

## **Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector**

**Umar Hayyat<sup>1</sup>, Maleeha Saeed<sup>2</sup>, Amir Hayat<sup>3</sup>, Rebecca Kelly Nzie<sup>4</sup>**

<sup>1,2,3,4</sup>School of Economics and Management, Chang'an University, Xi'an 710064, China

---

**ABSTRACT:** As a critical enabler of global trade and economic integration, the logistics sector has emerged as both a driver of development and a growing source of transport-related CO<sub>2</sub> emissions. While environmental technologies and structural reforms are increasingly prioritized in sustainability agendas, their combined impact on logistics performance and carbon intensity remains underexamined. This study investigates the determinants of logistics performance and transport CO<sub>2</sub> emissions across major logistics-performing economies from 2007 to 2023. A balanced panel of 1,105 observations is compiled using internationally recognized indicators, with unit root and cointegration tests employed to ensure data stability and long-run associations. A robust econometric framework combining Two-Step System Generalized Method of Moments (GMM), Quantile Regression (QR), and Two-Way Fixed Effects (TWFE) is implemented to address endogeneity, heterogeneity, and distributional variation. The results show that environmental technologies, urbanization, governance quality, and human development positively influence logistics performance across different quantiles, while employment and capital formation display diminishing or adverse effects at higher levels. Furthermore, logistics efficiency is positively linked to transport-sector CO<sub>2</sub> emissions and, in some cases, inversely related to economic growth, suggesting a carbon-intensive trajectory in logistics-driven economies. These findings offer important insights into the trade-offs between logistics expansion and environmental sustainability. The study contributes to the evolving literature on sustainable logistics by highlighting the distributional effects of environmental and structural drivers and presents evidence to guide future policymaking focused on low-carbon logistics infrastructure and green innovation integration.

**KEYWORDS:** Logistics performance, Transport CO<sub>2</sub> emissions, Environmental technology, green logistics Sustainable transport, Economic growth

---

### **1. INTRODUCTION**

Logistics constitutes a fundamental pillar of the global economy, as it enables the seamless distribution of goods to consumers worldwide (Hayyat et al., 2025). To this extent, logistics is becoming increasingly crucial for businesses seeking to integrate their supply chains and adapt to shifting market conditions (Starostka-Patyk et al., 2024). The logistics industry needs to systematically and methodically develop procedures, oversee staff, and arrange the supply of commodities in order to sustain a steady flow of goods. Purchasing, storing, and shipping materials to their final location are all included in the process of logistics. The selection of distributors and suppliers is based on their affordability, effectiveness, and accessibility. (Yazdani et al., 2020). Based on the literature, it refers to the collection of coordinated operations that include information processing, material handling, inventory storage and management, and freight transport, and that call for transferring goods via effective supply chain procedures (Martel & Klibi, 2016). Greenhouse gases (GHGs) are directly emitted into the atmosphere as a result of increased utilization of fossil fuels, which has adverse long-term impacts on the environment and human health (Magazzino et al., 2020). Specifically, it has been shown that logistics activities are a major contributor to environmental degradation, accounting for 22% of worldwide emissions of carbon dioxide (CO<sub>2</sub>) in 2014. (Hayyat et al., 2025). Transport-related CO<sub>2</sub> emissions are expected to increase by 60% by 2050 (and by 160% from global freight alone), requiring urgent environmental action and a move to a Green Supply Chain (GSC) (OECD, 2017). This study enhances the current literature by investigating the dilemma of whether operations may concurrently attain economic development and environmental sustainability via essential operational approaches. Specifically, it seeks to offer novel insights into strategies for harmonizing environmental conservation with profitability within the logistics sector. Given its pivotal role in employment generation, consumer activity, and overall economic development, logistics remains a fundamental driver of modern economies. Logistics operations are unquestionably essential to the economy, much like energy, because they

## Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

have important connections to employment and economic growth (Hasan et al., 2025; Liston et al., 2024; Magazzino, Mele, et al., 2021). Conversely, ineffective logistics operations that are poorly managed raise the capital and operating expenses related to waiting times and underutilization (Kallionpaa et al., 2015). Numerous empirical studies have confirmed that the effectiveness of both intra- and inter-organizational logistics structures is significantly responsible for logistics performance at the business level (Flynn et al., 2010; Goertler et al., 2024). Due to increased worldwide rivalry and the acceleration of globalization, outsourcing has become an advantage in strategy for businesses on a global level. This trend has significantly influenced territorial dynamics and operational frameworks, while also enhancing export potential across regions (D'Aleo & Sergi, 2017). On the other hand, logistics activities put a lot of strain on the environment. Because of the industry's substantial dependence on fossil fuels, especially for transportation and long lead times, hazardous chemicals are released, which greatly harm the environment. (Khan et al., 2016; Sundram et al., 2025). Consequently, a lack of green practices and fuel-efficient initiatives could jeopardize the sector's sustainability, requiring the creation of new networks of supply chains (Memari et al., 2016). This economic-environmental dilemma has spurred a growing research corpus concentrated on the concept of green logistics (GL), which seeks to reconcile economic efficiency with environmental sustainability in logistics and supply chain management (Ostrom, 2008; Zambujal-Oliveira & Fernandes, 2024). The Green Supply Chain's (GSC) inception concept can be traced to early initiatives aimed at incorporating environmental sustainability into conventional supply chain management practices (Nureen et al., 2023). Nevertheless, a well-recognized limitation persists, as businesses continue to prioritize economic viability over environmental sustainability in their strategic decision-making processes (Layode et al., 2024). Developing a "green" competitive advantage through the adoption of environmentally sustainable practices tailored to contemporary climate challenges can help address this constraint. Such sustainable approaches not only enhance economic efficiency but also align with evolving consumption patterns and create new opportunities for export growth and profitability, particularly in developed economies (Khan et al., 2018; Zelbst et al., 2010). Key policy instruments, including taxes, import charges, and subsidies enacted by regulatory bodies, are thoroughly examined as essential mechanisms to promote the shift from conventional logistical performance to ecologically friendly methods. Greener supply chain models can be promoted, for example, by offering targeted subsidies to businesses that integrate biofuels and renewable energy sources into their logistics operations. (Shahbaz et al., 2025). Additionally, Green Supply Chain Management (GSCM) offers a strategic way to reduce the negative environmental effects of logistics operations through the use of circular business models. (Goertler et al., 2024). These models emphasize practices such as energy recovery, waste recycling, responsible disposal, and the reduction of landfill use, thereby enhancing the sustainability of supply chain operations (Yu et al., 2018). Despite significant potential for further advancement, a substantial body of literature has emerged on this topic, offering groundbreaking insights and highlighting a promising direction for future research. This study focused on five macroeconomic pillars: innovation (R&D technology), infrastructure (transport and utilities), education (human capital development), employment (labor market dynamics), and capital (financial and physical investment). Recent empirical studies have investigated the nexus between economic development and logistics performance, particularly in the context of global trade dynamics and cross-border supply chains (Coto-Millán et al., 2013; Sharipbekova & Raimbekov, 2018; Töngür et al., 2020). Enhancing logistics operations such as border management, service quality, and product tracking contributes to reduced delivery costs while simultaneously improving the dependability and predictability the deliveries, which are essential elements in this scenario of modern just-in-time (JIT) production systems (Hlali, 2024). Undoubtedly, these improvements have a direct impact on firms' market share and profitability, subsequently contributing to higher levels of employment and income. In parallel, a growing body of recent macro-level research has investigated the relationship between environmental sustainability and green logistics practices, utilizing Logistics Performance Index (LPI) data as a key analytical tool (Khan et al., 2018; Liu et al., 2018). CO<sub>2</sub> emissions from the transport sector are widely utilized as a key indicator of environmental degradation. In addition, numerous studies have investigated the macroeconomic determinants that shape the performance and effectiveness of logistics systems (Wong & Tang, 2018). Nevertheless, such studies remain limited, and the findings from existing empirical research are often inconclusive. This study offers a novel contribution by integrating insights from three distinct strands of literature and advocating for more comprehensive quantitative analyses at the global level. While the role of technology in enhancing supply chain productivity has been widely acknowledged, it continues to warrant deeper empirical investigation within broader macroeconomic and environmental contexts (Lagorio et al., 2022; Yamoah et al., 2025). Its linkages to CO<sub>2</sub> emissions from transport and economic returns have received relatively limited scholarly attention. Innovation, by improving the efficacy and efficiency of logistical operations, has unquestionably been crucial in changing the dynamics of global trade. (Lee, 2004). Improved visibility in the movement of goods has contributed to reduced operational and transaction costs for firms; however, it has simultaneously led to increased electricity consumption. Moreover, the transition toward global supply chains (GSCs) stands to benefit substantially from technological innovation. Investment in cleaner technologies can play an important role in facilitating the adoption of green supply practices throughout the manufacturing process. By establishing a

## Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

sustainable competitive advantage, such initiatives have the potential to mitigate environmental externalities while enhancing the long-term profitability of firms (Mustafi et al., 2024). Finally, There is still an enormous gap in the literature regarding infrastructure-related insights. The development of a resilient supply chain is inherently dependent on the efficiency and integration of public infrastructure systems, such as ports, airports, and railways, which are essential components of modern trade operations (D'Aleo & Sergi, 2017; Thuy & Son, 2024). Enhancing the quality of logistics infrastructure also involves the development of energy-intensive components such as transportation vehicles and information and communication technologies (ICT). Given their high energy dependency, it is reasonable to question whether such advancements may contribute to increased global carbon emissions from transport. Additionally, the role of human capital warrants careful consideration. Empirical evidence suggests a positive correlation between income and education, which may, in turn, influence consumer behavior particularly in the increased consumption of energy-intensive goods (Wang et al., 2020; Zhu et al., 2024). Thus, it is crucial to look at how much human capital affects logistics performance and how it could help with the implementation of GSC (green supply chain) standards. Fortunately, the implementation of such intricate and thorough empirical investigations is made possible by the availability of the pertinent data.

