



Carbon footprint assessment and sustainable logistics management: An integrated analysis of inbound, transportation, and outbound logistics activities

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Abstract

Logistics and transportation activities generate greenhouse gas emissions through fuel consumption, electricity use, product handling, packaging, and waste management. This study aimed to assess carbon footprint indicators across inbound logistics, operations, and outbound logistics, quantify greenhouse gas emissions, identify carbon hotspots, and propose approaches for improving logistics environmental performance. A mixed-method approach was employed. Qualitative data were collected through interviews and observations to identify factors affecting emissions, while quantitative data covered transportation activity, product weight, distance, fuel, electricity, and waste. Greenhouse gas emissions were calculated in kilograms of carbon dioxide equivalent using emission factors based on ISO 14067 and the Greenhouse Gas Protocol. Carbon intensity was calculated per kilogram of product, trip, and kilometer. Total emissions were 547.65 kgCO₂e per day, equivalent to 199,892.25 kgCO₂e annually. Outbound Logistics Scope 3 was the largest contributor, accounting for 356.16 kgCO₂e per day (65.04%) of total emissions. Packaging waste was the largest individual Scope 3 source at 140.00 kgCO₂e per day, while transportation generated 72.63 kgCO₂e per day. Engine idling accounted for approximately 17% of transportation fuel consumption. The findings support an integrated carbon management approach emphasizing packaging and waste reduction, reduced vehicle idling, route optimization, energy efficiency, and carbon monitoring to improve logistics environmental performance and prioritize emission-reduction actions.

Keywords:

Carbon footprint
Carbon intensity
Green logistics
Sustainable logistics management
Transportation emissions.

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1. Introduction

1.1. Background and Importance of the Problem

Climate change has become one of the most significant environmental and economic challenges facing organizations and societies worldwide. The continuing accumulation of greenhouse gas (GHG) emissions from human activities, particularly energy consumption, industrial production, transportation, and land-use change, has contributed substantially to global warming and increased risks to ecological, social, and economic systems. The Intergovernmental Panel on Climate Change (IPCC) has confirmed that human activities have unequivocally caused global warming, while the need for rapid and sustained reductions in GHG emissions has become increasingly urgent (Intergovernmental Panel on Climate Change, 2023). Within this context, transportation represents a particularly important area for climate action because it is closely connected with economic activity, international trade, production, and the movement of people and goods. Freight transportation is especially significant because increasing demand for the movement of goods continues to create substantial energy requirements and associated emissions (International Transport Forum, 2018; McKinnon, 2018). Road transportation remains a major component of freight distribution and continues to depend heavily on fossil fuels. The International Energy Agency (International Energy Agency, 2023) identifies electrification, alternative fuels, improved vehicle utilization, energy efficiency, and operational improvements as important elements of road transport decarbonization. More broadly, freight decarbonization requires coordinated technological, operational, managerial, and policy interventions rather than reliance on a single solution (McKinnon, 2018; Tavasszy et al., 2026). Recent international assessments similarly indicate that freight transport is a difficult-to-abate sector because transport demand is closely linked to economic activity, while road freight remains highly dependent on conventional fuels (International Energy Agency, 2023; International Transport Forum, 2023). Consequently, understanding where and how emissions are generated within logistics operations has become increasingly important for organizations seeking to improve environmental performance.

The importance of transportation emissions extends beyond individual vehicle movements because logistics activities are embedded throughout supply chain systems. Logistics encompasses the planning, implementation, and control of the movement and storage of materials, products, and related information from suppliers through organizational operations to customers. Accordingly, GHG emissions may arise from multiple interconnected activities, including inbound transportation, internal material handling, warehousing, storage, electricity consumption, outbound transportation, and final delivery. This broader perspective is consistent with the development of green and sustainable supply chain management, which emphasizes the integration of environmental considerations throughout supply chain processes rather than treating environmental performance as a separate organizational activity (Ahi & Searcy, 2013; Srivastava, 2007). Green supply chain management has developed into an important field of research because environmental considerations increasingly influence sourcing, production, transportation, distribution, and reverse logistics decisions. Reviews of the literature demonstrate that green supply chain management encompasses a wide range of practices, including environmentally responsible transportation, green purchasing, eco-design, resource efficiency, waste reduction, and environmental performance measurement (Fahimnia, Sarkis, & Davarzani, 2015; Sarkis, Zhu, & Lai, 2011). More recent research further emphasizes the growing relationship between green supply chain management and carbon accounting, particularly as organizations face increasing pressure to quantify emissions across their value chains (Liew & Cao, 2025). Therefore, carbon measurement is not simply an environmental reporting exercise; it can provide operational information that supports managerial decision-making and the identification of emission-intensive activities.

