**OPERATIONS AND SUPPLY CHAIN MANAGEMENT**
Vol. 17, No. 3, 2024, pp. 141 - 151
ISSN 1979-3561 | EISSN 2579-9363

# Green E-commerce Supply Chain Management

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## ABSTRACT

**The continuous rise of e-commerce, driven by changing consumer behavior, has brought significant value to the supply chain. However, it also generates substantial waste through packaging, energy consumption, and vehicle usage. This research aims to mitigate the environmental impact of e-commerce by reducing its carbon footprint. A detailed green e-commerce model is proposed to lower environmental impacts, enhance economic performance, and improve competitiveness. Using the Life Cycle Assessment (LCA) discipline, activities are analyzed from cradle to grave, focusing on packaging, transportation, and disposal as primary sources of carbon emissions. In a case study, green strategies were implemented in key activities, demonstrating that reducing transportation distances and eliminating unnecessary packaging are critical to lowering carbon footprints. The study achieved a reduction of 0.1116 kg $CO_2$ equivalent per transaction, totaling 297,532 t $CO_2$ equivalent in 2023. This reduction equates to a carbon credit of 32 million THB and significant cost savings of 18 million THB by eliminating materials such as plastic bags, sleeves, and order receipts.**

**Keywords:** *carbon footprint, e-commerce, environmental impact, green supply chain management, life cycle assessment*

## 1. INTRODUCTION

In 2021, global e-commerce sales reached an estimated $5.2 trillion and are projected to grow to $8.1 trillion by 2026. As the value of e-commerce sales increases, its share in global retail sales continues to expand each year. In Thailand, the number of internet users has grown from 51 million in 2019 to 61.2 million in 2023, with an average daily internet usage of around 8 hours and 6 minutes (Kemp, 2023). E-commerce sales is expected to rise by 529%, from $3.4 billion in 2017 to $24.81 billion by 2027 (Statista, 2023). While e-commerce activities add substantial value to the supply chain, they also generate significant waste. The core competency of e-commerce lies in delivering products directly to consumers' addresses. However, this leads to an increase in the number of vehicles and complex transportation chains, resulting in traffic congestion and pollution from engine combustion, which contributes to the carbon footprint of the distribution system. The environmental impact of e-commerce is not limited to the last-mile delivery, it also includes the waste generated from packaging and protective materials sent from sellers to consumers. Additionally, the energy consumption, heat production, and carbon emissions from using hardware, devices, and information flow contribute to the problem. Consequently, online shopping significantly impacts the environment through waste, pollution, and congestion. As the demand for online shopping grows, the associated costs and environmental impacts. Thai parcel delivery value growing by 17% to 106 billion Baht in 2022, and parcel delivery volumes projected to exceed 7 million pieces per day (PPTV, 2023).

The researcher examined the environmental impact of e-commerce through literature, identifying four main contributing activities: packaging, energy consumption, transportation, and information flow. The key supply chain partners include warehouses, distribution centers, and consumers. The environmental impacts are measured in terms of cost, energy use, and carbon emissions, as documented by various studies (Scott Matthews *et al*., 2001; Siikavirta *et al*., 2002; Williams & Tagami, 2002; Edwards *et al*., 2009; Mckinnon & Cullinane, 2010; Tiwari & Singh, 2011; Weideli, 2013; Carling *et al*., 2015; Zhang *et al*., 2016; Cheris *et al*., 2017; Guo *et al*., 2017; Hidayatno *et al*., 2019). However, previous research has not comprehensively examined all dimensions of activities and supply chain partners, nor specifically focused on the environmental impact of e-commerce activities in Thailand. Therefore, this study explores e-commerce activities, analyzing all supply chain partners from cradle to grave, and calculates the carbon footprint for e-commerce and modern commerce models. The researcher then implements

a green model to eliminate unnecessary activities and reduce the overall carbon footprint.

There are three objectives of the study include to clarify the e-commerce process and identify activities that impact the environment, to analyze and compare the carbon footprint of e-commerce and modern commerce models and to propose a sustainable e-commerce model using green supply chain management concepts. The researcher has considered and selected the industry impacted by market sales share. The chosen industry is fashion, known for its significant sales value and complex processes. All related services contribute to environmental impact. Wacoal, an underwear brand within the fashion category, is chosen for detailed analysis. This study focuses on Bangkok, the capital city of Thailand, and encompasses the following three components include environmental impact measurement is quantified in terms of carbon footprint (kg $CO_2$ eq), the activities are analyzed from cradle to grave using the Life Cycle Assessment (LCA) discipline, emission factors and calculation table are based on the protocols of the Thailand Greenhouse Gas Management Organization (Public Organization). However, it is assumed that the electricity consumed by the e-commerce platform and third-party logistics provider warehouse operations is minimal and therefore excluded from the calculations.

# 2. LITERATURE REVIEW

E-commerce has emerged as a dominant trend for purchasing products online, allowing consumers to search for and buy items anywhere and have them delivered to their addresses. As consumer behavior shifts from in-store to online shopping, sellers are compelled to expand their sales channels to include both retail and online stores. Implementing e-commerce offers significant benefits to businesses by enabling their storefronts to be visible to consumers worldwide from buying and selling of information, products, and services via computer networks Schulze & Baumgartner (2001). The e-commerce ecosystem typically involves buyers, sellers, e-commerce platforms (marketplaces), and logistics providers. The e-commerce process can be understood as a series of interconnected flows: information, logistics, business, and financial flows (Zhang *et al.* (2014). Despite growing environmental concerns, few online retailers prioritize sustainability. Two major sources of emissions in e-commerce are last-mile delivery and packaging. Key factors contributing to the carbon footprint of e-commerce compared to traditional shopping include delivery speed and order frequency. Faster delivery requirements lead to more scheduling and split routes. $CO_2$ emissions are significantly influenced by the likelihood of successful first-time deliveries and the handling of returns for unwanted or damaged goods, resulting in additional packaging Cheris *et al*. (2017); Mckinnon & Cullinane (2010).