Overall, this study aims to offer four principal contributions to the existing body of literature. First, it is among the limited research efforts that establish a global-level connection between environmental-related technology factors influencing logistics performance and their subsequent impacts on the economy and the environment. Specifically, it explores whether environmental technology can enhance logistics efficiency while simultaneously reducing transport CO<sub>2</sub> emissions through critical transmission channels. Second, the study offers new insights into the roles of human capital and infrastructure as potential drivers of logistics performance, with particular attention to their economic and environmental implications. Following (Wong & Tang, 2018), given their direct and observable impacts on both income and CO<sub>2</sub> emissions, the perceived significance of human capital and infrastructure may strengthen logistics performance when integrated with environmental technology, labor force participation, and capital investment. Third, this study conducts a macro-level investigation of the 65 countries with the highest logistics performance, as recognized by the 2025 World Logistics Conference, thereby providing a comprehensive global perspective on supply chain management (SCM). By incorporating nationally representative indicators into a unified global dataset, the study can systematically identify the key economic and environmental factors that influence logistics performance. This approach enhances the credibility of the identified determinants and offers important understanding of the specific national contexts that influence logistics outcomes. Fourth and finally, this study distinguishes itself from earlier research through its methodological approach, utilizing a range of advanced panel data econometric techniques. This enables a stronger and in-depth examination of the evolving connections among logistics performance, economic factors, and environmental impacts. This study conducts an empirical assessment of the evolving linkages among logistics performance, environmental technology, education, employment, Gross Fixed Capital Formation, economic growth, and transport-related CO<sub>2</sub> emissions. The analysis further incorporates the human capital index and urbanization within a comprehensive multivariate framework. Macro-level data were gathered for the 65 countries with the highest logistics rankings worldwide, spanning the years 2007 to 2023. Employing various panel data econometric approaches—including tests for cross-sectional dependence, unit roots, and cointegration—the study's causality analysis relies on three separate panel data estimation techniques. Two-Step System (GMM), Quantile Regressions (QR), and Two-Way Fixed Effect. The estimators employed in this study ensure the generation of strong and reliable results. The Two-Step System GMM effectively addresses endogeneity in dynamic panel data settings where  $N > T$ , while Quantile Regression (QR) captures distributional heterogeneity and provides non-parametric robustness checks. The Two-Way Fixed Effects model controls for hidden variations across countries and over time. Taken together, these methodological approaches offer important insights for managers, stakeholders, and policymakers working to tackle the economic and environmental issues affecting the logistics sector. The rest of the manuscript is structured as follows. Section 2 reviews the pertinent literature. Section 3 outlines the data sources and the empirical methods employed. Section 4 presents and interprets the empirical findings. Section 5 provides concluding observations, and Section 6 offers several policy recommendations.

## 2. LITERATURE REVIEW

A substantial body of scholarly literature has examined various dimensions of supply chain systems. To align with the specific aims of this study, the literature review is organized into four thematic segments. The first segment analyzes the linkage between logistics performance and economic development. The second segment explores the environmental consequences of logistics activities, with a focus on sustainability outcomes. The third segment assesses the essential function of technological innovation in enhancing logistics efficiency and competitiveness. The final segment identifies prevailing empirical gaps in the literature and delineates the unique contributions offered by the present research.

## **Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector**

### *2.1. Environmental-related technology and logistics performance*

Environmental technologies are increasingly central to transforming logistics performance by improving both operational efficiency and sustainability. Practices within green logistics, such as the adoption of eco-friendly transportation technologies, have been shown to reduce carbon emissions and enhance operational effectiveness. Specifically, electric and hybrid vehicles have been identified as key contributors to reducing fuel consumption and greenhouse gas emissions within logistics operations (Kumar et al., 2024). These advancements not only meet environmental objectives but also drive financial benefits by reducing operational costs for logistics companies. The integration of renewable energy technologies in logistics facilities has become a primary focus in recent years (Song et al., 2024). Transitioning to renewable energy sources in logistics supports broader sustainability goals while providing economic benefits by reducing reliance on non-renewable energy and lowering associated energy costs (Shahzad et al., 2023). Moreover, the adoption of smart logistics technologies, including the Internet of Things (IoT), has revolutionized supply chain operations. IoT-enabled systems allow for real-time monitoring of shipments, which improves route optimization and fleet management, ultimately leading to fuel savings and more efficient logistics operations (Wang et al., 2024). These technologies not only facilitate improved decision-making and minimize operational waste but also significantly reduce the environmental footprint of logistics companies.

In addition to these technological advancements, energy-efficient warehousing solutions, such as automated sorting systems and LED lighting, have become integral to reducing energy consumption in logistics operations. These systems contribute to both environmental sustainability and operational efficiency by lowering energy costs in logistics facilities (Salihi et al., 2024). As sustainability regulations become more stringent, it is clear that the integration of environmental technologies will remain crucial for logistics companies. The ongoing adoption of green technologies will not only drive operational efficiency but also help companies meet sustainability targets while enhancing their competitive advantage (Garg & Vemaraju, 2025).

### *2.2. Investigating the empirical relationship between logistics activities and environmental sustainability.*

A segment of the literature adopts a macro-level perspective to investigate the empirical relationships among economic performance, logistics efficiency, and environmental degradation. The majority of these studies employ the 2007 Logistics Performance Index (LPI) dataset provided by the World Bank. Consequently, a notable limitation arises from the relatively short period of the data, compelling researchers to rely on extensive cross-country panels to compensate for the temporal constraints. (Khan & Qianli, 2017) examined the connections between environmental indicators of green logistics, such as greenhouse gas (GHG) emissions, the use of fossil fuels, and the deployment of renewable energy, and national-level economic factors, such as per capita income and foreign direct investment (FDI) inflows, in the context of the United Kingdom. Their findings, which were obtained using an Auto Regressive Distributed Lag (ARDL) bounds testing method, show a favorable correlation between renewable energy and green logistics. On the other hand, there is a negative correlation between the use of fossil fuels and green logistics. The study also reveals that higher per capita income, more use of renewable energy, and FDI inflows all improve logistical performance. (Khan et al., 2018) Compiled a large sample of 43 countries spanning low-income, middle-income, and high-income economies. Their analysis, employing a Generalized Method of Moments (GMM) model, demonstrated that logistics activities significantly contribute to carbon emissions, highlighting the sector's persistent dependence on fossil fuels. This reliance on non-renewable energy hurts economic growth. Conversely, a move to renewable energy from fossil fuel sources exerts a positive influence on the trajectory of economic development. (Sikder et al., 2024) Examined the relationship between carbon dioxide (CO<sub>2</sub>) emissions and logistics performance across 16 RCEP and SAARC countries, utilizing panel data from 2007 to 2018 within a Generalized Method of Moments (GMM) regression framework. Their findings indicate a strong association between environmental indicators and logistics performance in the region. Specifically, improvements in the international shipments component of the Logistics Performance Index (LPI) are associated with a significant reduction in environmental pollution. In contrast, inefficient shipments that fail to reach recipients within expected timeframes contribute to higher CO<sub>2</sub> emissions. The analysis also emphasizes the substantial moderating effect that other LPI subcomponents, including infrastructure standards, customs performance, service quality, competence, and tracking and tracing capabilities, have on environmental technology. Building on previous research (Hayyat et al., 2025), this analysis broadened the scope to assess the impact of logistics performance on three distinct groups of indicators: energy, environmental, and economic health, across 20 global manufacturing economies. Drawing on panel data covering the period from 2007 to 2023, they implemented three separate Generalized Method of Moments (GMM) estimations to analyze the effects of logistics performance indicators on each group. The empirical results demonstrate that the effect of logistics performance differs according to the particular indicator considered. Notably, improvements in international shipping logistics are generally associated with an increase in logistics performance. Finally, for 42 chosen, globally ranking countries (Khan et al., 2020). investigated the connections between FDI, logistics, GDP for each unit of consumed energy

## Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

demand, and CO<sub>2</sub> emissions. The results of OLS demonstrated that logistics performance reduces CO<sub>2</sub> emissions and is favorably correlated with FDI, energy demand, and renewable energy usage. (Li et al., 2021) Investigated the development and ecological implications of green logistics performance among countries involved in the Initiative for the One Belt and Road (OBRI) from 2007 to 2019. Employing a Generalized Method of Moments (GMM) estimation, their analysis reveals that green logistics performance has a significant contribution to economic development across all developed and underdeveloped economies. However, improvements in environmental quality were observed only in Europe and East and Southeast Asia, indicating regional disparities in the ecological outcomes of green logistics advancements. (Grunwald et al., 2025) Explored the connection between environmental issues and logistics performance across 160 countries using data for 2023. According to the investigation, better logistical performance is positively associated with broader socio-economic outcomes, including improved public health, education levels, income equality, effective governance, and equitable income distribution. Nevertheless, the analysis also highlights that, in its current form, logistics operations continue to pose significant risks to environmental sustainability and remain ineffective in reducing pollution emissions.

### 2.3. Logistics Performance and Economic Development

The correlation between the Logistics Performance Index (LPI) and global economic performance has garnered persistent interest in scholarly discussions regarding supply chain efficiency and international trade integration. (Hayyat et al., 2025). Empirically examined the influence of logistics performance on economic growth across countries during the 2007–2018 period (Liu et al., 2018). Their findings demonstrated the macroeconomic importance of effective logistics systems by showing that a 1% rise in the LPI is linked to an increase in global economic output of 0.011% to 0.035%. Complementing these findings, (Hlali, 2024) utilized a gravity model to examine how LPI components affected bilateral trade flows. Improvements in any LPI dimension, such as infrastructure, customs efficiency, and shipment reliability, have a positive impact on trade volumes, according to their analysis, highlighting the strategic significance of top-notch logistics services in promoting global economic integration. (Khan et al., 2018) Collected GDP and LPI data for 15 carefully chosen, globally ranked logistics economies, demonstrating that infrastructure and logistics expertise increase sectoral value added and economic growth. (Munim & Schramm, 2018) Investigated the economic impact of maritime trade in 91 seaport-dependent economies, focusing on logistics performance and port infrastructure quality. Results showed that improved logistics performance is correlated with port infrastructure quality. Considering those that are the Commonwealth of Independent States (CIS). (Goel et al., 2021) Conducted an empirical investigation into the nexus between economic growth and supply chain performance, with a particular emphasis on the implications for COVID-19-related policy interventions. Utilizing data from 130 countries, their findings revealed that enhanced logistics performance is positively associated with economic growth, underscoring the critical role of efficient supply chains in driving macroeconomic resilience. Similarly, (Janjua et al., 2021) Pandemic on Thailand's economic development and logistics performance. Their analysis highlighted a strong interdependence between these two variables, particularly mediated through the tourism sector, which constitutes a substantial portion of the country's GDP (gross domestic product). (See et al., 2024) assessed the direct relationship between logistics performance and a few chosen Global Competitiveness Index (GCI) components, dividing these elements into three groups: institutional considerations, human capital, and infrastructure. Utilizing data from the European Union, Asia, and Africa, their analysis, based on the ANOVA method, demonstrates that while the human capital component plays a critical role, overall logistics efficiency is significantly enhanced when improvements are made across all three clusters.

