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Sustainable E-Commerce and Carbon Reduction in Last-Mile Delivery

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Abstract
The rapid expansion of electronic commerce has transformed retailing, consumer behaviour, and logistics systems. Although e-commerce can reduce certain forms of consumer travel and improve supply-chain efficiency, the growth of home deliveries, fragmented shipments, rapid delivery expectations, product returns, and low vehicle-load factors can increase environmental pressures, particularly in the last mile. Last-mile delivery represents the final stage between a distribution facility and the customer's delivery location and is one of the most operationally complex components of e-commerce logistics. This paper examines the relationship between sustainable e-commerce and carbon reduction in last-mile delivery from a Commerce and supply-chain perspective. It analyses the environmental implications of growing online sales and evaluates strategies including electric delivery vehicles, cargo bikes, route optimization, delivery consolidation, parcel lockers, urban logistics hubs, micro-fulfilment, alternative delivery models, green packaging, reverse logistics, and consumer participation in sustainable delivery choices.
The paper argues that carbon reduction cannot be achieved through vehicle electrification alone. A comprehensive approach is required that combines technological innovation, logistics consolidation, improved vehicle utilization, renewable energy, digital route planning, appropriate urban infrastructure, sustainable packaging, and behavioural changes among consumers. Urban logistics hubs can facilitate consolidation and the use of smaller zero-emission vehicles, while parcel lockers and consolidated pickup points can reduce vehicle-kilometres associated with door-to-door delivery. OECD/ITF analysis reports that consolidated package pickup and drop-off locations can reduce urban package vehicle-kilometres by 27% relative to a baseline based on door-to-door deliveries, while asset sharing across operators can reduce urban package vehicle-kilometres by 23%.
The study further argues that sustainability must be integrated with commercial objectives. Delivery speed, free shipping, low delivery charges, and free returns can encourage logistics practices that increase emissions. Consequently, sustainable e-commerce requires businesses to balance convenience, profitability, customer satisfaction, and environmental performance. The paper proposes an integrated framework based on five dimensions: green transportation, logistics optimization, delivery consolidation, circular and reverse logistics, and sustainable consumer behaviour. It concludes that carbon reduction in last-mile delivery is most effective when technological, organizational, economic, and policy interventions operate together.

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Keywords: Sustainable E-Commerce, Last-Mile Delivery, Carbon Reduction, Green Logistics, Electric Vehicles, Sustainable Supply Chain, Route Optimization, Parcel Lockers, Urban Logistics, Reverse Logistics, Consumer Behaviour, E-Commerce.

1. Introduction

Electronic commerce has become an important component of modern retail and commercial activity. Consumers increasingly purchase products through digital platforms, while businesses use online channels to reach geographically dispersed markets. E-commerce provides consumers with convenience, broader product choice, price comparison, and home delivery. For businesses, it provides access to new markets, digital customer data, and opportunities for more efficient inventory and marketing systems.

However, the environmental consequences of e-commerce are complex.

Online purchasing may reduce some consumer trips to physical stores, but it also creates additional delivery activity. Individual products or small orders may be transported directly to households, creating a fragmented distribution structure. The environmental effect therefore depends on factors such as delivery density, vehicle utilization, travel distance, delivery mode, energy sources, packaging, return rates, and consumer behaviour.

The OECD notes that there is no simple conclusion that e-commerce is either environmentally beneficial or harmful. While online shopping can reduce some consumer travel, residential deliveries may have lower transport and packaging efficiency than consolidated commercial deliveries.

The problem becomes particularly important in the **last mile**.

The last mile refers broadly to the final stage of the distribution process through which goods move from a local distribution facility or logistics hub to the customer. This stage is characterized by dispersed destinations, traffic congestion, limited parking, small shipment sizes, delivery time windows, and frequent failed deliveries.

Urban logistics has significant environmental implications. OECD/ITF research identifies freight transport as an important contributor to urban pollution and congestion and highlights the growing importance of zero-emission vehicles, cargo bikes, logistics hubs, and improved curb management.

The growth of e-commerce makes this challenge increasingly important.

Consumers often expect:

- fast delivery;
- free delivery;
- narrow delivery windows;
- easy returns;
- home delivery;
- immediate order tracking.