The carbon footprint calculation for e-commerce activities involves several components, including packaging, transportation, energy consumption, and information flow (Weideli, 2013). Packaging encompasses both primary (directly contacting the product) and secondary (used during shipment) packaging, which includes paper bills, envelopes, plastic bags, tape, protective materials and cardboard boxes Chueamuangphan (2019). In 2014, China had 2.5 billion parcels from online orders, with cardboard and tape being the main components. Zhang *et al*. (2016) estimated that producing 2.5 billion cardboard boxes would require resources equivalent to 5 million trees, 4 million tons of straw, or 1.25 million tons of waste paper. The carbon dioxide evaluation is considered from product returns, transportation, buildings, and packaging Zhao *et al.* (2019). While research studies have examined the environmental impact of e-commerce, there remains uncertainty regarding whether it has a positive or negative effect. Some studies suggest that e-commerce may decrease the carbon footprint by reducing trips to physical stores. 60% of consumers believe e-commerce will significantly impact the environment in the next 10-50 years Tiwari and Singh (2011). However, contrasting perspectives argue that the frequent delivery associated with e-commerce may contribute to an increase in the carbon footprint.

A carbon footprint serves as a metric to quantify the greenhouse gas emissions attributed to a particular activity. Typically, it focuses on processes and practices associated with the release of $CO_2$ and other greenhouse gases (Growcom, 2008). Calculating the carbon footprint involves combining activity data (AD), representing human activities, with emission factors (EF), which quantify emissions or removals per unit of activity (IPCC, 2006). To assess the carbon footprint in this study, it is computed in kilograms of carbon dioxide equivalent (kg $CO_2$ eq) (IPCC, 2006). To assess the carbon footprint's value, the Life Cycle Assessment (LCA) approach is employed to oversee the entire process from cradle to grave, encompassing raw material acquisition, manufacturing, distribution, usage, and final disposal (Gungor and Gupta, 1999; Roy *et al*., 2009; Jacquemin *et al*., 2012). The LCA generic model is shown in **Figure 1**. Green supply chain management (GSCM) integrates environmental management with supply chain management practices. It is suggested as a promising approach to enhance environmental performance (Tseng *et al*., 2019). GSCM emphasizes the management and mitigation of environmental impacts within logistics activities across the supply chain. By improving efficiency, reducing logistics costs, and meeting consumer demands, GSCM can contribute to achieving business goals while enhancing economic performance and competitiveness (Swami & Shah, 2013).

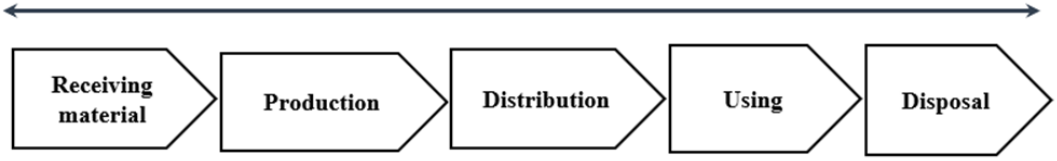


**Figure 1** The life cycle assessment (LCA) generic model

Green products or businesses significant influence in trade negotiations, driving high return on investment (ROI) and revenue. Moreover, green companies enhance employees' job satisfaction and commitment (Benjamin *et al*., 2023). Many businesses have scrutinized warehouses' impact on the supply chain to address environmental concerns. By reducing carbon dioxide emissions and striving for zero carbon operations, warehouses can bolster their value and contribute to environmental sustainability. It is imperative for businesses to comprehend and prioritize individual operating processes. According to the Salesforce report of 2019, 56% of consumers deem sustainability and ethical business practices essential (Blay, 2019). Green supply chain management (GSCM) has the potential to confer a competitive advantage. Companies that reduce environmental impact by incorporating a 'green' dimension into their supply chain management can fortify their competitiveness. Yu & Lee (2023) found that manufacturing flexibility and quality management were significantly affects environmental performance. These two factors are basic elements of manufacturing capability, improved environmental performance. The green e-commerce model is elaborated upon to illustrate how emissions can be reduced from materials receiving to disposal. Understanding and applying green concepts can enable businesses to raise awareness, enhance efficiency, cut logistics costs, meet consumer demands, and boost economic performance and competitiveness.