This study presents several key contributions that distinguish it from the existing literature. First, it employs the quantile regression approach, a method that remains underutilized in the field. Unlike conventional mean-based estimations, quantile regression allows for a more comprehensive analysis across the entire distribution of the dependent variable, offering deeper insights into heterogeneous effects, as recommended by prior research. Second, there is still a lack of research in the literature on the macroeconomic relationships between environmental technology and logistics performance. To the best of our knowledge, no previous empirical research has specifically looked at the connection between logistics performance, environmental technology, and more general national-level variables. This study aims to fill this important gap. Third, the roles of infrastructure and human capital, two fundamental drivers of logistics performance, have received limited attention in the context of innovation-led logistics development. Our findings underscore their significance and advocate for their inclusion in future empirical models. Fourth, unlike previous studies that often rely on broad and heterogeneous country samples, this research focuses specifically on top-ranking global logistics economies. This targeted approach enables more precise and context-specific insights, improving the relevance and applicability of the results. Finally, the literature reveals several conflicting findings regarding the determinants of logistics performance. By addressing these inconsistencies and integrating underexplored variables into a unified framework, the aim of

# Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

this research is to close current gaps and advance a more comprehensive macroeconomic knowledge of the innovation–logistics relationship.

## 3. Data and Empirical Methods

### 3.1. Data collection

This study uses data from the top 65 logistics-performing countries, as determined by the 2025 World Development Indicators (WDI) rankings, to undertake the empirical analysis. **Table A** in the Appendix has a detailed list of these countries.

### 3.1.2 independent variable

Numerous empirical studies have assessed environmental technologies using a range of variables. For instance, some have utilized the share of environment-related technologies as a proportion of total technological developments as a proxy indicator (Wang et al., 2025), while others, such as (Hayyat et al., 2025), have adopted per capita environmental technology inventions alongside the global share of such inventions to measure environmentally oriented innovations. In related work, (Hlali, 2024) and (Bai et al., 2025) have employed proxies such as advancements in environmental technologies and carbon emission reduction innovations to assess the effectiveness of environmental technology deployment. Moreover, environment-related patent technologies are widely recognized as critical tools for addressing ecological challenges (Muhammed et al., 2025). The inclusion of green innovation indicators from the World Intellectual Property Organization (WIPO) database also serves as a valuable measure of environmental performance, particularly in the context of emissions control and the preservation of environmental quality (Kumar et al., 2024). To construct a composite index of environmental technology (as shown in Table 1), principal component analysis (PCA) was applied using STATA version 17. Prior to analysis, all relevant variables were normalized to a 0–1 scale using the standard normalization formula.

$$VAR_{it} = \frac{X_{it} - \min(X_i)}{\max(X_i) - \min(X_i)} \tag{1}$$

In this study, the standardized value of each variable  $VAR_i$  for country  $i$  at time  $t$  is computed using the original value  $t, X_{it}$  where  $\min(X_i)$  and  $\max(X_i)$  represent the minimum and maximum values of the variable  $X$  across all 65 logistics-performing countries and the time period from 2007 to 2023. This normalization ensures comparability across countries and years by rescaling values to a uniform range between 0 and 1. The index  $i$  corresponds to the 65 selected countries, and  $t$  covers the period from 2007 to 2023. This methodological approach is consistent with recent empirical studies in the field (Aryee & Adaku, 2023).

**Table 1. Environmental-related technology index**

Variables	Measurement	Source
CMT	Climate change mitigation technology in the transportation sector	WDI
ETD	Environment-related technological development % as a percentage of all technology	OECD
ETR	Relative advantage in environmental technology (ratio)	OECD
ERTI	Development of ERT inventions worldwide % age	OECD
ERTPC	Inventions in environment-related technologies worldwide per capita	OECD
ERP	Environment-related patent technologies	OECD
EI	Environmental Innovation Score	WIPO

**Table 2: Variables, descriptions.**

Indicator	Definition	Source
Logistics performance	Logistics Performance Index (1=low to 5=high)	World Development Indicators (WDI, 2023)

## Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

Employment	Number of employed persons (total)	World Development Indicators (WDI, 2023)
Urbanization	Urban population (% of total population)	World Development Indicators (WDI, 2023)
Capital	Gross Fixed Capital Formation (% of GDP)	World Development Indicators (WDI, 2023)
Governance	Government Effectiveness	World Development Indicators (WDI, 2023)
Environmental-related technology	Environmental-related patent technology	WDI, OECD WIPO (2023)
Human Capital (proxied by the Human Development Index)	Human Development Index (health, education, income)	United Nations Development Program (UNDP, 2023)
GDP	(% of GDP)	World Development Indicators (WDI, 2023)
Transport CO <sub>2</sub> emissions	CO <sub>2</sub> emissions from Transport (thousand tons)	World Development Indicators (WDI, 2023)

Source: our elaborations.

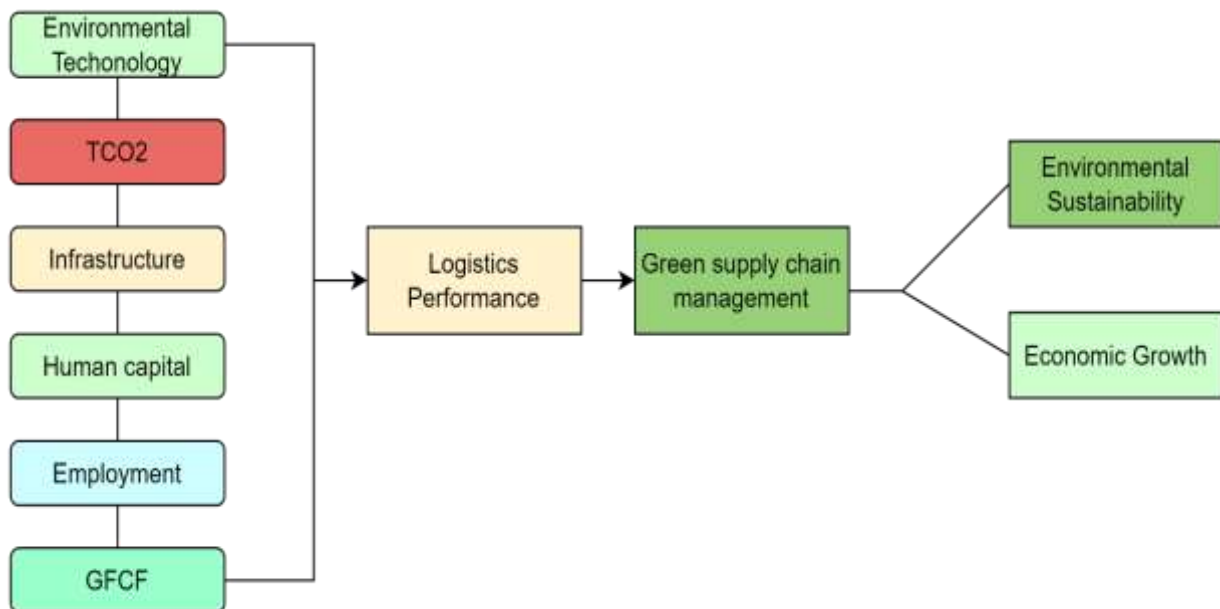
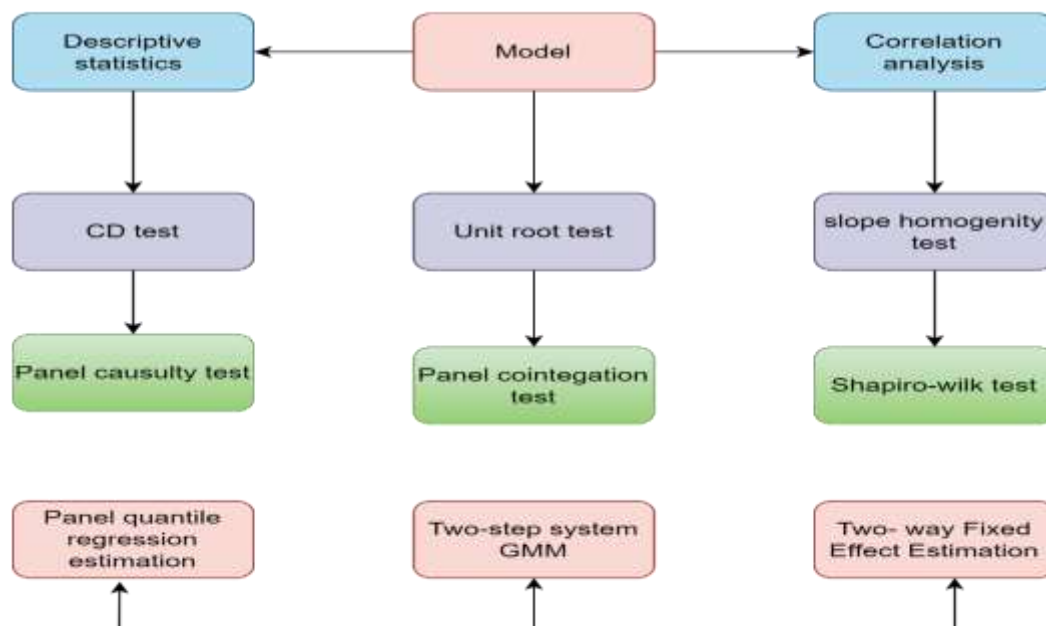


Fig. 1. Interconnection among logistics performance determinants, green supply chain management, economic growth, and environmental sustainability. Source: our elaborations.

# Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector



**Fig. 2. Conceptual Framework and Estimation Procedure of the Study**

Logistics Performance Index (LPI), as reported by the (WDI, 2023). The ability to track and trace shipments (LPITTC), the proficiency and caliber of logistics services (LPIQLS), the ease of planning competitively priced international shipments (LPICPS), the efficiency of customs clearance procedures (LPICCP), the promptness of shipments reaching their destination (LPST), and the caliber of trade and transport infrastructure (LPIQTTI) are the six sub-indicators that make up this calculation. A scale from 1 (poor performance) to 5 (excellent performance) is used to rate the LPI. This study uses the World Development Indicators' actual Gross Domestic Product (GDP) to measure economic performance. To define environmental pollution, this study uses CO<sub>2</sub> emissions from Transport (thousand tons) (WDI, 2023) The analysis is limited to the most current time frame for which reliable data are available, which is from 2007 to 2023, due to restrictions in the availability of Logistics Performance Index (LPI) data. There are 1,104 observations in the final dataset. Table 2 provides a summary of the important variables. Figure 1 depicts the links examined in this study, while Figure 2 presents the conceptual framework that underpins the investigation.

### 3.2. Model specification

The existing literature primarily investigates logistics performance by examining its socioeconomic factors. This study consolidates these diverse elements into an effective analytical model. Building on the logistics performance components identified by (Hayyat et al., 2025), (Janjua et al., 2021). We develop a novel framework, which is depicted in Figure 2.

