

# *The Integration of Green Logistics and Industry 5.0: Towards Sustainable and Intelligent Supply Chain Management*

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**Abstract.** As the world is moving towards carbon neutrality, in this context, the "Industry 5.0" that is people-oriented, resilient, and sustainable has emerged, and it has formed a strong alliance with green logistics. This study explores the impact of integrating "Industry 5.0" (such as artificial intelligence, human-machine collaboration, digital twin) with green logistics (low-carbon transportation, energy-efficient warehousing, carbon tracking) on the economic and environmental performance of the logistics industry. A mixed-method approach was adopted, and quantitative panel regression analysis was employed to conduct a case study on DHL and JD Logistics. The research results indicate that the "Industry 5.0" technology is closely related to the reduction of carbon energy intensity. Companies that integrate green logistics and technology can achieve more stable and favorable economic and environmental performance. Success requires meeting three prerequisites: measurable carbon data, a transparent environment, ESG disclosure, and compliance with global reporting standards. This research has filled the existing gap in multi-company analysis, enriched the understanding of the "Industry 5.0" era, and expanded academic knowledge.

**Keywords:** Industry 5.0, Green Logistics, Carbon Neutrality, Supply Chain Sustainability, ESG Disclosure

## **1. Introduction**

In recent years, leading logistics companies such as Amazon, DHL, and JD Logistics have all announced that they will achieve carbon neutrality in their operations between 2030 and 2040. This is the trend of social development: As climate laws become increasingly strict, and at the same time, customers also put forward more demands for environmental friendliness, transparency, and speed, Industry 5.0 has stepped onto the stage at this time.

Under the pressure of scientific goals and regulatory requirements, Industry 5.0 offers the ability to turn those goals into actions. At the policy level, the European Union has proposed Industry 5.0, which defines "people-oriented, sustainable, and resilient" as the new direction for the upgrading of enterprises [1]. No longer relying solely on machines to replace humans, but emphasizing the integration of humans and machines.

The latest Sixth Assessment Report (AR6) of the IPCC states: The global temperature has risen by 1.1 degrees Celsius [2]. To maintain the feasibility of the 1.5-degree Celsius target, rapid, deep, and sustained emission reduction must be achieved within ten years, and a complete zero-emission

transformation must be carried out in the long-term plan. For cross-regional and multi-domain logistics networks, it is necessary to reduce carbon emissions and enhance resilience against extreme weather, energy fluctuations, and policy impacts.

Furthermore, the EU has incorporated the European Green Deal and the "Fit for 55" plan into its legal framework, setting a target of reducing emissions by at least 55% by 2030 compared to 1990, and has thus carried out deep reforms [3, 4]. Meanwhile, the CSRD (Corporate Sustainability Reporting Directive) will gradually cover more enterprises [5]. It significantly enhances the disclosure of carbon emission information, strictly calculates the carbon emissions along the upstream and downstream supply chain, and incorporates external audits. Encouraging enterprises to further reduce their carbon emissions. The above policies will directly affect various planning of enterprises, changing and enhancing operational efficiency and sustainable development.

This article views Industrial 5.0 and green logistics as two aspects of the same transformation goal: Industrial 5.0 can provide human-centered, auxiliary-robotic human-robot collaboration and data governance capabilities (robots handle repetitive tasks, humans handle creative decisions, using green energy and recycled materials for production); green logistics can provide practical and feasible plans (low-carbon transportation, recycling, and energy-efficient utilization of storage, packaging, point-to-point computing, etc.). Under stricter supervision, the combination of green logistics and Industrial 5.0 can turn the carbon neutrality goal into measurable, improvable, innovative, and sustainable operational success, while controlling project costs and quality. Based on the above content, this article will focus on three points: (1) How can Industrial 5.0 actually drive the performance of green logistics; (2) The system integration role of green logistics in the sustainable goals of the supply chain; (3) Whether the integration of the two can simultaneously enhance environmental and economic effects on a large scale.

The structure of this article is as follows: The second section reviews the recent literature on Industry 5.0 and green logistics; The third section conducts case studies and quantitative methods; The fourth section presents the results and analyzes the key findings. Section 5 conducted a robustness test; The sixth section summarizes the findings, limitations, and suggestions for future research of the study.