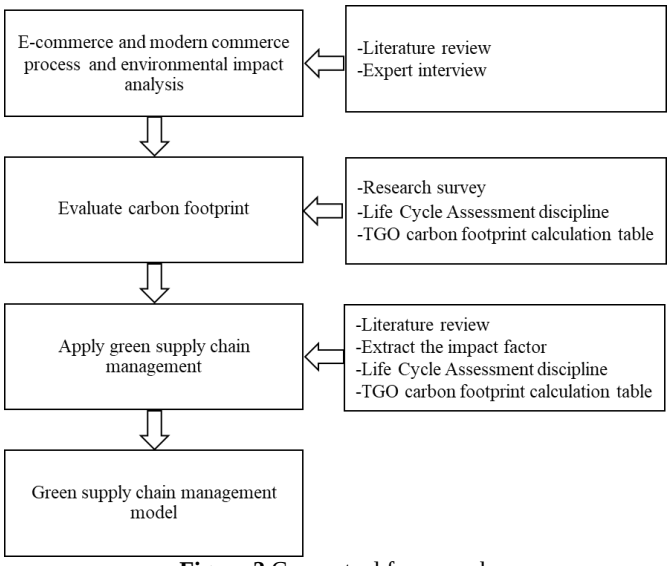


**Figure 2** Conceptual framework

# 3. RESEARCH METHODOLOGY

This research aims to explore the current e-commerce landscape in Thailand, identify the factors affecting its carbon footprint, and evaluate the environmental impact of each e-commerce activity. Additionally, it seeks to compare the carbon footprint of e-commerce and modern commerce to determine which model has a greater environmental impact. The researcher intends to review literature on green supply chain management to develop strategies for reducing the carbon footprint and creating a sustainable e-commerce model. To achieve these objectives, the researcher has outlined specific research tasks and developed a conceptual framework diagram, as shown in **Figure 2**.

According to the reviewed process, the researcher has interviewed an expert to explain the activities throughout both e-commerce and modern commerce processes and explored the process flow and activities that impact the environment. To deepen this understanding, the researcher has reviewed literature from various countries to identify environmental impact factors and gain insights into how these factors influence environmental sustainability. By examining these influences, the researcher has identified specific factors affecting the environment within the e-commerce and modern commerce sector. Based on this analysis, the researcher has developed a comprehensive process flow and created a generic model to calculate the carbon footprint in the context of Thailand. To evaluate the carbon footprint value, the research is divided into two tasks. First, after identifying the e-commerce processes that impact the environment, the researcher used questionnaires to collect missing data necessary for calculating the carbon footprint value. Second, after gathering all the required data, the researcher evaluated the carbon footprint using the Life Cycle Assessment discipline, which analyzes the process from cradle to grave. The evaluation table pattern and emission factors for each activity are based on data from the Thailand Greenhouse Gas Management Organization. These activities are divided into five steps: material receiving, production, distribution, use, and disposal. The emission factor related to vehicle use when consumers visit the store is based on Nilrit & Sampanpanish (2012). To understand the environmental impact of e-commerce activities, the researcher compared the carbon footprint values of e-commerce and modern commerce activities. If the carbon footprint of e-commerce activities is higher than that of modern commerce, it indicates that e-commerce activities have a greater environmental impact. To improve this issue, the researcher reviewed literature on green supply chain management to understand the concepts and practices implemented by other businesses. Based on these insights, a green e-commerce model was created, and the carbon footprint values of the current and green models were compared to

identify potential reductions. The third research objective is to develop a sustainable e-commerce model by incorporating green management principles to minimize the carbon footprint, resulting in an environmentally friendly e-commerce model.

# 4. RESEARCH RESULT

The research findings highlight the contrasting approaches of modern commerce and the e-commerce model in product accessibility. In the e-commerce model, consumers can conveniently purchase products online without visiting physical stores, opting instead for home delivery. In contrast, in the modern commerce model, consumers are required to visit brick-and-mortar stores to purchase products and then carry it back home.

## *4.1 E-commerce Model*

The e-commerce process flow begins when a consumer places an order on the E-marketplace platform. The order data is then transmitted to the seller, prompting their warehouse to pick and repack the items. Once the parcel is ready for shipping, a third-party logistics (3rdPL) provider collects it and delivers it to the consumer's address. The activities involved in the e-commerce logistics model is shown in **Figure 3**. The evaluation of carbon footprint follows the principles of Life Cycle Assessment (LCA). Accordingly, the e-commerce process is analyzed in five steps: material receiving, production, buying, using, and disposal. The model begins with receiving raw materials for product production at the factory, making the product available for sale.

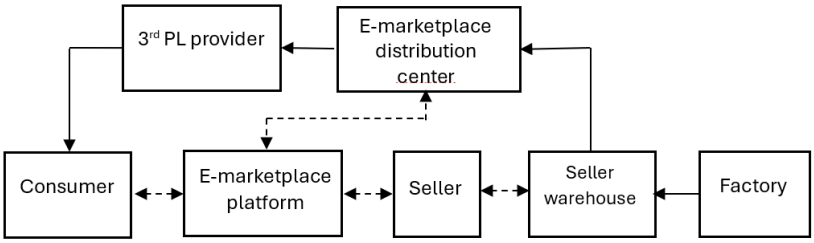


**Figure 3** E-commerce logistics model

Consumers typically place orders on the online marketplace. The data from similarweb found that the famous application in Thailand is Shopee and Lazada, with a duration of using the application around 6 minutes per person, and mobile phone is a famous device (similarweb, 2022). The warehouse picks the items according to the order details then plays a vital role in adding value to the order through repacking to ensure the product is protected during delivery. This additional packaging includes a parcel box, plastic bag, paper bill, consumer's address label, and tape. Once the parcel is ready for shipping, the E-marketplace sends a truck to collect it from the seller's warehouse and transport it to the platform's distribution center. The distribution center allocates the parcel to a third-party logistics (3rdPL) provider based on postal codes. The parcel is then dispatched to a depot and subsequently delivered to the consumer's location. After the consumer uses the product, it is ultimately disposed of via landfill methods. These processes are shown in **Figure 4**.

The detail of transportation process to deliver product parcels to the consumer's address includes four steps

1. A logistics provider from the marketplace platform picks up the product from the warehouse and transports it to the platform distribution center (DC). The approximate distance is 52 km, measured using Google Maps, with a 4-wheel truck.
2. The third-party logistics provider picks up the product from the platform DC and transports it to the third-party logistics DC. The approximate distance is 14 km, measured using Google Maps, with a 6-wheel truck.
3. The third-party logistics DC dispatches the product to the depot using a 4-wheel truck.
4. The depot dispatches the products to consumers' houses using a 4-wheel truck.