Three key aspects are emphasized: The determinants affecting logistics performance, the significance of logistics performance in fostering economic growth, and its role in advancing environmental sustainability. These aspects are illustrated in Figure 1. Accordingly, Equations (2) to (4) represent the respective models A, B, and C, which are analytical. That reflects these relationships.

$$LPI = f(HDI, GFCF, LF, ERT, LUP, GORV) \tag{2}$$

$$GDP = f(HDI, LPI, LUP, GORV) \tag{3}$$

$$LTCO2 = f(HDI, LPI, LUP, GORV) \tag{4}$$

This study examines the determinants of logistics performance, economic growth, and environmental sustainability, following the implementation of essential preliminary tests, including stationarity and cointegration assessments. To ensure analytical rigor and result reliability, the analysis employs a range of estimation techniques, specifically the Two-Step System (GMM), Two-Way Fixed Effect, and QR, or quantile regression. The empirical findings' validity and robustness are improved by the use of several estimation techniques.

The Quantile Regression (QR) technique is employed for each of the models presented in Equations (2) to (4). This method captures full distributional characteristics of the dependent variables, effectively addressing issues related to time-varying heterogeneity and the presence of outliers in the data (Hayyat et al., 2025; Janjua et al., 2021; Magazzino, Alola, et al., 2021).

Furthermore, the absence of normality across all variables reinforces the appropriateness of employing the Quantile Regression (QR) approach. Furthermore, QR provides a clear benefit by giving a thorough representation of the dependent variable's conditional distribution, going beyond the conventional emphasis on the conditional mean or median. (Mosteller &

## Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

Tukey, 1977). Considering a panel structure where time  $t = 2007, 2008, \dots, 2023$  and cross-sectional units  $i = 1, 2, \dots, 65$ , these three models, corresponding to Equations (1) to (3), are estimated using a modified QR approach as:

$$E[LPI_{it} | (HDI_{it}, GFCF_{it}, LF_{it}, ERT_{it}, LUP_{it}, GORV_{it}), \alpha_i] = (HDI_{it}^T, GFCF_{it}^T, LF_{it}^T, ERT_{it}^T, LUP_{it}^T, GORV_{it}^T) \beta + \alpha_i \quad (5)$$

$$E[GDP_{it} | (HDI_{it}, LPI_{it}, LUP_{it}, GORV_{it}), \alpha_i] = (HDI_{it}^T, LPI_{it}^T, LUP_{it}^T, GORV_{it}^T) \beta + \alpha_i \quad (6)$$

$$E[LTCO2_{it} | (HDI_{it}, LPI_{it}, LUP_{it}, GORV_{it}), \alpha_i] = (HDI_{it}^T, LPI_{it}^T, LUP_{it}^T, GORV_{it}^T) \beta + \alpha_i \quad (7)$$

$$Q_{LPI_{it}}[\tau | (HDI_{it}, GFCF_{it}, LF_{it}, ERT_{it}, LUP_{it}, GORV_{it}), \alpha_i] = \beta_{1\tau} HDI_{it} + \beta_{2\tau} GFCF_{it} + \beta_{3\tau} LF_{it} + \beta_{4\tau} ERT_{it} + \beta_{5\tau} LUP_{it} + \beta_{6\tau} GORV_{it} + \alpha_i \quad (8)$$

$$Q_{GDP_{it}}[\tau | (HDI_{it}, LPI_{it}, LUP_{it}, GORV_{it}), \alpha_i] = \beta_{1\tau} HDI_{it} + \beta_{2\tau} LPI_{it} + \beta_{3\tau} LUP_{it} + \beta_{4\tau} GORV_{it} + \alpha_i \quad (9)$$

$$Q_{LTCO2_{it}}[\tau | (HDI_{it}, LPI_{it}, LUP_{it}, GORV_{it}), \alpha_i] = \beta_{1\tau} HDI_{it} + \beta_{2\tau} LPI_{it} + \beta_{3\tau} LUP_{it} + \beta_{4\tau} GORV_{it} + \alpha_i \quad (10)$$

Where unobserved, the country-specific effects are represented by  $\alpha_i$ . Based on the extended least squares framework of (Koenker & Bassett Jr, 1978) The parameters  $\beta(\tau)$  in equations (8) to (10) are estimated as the  $\tau$ th ( $\tau = 0.10, 0.25, 0.50, 0.75, 0.90$ ) of the conditional distribution using the following quantile regression expressions:

$$\hat{\beta}(\tau) = \underset{\beta \in R^k}{\operatorname{argmin}} \left[ \sum_{i \in \{i: y_i \geq x_i \beta\}} \tau |y_i - x_i \beta| + \sum_{i \in \{i: y_i < x_i \beta\}} (1 - \tau) |y_i - x_i \beta| \right] \quad (11)$$

Additionally, the quantile of the conditional Logistics Performance Index, given the explanatory variables  $x_i$ , is determined by the parameter  $\tau$  (parameter size), which ranges within  $0 < \tau < 1$ , which minimizes the weighted total of the estimating process's absolute deviations.

$$Q_{LPI}(\tau | (HDI_i, GFCF_i, LF_i, ERT_i, LUP_i, GORV_i)) = (HDI_i, GFCF_i, LF_i, ERT_i, LUP_i, GORV_i) \quad (12)$$

$$Q_{GDP}(\tau | (HDI_i, LPI_i, LUP_i, GORV_i)) = (HDI_i, LPI_i, LUP_i, GORV_i) \beta_\tau \quad (13)$$

$$Q_{LTCO2}(\tau | (HDI_i, LPI_i, LUP_i, GORV_i)) = (HDI_i, LPI_i, LUP_i, GORV_i) \beta_\tau \quad (14)$$

### 3.3. Shapiro–Wilk Test

Samuel Sanford Shapiro developed this test in 1965 to assess the assumption of normality. Under the null hypothesis of the test, a sample  $x_1, \dots, x_n$  is assumed to be drawn from a population where the distribution is normal. The outcome of the statistical test provides evidence regarding the validity of this assumption.

$$W = \frac{(\sum_{i=1}^n a_i x_i)^2}{\sum_{i=1}^n (x_i - \bar{x})^2} \quad (15)$$

Where  $(\bar{x} - x)$  denotes the mean value and  $x_i$  denotes the order statistics that indicate the lowest value within a given sample.

$$a_1 \dots a_n = \frac{k^t W^{-1}}{C} \quad (16)$$

If  $C$  is a normal distribution vector that looks like this:

$$C = (W^{-1} k = k^t W^{-1} W^{-1} k)^2 \quad (17)$$

And vector

$$k = (k_1 \dots k_n) \quad (18)$$

The Shapiro–Wilk (SW) test's null hypothesis ( $H_0$ ) posits that the variable is normally distributed. Consequently, if the p-value falls below 0.05, the null hypothesis is rejected, implying that the data do not conform to a normal distribution. The findings indicate that all variables exhibit non-normal distributions, except for environmental technology. As a result, the panel quantile regression technique has been utilized to manage these econometric issues. (Hayyat et al., 2025).

We look at the full distributions of GDP, LTCO<sub>2</sub>, and LPI for every quantile in each category. Quantile Regression (QR), the two-step Generalized Method of Moments (GMM), and two-way fixed effects estimation techniques are used to compare the results with those derived from the conditional distributions.

## 4. EMPIRICAL FINDINGS AND DISCUSSION

The Appendix's Table B presents the variables' descriptive statistics, while Table C shows the correlation matrix. Assessing cross-sectional dependence is a crucial first diagnostic in panel data econometric analysis. Unobserved common factors, geographic effects, spillover effects, or strong cross-sectional dependence, where units within the same cross-section display significant intercorrelation, can all have an impact on panel datasets used in applied research.

The outcomes of the panel cross-sectional dependence tests for the sample are presented in Table 3. The null hypothesis ( $H_0$ ) of these tests asserts that cross-sectional dependence is absent. Since the null hypothesis is uniformly rejected for all variables at standard significance levels, it is necessary to account for cross-sectional dependence in the subsequent analysis.

# Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

**Table 3: Panel cross-section dependence tests.**

Variables	Pesaran	Breusch-Pagan LM		
	CD test	CD test	Friedman CD test (1937)	Frees CD test (1995)
LPI	23.801***	2.18	128.277***	1.679***
GDP	98.492***	41.30***	408.049***	7.876***
LTCO2	36.934***	55.24***	214.390***	16.085**
HDI	164.203***	653.82***	872.611***	0.6532***
GFCF	10.568***	1.72	49.204	4.2098**
LF	15.901***	123.34***	112.185***	2.7097***
ERT	45.86***	167.61***	232.011***	3.5730***
LUP	141.334***	556.66***	41.908***	6.3098***
GORV	2.131**	315.42***	23.232***	11.1740**

\*\*\*p<0.01, \*\*p<0.05, \*p<0.10.

**Table 4. Panel unit root tests**

Variables	CIPS (0)	CIPS (1)	CADF (0)	CADF (1)
LPI	-1.479	-2.537***	-2.588***	-2.715***
GDP	-2.808***	-4.777***	-2.687***	-3.922***
LTCO2	-1.848	-3.434***	-3.922*	-2.829***
HDI	-2.08***	-2.975***	-1.349	-3.231***
GFCF	-1.632	-3.333***	-2.682***	-2.684***
LF	-2.069**	-3.656***	-1.936	-2.729***
ERT	-2.525***	-4.388***	-2.355	-2.709***
LUP	-0.427	-1.258**	-1.561	-3.179***
GORV	-1.646	-3.951***	-2.418	-2.796***

Note: \*, \*\*, and \*\*\* denote significance at the 10%, 5%, and 1% levels, respectively.

We continue by using second-generation panel unit root tests because the series indicates cross-sectional dependence. By allowing correlations between residuals across panel units, these tests mitigate cross-sectional dependence and produce more reliable results in these situations. Overall, Table 4 results suggest that it is difficult to reject the null hypothesis, which holds that all series are non-stationary.

Under both deterministic specifications, only the (Pesaran, 2003). The cross-sectional Augmented Dickey–Fuller (CADF) test provides evidence against the null hypothesis for the LPI and LUP variables. However, these results are not corroborated by the (Pesaran, 2007) test. Consequently, it can be inferred that all variables in the dataset exhibit non-stationarity and are characterized by cross-sectional dependence.

To conduct the cointegration analysis, three distinct tests are employed: the Westerlund error-correction-based test, Pedroni’s cointegration test, and Kao’s residual-based cointegration test. The results of these tests, corresponding to the three model specifications in Equations (1)–(3), are presented in Table 5. Overall, the findings indicate the existence of a long-run (cointegrating) relationship among the variables in each of the three models. The findings about the factors of logistics performance and their consequent effects on environmental quality and economic growth are further discussed, with the results represented in Table 7.

