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Research on the Development Path of E-commerce Logistics in the Context of Carbon Neutrality

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Abstract. This research paper aims to explore the development path of e-commerce logistics in the context of carbon neutrality. With the increasing concerns about environmental sustainability, the e-commerce industry has been pushed to find innovative solutions to reduce carbon emissions and promote sustainable practices. This study examines various strategies and approaches that can be adopted to achieve a greener and more efficient e-commerce logistics system. By analyzing the current trends, challenges, and opportunities, this paper provides insights and recommendations for policymakers, companies, and stakeholders in the e-commerce logistics sector. It requires comprehensive planning and decomposition of the entire process of e-commerce logistics. There are several key points to consider in achieving carbon neutrality for e-commerce platforms, such as green warehousing, green packaging, green transportation, and technological innovation, some top logistics companies achieved a cumulative carbon reduction. Adding a touch of "green" to the performance report of e-commerce promotions has become a proactive choice for an increasing number of platforms.

1. Introduction

With the popularization of the low-carbon and environmental protection concept, the public's awareness of green and low-carbon has been continuously increasing. Under the "dual carbon" goals, all sectors of society in China are actively responding and seeking the path of low-carbon transformation and development. Among them, e-commerce logistics, as a major energy consumer, involves numerous and complex links. We discuss the implications of these findings for the e-commerce logistics industry and highlight the importance of adopting sustainable practices to achieve a greener and more efficient system. E-commerce has experienced tremendous growth, but its rapid expansion has also resulted in increased carbon emissions due to transportation, packaging waste, and energy consumption. As the world strives to mitigate climate change and achieve sustainable development, it is imperative to explore the development path of e-commerce logistics in the context of carbon neutrality.

1.1. Research Objectives

The primary objective of this research paper is to investigate and analyze the development path of e-commerce logistics in the context of carbon neutrality. The study aims to identify strategies, innovations, and best practices that can be adopted to reduce carbon emissions and promote sustainable practices within the e-commerce logistics sector. Additionally, it seeks to provide insights into the current trends, challenges, and opportunities faced by stakeholders in this domain.

1.2. Research Methodology
To achieve the research objectives, this study employs a comprehensive research methodology. It involves conducting a thorough literature review to gather relevant information on carbon neutrality, e-commerce logistics, and sustainable practices. Both qualitative and quantitative data will be utilized to analyze the current status and trends in e-commerce logistics and carbon emissions. Case studies and interviews with experts in the field will also be conducted to gain additional insights and practical experiences. The research findings will be presented and interpreted in a manner that provides valuable recommendations for policymakers, companies, and stakeholders in the e-commerce logistics sector.

2. The Importance of Carbon Neutrality in E-commerce Logistics

2.1. Environmental Impacts of E-commerce Logistics
E-commerce logistics operations have significant environmental impacts that contribute to climate change and environmental degradation. Some of the key environmental impacts include:
Greenhouse Gas Emissions: The transportation and delivery of e-commerce goods generate substantial greenhouse gas emissions, particularly carbon dioxide (CO_2) from fossil fuel combustion. These emissions contribute to global warming and climate change.
Air Pollution: E-commerce logistics activities, such as last-mile delivery, often involve a large number of vehicles operating in urban areas. The exhaust emissions from these vehicles contribute to air pollution, including harmful pollutants such as nitrogen oxides (NO_x) and particulate matter (PM).
Energy Consumption: E-commerce logistics operations require energy for transportation, warehousing, and packaging processes. The energy sources used in these operations, such as fossil fuels and grid electricity, can have significant environmental implications, especially if they are derived from non-renewable sources.
Waste Generation: Packaging materials, such as cardboard boxes, plastic wraps, and cushioning materials, generate substantial waste in e-commerce logistics. Improper disposal and excessive use of non-recyclable materials contribute to landfill waste and resource depletion.

2.2. Carbon Neutrality and its Relevance to E-commerce
Carbon neutrality refers to achieving a balance between carbon emissions and carbon removal or offsetting activities. It is a critical concept in the context of combating climate change and achieving sustainability goals. Consumers are increasingly conscious of environmental issues and prefer to engage with companies that prioritize sustainability. E-commerce companies that embrace carbon neutrality can enhance their reputation, attract environmentally aware consumers, and gain a competitive advantage in the market.