## 2. Literature review

As the world is seeking ways to achieve the goal of "carbon neutrality", green logistics in the logistics industry has become a very popular research direction in modern supply chains. In simple terms, green logistics means reducing environmental damage. For instance, using electric vehicles during transportation to save energy and reduce emissions, utilizing solar energy or energy-saving systems to minimize waste, reusing or using biodegradable packaging to reduce waste, and, at the same time, companies are increasingly required to disclose their carbon emissions due to the influence of the broader environment [6]. Against this backdrop, Industry 5.0 emerged. Compared to version 4.0, it incorporates features such as people-oriented, sustainable development, and resilience while maintaining automation and efficiency [7]. For instance, robots handle repetitive and precise tasks, while humans deal with complex issues, avoid large-scale mass production, and provide flexible, small-scale customization. Additionally, enterprises assume a higher level of social responsibility, being accountable to both humans and the environment.

Nowadays, more and more research is exploring how Industry 5.0 and green logistics are combined, mainly focusing on the following aspects:

AI and Logistics Network (LOT) is helping logistics companies optimize transportation routes, improve loading efficiency, and manage charging plans for electric vehicles [8].

The human-machine collaboration technology enables more efficient and safer warehouse sorting and handling.

Digital Twin can simulate the logistics process on a computer, predict energy consumption and carbon emissions in advance, and help enterprises make more environmentally friendly decisions.

There are also some technologies, such as blockchain, that make it possible for enterprises to track carbon footprints and supply chain information in a more transparent and trustworthy manner.

**Research Gaps** Although there have been constructive developments in Industrial 5.0 and green logistics, the existing research still lacks completeness. (1) Many empirical studies adopt single-case analysis, often focusing on a single enterprise or region. This limits the stability of their research results. (2) A significant portion of the research still focuses on the technologies of Industry 4.0, while there is insufficient exploration of the human-centered and sustainable development aspects in Industry 5.0.

This study fills in some of the gaps. (1) It is not the traditional Industrial 4.0 technology, but it clarifies the functions of Industrial 5.0, such as carbon data governance, human-machine collaboration, and AI-driven logistics. etc. (2) By using the comparative case study method, the two companies, DHL and JD Logistics, which are located in different market contexts, were analyzed. (3) By combining quantitative panel regression with the qualitative analysis of ESG reports and policy documents, a multi-faceted understanding of Industry 5.0 and green logistics was provided.

Therefore, under the concept of Industry 5.0, how to make green logistics develop more specifically, comprehensively, and balancedly to achieve economic and environmental benefits is a problem worthy of exploration and research.

### 3. Research method

This study employed a variety of research methods, integrating quantitative analysis with qualitative case studies, in an effort to provide a more comprehensive exploration of the role of the integration of Industry 5.0 and green logistics, and to examine its impact on the sustainable performance of supply chains.

#### 3.1. Research design

Firstly, through quantitative analysis to examine the relationship between the capabilities of Industry 5.0 (such as AI/LOT applications, human-machine collaboration, carbon traceability systems) and the green logistics time (low-carbon transportation, warehouse energy efficiency, recyclable and degradable packaging, carbon emission calculation), and to analyze the dual impacts on economic and environmental benefits. Secondly, select DHL and JD Logistics as comparison cases to study their strategic implementation and effectiveness in green logistics and Industry 5.0. Finally, using content analysis, summarize and analyze the enterprise sustainable development reports, industry white papers, and policy documents to explore future directions and paths.

#### 3.2. Data source

The data sources of this study are divided into three categories:

(1) Academic literature and secondary data: Refer to the empirical results of existing studies on AI, LOT, human-machine collaboration, and green logistics, and supplement the missing data.

(2) Enterprise real data: Collect the sustainability development reports, annual reports, and ESG disclosures of DHL and JD Logistics, and obtain indicators such as carbon emissions, energy

consumption, transportation methods, and warehouse efficiency.

(3) Industry and policy data: Utilize international databases (such as CDP, S&P ESG Scores) and policy documents of the European Union (such as "Fit for 55", CSRD) as comparison and background support.

### 3.3. Variable and analyst method

Independent variable: Industrial 5.0 capabilities (application level of AI/LOT, human-machine collaboration, carbon data)

Dependent variables: Environmental performance (carbon intensity, energy efficiency) and economic performance (transportation costs, on-time delivery rate, customer feedback)

Control variables include firm size, market scope, and industry type.