**Table 5**

Panel cointegration tests.	
LPI=f (HDI, GFCF, LF, ERT, LUP, GORV)	
<b>Kao’s residual cointegration test</b>	
Modified Dickey–Fuller t	0.052 (0.479)
Dickey–Fuller t	1.039 (0.149)

## Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

Augmented Dickey–Fuller t	-6.236*** (0.000)
Unadjusted modified Dickey–Fuller t	0.492 (0.311)
Unadjusted Dickey–Fuller t	1.375* (0.088)

### Pedroni's test for cointegration

Tests	Constant	Constant and trend
Modified Phillips–Perron t	11.996*** (0.000)	13.019*** (0.000)
Phillips–Perron t	1.7284** (0.042)	-0.807 (0.209)
Augmented Dickey–Fuller t	-0.059 (0.476)	-2.051** (0.020)

### Westerlund error-correction-based cointegration test

Tests	Constant	Constant and trend
Variance ratio	0.0313 (0.487)	4.790*** (0.000)

GDP=f (HDI, LPI, LUP, GORV)

### Kao's residual cointegration test

Modified Dickey–Fuller t	-4.179*** (0.000)
Dickey–Fuller t	-13.564*** (0.000)
Augmented Dickey–Fuller t	-7.398*** (0.000)
Unadjusted modified Dickey–Fuller t	-33.227*** (0.000)
Unadjusted Dickey–Fuller t	-26.945*** (0.000)

### Pedroni's test for cointegration

Tests	Constant	Constant and trend
Modified Phillips–Perron t	3.085*** (0.001)	6.092*** (0.000)
Phillips–Perron t	-28.170*** (0.000)	-27.523*** (0.000)
Augmented Dickey–Fuller t	-26.120*** (0.000)	-25.336*** (0.000)

### Westerlund error-correction-based cointegration test

Tests	Constant	Constant and trend
Variance ratio	-6.255*** (0.000)	-5.556*** (0.000)

LTCO<sub>2</sub>=f (HDI, LPI, LUP, GORV)

### Kao's residual cointegration test

Modified Dickey–Fuller t	-0.3665 (0.357)
Dickey–Fuller t	-1.8725** (0.030)
Augmented Dickey–Fuller t	-0.749 (0.226)
Unadjusted modified Dickey–Fuller t	-1.893** (0.029)
Unadjusted Dickey–Fuller t	-2.873*** (0.002)

### Pedroni's test for cointegration

Tests	Constant	Constant and trend
Modified Phillips–Perron t	6.745*** (0.000)	8.563*** (0.000)
Phillips–Perron t	-7.513*** (0.000)	-9.748*** (0.000)
Augmented Dickey–Fuller t	-7.706*** (0.000)	-9.761*** (0.000)

### Westerlund error-correction-based cointegration test

Tests	Constant	Constant and trend
Variance ratio	-2.904 *** (0.001)	0.133 (0.446)

Note: \*, \*\*, and \*\*\* denote significance at the 10%, 5%, and 1% levels, respectively.

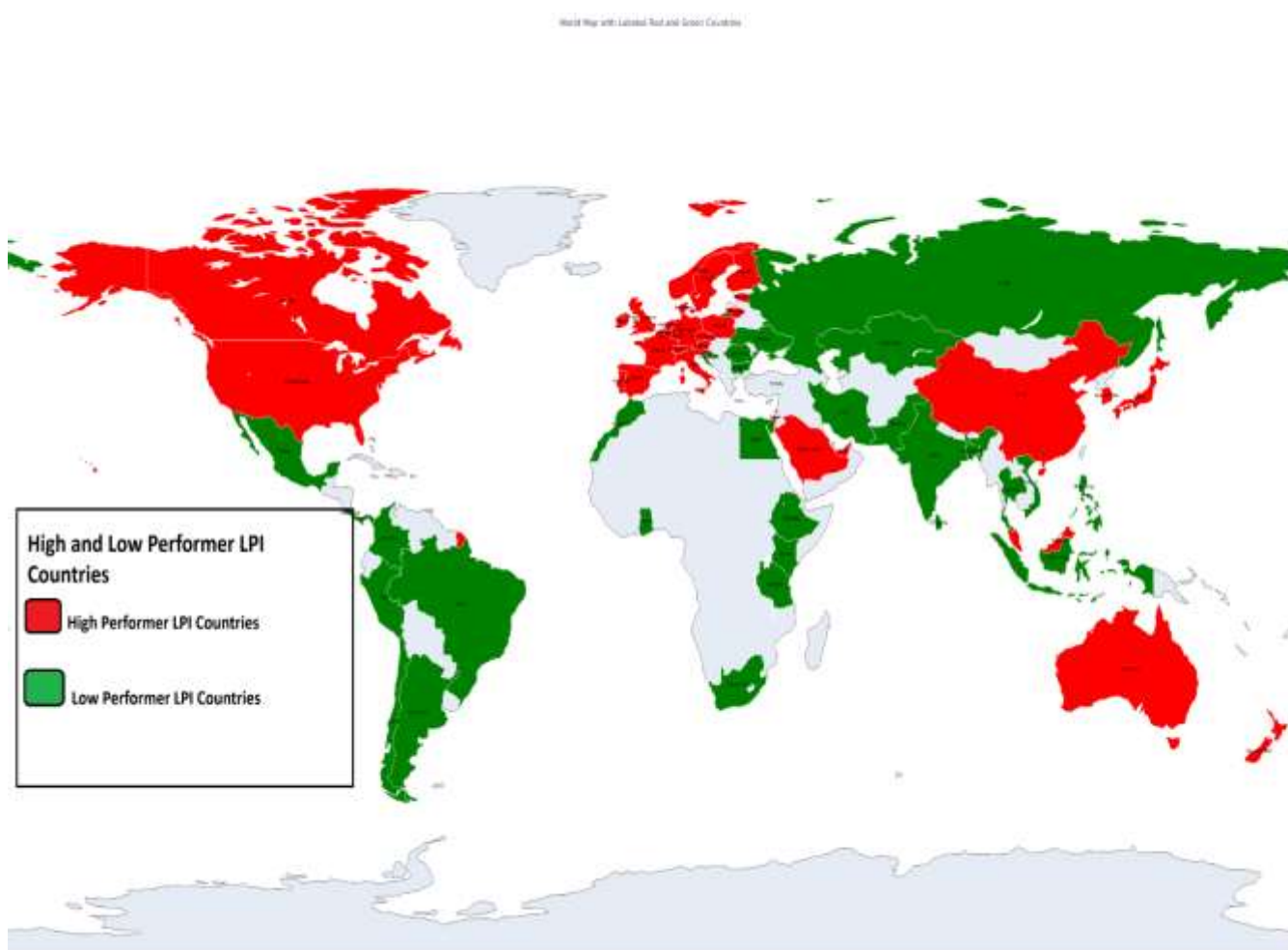
### Shapiro-Wilk test

In 1965, Samuel Sanford Shapiro introduced the test to determine normalcy (Table 6). A sample,  $X_1, X_n$ , is taken from a population that has a normal distribution, according to the test's null hypothesis. The following outcomes are obtained using the statistical test:

# Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

**Table 6: Shapiro-Wilk normality test**

Variable	W-statistic (swilk)	V-statistic	z-value (swilk)	p-value (swilk)
LPI	0.9549	32.6616	8.5491	0.000
GDP	0.9330	51.1603	9.5364	0.000
LTCO2	0.9713	20.5108	7.4299	0.000
HDI	0.8965	75.3456	10.6147	0.000
GFCF	0.9444	41.0282	9.0729	0.000
LF	0.8891	81.8417	10.7879	0.000
ERT	0.9800	13.6930	6.5334	0.000
LUP	0.8372	116.6452	11.7424	0.000
GORV	0.9425	41.2123	9.1555	0.000



**Fig. 3. Logistics performer Countries**

## 4.1. Drivers of Logistics Performance

According to the results in Table 7 (see Model A), the analysis indicates that a higher HDI is associated with a significant enhancement in logistics performance across several quantiles. The quantile regression outcomes demonstrate that improvements in human development—measured by life expectancy, education, and income (as represented by HDI)—have a positive impact on logistics performance, especially at the 10th (0.970), 25th (0.633), 75th (0.940), and 90th (0.995) quantiles. This highlights that HDI is a key factor in advancing logistics performance, particularly in economies situated at both the lower and upper ends of the performance distribution. However, the impact becomes statistically insignificant at the 50th quantile (0.296), indicating a moderate effect at the median level. Interestingly, the relationship turns negative and statistically significant at a higher quantile

## Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

(-1.378), which may imply diminishing returns or constraints in highly developed logistics systems. Overall, these results confirm that human development remains a critical factor in enhancing logistics capacity, with its influence varying across the distribution. Additionally, this finding is consistent with previous empirical evidence. (Zaman & Shamsuddin, 2017). In particular, (Zaman & Shamsuddin, 2017) highlighted a positive association between logistics performance and per capita health expenditures, which serve as a reliable proxy for life expectancy. Furthermore, this relationship was evident during the widespread distribution of COVID-19 vaccines, which underscored the role of efficient logistics systems in supporting public health outcomes. (Agueh et al., 2016) Argued that there is a considerable correlation between logistics performance and economic health as impacted by immunization programs.

Additionally, how logistics performance is affected by gross fixed capital formation (GFCF) varies across the distribution, exhibiting a generally negative pattern at higher quantiles. While the coefficients at the 10th (0.002), 25th (0.005\*), and 50th (0.003) quantiles are positive—though largely statistically insignificant—the relationship shifts at the upper end of the distribution. At the 75th quantile, the coefficient becomes negative (-0.004), and this effect intensifies, reaching statistical significance at the 90th quantile (-0.009\*\*). These findings suggest that increased capital investment may hinder logistics performance at advanced levels, potentially due to the strain such investments place on existing logistics infrastructure and processes. However, this adverse impact may diminish once a certain capacity threshold is reached, beyond which additional investment may no longer have an adverse effect on performance. This perspective is consistent with the logistics performance-FDI relationship documented by (Hayyat et al., 2025), and (Khan et al., 2018).