Carbon footprint assessment provides a systematic approach for quantifying GHG emissions associated with products, activities, processes, and supply chains. ISO 14067:2018 establishes principles, requirements, and guidelines for quantifying and reporting the carbon footprint of products, while ISO 14083:2023 provides a specific methodology for quantifying and reporting GHG emissions arising from transport chain operations involving freight and passenger transportation (International Organization for Standardization, 2018, 2023). The ISO 14083 standard is particularly relevant to logistics research because it provides a common methodological basis for evaluating emissions across transport-chain activities. Similarly, the Greenhouse Gas Protocol provides internationally recognized principles for organizational GHG accounting, including the distinction between direct emissions and indirect emissions throughout the value chain (World Resources

Institute, 2004, 2011). The classification of emissions into different scopes is important for understanding the environmental implications of logistics activities. Scope 1 covers direct emissions from sources owned or controlled by an organization, whereas Scope 2 addresses indirect emissions associated with purchased energy, particularly electricity. Scope 3 encompasses other indirect emissions occurring throughout the organization's value chain, including relevant upstream and downstream transportation and distribution activities (World Resources Institute, 2004, 2011). This classification enables organizations to move beyond an aggregated understanding of carbon emissions and examine specific operational activities that contribute to their overall environmental footprint. Such activity-based information is particularly important in logistics because emissions can be distributed across numerous transport, warehouse, energy, and distribution processes.

The measurement of logistics-related emissions also requires appropriate indicators. Transportation carbon footprint indicators can express emissions in absolute terms, such as kilograms of CO₂ -equivalent generated per trip or per day, or as intensity measures, such as kilograms of CO₂ -equivalent per kilometer, tonne of cargo, or tonne-kilometer. Absolute measures are useful for determining the overall environmental burden of an operation, whereas intensity indicators facilitate comparisons among activities that differ in scale, distance, cargo volume, or operational conditions (McKinnon, 2018; Smart Freight Centre, 2023). The distinction is particularly relevant to logistics organizations because a larger operation may naturally generate greater absolute emissions while simultaneously achieving a lower emissions intensity. Consequently, an effective measurement framework should consider both absolute emissions and emissions intensity. Research has increasingly demonstrated the importance of linking transportation emissions with operational decisions. Demir, Bektaş, and Laporte (2014) reviewed research on green road freight transportation and highlighted the importance of vehicle routing, fuel consumption, vehicle characteristics, load, and operational efficiency in reducing environmental impacts. Bektaş and Laporte (2011) similarly demonstrated that transportation planning can incorporate emissions, fuel consumption, travel time, and cost rather than focusing exclusively on distance. These studies indicate that transportation emissions are influenced by operational characteristics and that environmental performance can be improved through more efficient routing, vehicle utilization, loading, and scheduling decisions.

Route optimization and transportation planning are particularly important because vehicle speed, load, distance, congestion, and routing decisions can influence fuel consumption and emissions. The Pollution-Routing Problem introduced by Bektaş and Laporte (2011) demonstrates the importance of considering environmental impacts alongside traditional transportation objectives. From a managerial perspective, this means that logistics organizations can potentially reduce emissions through improvements in route planning, vehicle utilization, delivery consolidation, scheduling, and transportation-mode selection. Such measures are complementary to longer-term technological solutions such as electric vehicles and alternative fuels. At the supply chain level, logistics decarbonization requires a broader approach. McKinnon (2018) argues that reducing logistics-related emissions requires attention to freight demand, transport intensity, vehicle utilization, energy use, modal choice, and supply-chain structure. Similarly, recent research emphasizes that effective decarbonization requires organizations to understand the determinants of GHG calculations and establish sufficiently transparent and consistent measurement approaches before implementing reduction strategies (Bauer, Kummer, & Herold, 2025). Carbon measurement therefore functions as an important link between environmental assessment and operational management. Without reliable activity-level information, organizations may find it difficult to determine which processes should receive priority for emission reduction.

The need for reliable emissions measurement is further emphasized by challenges associated with standardizing carbon calculations across logistics systems. Dobers, Ehrler, Davydenko, Rüdiger, and Clausen (2019) noted that differences in the level of detail and methodological approaches used to calculate transport emissions can create difficulties in comparing environmental performance across transport chains. More recent research has likewise identified inconsistencies in GHG boundaries, calculation methods, data quality, and emission factors as continuing challenges in transport and supply-chain carbon accounting (Bauer et al., 2025; Liew & Cao, 2025). The use of standardized approaches such as ISO 14083 and the Global Logistics Emissions Council (GLEC) Framework can therefore improve methodological consistency and transparency in logistics emissions assessment (International Organization for Standardization, 2023; Smart Freight Centre, 2023). The role of logistics in environmental sustainability has also received increasing attention within green supply chain management research. Srivastava (2007) established the importance of integrating environmental considerations into supply chain management, while Ahi and Searcy (2013) demonstrated that green and sustainable supply chain management encompass environmental considerations across material and information flows and organizational relationships. Subsequent reviews have shown continued growth in research concerning green supply chain practices, environmental performance, and organizational sustainability (Fahimnia et al., 2015; Sarkis et al., 2011). More recently, Liew and Cao (2025) identified carbon accounting as an increasingly important component of green supply chain management research, reflecting the growing need to connect environmental information with organizational decision-making.

The issue is particularly relevant to Thailand, where road transportation plays an important role in domestic freight movement and logistics activities. The environmental performance of transportation systems is influenced by the characteristics of vehicles, fuel consumption, transport distances, cargo volumes,

infrastructure, and the technologies used. Recent research examining Thailand's transport sector has demonstrated that freight transportation and transport technologies have important environmental implications and that country-specific factors can influence the results of environmental assessments (Chotanapund et al., 2025). These findings reinforce the importance of considering the national and operational context when assessing transportation-related environmental performance rather than relying exclusively on generalized international emission assumptions. Recent empirical evidence from Thailand further demonstrates the value of activity-based logistics emissions assessment. Chanchaichujit, Jomthanachai, Soonthornsaratoon, Balasubramanian, and Wong (2026) for example, applied ISO 14083 and the GLEC Framework to assess GHG emissions across an end-to-end parcel supply chain in Thailand and identified major emissions hotspots across different transportation stages. This type of activity-level assessment demonstrates how carbon measurement can identify specific stages of a logistics process that require managerial attention. Similarly, research on Thailand's road freight sector has highlighted the importance of assessing carbon emissions and developing low-carbon strategies in response to increasing environmental and regulatory pressures (Mookda, 2026).