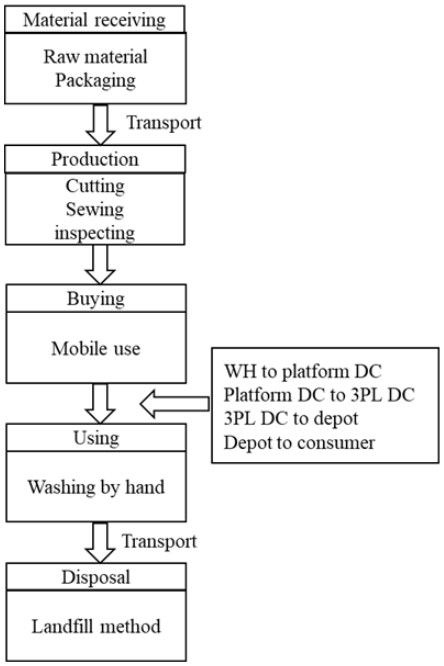


**Figure 4** Life cycle assessment (LCA) of e-commerce

## *4.2 Modern Commerce Model*

The modern commerce logistics model begins with consumers deciding to travel to a shopping center, which offers a wide range of products from various producers. The activities involved in the modern commerce logistics model is shown in **Figure 5**. The modern commerce model begins with product manufacturing at the factory, followed by transportation to a shopping center in Bangkok, Thailand, by a 4-wheel truck. Consumers visit the store to browse, purchase, and bring the product home.

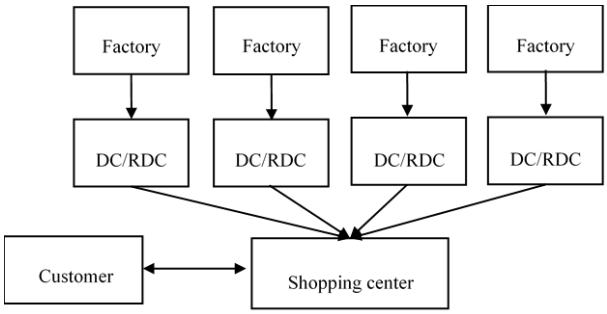


**Figure 5** Modern commerce logistics model

According to questionnaire results, most consumers prefer to drive a short distance, approximately 10 km, to the shopping center. Additionally, consumers use various modes of transportation to reach the store. Data collection shows that 92% of consumers use a private car, 4% use a motorcycle, 3% take the bus, and 1% opt for a taxi. After the product is used, it is disposed of via landfill methods. Carbon footprint evaluation is conducted in accordance with the principles of Life Cycle Assessment (LCA). The modern commerce models process is shown in **Figure 6**.

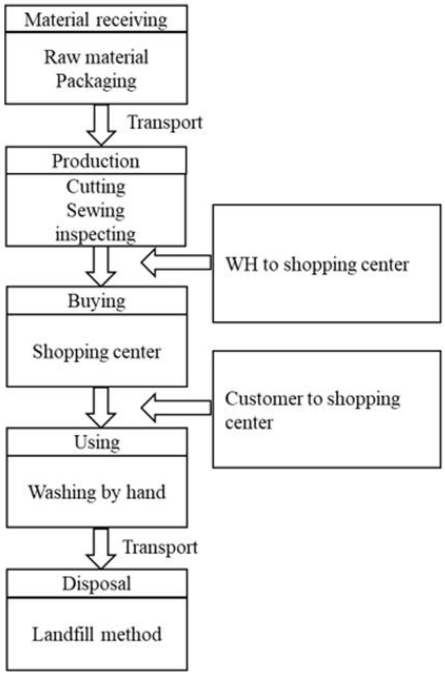


**Figure 6** Life cycle assessment (LCA) of modern commerce model

The carbon footprint value of both modern commerce and e-commerce models which refer to Life Cycle Assessment (LCA) is shown in **Figure 7**.

The e-commerce model generates a carbon footprint of 3.6292 kg $CO_2$ equivalent, while the modern commerce model produces 3.2246 kg $CO_2$ equivalent. Thus, the e-commerce model exceeds the carbon footprint of the modern commerce model by 0.4046 kg $CO_2$ equivalent. This higher carbon footprint in the e-commerce model is attributed to the processes involved in receiving, distribution, and disposal.

The e-commerce model's core value is to deliver the parcel of a product directly to the consumer's hands. Then, the use of additional packaging is generating a carbon footprint during material receiving and disposal activities. It generates emissions more than the modern commerce model of 0.166 kg $CO_2$ equivalent and 0.2394 kg $CO_2$ equivalent, respectively. Furthermore, the e-commerce model relies on multiple transportation chains to ensure complete delivery to consumers, which adds to its overall carbon footprint. However, in certain aspects, e-commerce can perform more efficiently in terms of transportation emissions, generating a slightly lower carbon footprint of 0.0008 kg $CO_2$ equivalent compared to modern commerce.

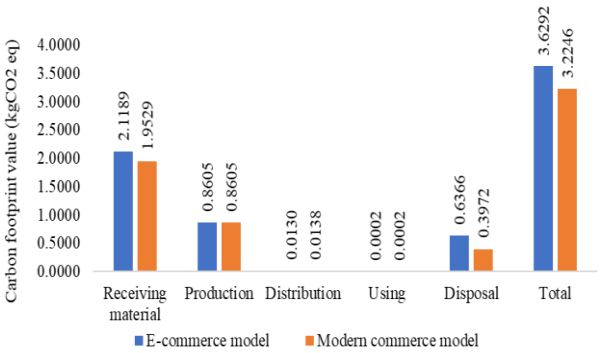


**Figure 7** The value of carbon footprint both modern commerce and e-commerce process

## *4.3 Development of Green E-commerce Model*

The researcher focused on applying green practices to relevant logistics processes, aiming to reduce transportation activities and eliminate unnecessary packaging in the existing e-commerce process. The effectiveness of the green concept was assessed by comparing the carbon footprint values between the current e-commerce model and the newly proposed green model, as detailed below.