Furthermore, employment (LF) has a notable adverse effect on logistics performance, as evidenced by the Two-Way Fixed Effects (TWFE) and Generalized Method of Moments (GMM) estimates, which show adverse impacts of 0.002 and 0.006, respectively. However, the adverse effects of employment on

**Table 7. Results of Two-way Fixed Effect, GMM, and Panel Quantile Regression.**

Variable	TWFE	GMM	Quantile Regression				
			0.10	0.25	0.50	0.75	0.90
<b>Model A, Dep. Var; LPI</b>							
HDI	0.970**(-0.617)	0.633*** (0.062)	0.296(0.257)	0.940*** (0.147)	0.995*** (0.350)	-0.117(0.468)	-1.378*** (0.369)
GFCF	-0.003*(0.002)	0.003** (0.0031)	0.002(0.004)	0.005*(0.002)	0.003(0.002)	-0.004(0.005)	-0.009** (0.005)
LF	0.002(0.008)	-0.006 (-0.008)	-0.003(0.009)	0.014*** (0.003)	0.012** (0.005)	-0.009(0.008)	-0.023** (0.012)
LP	0.007*** (0.016)	0.053** (0.026)	0.087*** (0.008)	0.081*** (0.005)	0.083*** (0.008)	0.052*** (0.008)	0.045*** (0.012)
LUP	0.070*** (0.188)	0.221*** (0.026)	-0.165** (0.082)	0.192*** (0.042)	0.268*** (0.059)	0.613*** (0.051)	-
GORV	0.120*** (0.027)	0.061* (0.036)	0.440*** (0.033)	0.355*** (0.017)	0.340*** (0.026)	0.458*** (0.042)	0.446*** (0.041)
<b>Model B, Dep. Var; GDP</b>							
HDI	10.322*** (1.809)	29.100* (15.297)	-	11.21*** (2.185)	9.457*** (2.060)	7.793*** (2.962)	-7.245** (3.321)
LPI	-0.522** (0.242)	1.159 (1.857)	-0.638 (0.754)	-0.329 (0.299)	0.811*** (0.224)	-	-0.067 (0.591)
LUP	1.572*** (0.443)	16.047** (6.198)	-2.341 (1.591)	1.743*** (0.436)	1.543*** (0.361)	-1.511** (0.625)	-0.411 (0.945)
GORV	0.835*** (0.259)	.8383*** (1.020)	2.377*** (0.385)	1.078*** (0.311)	0.684** (0.311)	0.321 (0.350)	-0.502 (0.531)
<b>Model C, Dep. Var; LCO2-t</b>							
HDI	0.061*** (0.0321)	-.0154*** (0.292)	3.036*** (0.546)	2.356*** (0.742)	1.691* (0.980)	-1.409 (2.565)	-6.483** (2.601)
LPI	0.090*** (0.031)	0.046*** (0.032)	0.698*** (0.117)	0.766*** (0.176)	1.168*** (0.152)	0.937 (0.571)	1.075 (0.669)
LUP	2.591*** (0.158)	0.032** (0.214)	0.721*** (0.112)	1.417*** (0.180)	1.798*** (0.158)	2.001*** (0.196)	1.791*** (0.434)
GOVR	0.036*** (0.030)	.046*** (0.0265)	0.795*** (0.123)	0.980*** (0.085)	1.140*** (0.146)	-0.622*** (0.163)	-0.068 (0.286)
<b>Diagnostic Model A</b>			<b>Model B</b>			<b>Model C</b>	
Sargan	X <sup>2</sup> 105=259.70*** (0.000)		X <sup>2</sup> 75= 517.57*** (0.000)			X <sup>2</sup> 75= 359.04*** (0.000)	
Hansen	X <sup>2</sup> 105=61.34 (1.000)		X <sup>2</sup> 75= 64.62 (0.798)			X <sup>2</sup> 75= 61.96 (0.860)	

# Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

AR (1)	Z= -0.05(0.958)	Z= -4.50***(0.000)	Z= -5.58***(0.000)
AR (2)	Z= -4.92***(0.000)	Z= -4.13***(0.000)	Z= -1.00(0.317)

Notes: \*\*\* p<0.01, \*\* p<0.05, \* p<0

Logistics performance varies across all quantiles. All adverse effects are statistically significant and tend to decline across higher quantiles. Similarly, an increase environmental related technology is associated with improvements in logistics performance across the panel. The positive relationship between environmental technology activity and logistics performance strengthens as it approaches the upper quantiles, as confirmed by the TWFE, GMM, and QR estimators. Lastly, although their effects are comparatively minor, both the urban population and governance contribute positively and significantly to enhancing logistics performance.

## 4.2. The Contribution of Logistics Performance to Economic Growth

Model B reveals that the expansion of the economy is primarily attributed to improvements in human development, as shown in the results presented in Table 7. Both the TWFE and quantile regression (QR) estimates indicate that logistics performance contributes to economic growth across the entire distribution, from the lower to the upper quantiles. Notably, similar findings have been reported by (Hayyat et al., 2025) and (Li et al., 2021) Those who emphasize the positive relationship between logistics performance and economic development. In particular, (Khan et al., 2020), argues that logistics performance influences economic expansion through its impact on foreign direct investment (FDI) and industrial value-added, a view further supported by (Ekwueme et al., 2021). Furthermore, the TWFE and GMM estimations reveal that urbanization has a significant influence on economic growth across all quantiles. At the same time, governance exerts a modest yet positive and noteworthy impact on economic development.

## 4.3. The Effect of Logistics Performance on Environmental Quality

Lastly, the results of Model C in Table 7 underscore the factors influencing environmental quality. Progress in human development substantially reduces environmental degradation, while logistics performance shows a mainly positive and statistically significant impact on environmental degradation across all quantiles, as well as in the TWFE and GMM estimations. Importantly, the strength of this effect is greater in the lower quantiles. This evidence supports the existing literature, indicating that the link between logistics performance and environmental sustainability can be either beneficial or harmful, depending largely on the types of energy sources employed. (Ibrahim & Alola, 2020). Specifically, (Liu et al., 2018) employed six logistics performance indicators in their study of Asian countries and found that two indicators contributed to environmental degradation, while one indicator was associated with improvements in environmental quality. The remaining three indicators showed no significant impact on environmental outcomes. (Zambujal-Oliveira & Fernandes, 2024)and (Razalli, 2022).

## 5. CONCLUDING REMARKS.

Despite extensive research, the connection between logistics performance and environmental outcomes remains inconclusive. Although the findings are often inconsistent, this issue remains highly relevant for scholars, as it intersects with green growth strategies, sustainable practices, and recently established global climate objectives. Moreover, previous empirical studies have frequently overlooked the role of environmental technology across different stages of the supply chain and have typically examined it in isolation from environmental and economic dimensions. Consequently, it is pertinent to investigate, using a representative panel of logistics-intensive economies, whether innovative practices can mediate the connection between logistical performance, economic development, and releases of pollution.

In summary, this study responds to the research question outlined above by estimating three separate econometric models.

- **Model (A):** The drivers of logistics performance (including infrastructure, education, employment, GFCF, environmental-related technology, and governance).
- **Model (B):** The impacts of logistics performance, governance, urban population, human capital, and GDP.
- **Model (C):** The impacts of logistics performance, human capital, transportation-related CO<sub>2</sub> emissions, and urban population.

A macro-level dataset containing 1,105 observations was assembled for the 65 top-ranked logistics countries spanning the period from 2007 to 2023. The analytical approach includes a series of panel cross-sectional dependence tests, second-generation panel unit root tests, and cointegration methods to identify causal relationships. Finally, three separate panel data estimators are applied in the estimation strategy because of their favorable statistical characteristics. Empirical evidence shows that progress in environmental-related technology, measured by the number of patents filed, together with enhancements in human capital, indicated by literacy levels within the Human Development Index (HDI), urbanization, and governance, has a positive and significant

## Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

effect on logistics performance. In contrast, the supply chain tends to be inherently less labor-intensive and less capital-intensive beyond certain levels, as reflected by the negative impacts of employment and gross fixed capital formation (GFCF) on the Logistics Performance Index (LPI). Importantly, the findings indicate that large-scale capital investments can negatively influence logistics performance once they exceed a particular threshold. Additionally, the results demonstrate that while the well-established positive link between HDI and economic growth is confirmed, logistics performance itself negatively affects both economic development and environmental sustainability. This latter finding aligns with a substantial body of research indicating that the relationship may assume a negative magnitude when non-renewable energy sources constitute the predominant basis of power generation. In this analysis of the top 65 logistics-performing countries, it is noteworthy that some countries exhibit strong logistics performance despite infrastructure that is less advanced than that of leading economies. These findings underscore the urgent need to advance the integration of low-carbon energy technologies across the supply chain. Accordingly, a focused policy framework can be developed to support and sustain this transition.

### 6. POLICY RECOMMENDATIONS AND IMPLICATIONS

Above all, supply chain and logistics activities should be managed to reduce resource consumption. The logistics sector ought to implement green practices, starting with enhancing the energy efficiency of international shipments and increasing their effectiveness through modal diversification. In the global logistics industry, considerable efforts are needed to lower the carbon intensity of the energy provided to upstream suppliers and to encourage more efficient energy utilization at each stage of the logistics process. Beyond lowering energy costs for suppliers, such measures would also attract foreign direct investment aimed at supporting more sustainable resource allocations. Ultimately, the objectives of sustainability and profitability in logistics operations could be effectively reconciled. In addition to reducing energy costs for suppliers, these measures could incentivize foreign direct investment (FDI) directed toward more sustainable resource allocations. Over time, the objectives of environmental sustainability and profitability in logistics operations may be successfully aligned. Second, particular emphasis should be placed on shipping punctuality and reliability, which are central not only to achieving carbon reductions but also to addressing broader environmental challenges. Accordingly, policymakers should implement measures to reduce the incidence of congestion zones at port entrances, as such bottlenecks contribute to elevated energy consumption and financial losses. Third, to mitigate carbon leakage and opportunistic practices, comprehensive and proactive government regulations are essential. Despite the inherent challenges, the capacity of public institutions to anticipate, prevent, and discourage firms from relocating or outsourcing segments of their production abroad is a crucial condition for establishing a sustainable global supply chain that operates effectively across international contexts to avoid the development of an environmental divide between countries that maintain strict sustainability standards and those that do not, and to provide timely and credible signals to high-emission suppliers, a robust and coordinated global policy response is necessary. More generally, it is important to recognize the increasing role of environmental technology in supporting these goals. Whether through robotics to automate warehousing operations (Azadeh et al., 2025) Drones to facilitate last-mile delivery (Wang et al., 2024) Blockchain technology can improve supply chain accessibility and data integrity (Uvet et al., 2025) Such technologies are anticipated to significantly reshape the logistics sector's operational efficiency and competitive landscape. However, we recommend that policymakers accelerate the implementation of these measures while carefully considering the associated externalities for low-skilled employment and natural resources.

The scope of this manuscript is subject to several empirical limitations. For instance, to capture country-specific features of the connection between logistics performance and environmental sustainability, appropriate empirical approaches could be applied to examine each country individually. In addition, future research should focus on the sectoral level with the goal of identifying environmental technologies that provide unforeseen economic and environmental benefits to the logistics industry. Country-level insights should also help expand the existing body of knowledge in this field. Lastly, further investigations employing Artificial Neural Networks (ANNs) and Machine Learning (ML) methods are recommended to enhance understanding of this subject.

### Appendix

Table A

Top 65 logistics countries.