Within this context, the present study focuses on the transportation and logistics operations of Elin Group Limited Partnership, a logistics and transportation service provider in Thailand. The organization provides an appropriate case setting because its operations involve commercial vehicles, multiple transportation routes, warehouse facilities, storage, material handling, and distribution activities. These activities require both transportation fuels and electricity and therefore create multiple potential sources of GHG emissions. The case organization provides an opportunity to examine how carbon emissions can be identified, measured, and compared across different stages of actual logistics operations rather than relying solely on an aggregated organizational carbon footprint. The research document identifies the organization's logistics structure as sufficiently comprehensive for examining transportation carbon footprint indicators across different operational activities. The selection of Elin Group Limited Partnership as a case study does not imply that the organization has inadequate environmental or operational performance. Rather, the organization provides an appropriate empirical setting for examining the relationship between logistics activities and carbon emissions. Its combination of inbound transportation, internal operations, outbound distribution, fuel consumption, electricity use, and warehouse activities allows the study to examine the distribution of emissions across different logistics stages. This activity-based perspective is important because an organization may have information concerning its overall carbon footprint but still lack sufficient information to identify which operational activities contribute most substantially to emissions.

Accordingly, the present study adopts three major logistics dimensions: Inbound Logistics, Operations, and Outbound Logistics. Inbound Logistics refers to the movement and receipt of materials and products from suppliers into the organization. Operations include internal activities such as storage, material handling, processing, warehouse activities, and related energy consumption. Outbound Logistics encompasses the movement and distribution of products from the organization to customers or other destinations. These dimensions provide a structured framework for identifying and comparing emissions generated throughout the logistics process. The research specifically links these logistics activities with the fuel and electricity consumed during operations. The use of these three dimensions also addresses an important limitation of aggregated carbon reporting. When emissions are reported only as a single organizational total, managers may have difficulty identifying the specific activities, routes, vehicles, or processes responsible for the largest share of emissions. Such aggregation can limit the ability to prioritize environmental interventions and can obscure differences among inbound, internal, and outbound activities. In contrast, activity-level carbon indicators can provide more actionable information by connecting environmental performance directly to operational processes. This approach is consistent with the increasing emphasis on transparent, comparable, and decision-useful GHG calculations in logistics and supply-chain management (Bauer et al., 2025; Liew & Cao, 2025).

The development of meaningful transportation carbon footprint indicators should therefore balance methodological accuracy with operational practicality. Indicators should be sufficiently rigorous to represent actual sources of GHG emissions while remaining practical for routine organizational use. They should also provide meaningful comparisons across routes, trips, vehicles, cargo volumes, and logistics activities. The GLEC Framework emphasizes the importance of consistent activity data, emission factors, transport-chain boundaries, and reporting practices in establishing credible logistics emissions information (Smart Freight Centre, 2023). ISO 14083:2023 similarly provides a standardized basis for quantifying and reporting emissions arising from transport-chain operations (International Organization for Standardization, 2023). These principles support the development of indicators that are both technically defensible and useful for managerial decision-making. International evidence indicates that transportation decarbonization requires a combination of technological and managerial interventions. These include improving vehicle energy efficiency, increasing vehicle utilization, optimizing routes, reducing unnecessary travel, improving load factors, consolidating shipments, shifting freight toward lower-carbon modes where feasible, and adopting lower-carbon energy technologies (International Energy Agency, 2023; International Transport Forum, 2023; McKinnon, 2018). Recent research also suggests that modal shifts and technological improvements can contribute substantially

to freight decarbonization, although their potential varies across countries and transport systems (Tavasszy et al., 2026). Thus, organizations require reliable carbon indicators to determine which interventions are most appropriate for their specific operational conditions.

The development of transportation carbon footprint indicators is therefore important not only for environmental reporting but also for logistics management. By connecting emissions directly to operational activities, organizations can establish environmental baselines, identify emission-intensive processes, compare alternative operational practices, monitor performance over time, and evaluate the effectiveness of emission-reduction initiatives. Carbon indicators can consequently complement conventional logistics performance indicators such as transportation cost, delivery time, vehicle utilization, inventory performance, and service quality by introducing an explicit environmental dimension into logistics decision-making. The present study consequently focuses on developing, applying, and evaluating transportation carbon footprint indicators within an actual logistics operating environment. The analysis considers Inbound Logistics, Operations, and Outbound Logistics together with the fuel and electricity consumption associated with these activities. Rather than focusing exclusively on a single aggregate carbon footprint, the study seeks to establish a structured measurement approach capable of identifying and comparing emissions across logistics activities. This approach is consistent with the broader movement toward activity-based environmental performance management and the increasing importance of transparent GHG accounting in supply chains.