### *4.3.1 Delivery Process*

The creation of a carbon footprint in the e-commerce model is primarily driven by multiple transportation chains. In the green design, sellers integrate their systems with an online marketplace platform to streamline the collection of order details. Additionally, sellers collaborate with a third-party logistics provider to manage product deliveries. This green approach simplifies the process by allowing the third-party logistics provider to collect parcels directly from the seller, thereby eliminating the need for the online marketplace platform's distribution center. In this green model, the third-party logistics provider's distribution center takes on the responsibilities of sorting and routing the orders before sending them to local depots. From there, the depots dispatch the product parcels directly to the consumers. This streamlined process reduces the number of transportation steps and minimizes the carbon footprint associated with the delivery process. The effectiveness of this green design was evaluated by comparing the carbon footprint values between the current e-commerce model and the green model, demonstrating the potential for significant environmental benefits through improved logistics practices.

### *4.3.2 Packaging*

The current e-commerce process generates significant

waste due to the use of extra packaging materials such as cardboard boxes, bubble wrap, and plastic bags, which are used to protect products during delivery. To address this issue, redesign concepts have been implemented to reduce packaging waste. Despite products already being packaged in boxes, some sellers still place them in larger boxes, resulting in unnecessary double packaging. This practice can be avoided if the seller or producer ensures that the primary packaging is sufficient to protect the product. Additionally, the carbon footprint of packaging can be directly reduced by limiting the use of extra materials such as plastic bags and plastic envelope sleeves. The impact of these changes was assessed by comparing the carbon footprint values between the current and redesigned e-commerce models, highlighting the potential for substantial environmental benefits through improved packaging practices. The current packaging consists of a plastic envelope sleeve with two parts of an airway bill attached to the parcel. However, with the streamlined delivery process, the new packaging will reduce the airway bill to a single part and eliminate the use of plastic bags, plastic sleeves, and order receipts.

### *4.4 Green E-commerce process and carbon footprint calculation*

The green e-commerce model begins once the product has been manufactured and stored in the seller's warehouse. After receiving a consumer order, the item is picked, repacked, and prepared for shipment. The transportation process is streamlined by having a third-party logistics provider collect the product from the seller's warehouse, transport it to their distribution center, and then deliver it to the consumer's address. The activities involved in the green e-commerce logistics model is shown in **Figure 8**.

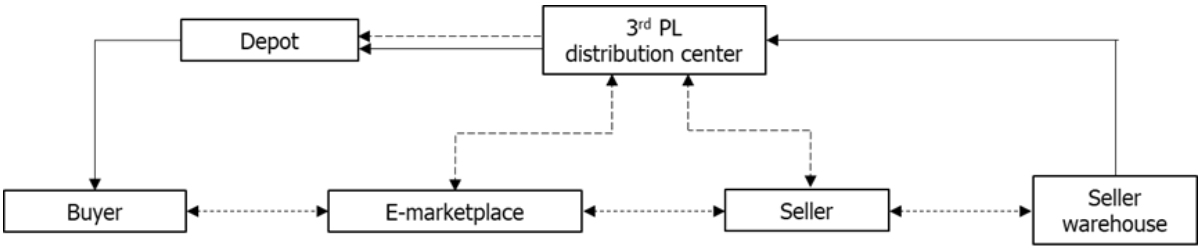


**Figure 8** Green e-commerce logistics model

To evaluate the carbon footprint following the principles of Life Cycle Assessment (LCA), the green e-commerce process begins the same way as the current model in receiving material and production process. After the consumer places an order via mobile phone, the product is picked and repackaged in the seller's warehouse, where unnecessary materials are eliminated. In this green model, the process is optimized by linking the seller's system to the e-commerce platform and the third-party logistics (3rdPL) distribution center. This integration reduces the need for printing two airway bills to just one. The 3rdPL provider collects the product directly from the seller's warehouse and transports it to their distribution center, eliminating the e-commerce platform's distribution center from the loop and avoiding double transportation. The product is then carried by a 4-wheel truck for an approximate distance of 42 km, as measured by Google Maps and subsequently transferred to the depot corresponding to the postal code. Finally, the depot dispatches the parcel to the consumer. Once the consumer has used the product, it is typically disposed of in a landfill. The green processes are shown in **Figure 9**.

The carbon footprint values for both the current and green e-commerce models, as assessed using Life Cycle Assessment (LCA) principles, are shown in **Figure 10**.

By eliminating unnecessary materials such as plastic bags, order detail papers, and plastic envelopes during the receiving process, the carbon footprint is reduced from 2.2189 kg $CO_2$ equivalent to 2.0576 kg $CO_2$ equivalent. Additionally, the distribution process has been optimized by removing the step of sending products through intermediary locations. Instead, products are now sent directly from the seller's warehouse to a third-party logistics distribution center. This streamlined approach reduces the carbon footprint from 0.0130 kg $CO_2$ equivalent to 0.0099 kg $CO_2$ equivalent. Furthermore, the carbon footprint from the disposal process is aligned with the improvements made in the receiving process, resulting in decreasing from 0.6366 kg $CO_2$ equivalent to 0.5920 kg $CO_2$ equivalent.