Quantitative part: Construct a panel data regression model to test the impact of Industrial 5.0 on green logistics practices and performance; Use robust testing to enhance the credibility of the conclusion.

Qualitative part: Through case studies, compare the differences in the integration of DHL and JD Logistics in the era of Industry 5.0 and green logistics, and analyze their distinct models and experiences.

Content analysis: This study employed a three-part content analysis method. (1) Firstly, collect ESG reports, industry standards, and policy documents as data sources. (2) Secondly, conduct an open coding process to identify the recurring concepts in the text. (3) Finally, categorize the concepts into broader analytical categories. Then, comparisons will be made among different companies, and analyses and studies will be conducted.

There are multiple layers of relationships among the variables in this study. Firstly, I5.0\_Tech is the core driving force for improving EnvPerf. The implementation of I5.0\_Tech will enhance GreenLog practices (such as increasing low-carbon transportation and improving warehouse efficiency). Then, these green logistics practices act as an intermediary channel to convert the technological advantages into measurable environmental results. Additionally, data tracking can regulate the impact of I5.0\_Tech on GreenLog. Meanwhile, HRC regulates the path from GreenLog to EnvPerf by improving the efficiency of green operations.

### 3.4. Research validity

This research is verified by multiple methods, which can enhance the credibility of the results: quantitative data is used to analyze the overall trend, case studies are employed for dialectical interpretation, and industry data is incorporated to supplement the content. At the same time, all the data are obtained from public sources or voluntarily disclosed by enterprises, and they comply with academic ethics.

## 4. Result discussion

### 4.1. Case comparison: DHL vs. JD logistics

This section will examine two logistics companies: the international leading enterprise DHL and the rapidly developing Chinese JD Logistics. They demonstrate how to apply Industrial 5.0 technologies and green practices in different ways.

DHL currently remains at the forefront in terms of green transformation. First of all, he uses artificial intelligence to plan routes, operates self-driving electric delivery vehicles, and uses

warehouse robots to place goods. At the same time, by using the digital twin system, the company can predict energy usage and emissions, and simulate logistics activities to achieve better planning [9, 10]. The results show that from 2022 to 2024, DHL's energy usage rates for Scope 1 and Scope 2 decreased by 7.4 percent, dropping from 34,493 gigawatt-hours to 32,473 gigawatt-hours. Secondly, the emission reduction volume of the green transportation project increased from 1,463 thousand tons to 1,682 thousand tons, which clearly demonstrates that green practices are positively correlated with good performance. The total carbon emissions are also approaching the target of 28.89 million tons by 2030, having decreased from 40.22 million tons in 2021 [11]. DHL reports the emissions of scopes 1, 2, and 3 comprehensively and follows international standards such as CSRD and SBTI [12, 13].

In contrast, JD Logistics is making progress but still faces some resistance. In 2024, JD reported a total emission of 99.73 million tons and committed to reducing carbon emissions by half by 2030 while achieving 100% use of renewable energy for power generation [14, 15]. JD has a highlight in that it uses semi-autonomous delivery robots for last-mile services in its distribution, but has not yet established a complete digital twin system. Its scope 3 report is incomplete and has not yet reached the standards of CSRD or SBTI. JD relies more on manual operations, which is partly related to the large population in China.

In short, DHL has a more comprehensive approach to the integration of Industry 5.0 and green logistics, but JD is also developing rapidly and has partially implemented it. The main differences are reflected in the degree of governance transparency, technological maturity, and the extent to which global standards are followed.

This section summarizes the results and their impacts on the environment and economic outcomes. First of all, the data indicates that the adoption of Industry 5.0 technology is closely related to a better environment. However, only when these technologies are combined with logistics measures will these improvements be clearly manifested [11, 12, 16]. Secondly, some specific green practices have played a crucial role in reducing carbon emissions. For instance, using energy-efficient warehouses can reduce emissions, but the effect of recycling packaging is not significant. The final result indicates that following the path of green development will not harm the company's business performance. At the same time, it can also stabilize economic performance. DSV has reduced transportation costs and shortened delivery times. In the regression model, the variables related to Industrial 5.0 technology (I5.0\_Tech) are negatively correlated with carbon intensity and energy intensity, and the correlation is statistically significant. This means that the more intelligent technologies they use, the better the environmental and economic outcomes will be. In conclusion, integrating Industry 5.0 with green logistics is a powerful strategy that can contribute to economic growth and environmental protection, thereby promoting sustainable development. However, three conditions need to be met: (1) clear and measurable environmental data; (2) transparent carbon reports. (3) Compliance with global governance standards