The study is particularly relevant because recent logistics research continues to identify challenges in translating carbon measurement into practical operational decision-making. Although organizations increasingly recognize the importance of decarbonization, effective action requires information that is sufficiently detailed to identify emission sources and sufficiently consistent to support monitoring and comparison (Bauer et al., 2025; Liew & Cao, 2025). The development of organization-specific indicators can therefore help bridge the gap between general sustainability objectives and operational-level environmental management. In summary, the continuing effects of climate change, the substantial contribution of transportation to GHG emissions, the importance of road freight in logistics systems, and the increasing demand for transparent environmental performance information create a strong need for practical transportation carbon footprint indicators. Existing research provides substantial evidence concerning green logistics, freight decarbonization, carbon accounting, transport emissions, and supply-chain sustainability; however, there remains a practical need to connect carbon emissions with specific logistics stages within actual organizational operating environments. The present study addresses this need by using Elin Group Limited Partnership as a case study and by examining carbon emissions across Inbound Logistics, Operations, and Outbound Logistics. By developing indicators that connect carbon emissions with specific logistics activities, the study aims to provide information that can support environmental performance assessment and logistics management. The resulting framework can enable managers to identify emission-intensive activities, establish operational carbon baselines, compare environmental performance across logistics processes, and identify opportunities for targeted emission reduction. In this way, transportation carbon footprint assessment can move beyond general environmental reporting toward an activity-based approach that integrates carbon performance into everyday logistics decision-making and supports the longer-term transition toward lower-carbon logistics operations.

1.2. Research Question

Based on the background and significance of the problem, the present study focuses on the development of transportation carbon footprint indicators that can be practically applied to logistics activities. The research is designed around three major questions.

1. What components should be included in appropriate transportation carbon footprint indicators for assessing Inbound Logistics, Operations, and Outbound Logistics?
2. Are there differences in the level of carbon footprint emissions among Inbound Logistics, Operations, and Outbound Logistics?
3. To what extent can the developed transportation carbon footprint indicators effectively reflect the level of carbon footprint emissions generated by the logistics activities of the case organization?

1.3. Research Objective

The overall objective of this research is to investigate carbon footprint emissions generated by logistics activities, develop appropriate transportation carbon footprint indicators, and apply the resulting indicators to support improvements in logistics operations and environmental performance. The objectives are as follows:

1. To develop and establish appropriate transportation carbon footprint indicators for Inbound Logistics, Operations, and Outbound Logistics.
2. To assess the level of carbon footprint emissions generated by Inbound Logistics, Operations, and Outbound Logistics using Elin Group Limited Partnership as a case study.
3. To evaluate the effectiveness of the developed transportation carbon footprint indicators in reflecting the carbon emissions of the organization's logistics activities.

2. Research Methodology

2.1. Research Design

This study employed a mixed-methods research design, integrating qualitative and quantitative approaches. The qualitative approach was used to understand logistics operations, energy consumption, and factors affecting greenhouse gas emissions, while the quantitative approach was used to calculate carbon footprint emissions from Inbound Logistics, Operations, and Outbound Logistics. The calculation followed the principles of ISO 14067 and the Greenhouse Gas Protocol, with emissions expressed as carbon dioxide equivalent (CO₂e). The research process consisted of reviewing relevant literature and standards, defining the system boundary and functional unit, collecting qualitative and quantitative data, calculating carbon emissions, and integrating the findings to identify emission hotspots and potential improvement areas.

2.2. Population and Sample

The population comprised personnel and organizational units involved in logistics and transportation activities across the supply chain, including the upstream/source, logistics and transportation, and downstream/destination stages. Purposive sampling was used to select participants with direct knowledge and experience of logistics and transportation operations. The qualitative sample consisted of 18 key informants, divided into three groups of six participants: upstream/source, logistics and transportation, and downstream/destination. Participants included management, planning, and operational personnel. For the quantitative component, actual logistics activity data were used rather than questionnaire responses. These data covered activities associated with inbound logistics, internal operations, and outbound logistics.

2.3. Research Instruments

The study employed four main research instruments.

- Semi-structured interview guide – used to collect information regarding logistics operations, energy consumption, factors affecting emissions, operational problems, and improvement measures.
- Observation form – used to record actual logistics activities, including product preparation, material handling, vehicle use, transportation, and route planning.
- Logistics activity data recording form – used to collect quantitative information such as fuel and energy consumption, transportation distance, number of trips, vehicle type, and cargo volume or weight.
- Carbon footprint calculation framework - based on ISO 14067 and the Greenhouse Gas Protocol. Activity data were converted into CO₂e using appropriate emission factors, with Microsoft Excel used for calculation and data processing.

2.4. Data Collection

Data were collected from both qualitative and quantitative sources. Qualitative data were obtained through semi-structured interviews, focus group discussions, and direct observations of logistics operations. The information focused on operational processes, energy use, emission-related factors, and opportunities for improvement. Quantitative data were obtained from organizational records and information systems, including transportation distance, number of trips, cargo weight or volume, fuel consumption, transportation time, and GPS tracking information. These data were used to calculate greenhouse gas emissions in CO₂e. The qualitative and quantitative findings were subsequently integrated to identify carbon emission hotspots and develop appropriate recommendations for reducing carbon emissions and improving logistics efficiency.