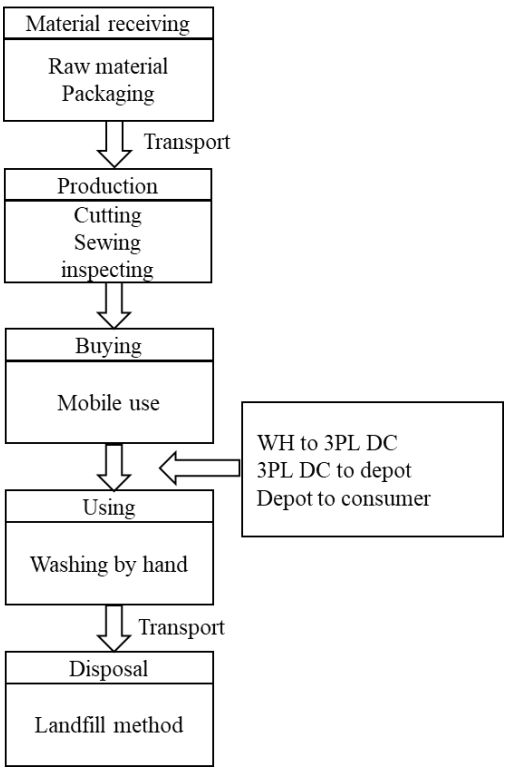


**Figure 9** The e-commerce green process

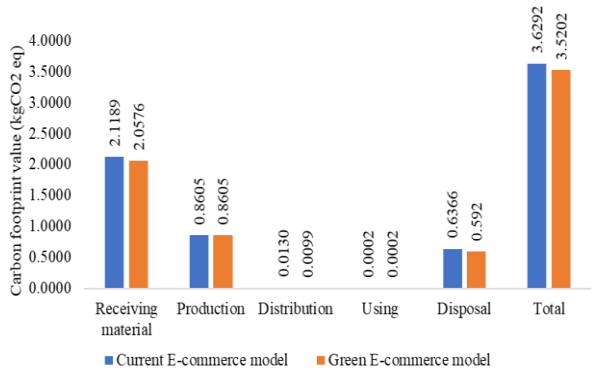


**Figure 10** The value of carbon footprint of current and green e-commerce process

The carbon footprint of the green e-commerce model has been reduced by 0.1090 kg $CO_2$ equivalent per order, or 3% reduction. According to PPTV (2023), Thailand's e-commerce order volume was predicted to reach 7 million orders per day in 2022. This reduction results in a daily decrease of 762,890 kg $CO_2$ equivalent in carbon footprint. Based on the e-commerce sales data in Thailand and the assumption of daily order quantities in 2022, the cumulative environmental benefits of implementing the green e-commerce model are shown in **Figure 11**.

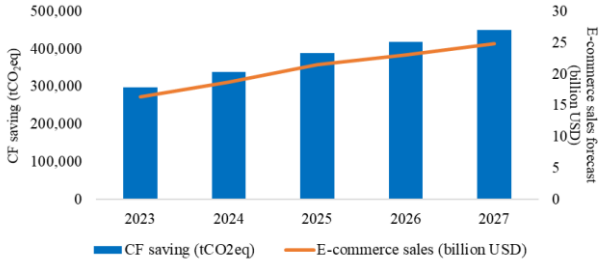


**Figure 11** Carbon footprint saving forecast in the next 4 years

In 2023, the carbon footprint savings from the green e-commerce model amounted to 297,532 t $CO_2$ equivalent, with a corresponding sales value of 16.41 billion U.S. dollars. This savings is projected to increase to 449,834 t $CO_2$ equivalent, with an expected sales value of 24.81 billion U.S. dollars in 2027. Considering carbon credits as transferable instruments certified by governments or independent certification bodies, they represent a reduction in the emission of tons of carbon dioxide ($CO_2$).

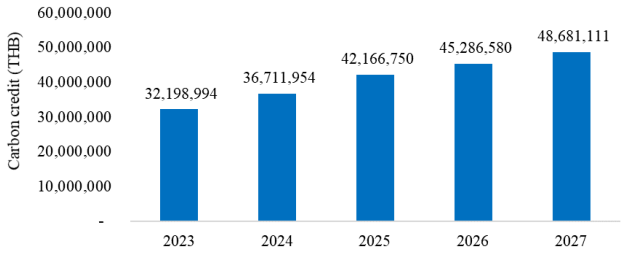


**Figure 12** Carbon credit

These credits can be quantified and traded on the market, providing a financial incentive for reducing carbon emissions. The average cost per ton of carbon credit is 108.22 Thai Baht (THB). By applying the green e-commerce model, the savings in carbon footprints can be convert into monetary value through carbon credits. The saving of carbon credit is shown in **Figure 12**.

The green e-commerce model can significantly reduce carbon dioxide emissions and convert these reductions into carbon credits. This approach is projected to generate financial benefits of approximately 32 million THB in 2023, with an anticipated increase to 48 million THB by 2027. Additionally, the elimination of unnecessary packaging materials, such as plastic bags, plastic sleeves, and order receipts, results in direct cost savings. The cost of these materials is 2.42 THB per order. The total cost savings achieved by removing these materials from the packaging process approximately 18 million THB in 2023, with an anticipated increase to 27 million THB by 2027 as shown in **Figure 13**.