World Bank ranking 2023

Germany	Luxembourg	Portugal	India	Bulgaria
Sweden	United States	Malaysia	Vietnam	Croatia
Belgium	France	Poland	Indonesia	Ukraine

## Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

Austria	Canada	Slovenia	Mexico	Russia
Switzerland	Australia	Estonia	Brazil	Panama
Netherlands	New Zealand	Lithuania	Argentina	Costa Rica
Singapore	UAE	Israel	Colombia	Kenya
Denmark	South Korea	Saudi Arabia	Peru	Ghana
Finland	Türkiye	China	Morocco	Bangladesh
United Kingdom	Spain	Thailand	Egypt	Pakistan
Hong Kong	Italy	Iran	Philippines	Sri Lanka
Japan	Czech Republic	Chile	Kazakhstan	Tanzania
Norway	Ireland	South Africa	Romania	Ethiopia

Source:(WDI, 2023).

Table B  
Descriptive Statistics.

Variable	Mean	Median	SD	Max	Min
LPI	3.412	3.46	0.509	4.3	1.51
GDP	2.926	2.95	4.024	24.62	-28.76
LTCO2	3.398	3.198	1.369	7.499	.756
HDI	.811	.845	0.125	.989	.376
GFCF	23.574	22.86	5.695	53.222	10.692
LF	3.645	3.55	1.866	15.71	.13
ERT	5.331	5.055	1.773	10.008	1.617
LUP	4.171	4.3	0.378	4.605	2.78
GORV	.64	.54	0.879	2.47	-1.02

Table C (Correlation matrix)

LPI	1.000								
GDP	-0.118	1.000							
LTCO2	0.088	-0.073	1.000						
HDI	0.463	-0.310	0.089	1.000					
GFCF	0.025	0.314	0.019	-0.216	1.000				
LF	0.018	-0.064	0.103	0.186	-0.143	1.000			
ERT	0.518	-0.139	0.641	0.469	-0.017	0.051	1.000		
LUP	0.179	-0.291	0.215	0.750	-0.286	0.203	0.353	1.000	
GORV	0.676	-0.213	-0.015	0.825	-0.101	0.152	0.530	0.595	1.000

# Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

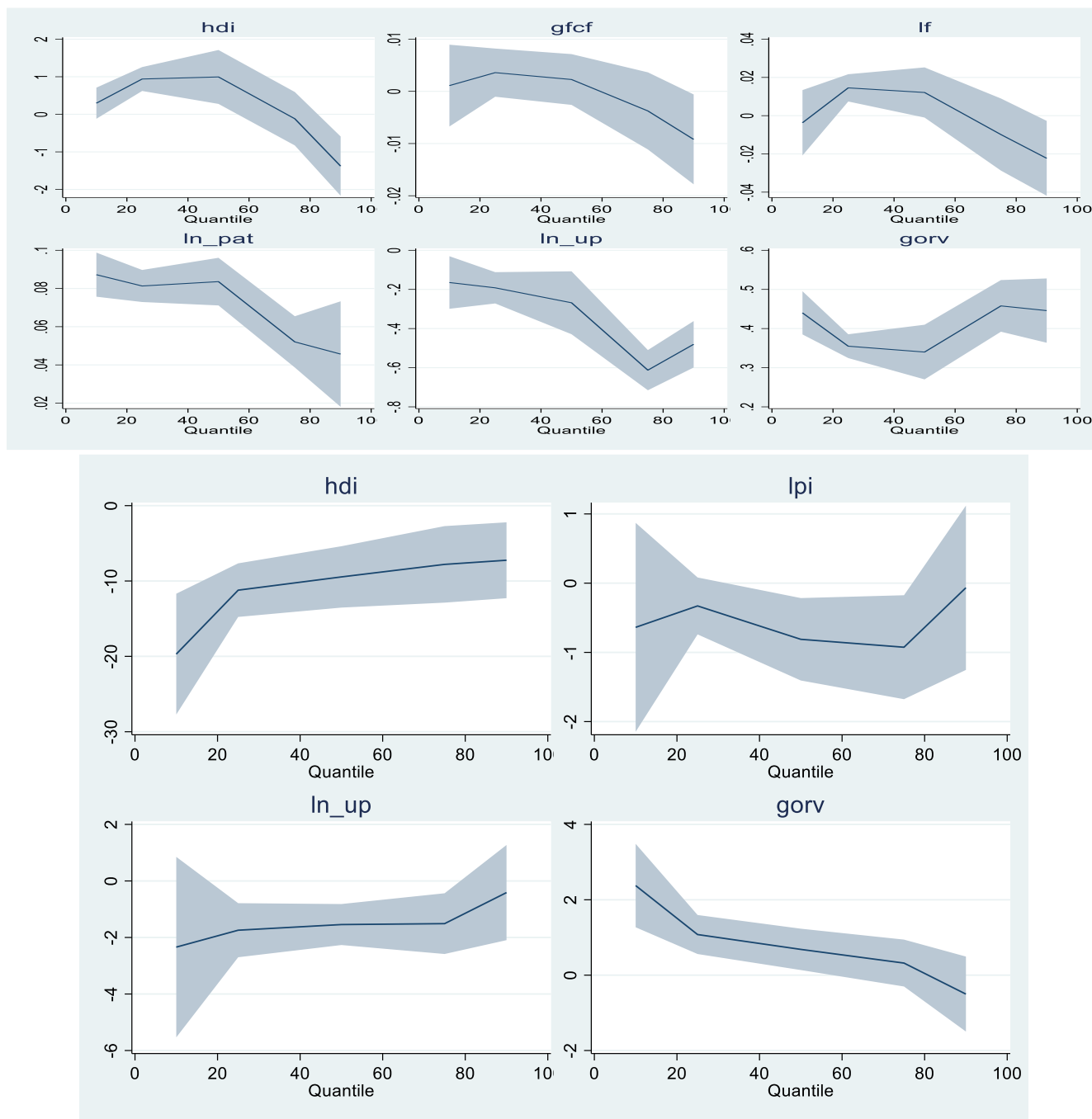


Fig.4. Plots of selected variables

## DECLARATIONS

### Funding

This research received no external funding.

### Conflicts of Interest

The authors declare no conflict of interest.

### Data Availability

The data supporting the findings of this study are available upon reasonable request from the corresponding author.

## REFERENCES

- 1) Agueh, V., Jerome, C., Nyametso, D., Paraiso, M., Azandjemè, C., Metonou, C., & Ouédraogo, L. T. (2016). Evaluation of the performance of expanded immunization programme supply chain and logistics management in Southern Benin rural health district. *Universal Journal of Public Health*, 4(4), 160-170.

## Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

- 2) Aryee, R., & Adaku, E. (2023). The reverse logistics resource matrix: a novel classification scheme. *Journal of Manufacturing Technology Management*, 34(3), 435-454.
- 3) Azadeh, K., Roy, D., de Koster, R., & Khalilabadi, S. M. G. (2025). Zoning strategies for human–robot collaborative picking. *Decision Sciences*, 56(1), 50-70.
- 4) Bai, J. Y., Huan, T. C. T., Leong, A. M. W., Luo, J. M., & Fan, D. X. (2025). Examining the influence of AI event strength on employee performance outcomes: Roles of AI rumination, AI-supported autonomy, and felt obligation for constructive change. *International journal of hospitality management*, 126, 104111.
- 5) Coto-Millán, P., Agüeros, M., Casares-Hontañón, P., & Pesquera, M. Á. (2013). Impact of logistics performance on world economic growth (2007–2012). *World Review of Intermodal Transportation Research*, 4(4), 300-310.
- 6) D'Aleo, V., & Sergi, B. S. (2017). Does logistics influence economic growth? The European experience. *Management Decision*, 55(8), 1613-1628.
- 7) Ekwueme, D. C., Zoaka, J. D., & Alola, A. A. (2021). Carbon emission effect of renewable energy utilization, fiscal development, and foreign direct investment in South Africa. *Environmental Science and Pollution Research*, 28(31), 41821-41833.
- 8) Flynn, B. B., Huo, B., & Zhao, X. (2010). The impact of supply chain integration on performance: A contingency and configuration approach. *Journal of operations management*, 28(1), 58-71.
- 9) Garg, A., & Vemaraju, S. (2025). Green Logistics Management Effect on Sustainable Logistics Performance. *Journal of Environmental & Earth Sciences | Volume*, 7(02).
- 10) Goel, R. K., Saunoris, J. W., & Goel, S. S. (2021). Supply chain performance and economic growth: The impact of COVID-19 disruptions. *Journal of Policy Modeling*, 43(2), 298-316.
- 11) Goertler, T., Papert, M., & Fischer, I. (2024). Theorizing Supply Chain Management and Logistics Research: A Comprehensive Review of Trends, Gaps, and Future Directions. *Operations and Supply Chain Management: An International Journal*, 17(4), 329-343.
- 12) Grunwald, G., Kara, A., & Spillan, J. E. (2025). Forging a relationship between quality management and sustainable development in higher education institutions: insights from a cross-country Kano study. *The TQM Journal*.
- 13) Hasan, M. K., Lei, X., Tang, W., Nishi, N. N., & Latif, Z. (2025). Exploring logistics performance index (LPI) from global perspective: a study based on network analysis (NA). *Operations Management Research*, 1-25.
- 14) Hayyat, U., Qian, L., Saeed, M., & Nawaz, W. (2025). Modeling the Growth Dynamics of Logistics Performance: Industrialization, Environmental Technology, and Economic Transformation in Manufacturing Economies. *Systems*, 13(5), 375.
- 15) Hlali, A. (2024). Impact of logistics and economic structure on seaport infrastructure: A case of Mediterranean countries. *Australian Journal of Maritime & Ocean Affairs*, 16(2), 175-185.
- 16) Ibrahim, M. D., & Alola, A. A. (2020). Integrated analysis of energy-economic development-environmental sustainability nexus: Case study of MENA countries. *Science of the Total Environment*, 737, 139768.
- 17) Janjua, L. R., Muhammad, F., Sukjai, P., Rehman, A., & Yu, Z. (2021). Impact of COVID-19 pandemic on logistics performance, economic growth and tourism industry of Thailand: an empirical forecasting using ARIMA. *Brazilian Journal of Operations & Production Management*, 18(2).
- 18) Kallionpaa, E., Helander, N., & Rantala, J. (2015). Managing tomorrow's daily consumer goods logistics value network. *International Journal of Supply Chain and Operations Resilience*, 1(2), 201-218.
- 19) Khan, S. A. R., Dong, Q. L., & Yu, Z. (2016). Research on the measuring performance of green supply chain management: In the perspective of China. *International Journal of Engineering Research in Africa*, 27, 167-178.
- 20) Khan, S. A. R., & Qianli, D. (2017). Does national scale economic and environmental indicators spur logistics performance? Evidence from UK. *Environmental Science and Pollution Research*, 24, 26692-26705.
- 21) Khan, S. A. R., Zhang, Y., Anees, M., Golpîra, H., Lahmar, A., & Qianli, D. (2018). Green supply chain management, economic growth and environment: A GMM based evidence. *Journal of Cleaner Production*, 185, 588-599.
- 22) Khan, S. A. R., Zhang, Y., Kumar, A., Zavadskas, E., & Streimikiene, D. (2020). Measuring the impact of renewable energy, public health expenditure, logistics, and environmental performance on sustainable economic growth. *Sustainable development*, 28(4), 833-843.
- 23) Koenker, R., & Bassett Jr, G. (1978). Regression quantiles. *Econometrica: journal of the Econometric Society*, 33-50.

## Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

- 24) Kumar, R., Kanwal, A., Asim, M., Pervez, M., Mujtaba, M., Fouad, Y., & Kalam, M. (2024). Transforming the transportation sector: Mitigating greenhouse gas emissions through electric vehicles (EVs) and exploring sustainable pathways. *AIP Advances*, 14(3).
- 25) Lagorio, A., Zenezini, G., Mangano, G., & Pinto, R. (2022). A systematic literature review of innovative technologies adopted in logistics management. *International Journal of Logistics Research and Applications*, 25(7), 1043-1066.
- 26) Layode, O., Naiho, H. N. N., Labake, T. T., Adeleke, G. S., Udeh, E. O., & Johnson, E. (2024). Addressing cybersecurity challenges in sustainable supply chain management: A review of current practices and future directions. *International Journal of Management & Entrepreneurship Research*, 6(6), 1954-1981.
- 27) Lee, H. L. (2004). The triple-A supply chain. *Harvard business review*, 82(10), 102-113.
- 28) Li, X., Sohail, S., Majeed, M. T., & Ahmad, W. (2021). Green logistics, economic growth, and environmental quality: evidence from one belt and road initiative economies. *Environmental Science and Pollution Research*, 28, 30664-30674.
- 29) Liston, J., Kaur, T., & Devitt, A. (2024). Decent work and economic growth (SDG 8). In *Teaching the Sustainable Development Goals to Young Citizens (10-16 years)* (pp. 235-258). Routledge.
- 30) Liu, J., Yuan, C., Hafeez, M., & Yuan, Q. (2018). The relationship between environment and logistics performance: Evidence from Asian countries. *Journal of Cleaner Production*, 204, 282-291.
- 31) Magazzino, C., Alola, A. A., & Schneider, N. (2021). The trilemma of innovation, logistics performance, and environmental quality in 25 topmost logistics countries: A quantile regression evidence. *Journal of Cleaner Production*, 322, 129050.
- 32) Magazzino, C., Mele, M., & Schneider, N. (2020). The relationship between municipal solid waste and greenhouse gas emissions: Evidence from Switzerland. *Waste Management*, 113, 508-520.
- 33) Magazzino, C., Mele, M., & Schneider, N. (2021). A machine learning approach on the relationship among solar and wind energy production, coal consumption, GDP, and CO<sub>2</sub> emissions. *Renewable Energy*, 167, 99-115.
- 34) Martel, A., & Klibi, W. (2016). *Designing value-creating supply chain networks*. Springer.
- 35) Memari, A., Rahim, A. R. A., Ahmad, R., & Hassan, A. (2016). A literature review on green supply chain modelling for optimising CO<sub>2</sub> emission. *International Journal of Operational Research*, 26(4), 509-525.
- 36) Mosteller, F., & Tukey, J. W. (1977). Data analysis and regression. A second course in statistics. *Addison-Wesley series in behavioral science: quantitative methods*.
- 37) Muhammed, I. A., Premaratne, G., Omar, N. H., & Khalid, A. M. (2025). The Role of Environment-Related and Climate Adaptation Technologies in Sustainable Energy Use: A Dynamic Quantile Regression Approach. *Sustainable Futures*, 100998.
- 38) Munim, Z. H., & Schramm, H.-J. (2018). The impacts of port infrastructure and logistics performance on economic growth: the mediating role of seaborne trade. *Journal of shipping and trade*, 3(1), 1-19.
- 39) Mustafi, M. A. A., Dong, Y.-J., Hosain, M. S., Amin, M. B., Rahaman, M. A., & Abdullah, M. (2024). Green Supply Chain Management Practices and Organizational Performance: A Mediated Moderation Model with Second-Order Constructs. *Sustainability*, 16(16), 6843.
- 40) Nureen, N., Sun, H., Irfan, M., Nuta, A. C., & Malik, M. (2023). Digital transformation: fresh insights to implement green supply chain management, eco-technological innovation, and collaborative capability in manufacturing sector of an emerging economy. *Environmental Science and Pollution Research*, 30(32), 78168-78181.
- 41) OECD. (2017). <https://www.itf-oecd.org/tags/freight>.
- 42) Ostrom, E. (2008). The challenge of common-pool resources. *Environment: Science and Policy for Sustainable Development*, 50(4), 8-21.
- 43) Pesaran, M. H. (2003). Estimation and inference in large heterogenous panels with cross section dependence. *Available at SSRN 385123*.
- 44) Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of applied econometrics*, 22(2), 265-312.
- 45) Razalli, M. R. (2022). 1 Greening the Supply Chain for. *Greening The Supply Chain: Responsive and Responsible Approaches (UUM Press)*, 7.
- 46) Salihi, A. A., Ibrahim, H., & Baharudin, D. M. (2024). Environmental governance as a driver of green innovation capacity and firm value creation. *Innovation and Green Development*, 3(2), 100110.
- 47) See, K. F., Guo, Y., & Yu, M.-M. (2024). Enhancing logistics performance measurement: an effectiveness-based hierarchical data envelopment analysis approach. *INFOR: Information Systems and Operational Research*, 62(3), 449-479.

## Environmental and Economic Drivers of Transport CO<sub>2</sub> Emissions: Insights from Econometric Modeling in the Global Logistics Sector

- 48) Shahbaz, M. H., Ahmad, S., & Malik, S. A. (2025). Green intellectual capital heading towards green innovation and environmental performance: assessing the moderating effect of green creativity in SMEs of Pakistan. *International Journal of Innovation Science*, 17(3), 683-704.
- 49) Shahzad, U., Mohammed, K. S., Schneider, N., Faggioni, F., & Papa, A. (2023). GDP responses to supply chain disruptions in a post-pandemic era: Combination of DL and ANN outputs based on Google Trends. *Technological Forecasting and Social Change*, 192, 122512.
- 50) Sharipbekova, K., & Raimbekov, Z. S. (2018). Influence of logistics efficiency on economic growth of the CIS countries.
- 51) Sikder, M., Wang, C., Yeboah, F. K., & Wood, J. (2024). Driving factors of CO<sub>2</sub> emission reduction in the logistics industry: an assessment of the RCEP and SAARC economies. *Environment, Development and Sustainability*, 26(1), 2557-2587.
- 52) Song, M., Roh, S., & Lee, H. (2024). Exploring the implications of logistics efficiency and renewable energy for sustainable development. *Environment, Development and Sustainability*, 1-22.
- 53) Starostka-Patyk, M., Bajdor, P., & Biały, J. (2024). Green logistics performance Index as a benchmarking tool for EU countries environmental sustainability. *Ecological Indicators*, 158, 111396.
- 54) Sundram, S., HIREMATH, C. V., ARORA, M., AGARWAL, V., & SEKAR, S. (2025). A Study on Green Practices and Strategies in Supply Chain Management. *Green Supply Chain Management*, 94.
- 55) Thuy, T. T., & Son, T. A. (2024). RELATIONSHIP BETWEEN LOGISTICS SECTOR AND ECONOMIC GROWTH IN ASEAN COUNTRIES. *Economics, Finance and Management Review*(3 (19)), 67-77.
- 56) Töngür, Ü., Türkcan, K., & Ekmen-Özçelik, S. (2020). Logistics performance and export variety: Evidence from Turkey. *Central Bank Review*, 20(3), 143-154.
- 57) Uvet, H., Park, A., Dickens, J., Oh, J., & Hazen, B. (2025). How blockchain technology utilization influences corporate social responsibility through supply chain transparency and the role of supplier risk. *The International Journal of Logistics Management*.
- 58) Wang, S., Zheng, C., & Wandelt, S. (2024). Policy challenges for coordinated delivery of trucks and drones. *Journal of the Air Transport Research Society*, 100001.
- 59) Wang, T., Wen, Y., & Lin, B. (2020). Energy consumption and the influencing factors in China: a nonlinear perspective. *Journal of Cleaner Production*, 249, 119375.
- 60) Wang, Y., Ali, A., & Chen, Z. (2025). Dynamic relationships between environment-related technologies, agricultural value added, transport infrastructure and environmental emissions in the five most populous countries. *Scientific Reports*, 15(1), 2308.
- 61) WDI. (2023). <https://lpi.worldbank.org/international/global>.
- 62) Wong, W. P., & Tang, C. F. (2018). The major determinants of logistic performance in a global perspective: evidence from panel data analysis. *International Journal of Logistics Research and Applications*, 21(4), 431-443.
- 63) Yamoah, L. E., Mensah, R. O., & Frimpong, A. (2025). The benefits, challenges and implications for integrating emerging technologies in risk evaluation procedures for supply chains in transportation logistics. *Discover Sustainability*, 6(1), 1-20.
- 64) Yazdani, M., Chatterjee, P., Pamucar, D., & Chakraborty, S. (2020). Development of an integrated decision making model for location selection of logistics centers in the Spanish autonomous communities. *Expert Systems with Applications*, 148, 113208.
- 65) Yu, Z., Golpira, H., & Khan, S. A. R. (2018). The relationship between green supply chain performance, energy demand, economic growth and environmental sustainability: An empirical evidence from developed countries. *LogForum*, 14(4), 479-494.
- 66) Zaman, K., & Shamsuddin, S. (2017). Green logistics and national scale economic indicators: Evidence from a panel of selected European countries. *Journal of Cleaner Production*, 143, 51-63.
- 67) Zambujal-Oliveira, J., & Fernandes, C. (2024). The contribution of sustainable packaging to the circular food supply chain. *Packaging Technology and Science*, 37(5), 443-456.
- 68) Zelbst, P. J., Green, K. W., Abshire, R. D., & Sower, V. E. (2010). Relationships among market orientation, JIT, TQM, and agility. *Industrial Management & Data Systems*, 110(5), 637-658.
- 69) Zhu, Y., Li, X., Mu, X., & Zhao, Y. (2024). Analysis of the Relationships between Variables and Their Applications in the Energy Saving Field. *Energies*, 17(15), 3753.



There is an Open Access article, distributed under the term of the Creative Commons Attribution – Non Commercial 4.0 International (CC BY-NC 4.0) (<https://creativecommons.org/licenses/by-nc/4.0/>), which permits remixing, adapting and building upon the work for non-commercial use, provided the original work is properly cited.