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Determinants of Green Logistics Performance in China and India: An ARDL and Time-Varying Model Application

Gunay Yesilbas[1]

Abstract

This study is attempting to evaluate the performance of Chinese and Indian Green Logistics (GRL) between the years 1992–2020 by estimating GRL as total GDP divided by transport-related TCO_2 emissions. Both short-run and long-run impacts of GDP, foreign direct investment (FDI), renewable energy consumption (REC), and TCO_2 emissions are examined using ARDL bounds tests and Dynamic Conditional Correlation (DCC) analysis. By deviating from traditional country or sector-specific index approaches, this research introduces an innovative comparative analysis of two leading economies and depicts the time-varying correlation pattern among top drivers. The results show that long-run economic growth significantly enhances GRL performance in China and India but significantly worsens it by TCO_2 emissions. In addition, FDI becomes a significant driver for India, while REC exhibits differential effects between the two environments. The findings from DCC on China and India reveal that GDP has a strong and positive relationship with green logistics performance.

Keywords: *Green Logistics, Environmental Sustainability, ARDL Model, DCC Model.*

Introduction

This study systematically explores the determinants of the performance of Green Logistics (GRL) in China and India, which are significant to lowering the environmental footprint of global logistics networks and supply chains. Over the past decades, the rising growth of logistics industries that transformed China into a robust manufacturing hub and enhanced India's commerce activities has also extensively contributed to rising carbon emissions, driven by the speeded-up urbanization and growing transportation demands, as revealed in the studies conducted by Zhang et al. (2023) and Li et al. (2023). In the Paris Agreement target system, transport CO_2 emissions reduction requirement necessitates the "greening" of logistics processes in both countries, aligning economic growth with sustainable development approaches (IPCC, 2021).

The target of carbon neutrality has been universally accepted as a key strategy to combat global warming. Thus, it targets to manage and minimize both direct and indirect emissions of greenhouse gases particularly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) which are major contributors of the climate emergency and pose very significant threats to human health and ecosystems (Kirikkaleli et al.2023a; Kirikkaleli et al. 2023b). Transportation-related CO_2 emissions (TCO_2) serve as a core variable in Green Logistics (GRL) research, as they offer a direct measure of the environmental footprint associated with logistics operations. In China, the transportation sector contributes around 14% to the country's overall CO_2

[1] Istanbul Esenyurt University, Email: gunayyesilbas@esenyurt.edu.tz

emissions, while in India, it is responsible for over 12% of the national emissions inventory (World Bank, 2023). Heterogeneous emission patterns are due to variation in fuel efficiencies and infrastructure development among transport modes; therefore, variations in TCO_2 have a central role in accounting for short- and long-term GRL performance dynamics (IPCC, 2022; IEA, 2021).

Gross domestic product (GDP) is directly linked to the financing capacity of logistics infrastructure investments and elucidates the interplay between economic growth rates and logistics demand. In China, public and private sector expenditures on logistics service infrastructure have risen in parallel with GDP growth, yielding a marked enhancement in logistics efficiency (Fitch Ratings, 2023). In India, it has been observed that GDP expansion lowers logistics costs and strengthens supply chain efficiency, thereby promoting the broader adoption of sustainable logistics practices (Malhotra and Mishra, 2019).

Renewable energy consumption (REC) and foreign direct investment (FDI) embody the capital and technology sides of green logistics. Increased REC ratio has been found to be an effective way in reducing CO_2 emissions from transportation, especially in terms of greater usage of electric vehicles and energy-efficient transport means (Du et al., 2023). In the meantime, FDI is also a driving force for infrastructure upgrading through foreign technology importation and foreign innovation; foreign investment has covered approximately 30 % of logistics technology spending in China and FDI inflows have led the upgrading of Indian logistics centers for distribution (Wang et al., 2018; Barut et al., 2023).

In this research, both dynamic interdependencies and long-run equilibria, we have made use of AutoRegressive Distributed Lag (ARDL) and Dynamic Conditional Correlation (DCC) model estimation. The ARDL method has the benefit of being able to handle jointly integrated variables of order I(0) and I(1) (Pesaran et al., 2001), while the DCC model facilitates intricate exploration of the time-varying correlation relationship between the two countries (Engle, 2002). The results from these complementary approaches assist in informing the construction of effective green logistics policies for China and India. The second section is a literature review of the issue; the third section is a methodology and data introduction, and the fourth section explains the analysis conclusions and findings in detail.

Literature Review

In the literature, several indices have been proposed to operationalize the Green Logistics (GRL) concept. The Green Logistics Performance Index was proposed by Lau (2011), which is limited to and Japan's and China's industrial sectors. Similarly, On the other hand, Khan et al. (2017) adopted a more extensive approach in utilizing the World Bank's Logistics Performance Index which assesses countries' logistics infrastructure and quality of logistics services as the foundation of GRL measurement. Researchers have since augmented this index through the inclusion of overall CO_2 emissions to create the Environmental LPI.