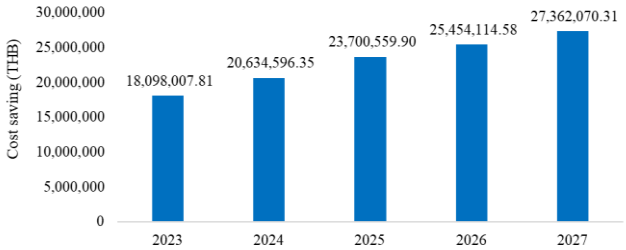


**Figure 13** Cost saving from elimination of unnecessary packaging material

# 5. DISCUSSION

The rise of global e-commerce sales signifies a profound transformation in retail dynamics. e-commerce sales in Thailand are expected to see a staggering 529% increase from $3.4 billion in 2017 to $24.81 billion by 2027 reflecting a significant rise in online shopping behavior. However, this growth brings with it substantial environmental concerns, as e-commerce activities contribute significantly to waste, pollution, and traffic congestion due to complex transportation chains and increased packaging requirements. This study addresses these concerns by exploring the environmental impact of e-commerce, focusing on carbon footprint assessment and proposing a sustainable e-commerce model through green supply chain management (GSCM). E-commerce impacts the environment through four primary activities: packaging, energy consumption, transportation, and information flow. Each activity involves key supply chain partners such as warehouses, distribution centers, and consumers, contributing to environmental costs measured in terms of energy use and carbon emissions. Previous studies have documented these impacts extensively, yet there remains a gap in comprehensively examining all dimensions of e-commerce activities, particularly in the context of Thailand. This study aims to fill this gap by analyzing the entire e-commerce supply chain and calculating the carbon footprint for both e-commerce and modern commerce models, subsequently implementing a green model to reduce the overall carbon footprint.

The research findings underscore the significant differences between modern commerce and e-commerce models in terms of their environmental impact, particularly focusing on carbon footprints. This discussion will explore

the implications of these differences, the development of a green e-commerce model, and its potential benefits. The Life Cycle Assessment (LCA) conducted for both models reveals that the e-commerce model generally has a higher carbon footprint than the modern commerce model. The e-commerce model generates a carbon footprint of 3.6292 kg $CO_2$ equivalent per product, compared to 3.2246 kg $CO_2$ equivalent for the modern commerce model. This finding contrasts with Zhao *et al.* (2019) who concluded that conventional retail trade has higher $CO_2$ emissions than e-commerce. The primary contributors to this increased carbon footprint in e-commerce include the distribution process and the use of additional packaging materials. E-commerce often requires extra packaging to protect products during transit, which adds to the carbon footprint. This is consistent with Zhao *et al.* (2019) who found that packaging from e-commerce activities is a significant source of carbon emissions, a factor does not present in conventional retail trade. Despite these challenges, the e-commerce model shows slightly lower transportation emissions due to optimized logistics in certain aspects.

To address the environmental impacts of e-commerce, the study proposes a green e-commerce model focused on reducing transportation activities and eliminating unnecessary packaging. Key changes include streamlining the delivery process by integrating seller systems with third-party logistics providers, bypassing the online marketplace platform's distribution center, and optimizing packaging to reduce waste. The green delivery process simplifies transportation by allowing third-party logistics providers to collect parcels directly from sellers, sort orders at their distribution centers, and dispatch them to local depots before final delivery to consumers. This reduces the number of transportation steps and associated carbon footprint. The green packaging approach eliminates unnecessary double packaging and reduces the use of extra materials such as plastic bags and sleeves. By ensuring that primary packaging is sufficient for product protection, the carbon footprint from packaging is significantly reduced. These two key environmental impact issues align with finding from Cheris *et al*. (2017); Mckinnon & Cullinane (2010).

