0.975]
-----------------------------------------------------------------------------------------
transit_time              0.6747      0.000   1435.905      0.000       0.674       0.676
Shipment_type_Regular     0.1306      0.001    217.705      0.000       0.129       0.132
==============================================================================
Omnibus:                     50392.793   Durbin-Watson:                   0.884
Prob(Omnibus):                   0.000   Jarque-Bera (JB):           679553.765
Skew:                            0.667   Prob(JB):                         0.00
Kurtosis:                       11.270   Cond. No.                         2.89
==============================================================================

Notes:
[1] R² is computed without centering (uncentered) since the model does not contain a constant.
[2] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

Figure 28

Sourcing & Procurement Regression Analysis Results (GLEC Method)

```
                            OLS Regression Results
==============================================================================
Dep. Variable:            CO2eq_GLEC   R-squared:                       0.057
Model:                           OLS   Adj. R-squared:                 -0.115
Method:                Least Squares   F-statistic:                    0.3295
Date:               Mon, 02 May 2022   Prob (F-statistic):              0.855
Time:                       15:55:11   Log-Likelihood:                 1.6538
No. Observations:                 27   AIC:                             6.692
Df Residuals:                     22   BIC:                             13.17
Df Model:                          4
Covariance Type:           nonrobust
=======================================================================================
                          coef    std err          t      P>|t|      [0.025      0.975]
---------------------------------------------------------------------------------------
Shipment_Mode_Air       0.2121      0.095      2.226      0.037       0.014       0.410
Shipment_Mode_Ocean     0.1198      0.113      1.063      0.299      -0.114       0.354
Shipment_Mode_Rail           0      0.252          0      1.000      -0.523       0.523
Shipment_Mode_Truck     0.1921      0.076      2.528      0.019       0.034       0.350
Shipment_Mode_Van       0.0779      0.146      0.535      0.598      -0.224       0.380
==============================================================================
Omnibus:                      24.447   Durbin-Watson:                   2.087
Prob(Omnibus):                 0.000   Jarque-Bera (JB):               38.054
Skew:                          2.034   Prob(JB):                     5.45e-09
Kurtosis:                      7.157   Cond. No.                         3.32
==============================================================================

Warnings:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

Figure 29

Sourcing & Procurement Regression Analysis Results (NTM Method)

```
                            OLS Regression Results
==============================================================================
Dep. Variable:             CO2eq_NTM   R-squared:                       0.084
Model:                           OLS   Adj. R-squared:                 -0.083
Method:                Least Squares   F-statistic:                    0.5030
Date:               Mon, 02 May 2022   Prob (F-statistic):              0.734
Time:                       15:55:28   Log-Likelihood:                 5.9639
No. Observations:                 27   AIC:                            -1.928
Df Residuals:                     22   BIC:                             4.551
Df Model:                          4
Covariance Type:           nonrobust
=======================================================================================
                          coef    std err          t      P>|t|      [0.025      0.975]
---------------------------------------------------------------------------------------
Shipment_Mode_Air       0.1372      0.081      1.688      0.105      -0.031       0.306
Shipment_Mode_Ocean  8.398e-05      0.096      0.001      0.999      -0.199       0.199
Shipment_Mode_Rail      0.0001      0.215      0.001      1.000      -0.446       0.446
Shipment_Mode_Truck     0.1362      0.065      2.102      0.047       0.002       0.271
Shipment_Mode_Van       0.0440      0.124      0.355      0.726      -0.213       0.301
==============================================================================
Omnibus:                      46.896   Durbin-Watson:                   1.514
Prob(Omnibus):                 0.000   Jarque-Bera (JB):              210.801
Skew:                          3.358   Prob(JB):                     1.68e-46
Kurtosis:                     14.928   Cond. No.                         3.32
==============================================================================