Aldakhil et al. (2018) used annual time-series data between 1995 and 2015 to analyze the key determinants of green business growth with supply chain management incorporated in BRICS countries with reference to socioeconomic and environmental factors. The authors' findings have established that green logistics measures are positively associated with per-capita income, with an observation of the catalytic role of supply chain management in buttressing economic growth and sustainable profitability. Karaman et al. (2020) examined 117 nations from 2007 to 2016 with the use of signaling theory to find the relationship between the Logistics Performance

Index (LPI) as a measure of green logistics performance and company-level disclosure of sustainability. They find that LPI and sustainability disclosure are highly positively related, thereby proving the applicability of signaling theory in logistics. Gu et al. (2022) analyzed data for ten Asian economies from 2010–2018 and found that the LPI is strongly correlated with population welfare and technological progress indicators, effects that have a root impact on economic growth trajectories and carbon emissions.

Mohsin et al. (2022) revealed that, within BRI nations, the performance of Green Logistics is negatively linked to the consumption of fossil-fuel energy and CO_2 emissions. Du and Ali (2023) focused on BRICS-T economies for the period 2000-2018 and determined that green logistics practices, green innovation, and renewable resource utilization have emerged as effective impetuses towards carbon neutrality, leading to net-zero emissions and enabling environmental sustainability in these countries. Barut et al. (2023) opined that foreign direct investment differentially affects the performance of GRL and actually suppresses the same for the E7 economies but promotes the same for the G7 nations. Kirikkaleli and Ali (2023) and Zhou et al. (2023) demonstrated that green logistics significantly contributes to the reduction of CO_2 emissions. In another study, Ouni and Abdallah (2023) explored how economic growth, green innovation, foreign direct investment, transportation-related CO_2 emissions, renewable energy usage, and trade openness influence green logistics across BRICS nations over the period 1992–2020. Their results indicated that economic development, transportation sector emissions, trade liberalization, renewable energy adoption, and advancements in green innovation all have a beneficial impact on enhancing green logistics performance.

Methodology and Data

The Autoregressive Distributed Lag (ARDL)

The Autoregressive Distributed Lag (ARDL) approach was originally proposed by Pesaran and Shin (1999) and later developed within the framework of bounds testing by Pesaran, Shin, and Smith (2001). By easing the constraint of conventional cointegration methodswhich necessitate that all series be of the same order of integrationARDL permits both I(0) and I(1) variables, a feature which has earned it extensive popularity in applied research. In addition, its relative insensitivity to small sample sizes has further boosted its popularity in financial and macroeconomic applications. Within the ARDL framework, the first step entails assessing the integration properties of each series using unit root tests. The absence of any series at the I(2) integration level constitutes a fundamental prerequisite for the application of the bounds testing procedure developed by Pesaran and colleagues. Lag selection is typically guided by the Akaike Information Criterion (AIC) or the Schwarz Information Criterion (SIC), thereby achieving an optimal balance between model parsimony and goodness of fit. To assess the existence of a longrun equilibrium relationship, the ARDL model is subjected to the bounds test, in which the computed Fstatistic evaluates the joint significance of both the intercept and the lagged difference terms. If this F statistic exceeds the critical upper bound, it indicates the presence of a stable, longrun relationship among the variables. Confirmation of this finding in the literature is taken to imply that the series share a common stochastic trend and exhibit permanent comovement.

While longrun parametric estimates are derived from the model's level form, shortrun dynamics are uncovered through the error correction model (ECM). The error correction coefficient in the ECM quantitatively gauges both the magnitude and the speed with which temporary deviations are restored to the longrun equilibrium. In this way, the persistence of policy effects and the

transitory impacts of shortrun shocks can be analyzed simultaneously (Narayan and Smyth, 2005, p. 103). While long-run parametric estimates are derived from the model's level form, short-run dynamics are uncovered through the error correction model (ECM). In a basic ARDL(1,1) specification given by:

$$Y = \alpha + \beta Y_{t-1} + \gamma X + \delta X_{t-1} \qquad (1)$$

the coefficient of the error correction term in the ECM representation corresponds to $-(1-\beta)$. In this context, if $\beta < 0$, then $-(1-\beta)$ can take values lower than -1, but it cannot be smaller than -2. Conversely, when $\beta > 0$, the coefficient cannot fall below -1. For a detailed derivation of this result, you may refer to equation (21.168) in the Microfit 5 manual, written by Bahram Pesaran and M. Hashem Pesaran.

To reinforce the reliability and validity of the ARDL model, a number of underlying assumptions must be satisfied. Tests for serial correlation, heteroskedasticity, functional form adequacy (Ramsey RESET test), and parameter stability (CUSUM and CUSUMSQ tests) are employed to detect any violations of these assumptions. In the literature, the comprehensive application of these diagnostic procedures is regarded as essential for anchoring both longrun and shortrun findings on a robust statistical foundation. The general equation for the unrestricted error correction model is presented as follows (Pesaran et al., 2001:296):

$$\Delta y_t = c_{0+} c_1 t + \pi_{yy} y_{t-1} + \pi_{yxx} X_{t-1} \sum_{i=1}^{p-1} \psi_i \, \Delta z_{t-i} + \omega \Delta x_t + \theta w_t + u_t \qquad (2)$$