2.3. Benefits of Carbon Neutrality in E-commerce Logistics
The pursuit of carbon neutrality encourages e-commerce logistics companies to explore innovative solutions, such as sustainable transportation options, packaging optimization, and renewable energy integration. These practices can lead to long-term operational efficiency gains, improved resource management, and reduced environmental impacts.

3. Current Trends and Challenges in E-commerce Logistics
Despite the growth and opportunities, the e-commerce logistics industry faces several challenges that need to be addressed to ensure smooth operations and customer satisfaction. Some of the key challenges include: The last-mile delivery, which refers to the final leg of the delivery process from the distribution centre to the customer's doorstep, as it involves reverse logistics and inventory management challenges. The introduction of smart logistics management platforms utilizing cloud computing, cloud storage, big data, and artificial intelligence can effectively control and regulate the

entire process of logistics. This enhances communication speed between various logistics sections, improves inventory utilization efficiency, optimizes logistics transportation by saving mileage and capacity, and streamlines logistics processes.

3.1. Quantitative CO2 Emission Analysis
Our joint effort addresses the complexity of assessing CO2 emissions in logistics transportation systems. We expand on the considerations of uni-modal and intermodal systems, emphasizing the need to account for emissions at different stages, including long-haul and drayage. Furthermore, our research introduces the concept of life cycle and semi-life cycle assessments to capture both short-term and long-term environmental effects.

3.2. Formulation for Intermodal Systems
As discussed above, this study attempts to estimate the CO2 mass of combined freight systems, the relationship between entire door-to-door freight activities and emissions emitted by separate modes is mathematically modeled and combined in intermodal freight systems as follows:

$$E = \sum_{M}\sum_{I}\sum_{K}\left[d_{ik}W_m x_{ikm}E^{T}_{m} + f_{ikm}d_{ik}W_m x_{ikm}E^{P}_{m(s)}\right] +$$

$$\sum_{M}\sum_{K}\sum_{J}\left[d_{kj}W_m x_{kjm}E^{T}_{m} + f_{kjm}d_{kj}W_m x_{kjm}E^{P}_{m(s)}\right] +$$

$$\sum_{M}\sum_{K}\left[f_{k,k+1,\,m}\, d_{k,k+1}\, W_m x_{k,k+1}\left(E^{P}_{m(s)} + L\right)\right] Q_{k,k+1} +$$

$$2(1 + L)\left[E^{C}\sum_{I}\sum_{J}\sum_{M} x_{ijm}\right]E^{P}Trans(s).$$

E is total emissions, tone;
K is set of terminals, K = {1, 2, …k};
I is set of shippers, I = {1, 2, …i};
J is set of consignees, J = {1, 2, …j};
M is set of mode, M = {Truck, Diesel locomotive train, Electric locomotive train, Vessel, Transshipment};
S is set of source of electricity generation, S = {Coal, Hydro, Oil, Nuclear};
X ijm is 1 if a trip from i to j is made by m, 0 otherwise.
F ijm is fuel consumption of mode m from i to j (or from k to k+1), KJ/tone-km;
D ij is distance travelled from i to j, km;
Wm is gross weight of load per trip by m, kg;
L is average transmission loss of electricity between power plants and railways, %;

3.3. Different Freight Transport Systems Analysis
Integrated Freight Systems is applicable to the CO 2 emissions assessments for different freight transport systems: truck-only system (TO), Diesel powered train intermodal systems (DI), electric powered train intermodal systems (EI). The CO 2 emissions of DI systems fall 55% compare with TO system, but the DE systems' is 30% less than TO system. Besides the general benefits to the reduction of CO 2 emissions by shifting flows from road to rail, the dry port mainly offers seaports a possibility to increase the throughput without physical expansion as well as better services to shippers and

transport operators. Thus there are opportunities to transfer activities currently causing congestion at the seaport gates to the dry ports.

4. Strategies for Carbon-Neutral E-commerce Logistics

4.1. Green Supply Chain Management
Implementing green supply chain management practices can help minimize the environmental impact of e-commerce logistics. Some strategies include:

4.1.1 Sustainable Transportation Options
Promoting sustainable transportation alternatives can reduce carbon emissions. E-commerce logistics companies can consider utilizing electric vehicles, bicycles, public transportation, or even rail freight for transporting goods. Implementing efficient route planning and optimizing delivery schedules can further enhance sustainability.