Warnings:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

Figure 30

Inbound Transportation Spend Correlation Results (Linear Regression): GHG Method

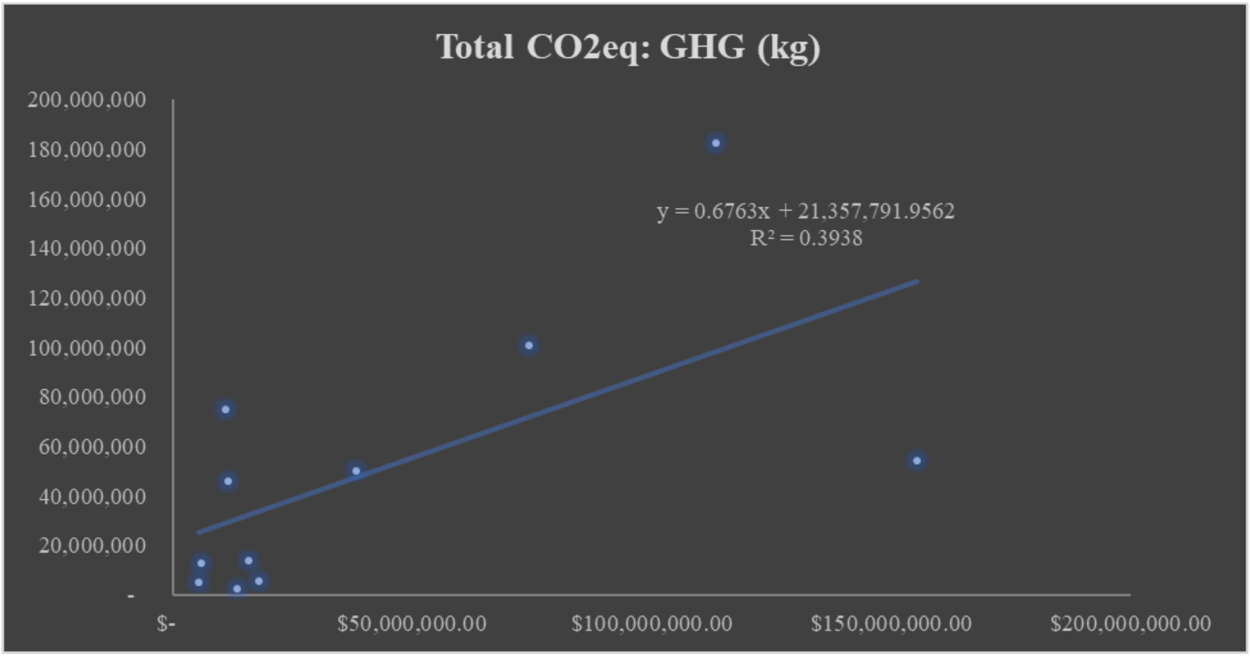


Figure 31

Inbound Transportation Spend Correlation Results (Logarithmic Regression): GHG Method