3. Data Analysis and Findings

3.1. Introduction

This chapter presents the results of the analysis of qualitative and quantitative data concerning the transportation carbon footprint of the case organization. The analysis focuses on three major logistics activities: Inbound Logistics, Operations, and Outbound Logistics. Qualitative data were analyzed through content analysis to identify operational factors associated with greenhouse gas emissions, while quantitative data were analyzed based on transportation activity, fuel consumption, energy consumption, product weight, transportation distance, and relevant emission factors. The results are presented in terms of carbon dioxide equivalent (CO₂e) and carbon intensity to facilitate comparison among different logistics activities. The analysis was conducted to identify the major sources of carbon emissions, determine the relative contribution of each logistics activity, and establish appropriate indicators for evaluating transportation carbon footprint performance. The results also provide a basis for identifying carbon hotspots and developing recommendations for improving logistics efficiency and reducing greenhouse gas emissions.

3.2. Data Analysis of the Qualitative Data

The qualitative analysis was conducted using information obtained from interviews and observations of personnel involved in logistics and transportation activities. The analysis focused on transportation planning,

vehicle management, energy consumption, route management, operational practices, and the use of technology for monitoring logistics activities.

Table 1. Summary of qualitative findings.

Logistics Activity	Major Finding	Factors Affecting Carbon Emissions
Inbound Logistics	Energy is consumed in preparation, refrigeration, and storage activities	Electricity consumption and equipment efficiency
Operations	Transportation activities generate direct fuel-related emissions	Fuel consumption, distance, route planning, and engine idling
Outbound Logistics	Destination activities generate substantial indirect emissions	Product use, food waste, and packaging waste
Transportation Management	Route planning and vehicle management influence operational efficiency	Vehicle utilization, traffic conditions, and scheduling
Technology	GPS Tracking and TMS support transportation monitoring	Data availability and operational control

Table 1 illustrates that greenhouse gas emissions are generated from several interconnected logistics activities rather than transportation alone. In the inbound logistics process, electricity consumption associated with preparation, refrigeration, and storage represents an important source of emissions. In the operations stage, fuel consumption is the primary source of direct transportation emissions, while route planning and engine idling can influence fuel efficiency. The findings further indicate that outbound logistics generates emissions beyond the transportation process. In particular, product use, food waste, and packaging waste contribute to Scope 3 emissions. Therefore, the qualitative findings suggest that an effective carbon footprint measurement system should consider the entire logistics process, rather than focusing exclusively on vehicle movement. The interviews also indicate that technology can support carbon management. GPS Tracking and Transportation Management Systems provide information regarding vehicle movement, transportation routes, and operational performance. Such information can be used to identify inefficient activities and support evidence-based decisions concerning transportation and carbon reduction.

3.3. Data Analysis of the Quantitative Data

3.3.1. Transportation Activity

The first stage of quantitative analysis examined the transportation activity of the case organization. The main variables included product weight, number of trips, transportation distance, driving time, and engine idling time.

Table 2. Transportation activity data.

Indicator	Value
Product weight	1,195 kg
Number of trips	2 trips/day
Distance per trip	45 km
Total distance	90 km/day
Driving time	117.65 minutes
Engine idling time	110.72 minutes

As shown in Table 2, the organization transported 1,195 kg of products per day through two transportation trips, with each trip covering approximately 45 km. Consequently, the total transportation distance was 90 km per day. The data also show that the vehicle operated for 117.65 minutes while driving and experienced 110.72 minutes of engine idling. An important observation is that the engine idling time was relatively high compared with the driving time. The idling time represented approximately 94.1% of the driving time. This finding suggests that transportation efficiency is influenced not only by the distance traveled but also by operational conditions such as traffic, waiting time, loading and unloading, and route management.

3.3.2. Fuel Consumption and Transportation Emissions

The next stage examined fuel consumption associated with transportation operations.

Table 3. Fuel consumption and transportation emissions.

Indicator	Value
Fuel consumed during driving	22.50 liters/day
Fuel consumed during idling	4.61 liters/day
Total fuel consumption	27.11 liters/day
Emission factor	2.68 kgCO ₂ e/liter
Total emissions	72.63 kgCO ₂ e/day

Table 3 illustrates that total fuel consumption was 27.11 liters per day, consisting of 22.50 liters consumed during driving and 4.61 liters consumed during engine idling. Driving therefore accounted for approximately 83.0% of fuel consumption, while idling accounted for approximately 17.0%. Using the emission factor of 2.68 kgCO₂e per liter, total transportation emissions were calculated at 72.63 kgCO₂e per day. The result indicates that fuel consumption is a significant determinant of direct transportation emissions. More importantly, the 4.61 liters of fuel consumed during idling represent an emission source that may be reduced without reducing transportation distance or cargo volume. Therefore, reducing unnecessary idling may provide a practical opportunity for improving transportation carbon efficiency.

3.3.3. Transportation Carbon Intensity

In addition to total emissions, the study calculated carbon intensity indicators to provide a standardized measurement of transportation environmental performance.

Table 4. Transportation carbon intensity.

Indicator	Result
kgCO ₂ e per kg of product	0.0608
kgCO ₂ e per transportation trip	36.32
kgCO ₂ e per kilometer	0.807

Table 4 illustrates that transportation generated 0.0608 kgCO₂e for every kilogram of product transported. The emissions per trip were 36.32 kgCO₂e, while emissions per kilometer were 0.807 kgCO₂e. Among these indicators, the emissions-per-kilogram indicator is particularly useful for evaluating transportation efficiency because it considers both the amount of emissions generated and the amount of goods transported. It can therefore be used as a performance indicator when comparing transportation activities with different shipment volumes.