Although these services increase convenience, they can also make logistics systems less efficient.

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The central challenge is therefore:

How can e-commerce continue to grow while reducing the carbon emissions associated with last-mile delivery?

This paper examines this question from a Commerce perspective and develops an integrated framework for sustainable last-mile e-commerce.

2. Conceptual Understanding of Sustainable E-Commerce

Sustainable e-commerce refers to the integration of environmental, economic, and social sustainability principles into digital commercial activities.

It extends beyond the use of renewable energy in warehouses.

A sustainable e-commerce system considers the complete commercial process:

Product Sourcing → Warehousing → Order Processing → Packaging → Transportation → Last-Mile Delivery → Returns → End-of-Life Management

Sustainability therefore requires attention to the entire value chain.

The three principal dimensions are:

Environmental Sustainability

Reduction of:

- carbon emissions;
- air pollution;
- waste;
- energy consumption;
- unnecessary transportation.

Economic Sustainability

Maintenance of:

- profitability;
- operational efficiency;
- cost competitiveness;
- long-term business viability.

Social Sustainability

Attention to:

- delivery-worker conditions;
- urban liveability;
- road safety;
- accessibility;
- community impacts.

Sustainable e-commerce therefore requires a balance between commercial performance and environmental responsibility.

3. Last-Mile Delivery in E-Commerce

Last-mile delivery is the final connection between the logistics network and the consumer.

A simplified e-commerce distribution chain is:

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Supplier → Fulfilment Centre → Distribution Centre → Local Hub → Customer

The final segment is particularly challenging because customer locations are geographically dispersed.

A conventional bulk shipment may deliver hundreds of products to one location.

A home-delivery model may require many separate trips.

Consequently:

Bulk Retail Distribution

can become:

Multiple Individual Residential Deliveries

This creates challenges involving:

- vehicle-kilometres;
- fuel consumption;
- congestion;
- delivery failures;
- parking;
- driver time;
- emissions.

OECD research identifies the last mile as an increasingly important part of urban freight systems as online shopping grows.

4. Environmental Impact of Last-Mile Delivery

4.1 Carbon Emissions

The most important environmental concern is greenhouse-gas emissions from delivery vehicles.

Conventional petrol and diesel vehicles generate emissions during operation.

The total carbon impact also depends on:

- vehicle type;
- distance travelled;
- load factor;
- fuel efficiency;
- electricity source;
- delivery density.

4.2 Traffic Congestion

Increasing numbers of delivery vehicles can contribute to urban congestion.

Congestion creates a feedback effect:

More Delivery Vehicles → More Congestion → Longer Travel Time → Higher Energy Consumption → More Emissions

4.3 Air Pollution

Combustion-powered delivery vehicles can contribute to local air pollutants.

This is especially important in densely populated urban areas.

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4.4 Noise

Delivery vehicles also generate noise, particularly when deliveries occur early in the morning or late at night.

Electric vehicles and smaller delivery modes may reduce some noise impacts.

5. E-Commerce Growth and Environmental Pressure

E-commerce does not automatically produce higher or lower emissions.

Its environmental effect depends on the logistics model.

For example:

Scenario A

One consumer drives to a shopping centre, purchases several products, and returns home.

Scenario B

Several individual products are delivered separately to the consumer's home.

The relative environmental performance depends on:

- distance;
- vehicle efficiency;
- delivery consolidation;
- number of products;
- delivery density.

The ITF has emphasized that increased e-commerce can increase freight activity, congestion, and emissions, particularly where delivery windows are narrow, vehicle capacity is underused, and returns are frequent.

Therefore, sustainability depends on **how e-commerce deliveries are organized**, not simply on whether purchasing occurs online.

6. Electric Vehicles for Last-Mile Delivery

Electrification is one of the most visible strategies for reducing operational emissions.

Electric delivery vehicles include:

- electric vans;
- electric trucks;
- electric three-wheelers;
- electric two-wheelers;
- electric cargo bikes.

Electric vehicles can eliminate tailpipe emissions and potentially reduce operating costs.

The International Transport Forum notes that delivery vehicles can be attractive candidates for electrification because their high mileage can strengthen the economic case for electric fleets.