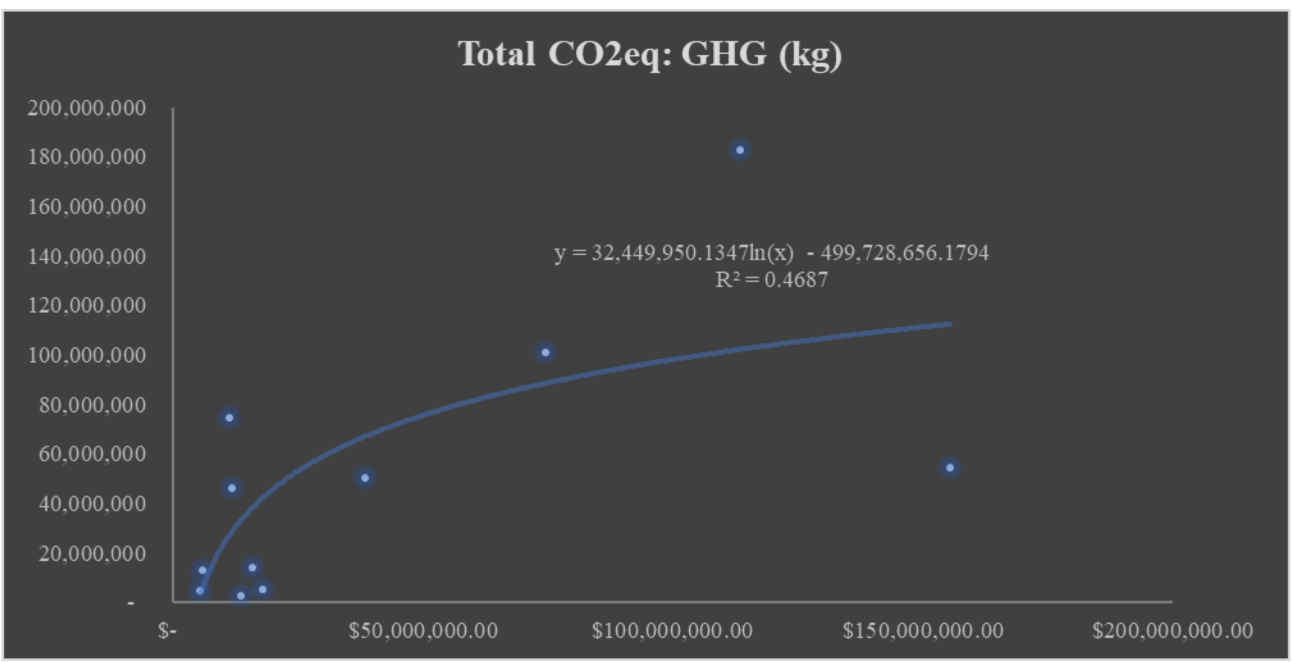


Figure 32

Inbound Transportation Spend Correlation Results (Polynomial Regression): GHG Method

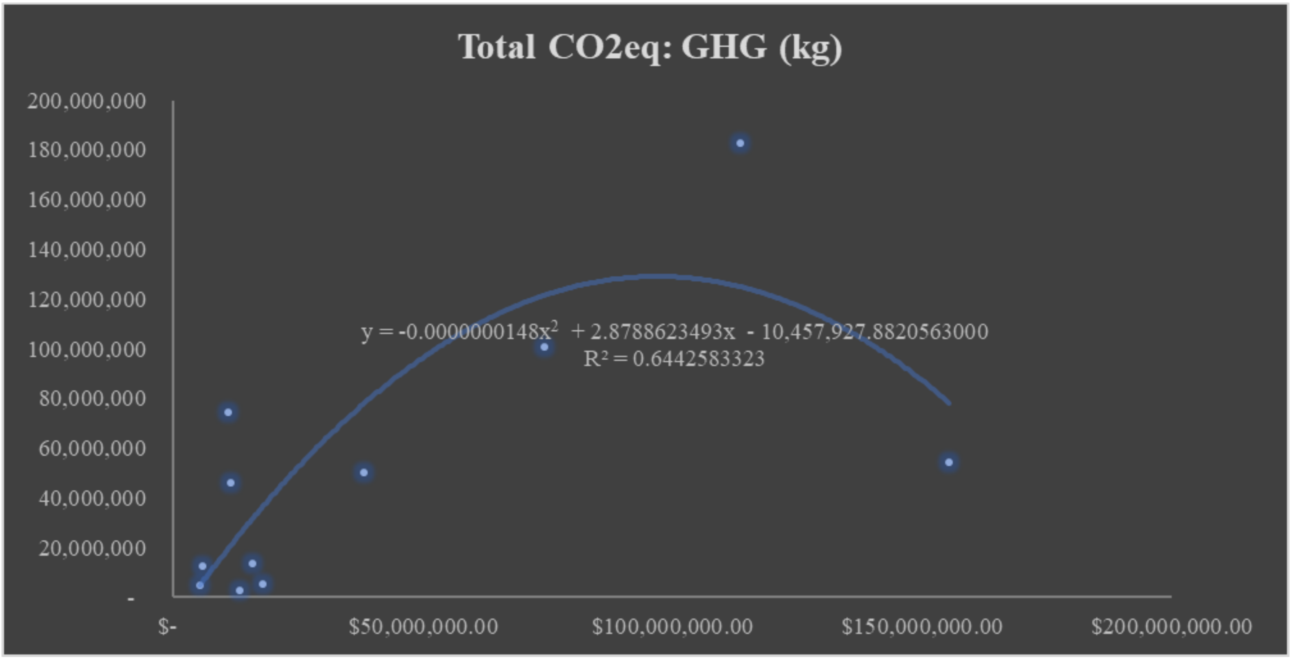


Figure 33

Inbound Transportation Spend Correlation Results (Linear Regression): GLEC Method