3.3.4. Inbound Logistics

The analysis of inbound logistics focused on activities at the central kitchen, particularly electricity consumption associated with preparation, refrigeration, and storage.

Table 5. Carbon footprint of inbound logistics.

Indicator	Result
Total emissions	67.92 kgCO ₂ e/day
Emissions per kg of product	0.0568 kgCO ₂ e/kg
Emissions per item	0.799 kgCO ₂ e/item
Emissions per purchase order	1.013 kgCO ₂ e/order

As shown in Table 5, inbound logistics generated 67.92 kgCO₂e per day. When standardized by product weight, the carbon intensity was 0.0568 kgCO₂e/kg. The carbon intensity of inbound logistics was slightly lower than the transportation carbon intensity of 0.0608 kgCO₂e/kg. This indicates that, based on the weight-based indicator, transportation generated a somewhat higher level of emissions per kilogram of product than the inbound logistics process. However, the findings also indicate that electricity consumption associated with refrigeration and storage should not be overlooked. Improving equipment efficiency, temperature control, and maintenance may reduce electricity consumption and consequently reduce the associated carbon footprint.

3.3.5. Outbound Logistics

The outbound logistics analysis examined emissions generated at the destination. The results were separated into Scope 2 and Scope 3 emissions.

Table 6. Carbon footprint of outbound logistics.

Outbound Activity	kgCO ₂ e/day	Percentage of Total
Scope 2	50.94	9.30%
Scope 3	356.16	65.04%
Total Outbound Logistics	407.10	74.34%

Table 6 illustrates that outbound logistics generated 407.10 kgCO₂e per day, representing approximately 74.34% of the total emissions identified in the study. Scope 3 emissions were substantially higher than Scope 2 emissions. Specifically, Scope 3 emissions amounted to 356.16 kgCO₂e/day, compared with only 50.94 kgCO₂e/day for Scope 2. This indicates that downstream activities have a substantially greater environmental impact than electricity consumption alone.

3.3.6. Analysis of Scope 3 Emissions

To better understand the major source of outbound emissions, Scope 3 emissions were further separated into product use, food waste, and packaging waste.

Table 7. Components of scope 3 emissions.

Scope 3 Activity	kgCO ₂ e/day	Percentage of Scope 3
Product use	129.33	36.31%
Food waste	86.83	24.38%
Packaging waste	140.00	39.31%
Total	356.16	100.00%

Table 7 illustrates that packaging waste was the largest source of Scope 3 emissions, accounting for 140.00 kgCO₂e/day or 39.31% of Scope 3 emissions. Product use represented the second-largest source at 129.33 kgCO₂e/day, while food waste accounted for 86.83 kgCO₂e/day. The findings suggest that packaging management should be considered a major component of the organization's carbon-reduction strategy. Although transportation is traditionally regarded as an important source of logistics emissions, the results demonstrate that downstream waste-related activities can generate substantially greater emissions.

Table 8. Comparison of carbon emissions by logistics activity.

Rank	Logistics Activity	kgCO ₂ e/day	Percentage
1	Outbound Logistics - Scope 3	356.16	65.04%
2	Operations/Transportation	72.63	13.26%
3	Inbound Logistics	67.92	12.40%
4	Outbound Logistics - Scope 2	50.94	9.30%
Total		547.65	100.00%

3.3.7. Comparison of Carbon Emissions among Logistics Activities

As shown in Table 8, Outbound Logistics - Scope 3 was the largest source of carbon emissions, accounting for 356.16 kgCO₂e/day or 65.04% of the total. Transportation operations ranked second, contributing 72.63 kgCO₂e/day or 13.26%. The results indicate a substantial difference between direct transportation emissions and downstream emissions. Scope 3 emissions were approximately 4.9 times greater than transportation emissions. This finding is particularly important because it suggests that an emission-reduction strategy focusing only on vehicles and fuel efficiency would address only a limited portion of the organization's total carbon footprint.

Table 9. Annual carbon emissions by emission scope.

Scope	Main Source	kgCO ₂ e/year	Percentage
Scope 1	Transportation	26,509.95	13.26%
Scope 2	Electricity consumption	43,383.90	21.70%
Scope 3	Downstream activities	129,998.40	65.04%
Total		199,892.25	100.00%

3.3.8. Analysis by Emission Scope

Table 9 illustrates that Scope 3 accounted for the largest proportion of annual carbon emissions, at 129,998.40 kgCO₂e or 65.04% of total emissions. Scope 2 accounted for 21.70%, while Scope 1 represented 13.26%. The results demonstrate that the carbon footprint of the logistics system is predominantly associated with indirect emissions. Therefore, environmental management should extend beyond direct fuel consumption and incorporate electricity consumption, product use, packaging, and waste management.

Table 10. Comparison of carbon intensity among logistics activities.

Logistics Activity	Carbon Intensity (kgCO ₂ e/kg)	Sustainability Index
Destination - Scope 2	0.0426	100.00
Inbound Logistics	0.0568	75.00
Transportation	0.0608	70.07
Destination - Scope 3	0.2981	14.29

3.3.9. Carbon Intensity Comparison

Table 10 illustrates that Destination – Scope 3 had the highest carbon intensity, at 0.2981 kgCO₂e/kg. This value was substantially higher than transportation at 0.0608 kgCO₂e/kg. The Scope 3 carbon intensity was approximately 4.9 times higher than the transportation carbon intensity. In contrast, Destination – Scope 2 had the lowest carbon intensity at 0.0426 kgCO₂e/kg. These results reinforce the importance of using carbon intensity as a complementary performance indicator. Absolute emissions identify the largest contributors, while carbon intensity allows comparison of environmental efficiency relative to the quantity of goods or activity.