4.1.2 Reverse Logistics and Circular Economy
Embracing reverse logistics and the circular economy principles can minimize waste and resource consumption. Establishing processes for product returns, repairs, refurbishment, or recycling can help extend product lifecycles and reduce environmental impact.

4.1.3 Supplier Collaboration and Green Procurement
Collaborating with suppliers who prioritize sustainable practices and offer eco-friendly products and packaging is crucial. Implementing green procurement policies and considering the environmental impact of the entire supply chain can result in more sustainable e-commerce logistics operations.

4.2 Regional Warehousing and Distribution Centers
Optimizing the location and operations of warehousing and distribution centers can minimize transportation distances and associated carbon emissions. Some strategies include:

4.2.1 Optimal Location Selection
Strategic selection of warehousing and distribution center locations considers proximity to major markets, transportation infrastructure, and availability of renewable energy sources. Opting for locations closer to customer clusters can reduce last-mile delivery distances.

4.2.2 Consolidation and Hub-and-Spoke Models
Employing consolidation and hub-and-spoke models in the distribution network can optimize delivery routes and reduce overall transportation mileage. Consolidating shipments or utilizing centralized hubs for sorting and distributing packages can increase operational efficiency and minimize emissions.

4.2.3 Efficient Inventory Management
Efficient inventory management techniques, such as demand forecasting, just-in-time inventory, and cross-docking, help minimize warehouse space requirements and reduce unnecessary transportation trips. Optimizing inventory levels reduces energy consumption and lowers carbon footprint.

4.3 Intelligent Logistics Management
Leveraging technology and data-driven approaches can enhance the efficiency and sustainability of e-commerce logistics processes. Some strategies include:

4.3.1 Internet of Things (IoT) in Logistics
Utilizing IoT devices, sensors, and connectivity solutions can enable real-time monitoring of shipments, optimize routing decisions, and improve overall supply chain visibility. This leads to better resource utilization, reduced delays, and enhanced sustainability.

4.3.2 Data Analytics and Predictive Modeling
Leveraging data analytics and predictive modeling techniques helps optimize transportation routes, demand forecasting, and inventory management. By making data-informed decisions, e-commerce logistics companies can reduce fuel consumption, minimize empty miles, and improve operational efficiency.

4.3.3 Automation and Robotics in Warehousing and Delivery
Implementing automation technologies, such as robotics, autonomous vehicles, and warehouse systems, streamlines operations and improves productivity. Automation reduces energy consumption, eliminates human errors, and enhances the overall sustainability of e-commerce logistics.

4.4 Packaging Optimization and Waste Reduction
Minimizing packaging waste and optimizing packaging designs are essential for sustainable e-commerce logistics:

4.4.1 Eco-Friendly Packaging Materials
Using eco-friendly and recyclable packaging materials, such as biodegradable plastics or sustainable alternatives like molded pulp, reduces the environmental impact. Additionally, opting for packaging suppliers committed to sustainability can promote waste reduction.

4.4.2 Right-Sizing and Efficient Packaging Design
Right-sizing packaging to match product dimensions reduces the use of excess materials and transportation space. Implementing efficient packaging designs, including collapsible or reusable packaging solutions, minimizes waste and enhances resource efficiency.

4.4.3 Reverse Logistics for Packaging Recovery
Establishing effective reverse logistics processes for packaging recovery and recycling ensures proper disposal or reuse. Partnering with recycling facilities or implementing take-back programs enables the recovery of packaging materials and reduces waste generation.

4.5 Renewable Energy Integration
Transitioning to renewable energy sources in e-commerce logistics operations supports carbon-neutrality:

4.5.1 Solar Power and Energy Storage Solutions
Installing solar panels on warehouses and distribution centers can generate renewable energy. When combined with energy storage solutions, excess energy can be stored and utilized during periods of high demand, reducing reliance on non-renewable energy sources.

4.5.2 Electric Vehicle Adoption in Logistics
Replacing traditional delivery vehicles with electric vehicles (EVs) significantly reduces carbon emissions. Investing in EV fleets and establishing charging infrastructure supports sustainable transportation in e-commerce logistics.