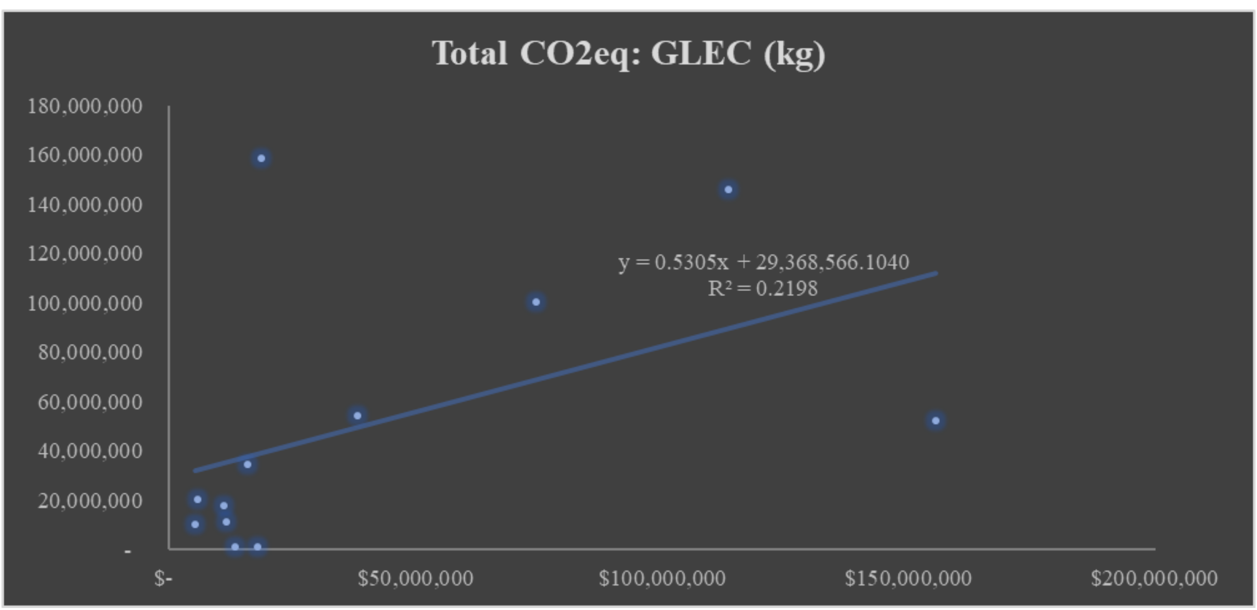


Figure 34

Inbound Transportation Spend Correlation Results (Logarithmic Regression): GLEC Method