Table 11. Identification of carbon hotspots.

Carbon Source	kgCO ₂ e/day	Contribution	Priority
Packaging waste	140.00	25.57%	Very High
Product use	129.33	23.62%	Very High
Food waste	86.83	15.85%	High
Transportation	72.63	13.26%	High
Inbound Logistics	67.92	12.40%	Moderate
Outbound Scope 2	50.94	9.30%	Moderate

3.3.10. Carbon Hotspot Analysis

Table 11 provides a more detailed view of the carbon hotspots. Packaging waste was the single largest emission source, followed by product use and food waste. Together, these three Scope 3 components accounted for approximately 65.04% of total daily emissions. The analysis therefore indicates that the organization's most important carbon-reduction opportunities are not limited to transportation. Packaging reduction, waste separation and reduction, improved product utilization, and downstream operational efficiency should also be considered.

3.4. Summary of the Results

The quantitative analysis identified total emissions of 547.65 kgCO₂e/day across the logistics activities examined. As illustrated in Table 8, the largest contributor was Outbound Logistics - Scope 3, followed by transportation operations, inbound logistics, and outbound Scope 2 activities. The transportation analysis showed that the organization consumed 27.11 liters of fuel per day, resulting in 72.63 kgCO₂e/day. Approximately 17% of the fuel was consumed during engine idling, indicating an opportunity to improve transportation efficiency through better route management, reduced waiting time, and improved vehicle operating practices. The inbound logistics analysis demonstrated emissions of 67.92 kgCO₂e/day, with a carbon intensity of 0.0568 kgCO₂e/kg. Although this value was lower than transportation, electricity consumption associated with refrigeration and storage remains an important area for operational improvement. The most significant finding concerns outbound Scope 3 emissions. As shown in Table 7, packaging waste, product use, and food waste generated a combined 356.16 kgCO₂e/day. Packaging waste was the largest individual contributor, accounting for 140.00 kgCO₂e/day. Overall, the results demonstrate that transportation carbon footprint should be evaluated across the entire logistics system rather than transportation activities alone. The findings indicate that direct transportation emissions represent only 13.26% of the total annual emissions, while Scope 3 emissions account for 65.04%.

Table 12. Overall summary of the quantitative findings.

Indicator	Result
Total daily carbon emissions	547.65 kgCO ₂ e/day
Total annual carbon emissions	199,892.25 kgCO ₂ e/year
Transportation emissions	72.63 kgCO ₂ e/day
Inbound Logistics emissions	67.92 kgCO ₂ e/day
Outbound Scope 2 emissions	50.94 kgCO ₂ e/day
Outbound Scope 3 emissions	356.16 kgCO ₂ e/day
Transportation carbon intensity	0.0608 kgCO ₂ e/kg
Highest emission source	Packaging waste
Highest emission category	Outbound Scope 3
Largest emission scope	Scope 3 (65.04%)

As summarized in Table 12 the findings clearly identify Outbound Scope 3 as the principal carbon hotspot, while transportation remains an important operational source that can be addressed through improved fuel efficiency and reduced engine idling. The findings provide a quantitative basis for developing targeted carbon-reduction strategies in the subsequent discussion and recommendations.

4. Conclusion, Discussion, and Recommendation

4.1. Conclusion

This study examined the transportation carbon footprint of the case organization by focusing on three major logistics activities: Inbound Logistics, Operations, and Outbound Logistics. The study employed qualitative and quantitative approaches to identify the operational factors contributing to greenhouse gas emissions and to quantify emissions in terms of carbon dioxide equivalent (CO₂e). The findings indicate that carbon emissions are generated throughout the logistics system and are not limited to transportation activities. The total emissions identified from the assessed activities were 547.65 kgCO₂e per day, equivalent to approximately 199,892.25 kgCO₂e per year. Among the activities examined, Outbound Logistics–Scope 3 represented the largest source of emissions, contributing 356.16 kgCO₂e per day or 65.04% of total emissions. This finding demonstrates that downstream activities represent a substantial component of the organization's overall carbon footprint. The transportation operation generated 72.63 kgCO₂e per day, representing 13.26% of total emissions. The transportation activity involved 1,195 kg of products, two trips, and a total transportation distance of 90 km per day. The calculated transportation carbon intensity was 0.0608 kgCO₂e per kilogram of product. The analysis also found that 4.61 liters of fuel, equivalent to approximately 17% of total fuel consumption, were consumed during engine idling. This result indicates that transportation emissions are influenced not only by distance traveled but also by operational practices such as waiting time, route conditions, and vehicle utilization. Inbound Logistics generated 67.92 kgCO₂e per day, with a carbon intensity of 0.0568 kgCO₂e/kg, indicating that electricity consumption associated with refrigeration, storage, and related activities is also relevant to the organization's carbon footprint. The most significant finding concerns downstream Scope 3 emissions. Packaging waste generated 140.00 kgCO₂e/day, product use generated 129.33 kgCO₂e/day, and food waste generated 86.83 kgCO₂e/day. These results demonstrate that packaging and waste-related activities can generate considerably more emissions than direct transportation. Therefore, the study concludes that transportation carbon footprint assessment should adopt a whole-logistics-system perspective. Measuring fuel consumption and transportation distance alone is insufficient to represent the organization's overall environmental impact. An effective carbon footprint assessment should incorporate transportation, electricity consumption, product-related activities, packaging, and waste management.