4.5.3 Green Energy Partnerships and Offsetting Mechanisms
Collaborating with green energy providers and participating in carbon offset programs helps neutralize the carbon footprint of e-commerce logistics operations. Purchasing renewable energy certificates or investing in sustainable projects can offset emissions.

4.6 Collaboration and Resource Sharing
Promoting collaborative approaches and resource sharing can enhance sustainability in e-commerce logistics:

4.6.1 Collaborative Logistics Networks

Collaborating with other logistics providers or retailers in shared networks can optimize delivery routes, enhance vehicle fill rates, and reduce the number of vehicles on the road. Sharing physical resources, such as warehouses or distribution centers, further improves operational efficiency.

4.6.2 Sharing Economy Models in Logistics

Implementing sharing economy concepts, such as crowdshipping or peer-to-peer delivery networks, allows individuals. Under normal circumstances, plant photosynthesis consumes $CO2$ while plant respiration and human and animal activities produce $CO2$, realizing the dynamic balance of C in nature, so that the natural temperature will not rise significantly. Since the industrial revolution, human activities have exploited and utilized a large amount of coal, oil and natural gas, which has destroyed the dynamic balance of C for hundreds of millions of years, leading to the rise of temperature. It can be considered that the excessive exploitation and utilization of coal, oil and natural gas led to the increase of carbon emissions and temperature.

5. Best Practices in Carbon-Neutral E-commerce Logistics

5.1 Company A's Sustainable Supply Chain Management

Company A (Jingdong Logistics) is committed to sustainable supply chain practices in their e-commerce logistics operations. Jingdong Logistics has always emphasized the important role of technological innovation in enterprise development. Based on underlying technologies such as 5G, artificial intelligence, big data, cloud computing and the Internet, and has not only greatly improved its efficiency in warehousing, transportation, sorting and distribution through automated handling robots, sorting robots, intelligent express vehicles, drones, etc., but also independently researched and developed warehousing, transportation and order management systems, etc. By optimizing local warehouse resources and effectively increasing the utilization of idle warehouses, small and medium-sized logistics enterprises can also make full use of Jingdong Logistics' technologies, standards and brands to improve their service capabilities. As the core of logistics business cluster development, logistics parks play an important role in the low-carbon transportation system. The informatization and intelligent upgrading of logistics parks is committed to promoting the dual sustainable goals of reducing social logistics costs and optimizing carbon emissions, and is the key "breaking point" for realizing the transformation and upgrading of the industry and sustainable development. Jingdong Logistics converges intelligent logistics robots, video convergence terminals, label recognition gateways, AR and other on-site intelligent devices across geographic parks through a unified 5G network, as well as the cooperative control and scheduling of robot clusters, the remote operation and maintenance guidance of robotic equipment, the application of intelligent sensing of personnel, vehicles, and energy, and the carbon-neutral and energy management. The project product system serves the sustainable development needs of logistics parks:

1) Demand for continuous enhancement of digital information infrastructure: There are pain points in the park network such as network fragmentation, system localization, difficulties in collaboration, and difficulties in operation and maintenance; the existing network is also unable to meet the communication demand for denser, high-speed automation equipment and IOT terminals, as well as the demand for cross-park system sharing and collaboration.

2) Demand for intelligent upgrading of security monitoring facilities: abnormality discovery relies on manual experience, uncontrolled abnormality response time, and possible safety hazards and production failures caused by abnormality.

3) Cost of automation equipment and pain points of upgrading and maintenance: Early detection and treatment of operation and maintenance events directly affects productivity and the guarantee of strong time-sensitive logistics production waves. Flexible upgrades and iterations are key requirements for sustainable automation development.

(4) Energy optimization needs: High automation and high throughput in the park also correspond to large energy consumption. Under the background of double-carbon target, how to take into account intelligentization, energy supply and sustainable development is a topic that the park has been thinking about.