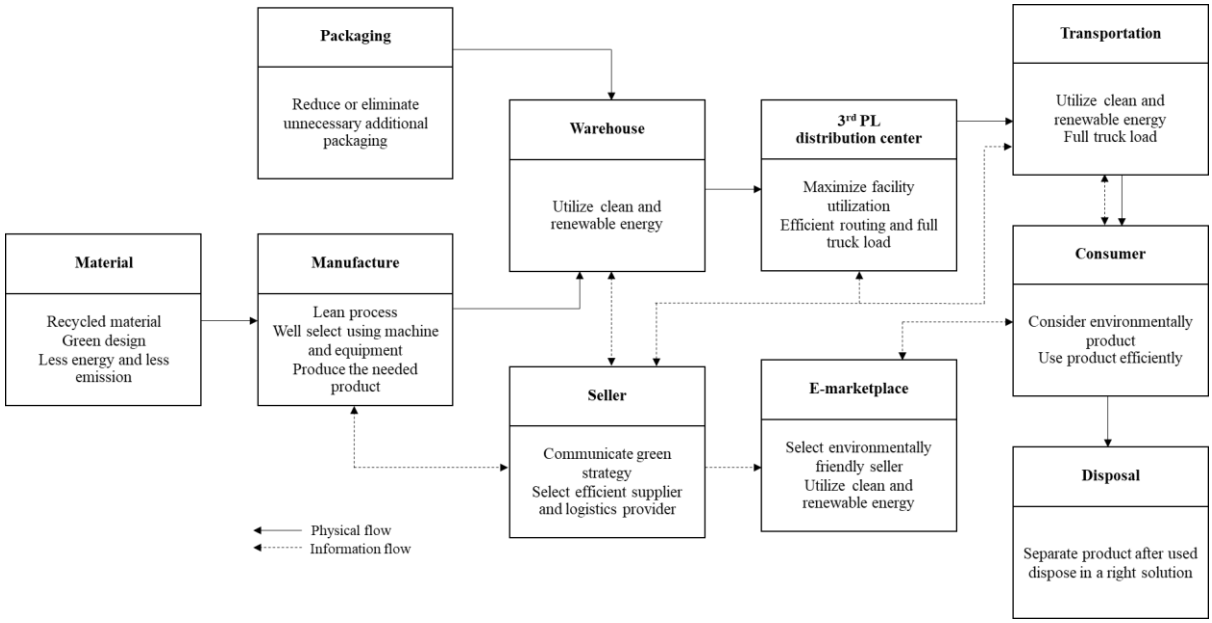


**Figure 14** Green e-commerce model

The green e-commerce model results in a carbon footprint reduction of 0.1090 kg $CO_2$ equivalent per order, a 3% decrease. Considering Thailand's predicted e-commerce order volume of 7 million orders per day in 2022, this reduction translates to a daily decrease of 762,890 kg $CO_2$ equivalent. This substantial reduction in carbon footprint highlights the environmental benefits of adopting green practices in e-commerce. In addition to environmental benefits, the green e-commerce model offers financial advantages through carbon credits, which represent a reduction in $CO_2$ emissions and can be traded on the market. The projected financial benefits from carbon credits amount to approximately 32 million THB in 2023, increasing to 48 million THB by 2027. Furthermore, eliminating unnecessary packaging materials results in direct cost savings approximately 18 million THB in 2023, increasing to 27 million THB by 2027.

However, achieving Green Supply Chain Management (GSCM) involves more than just green packaging and shortening transportation routes. Key implementations also include reducing energy consumption, decreasing the use of natural resources, reducing pollution-related problems and increasing recycling of raw materials and supplies (Jaggernath & Khan, 2015). The green e-commerce supply chain management model is implemented by integrating 4Rs practices-reduce, reuse, recycle and redesign-throughout the entire supply chain process from sourcing materials to manufacturing, selling, E-marketplaces, warehousing, third-party logistics distribution centers, transportation, consumer delivery, and disposal, as shown in **Figure 14**.

Material receiving step is crucial for ensuring environmental sustainability. Sellers should opt for eco-friendly materials and equipment to reduce the high carbon footprint intensity (Alvarez & Rubio, 2015). This green

design process involves creating products that produce fewer emissions during manufacturing and usage. Green manufacturing transforms raw materials into finished products with minimal negative environmental impact, reducing waste and emissions. Sellers should produce needed products to avoid unwanted stock, utilize green technology, and focus on recyclable, reusable, or upcyclable materials. Sellers should use recycled materials for primary and secondary packaging and limit the use of tertiary paper packaging. Properly packed products reduce the need for additional protective materials. Renewable energy-powered machinery and equipment are essential to reduce carbon footprints. Sellers should communicate their green initiatives effectively and select efficient logistics providers who consolidate orders and use short routes, reducing transportation emissions. E-marketplaces facilitate communication of green strategies and promotions, encouraging consumers to purchase multiple items to reduce packaging and shipping activities. They should prioritize sellers with eco-friendly products and consider using clean energy for operations. Reducing and recycling packaging is critical due to its significant environmental impact (Sanyé-Menguala *et al*., 2014).

Efficient warehouse management is crucial for reducing supply chain carbon footprints (Minashkina & Happonen, 2019). Warehouses should use renewable energy, efficient lighting, and temperature control, and consider alternative energy sources such as hydrogen and biodiesel for transportation. Tesco's zero-carbon store serves as a model, utilizing solar and wind energy, natural lighting, rainwater collection, and eco-friendly refrigeration systems. Distribution centers should optimize routing and full truckload management to ensure efficient delivery. Renewable energy and well-designed facilities further contribute to reducing the carbon footprint. Last-mile delivery emissions are expected to rise by 30% in the next decade. To mitigate this, sellers should communicate the benefits of longer delivery times and offer eco-friendly delivery options such as electric or hydrogen-powered vehicles. Efficient routing can reduce delivery costs and $CO_2$ emissions by 25-30% by 2030 (World Economic Forum, 2020). This aligns with the findings of Cheris *et al.* (2017), which demonstrate that reducing split shipments can lower average per-item emissions by 30% and shipping costs by 50%. Consumers play a crucial role in e-commerce sustainability by making informed purchasing decisions. Promotions that encourage bulk purchases can reduce packaging waste. Proper product and packaging disposal also facilitate recycling efforts. Proper waste management ensures that materials are appropriately composted, recycled, or safely disposed of, reducing environmental harm.

# 6. CONCLUSION

The research highlights the need for sustainable practices in the e-commerce sector to mitigate its environmental impact. The proposed green e-commerce model demonstrates the way for more sustainable commerce practices. The adoption of such models can lead to significant environmental and financial benefits, contributing to global efforts in reducing carbon emissions and promoting sustainable development. The green supply chain management approach can be extended to the production process as green operation in order to face the challenge of gaining competitive advantage from the process of green supply chain management to improve firm performance (Novitasari & Agustia, 2022) by incorporating green energy and recycled materials as replacements for conventional resources. For the delivery process, the researcher considers using 4-wheel trucks for dispatching parcels. To optimize the entire logistics chain by selecting different transportation modes in different scenarios such as motor bike might have a higher carbon footprint reduction.

Implementing green design and processes to eliminate unnecessary packaging and streamline distribution are essential strategies for e-commerce. These strategies can be broadly applied across various e-commerce products. Additionally, adopting the 4Rs (reduce, reuse, recycle, and recover) practices throughout the entire supply chain from cradle to grave is crucial for reducing the carbon footprint. However, it is important to recognize that different product categories have unique processes. By understanding these specific processes, opportunities for incorporating green practices can be identified. This tailored approach ensures accurate calculation of the total carbon footprint for each product.

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