4.2. Discussion

The findings demonstrate that transportation carbon emissions are influenced by both transportation characteristics and broader logistics activities. The transportation activity generated 72.63 kgCO₂e/day, with a carbon intensity of 0.0608 kgCO₂e/kg. Although transportation was not the largest source of total emissions, it remains an important operational emission source because fuel consumption is directly associated with vehicle operation. The finding that approximately 17% of fuel consumption occurred during engine idling is particularly important. It indicates that some transportation emissions may be reduced through operational improvements without necessarily reducing the amount of goods transported. Improved route planning, delivery scheduling, loading and unloading coordination, and driver behavior could therefore contribute to improved transportation efficiency. The findings also demonstrate the importance of evaluating Inbound Logistics and energy consumption. Inbound Logistics generated 67.92 kgCO₂e/day and had a carbon intensity of 0.0568 kgCO₂e/kg, which was slightly lower than the transportation carbon intensity. However, the relatively close values indicate that both activities should be incorporated into the organization's carbon management system. Electricity consumption associated with refrigeration and storage represents an important area for improvement because these activities may require continuous energy use. Improving equipment efficiency, temperature management, maintenance, and energy monitoring could therefore reduce emissions associated with inbound logistics.

The most important finding is the dominant contribution of Outbound Logistics - Scope 3, which accounted for 65.04% of total emissions. Within Scope 3, packaging waste was the largest individual contributor at 140.00 kgCO₂e/day, followed by product use at 129.33 kgCO₂e/day and food waste at 86.83 kgCO₂e/day. This finding has important implications for carbon management because a strategy focusing exclusively on vehicle fuel efficiency would address only a relatively small proportion of the total emissions identified in the study. Therefore, the organization should adopt a broader approach that incorporates packaging management, waste reduction, product utilization, and downstream operational efficiency alongside transportation management. The comparison of carbon intensity further supports this conclusion. Transportation had a carbon intensity of 0.0608 kgCO₂e/kg, whereas Outbound Logistics - Scope 3 had a substantially higher intensity of 0.2981 kgCO₂e/kg. The difference indicates that downstream activities have a considerably greater carbon burden relative to the quantity of product involved. Therefore, both absolute emissions and carbon intensity should be used when evaluating logistics environmental performance. Absolute emissions identify the activities that contribute most to the total carbon footprint, while carbon intensity allows management to evaluate efficiency relative to the amount of product or logistics activity. Overall, the findings suggest that carbon reduction should be approached as an integrated logistics-management issue. Transportation efficiency remains important, particularly through the reduction of unnecessary engine idling

and improvement of route planning. However, the largest potential impact appears to be associated with downstream Scope 3 activities, particularly packaging waste, product use, and food waste. The findings therefore support the development of a comprehensive carbon footprint management system covering the entire logistics process rather than a narrow focus on transportation fuel consumption.

4.3. Recommendation

Based on the findings, the organization should prioritize carbon-reduction activities according to their contribution to the total carbon footprint. Because Outbound Logistics–Scope 3 represents the largest emission source, management should initially focus on reducing packaging waste, food waste, and emissions associated with product use. Packaging materials should be reviewed to identify opportunities to reduce material quantities, improve packaging efficiency, and increase the use of recyclable or lower-carbon materials. At the same time, food-waste management should be strengthened through improved inventory control, demand forecasting, storage management, and waste monitoring. These measures would directly address the largest carbon hotspot identified by the study. The organization should also improve transportation efficiency by reducing unnecessary engine idling. Since approximately 17% of fuel consumption was associated with idling, an anti-idling policy could be introduced and monitored through GPS Tracking and transportation management systems. Drivers should receive appropriate training concerning efficient driving and engine operation, while transportation planners should improve route planning and delivery scheduling to minimize waiting time and unnecessary vehicle operation. These measures could reduce fuel consumption and transportation emissions while maintaining the existing delivery requirements.

Energy efficiency should also be improved within inbound logistics and destination operations. The organization should continuously monitor electricity consumption associated with refrigeration, storage, and other energy-intensive activities. Regular maintenance of equipment, improved temperature control, and the identification of abnormal energy consumption should be incorporated into routine operational management. In addition, the organization should establish a carbon footprint dashboard that reports total kgCO₂e, kgCO₂e/kg of product, fuel consumption, engine idling time, electricity consumption, and waste-related emissions. Such a system would enable managers to monitor environmental performance and evaluate the effectiveness of carbon-reduction initiatives over time. Finally, carbon indicators should be incorporated into the organization's logistics performance management system. Carbon performance should be evaluated together with transportation cost, delivery time, vehicle utilization, and service quality so that environmental sustainability becomes part of normal operational decision-making. Future research should expand the analysis to additional transportation routes, vehicle types, shipment volumes, and operating conditions. Further studies could also evaluate the effects of specific interventions, such as route optimization, electric vehicles, alternative fuels, anti-idling programs, and sustainable packaging. Such research would provide additional evidence for developing a more comprehensive and measurable low-carbon logistics management model.

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