5.2 Specific implementation mode and process
The project is based on six basic capabilities, 5G cross-park collaborative private network, edge computing, cloud-side collaboration, AR, automation, and carbon neutral technology, covering the solution of different problems in multiple scenarios, such as resource digitization, monitoring and control intelligence, warehousing automation, remote collaborative operation and maintenance, and carbon neutral energy management. Jingdong Group internal operation analysis, conveyor belt congestion identification algorithms, timely detection of congestion and congestion trends, can significantly reduce the logistics losses caused by sorting line congestion and the time consumed by the need to stop production and channeling after the production line congestion. The park introduces photovoltaic, charging piles and other infrastructure to optimize the energy structure, and the introduction of non-transportation. Edge computing digital platform solution intelligently empowers the stock of logistics park cameras, compared to the use of high-end algorithms camera solution will reduce the implementation cost by more than 30%. It relies on its own operational data to qualify platform algorithm identification, further improving the accuracy of vehicle and platform identification and reducing arithmetic costs. Edge computing, such as used in face recognition, also helps to reduce the risk of data exposure, data hijacking, and effective protection of data privacy, while guaranteeing real-time digitization of on-site resources as well as real-time digitization-based scheduling management and security compliance management.

6. AI Reduction Solutions
Data-driven models enable us to analyze and predict the consequences of different carbon reduction measures. By employing machine learning algorithms, we can leverage historical emissions data to identify patterns and develop accurate forecasting models for future emissions scenarios. Furthermore, agent-based modeling can simulate complex systems, considering various factors such as geographical locations, population dynamics, and economic variables. Deep learning, a subfield of AI, can leverage its capabilities to analyze complex datasets, uncover hidden patterns, and make highly accurate predictions. AI can analyze energy consumption patterns, identify inefficiencies, and recommend strategies for reducing carbon emissions. AI algorithms can optimize transport routes, reduce congestion, and promote the use of electric vehicles. By leveraging data on traffic patterns, electric charging infrastructure, and user preferences, intelligent transportation systems can facilitate the transition to low-carbon mobility.
Carbon Capture and Storage (CCS): AI can play a vital role in optimizing CCS technologies. Machine learning algorithms can assist in analyzing geological data to identify suitable and secure storage sites for captured carbon dioxide (CO_2). Additionally, AI can improve the efficiency of carbon capture processes, enabling cost-effective and scalable deployment of CCS initiatives.

7. Government Initiatives and Carbon Neutrality Goals
Government initiatives play a crucial role in promoting carbon neutrality in e-commerce logistics. To support these initiatives, governments can implement various measures such as providing financial incentives, grants, or tax breaks to encourage e-commerce companies to adopt sustainable practices and invest in green technologies. Governments should facilitate collaboration between e-commerce stakeholders, including companies, research institutions, and industry associations. This collaboration can lead to the sharing of best practices, joint research, and innovation in sustainable logistics. Governments can establish standardized methods for measuring and reporting carbon emissions in e-commerce logistics. This data can help track progress, identify areas for improvement, and inform policy decisions.

8. Stakeholder Engagement and Partnership Building

To ensure smooth and sustainable e-commerce operations, fostering collaboration between e-commerce platforms and logistics providers is crucial. By working closely together, they can streamline processes, optimize supply chains, and enhance overall efficiency. Encouraging consumers to make sustainable choices can be done through incentives. Offering discounts or rewards for eco-friendly products, packaging, or delivery options can motivate individuals to opt for more sustainable e-commerce practices. Engaging non-governmental organizations (NGOs) and civil society is crucial for sustainable e-commerce. These organizations can provide valuable insights, expertise, and advocacy to enhance environmental and social responsibility within the industry.

9. Discussion and Conclusion

In conclusion, the "dual carbon" policy demands collective action and the active participation of all individuals to achieve carbon neutrality. The logistics supply chain industry, as one of the highest carbon-emitting sectors, necessitates the utilization of new technologies such as the internet, big data, and blockchain to implement online ordering, eliminating several intermediate steps in the supply chain.

This paper has delved into technological innovations, policy frameworks, and consumer behavior analysis as avenues for overcoming challenges and advancing the industry. The detailed examination of Company A's sustainable practices and the quantitative analysis of AI reduction solutions demonstrate the tangible benefits of integrating advanced technologies. Furthermore, the role of government initiatives and stakeholder engagement is acknowledged as indispensable in shaping a sustainable and carbon-neutral e-commerce logistics landscape.

As we navigate the path towards carbon neutrality, continued exploration of these strategies and collaborative efforts will be instrumental in realizing a more sustainable future for the e-commerce logistics industry. The findings of this research lay a foundation for further studies, policy implementations, and industry transformations to achieve the ambitious goals of carbon neutrality in the ever-evolving landscape of e-commerce logistics.

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