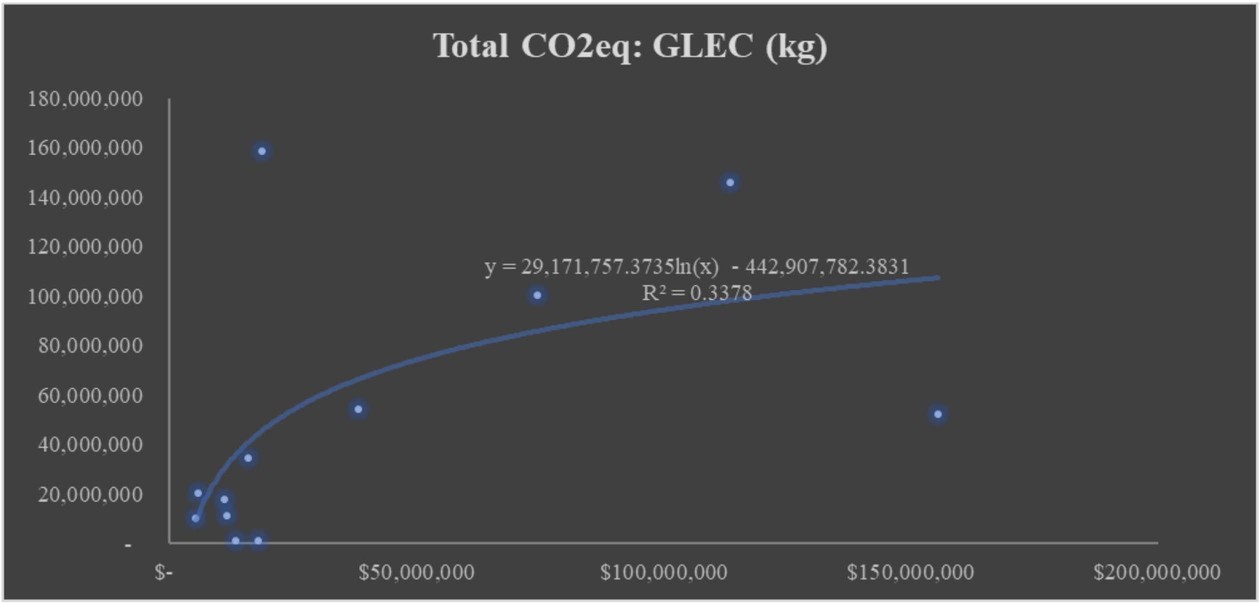


Figure 35

Inbound Transportation Spend Correlation Results (Polynomial Regression): GLEC Method