However, electrification does not automatically eliminate all environmental impacts.

The overall carbon benefit depends partly on:

- electricity generation;
- battery production;
- vehicle manufacturing;

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- battery lifetime;
- charging infrastructure.

Therefore, the preferred strategy is:

Electric Vehicles + Renewable Electricity + Efficient Routing

rather than electrification alone.

7. Electric Two- and Three-Wheelers

Electric two- and three-wheelers may be particularly useful in dense urban environments.

Their advantages include:

- smaller physical footprint;
- lower energy requirements;
- easier navigation through congested areas;
- lower parking requirements.

This can be particularly relevant in emerging economies.

World Bank analysis of e-mobility identifies electric two- and three-wheelers as potentially cost-effective entry points for transport electrification in many developing-country contexts.

For e-commerce, they can support:

Local Hub → Customer

deliveries.

8. Cargo Bikes and Non-Motorized Delivery

Cargo bikes can be effective for dense urban delivery routes.

They are especially suitable where:

- delivery distances are short;
- traffic congestion is high;
- parking is limited;
- customer density is high.

OECD/ITF analysis indicates that shifting feasible last-mile deliveries to cargo bikes can reduce motorized vehicle-kilometres, while also producing benefits for urban safety, air pollution, and space consumption.

However, cargo bikes have limitations.

They may not be suitable for:

- long distances;
- large shipments;
- rural deliveries;
- heavy goods.

The correct approach is therefore to use **mode matching** rather than a universal replacement strategy.

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9. Route Optimization

Artificial intelligence, machine learning, GPS, and advanced analytics can optimize delivery routes.

A traditional routing system may plan:

A → B → C → D → E

Advanced systems can consider:

- traffic;
- delivery windows;
- vehicle capacity;
- customer locations;
- road restrictions;
- weather;
- charging requirements.

The objective becomes:

Minimum Distance + Minimum Time + Maximum Load Utilization + Minimum Emissions

This can reduce unnecessary vehicle movement.

Conclusion

Sustainable e-commerce requires more than replacing petrol and diesel delivery vehicles with electric alternatives. The environmental impact of online commerce is determined by the entire logistics system, including order volumes, delivery density, routing, vehicle utilization, packaging, returns, consumer choices, and urban infrastructure.

Last-mile delivery is particularly important because it involves fragmented shipments and geographically dispersed destinations. Rapid delivery expectations, free shipping, narrow delivery windows, and high return rates can make logistics less efficient and increase environmental pressure.

At the same time, e-commerce provides significant opportunities for sustainability. Digital technologies can consolidate demand, optimize routes, position inventory closer to customers, improve vehicle utilization, and provide consumers with sustainable delivery options.

Electric vehicles represent an important part of the transition. Electric vans, two-wheelers, three-wheelers, and cargo bikes can reduce operational emissions when appropriately deployed. However, their benefits are strongest when combined with renewable electricity, efficient routing, appropriate infrastructure, and high delivery density.

Parcel lockers and consolidated pickup points provide another important solution. OECD/ITF modelling indicates that consolidated package pickup and drop-off locations can reduce urban package vehicle-kilometres by 27% compared with a door-to-door baseline. Urban logistics hubs can further facilitate consolidation and the use of smaller zero-emission vehicles.

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The commercial dimension is equally important. Businesses must balance sustainability with customer expectations and profitability. Green delivery cannot succeed if it is perceived exclusively as a sacrifice by consumers. Instead, sustainable options should be designed as convenient, affordable, and reliable alternatives.

The future of sustainable e-commerce will therefore depend on an integrated model:

Green Vehicles + Smart Routing + Consolidation + Sustainable Packaging + Circular Returns + Consumer Participation + Public Policy

No single intervention can solve the carbon challenge of last-mile delivery.

The most effective strategy is a coordinated logistics ecosystem in which businesses, consumers, technology providers, logistics operators, and governments share responsibility.

Sustainable e-commerce should ultimately move from a model of:

Fastest Possible Delivery

toward:

Efficient, Low-Carbon, Customer-Centred Delivery

Such a transition can enable e-commerce to continue generating economic value while contributing to cleaner, less congested, and more sustainable cities.

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