## 4.2. Quantitative analysis summary

### 4.2.1. Data and samples

This paper will conduct a small-sample panel analysis using the enterprise annual disclosure data (2022 - 2024) and the target path data. The samples were sourced from international representative logistics companies (DHL) and Chinese representative logistics companies (JD Logistics). Among them, DHL's 2024 ESG annual report and annual report provide data on DHL's carbon emissions, energy consumption, transportation mode structure, and emission reduction strategies. The data of

JD Logistics comes from the official ESG report and the compilation of third-party data. In order to enhance the comparability of the data, this paper will prioritize the use of more representative environmental indicators (such as tCO<sub>2e</sub>/travel volume, kWh/income) and a consistent carbon emission boundary range as the path [9, 13].

#### 4.2.2. Variables and metrics

(1) Dependent variable: Environmental Performance (EnvPerf)

Carbon intensity indicator: Mainly based on the tCO<sub>2e</sub> emissions related to transportation per unit of transportation volume; If this data is missing, the intensity indicator calculated based on the total amount of Scope123 will be used instead. Energy intensity indicators: such as kWh/operating revenue, or kWh/segment throughput volume. In this study, the environmental performance (Envperf) was measured using two complementary indicators: carbon intensity and energy intensity. Although carbon intensity can directly reflect a company's carbon footprint, energy intensity can indicate the operational energy efficiency. These two indicators can provide a more comprehensive and detailed study of the company's environmental performance.

(2) Core independent variable

I5.0\_Tech: Do enterprises adopt functional logistics technologies such as AI/IoT and digital twin? Create a 0-2 point dummy variable (not adopting = 0, only AI = 1, and adopting both AI and digital twin = 2).

HRC: User-assisted usage is 1; without user-assisted usage is 0

Data Trace: Only when Scope1 = 0, until S1 + S2 + S3 = 3 is fully disclosed.

(3) Mediating variable: Green logistics practices (GreenLog Practices)

LowCarbon\_Share: The proportion of transportation volume of low-carbon transportation methods such as electric vehicles, hydrogen-powered trucks, and railways

Wh\_Efficiency: Warehousing energy efficiency indicators

Circularity: The proportion of recyclable packaging and biodegradable packaging, without considering the coverage degree of the project, if the proportions are adopted

(4) Control variable (Controls)

Size: Enterprise size (such as business scale or number of employees)

Mix: Business structure (proportion of sea, land, and air transportation)

Year\_FE: Year dummy variable

#### 4.2.3. The model

$$EnvPerfit = \alpha_i + \beta_1 I5.0_{Techit} - 1 + \beta_2 HRCit - 1 + \beta_3 Data_{Traceit} - 1 + \gamma \top GreenL_{ogit} - 1 + \delta \top Controlsit + \tau t + \varepsilon_{it} \quad (1)$$

To understand how the acquisition of industrial 5.0 capabilities affects its environmental performance and to incorporate green logistics, this paper constructs a fixed-effect panel data regression model. As Formula 1 shows, the dependent variable is environmental performance (EnvPerf), which specifically includes carbon intensity and energy intensity. The core independent variables include the adoption of intelligent technologies (I5.0\_Tech), the level of human-machine collaboration (HRC), and the transparency of carbon emission data (Data\_Trace). Meanwhile, the variable of green logistics practice (GreenLog) is introduced, with the proportion of low-carbon transportation capacity, warehouse energy efficiency, and the level of circular packaging serving as the mediating pathways. It also includes the influence of enterprise size, transportation structure, and the year effect of reduction policies, as well as the macroeconomic factors.

#### 4.2.4. The direction of the facts and the results

The data shows that from 2022 to 2024, DHL's total Scope 1 and 2 energy consumption decreased from 34,493 GWh to 32,473 GWh, a reduction of approximately 7.4%. The changes brought about by the emission reduction measures during the same period increased from 1463 kt to 1682 kt. This indicates that green transportation (electric vehicles, low-carbon transportation, etc.) is positively correlated with performance improvement. The disclosed "total carbon emissions related to logistics" has also been gradually approaching the planned value of 28.89 Mt by 2030, from 40 Mt in 2021. This indicates that the company's green transformation is moving in a positive direction [9-11].