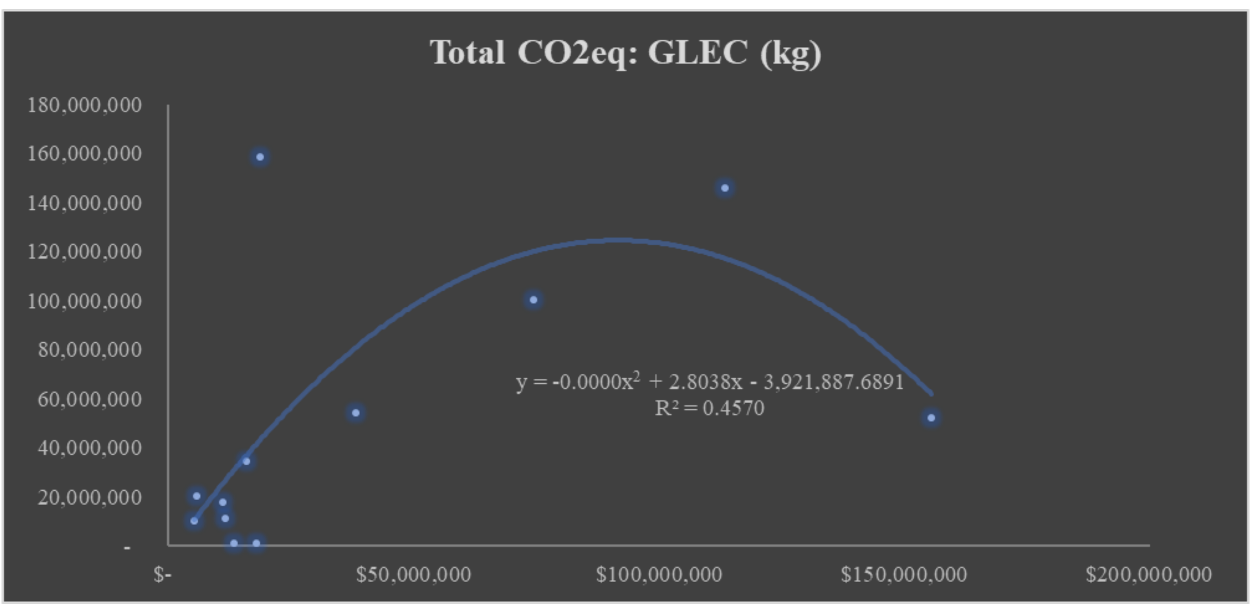


Figure 36

Inbound Transportation Spend Correlation Results (Linear Regression): NTM Method

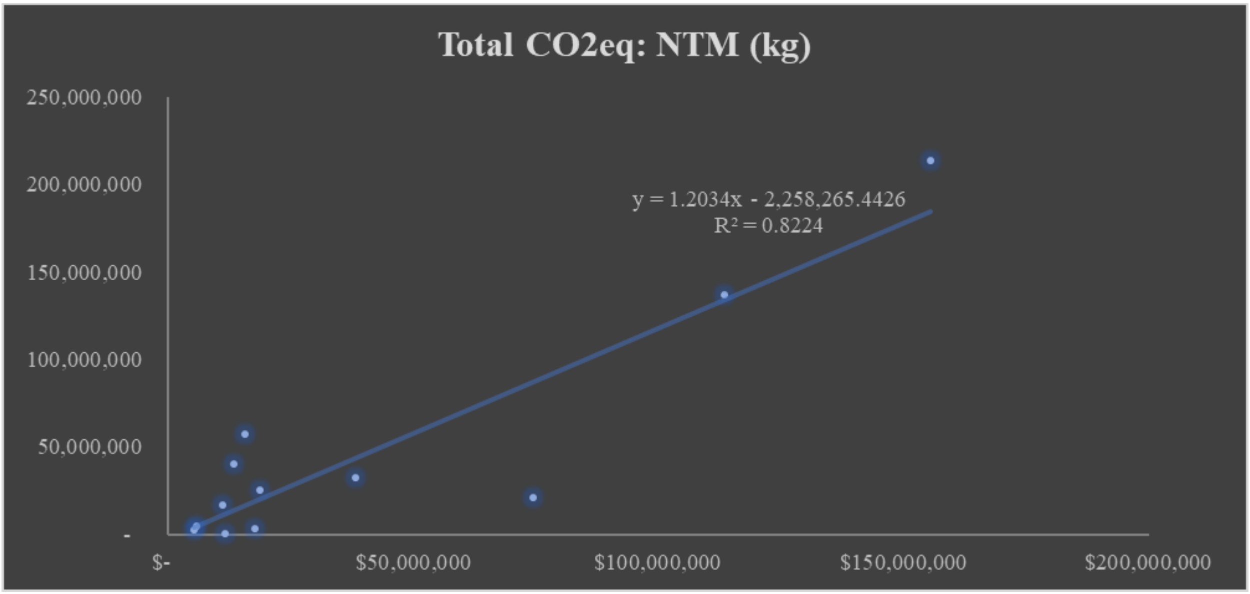


Figure 37

Inbound Transportation Spend Correlation Results (Logarithmic Regression): NTM Method

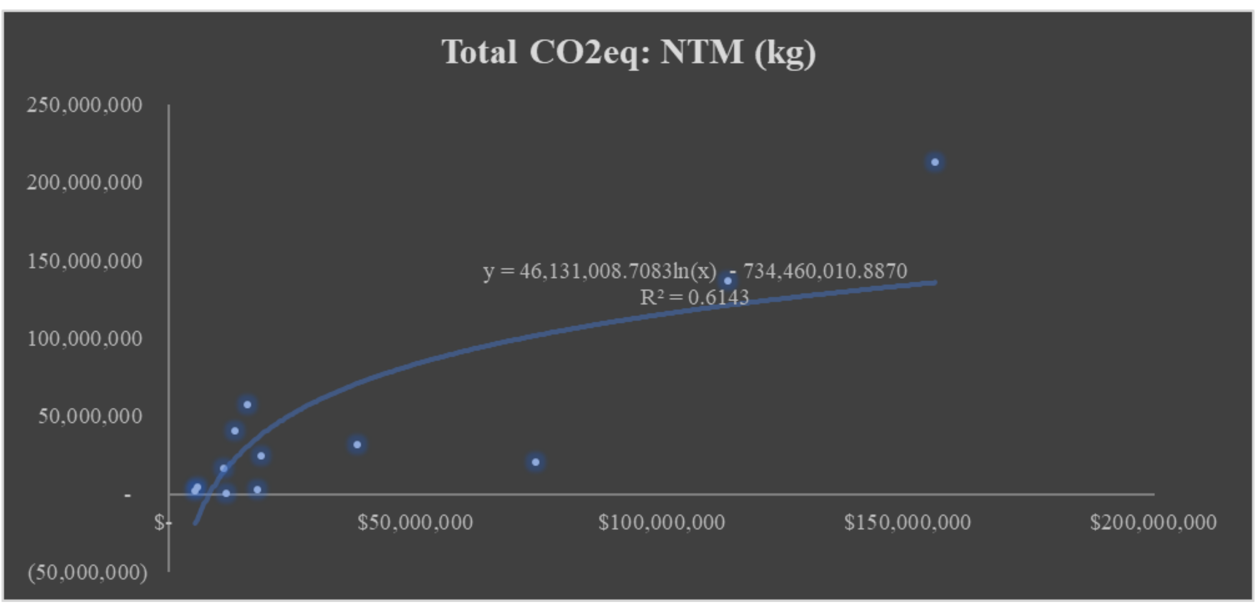


Figure 38

Inbound Transportation Spend Correlation Results (Polynomial Regression): NTM Method