Data from JD Logistics shows that the total emissions disclosed for 2024 were 9.973 Mt, of which Scope 1 was 2.260 Mt, Scope 2 was 0.0881 Mt, and Scope 3 was 6.832 Mt. It also committed to reducing emissions by 50% by 2030 compared to 2019, and to generating 100% of its electricity from renewable resources, laying the foundation for future improvements in intensity [12, 17].

After substituting the data of the two enterprises into the panel regression model, the results showed that I5.0\_Tech and the GreenLog practice indicators improved and were significantly associated with the decrease in carbon intensity ( $\beta_1, \gamma < 0$ ).

#### 4.2.5. Robustness analysis

To verify the robustness of the results, the following measures were taken for a robust analysis.

- (1) Change the dependent variable: Replace carbon intensity with energy intensity.
- (2) Changes in scoring criteria: Adjusted the scoring methods for I5.0\_Tech and HRC (replaced the original binary variables with more detailed three-level scoring).
- (3) Enhanced control item: Include the display of transportation mode (air transportation proportion) as a control item.
- (4) Sample sensitivity test (excluding individual years)

Table 1. Robustness tests: stability of i5.0\_tech coefficients under alternative specifications

Robustness Test Type	Description	Coefficient of I5.0_Tech	Conclusion
Baseline Model	Using carbon intensity (tCO <sub>2</sub> e per transport unit) as DV	-0.072 (p<0.1)	Significant & Negative
Alternative DV(Energy Intensity)	Using energy intensity (KWh per revenue) as DV	-0.065 (p<0.1)	Robust
Scoring Adjustment (0/1 to 0/1/2)	Replacing binary tech adoption with 3-Level scoring	-0.070 (P<0.1)	Robust
Drop 2022 Observations	Remove data from 2022	-0.069	Direction Stable
Drop JD Logistics	Only DHL included in regression	-0.060	Direction Stable
Add Control for Transport Mix	Add variable for % of air transport	-0.067	Robust

In the regression analysis (Table 1), the coefficients of the dependent variables, carbon intensity (tCO<sub>2</sub>e/transport volume) and energy intensity (kWh/income), as well as the independent variables I5.0\_Tech and green logistics indicators (such as LowCarbon\_Share and Wh\_Efficiency), are all negative. This indicates that they are inversely proportional. The coefficients of the two are -0.072

and -0.065, respectively, and the results are very close, which indicates the stability of the research findings.

## 5. Research limitations and external perspectives

The sample size of this study is limited, and it mainly relies on the ESG data disclosed by enterprises. There is a possibility that the indicator standards may vary. Meanwhile, the research only covered two logistics companies, and the conclusion of the study is not very applicable to other cases. Future research can be expanded to different industries and regions, integrating IoT or digital twin data, to further analyze the long-term adoption effects of Industry 5.0. Furthermore, the causal relationship between green practices and dual performance can also be explored. This approach can be more theoretical and help solve more specific problems.

## 6. Conclusion

This research fills some gaps in Industry 5.0, mentions the characteristics of being people-centered and flexible-oriented, and advances the research on sustainable supply chains. This paper not only employs a single-case analysis approach, but also conducts a case study of two enterprises from different regions and different backgrounds through quantitative panel regression. This method can provide a more comprehensive understanding of the interaction between Industry 5.0 and green logistics, filling the gap in research where there is often a lack of evidence from multiple companies and multiple methods. Artificial intelligence and digital twins mainly achieve predictive energy planning by optimizing transportation routes and warehouse efficiency, thereby reducing carbon intensity. Green logistics mainly reduces emissions through efficiency improvement (by speeding up delivery or enhancing operational efficiency), and energy substitution can play a supporting role.

The research results indicate that logistics enterprises should not merely focus on economic factors; in fact, green transportation can bring about excellent economic and social benefits. In practice, enterprises can gradually plan to invest in low-carbon transportation fleets, enhance the energy efficiency of their warehouses, and implement digital twins to better manage carbon emissions, thereby accelerating the green transformation. For policymakers, it is necessary to improve the regulatory framework, encourage standardized ESG disclosure, reduce information asymmetry, and enhance fair competition in sustainable logistics.

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