The adapted forms of the models used in the study according to ARDL are shown as Equal 3 and Equal 4:

$$ChinaGRL_t = \alpha_0 + \beta_1 China\ FDI_{\ 1} + \beta_2 China\ GDP_2 + \beta_3 China\ REC_{\ 3} + \beta_4 China\ TCO2_4 + \varepsilon_t$$

$$IndiaGRL_t = \alpha_0 + \beta_1 India\ FDI_{\ 1} + \beta_2 India\ GDP_2 + \beta_3 India\ REC_{\ 3} + \beta_4\ India\ TCO_{24} + \varepsilon_t$$

3.2 *The Dynamic Conditional Correlation (DCC) Model*

The Dynamic Conditional Correlation (DCC) model, as introduced by Engle (2002), is a time-series framework that flexibly embeds a time-varying correlation structure within multivariate volatility models. By relaxing the traditional assumption of constant correlations, it permits the correlations among financial assets or macroeconomic variables to evolve over time. As a result, the contemporaneous interdependencies between series are continuously updated in response to episodic shocks and shifting market conditions.

The DCC model first estimates conditional variances for each series using univariate GARCH specifications; it then derives a time-varying correlation matrix from the standardized residuals obtained in this initial step. This two-stage procedure reduces the overall parameterization burden while enhancing the flexibility and forecasting accuracy of multivariate volatility models. The resulting dynamic correlations enable a more realistic representation of interdependence dynamicscrucial for applications such as risk management, portfolio optimization, and the analysis of shock transmission.

The general form of the DCC model can be expressed as follows:

$$H_t = D_t R_t D_t$$

where:

H_t is the conditional covariance matrix at time t,

D_t is a diagonal matrix of time-varying standard deviations obtained from univariate GARCH models,

R_t is the time-varying correlation matrix.

The standard deviations D_t are modeled using standard univariate GARCH processes for each variable. The dynamic correlation matrix R_t evolves according to the following structure:

$$Q_t = (1 - \alpha - \beta)\underline{Q} + \alpha\varepsilon_{t-1}\varepsilon'_{t-1} + \beta Q_{t-1}$$

$$R_t = diag(Q_t)^{-1/2} Q_t diag(Q_t)^{-1/2}$$

where:

Q_t is an intermediate positive definite matrix,

$\underline{Q}$ is the unconditional covariance matrix of the standardized residuals ε'_t,

$\alpha \; and \; \beta$ are non-negative scalar parameters such that $\alpha + \beta < 1$, ensuring stationarity, ε_t are standardized residuals from the univariate GARCH models.

3.3 *Data*

This research investigates the factors influencing Green Logistics (GRL) performance in India and China. Although the literature presents various metrics for defining GRL, in this study, it is measured as the ratio of transportation-related CO_2 emissions (TCO_2) to total GDP, following the approach used by Barut et al. (2023), Du et al. (2023), Wang et al. (2018), and Zhou et al. (2023). Here, TCO_2 is expressed in metric tons per capita, while GDP figures are based on constant 2015 U.S. dollars. Renewable energy consumption (REC) is considered as a percentage of total final energy consumption, and foreign direct investment (FDI) is represented as a share of GDP. Data for GDP, TCO_2, FDI, and REC for both India and China have been retrieved from the World Development Indicators (WDI, 2023).

The dataset comprises annual observations for China and India from 1992 to 2020. This interval was chosen because it affords the most complete and internationally comparable coverage of both countries economic and environmental indicators. Moreover, the series are truncated at 2020 to preclude the potentially distorting effects of the COVID19 pandemic on logistics and energy markets. Table 1 presents descriptive information about the variables used in the analysis.

Variable	**Symbol**	**Source**
Green Logistics Ratio	GRL	World Bank (calculated by the author)
Economic Growth	GDP	World Bank
Renewable Energy Consumption	REC	World Bank
CO_2 Emissions	CO_2	World Bank

Foreign Direct Investment	FDI	World Bank

Table 1. Definitions, Codes, and Sources of Variables

The following research questions are addressed:

How do gross domestic product (GDP), foreign direct investment (FDI), renewable energy consumption (REC), and transportrelated CO_2 emissions (TCO_2) shape the longrun performance of Green Logistics (GRL) in China and India?

To what extent and at what speed do shortrun deviations return to the longrun equilibrium via the errorcorrection mechanism?

In what dimensions does renewable energy consumption contribute to GRL performance, and how do these contributions differ between the two countries?

What persistent effects do increases in TCO_2 exert on the short and longrun dynamics of GRL performance?

What role does the interaction between foreign direct investment (FDI) and GRL play in improving GRL performance?

Using ARDL and DCC models, what dynamic patterns emerge in the short and longrun relationships among these variables?

The following hypotheses are formulated for empirical testing:

H_1: GDP growth exerts a positive influence on longrun GRL performance in both China and India.

H_2: FDI inflows constitute a significant and positive determinant of GRL performance.

H_3 An increase in REC strengthens GRL performance in both countries.

H_4Rising transportrelated CO_2 emissions have a significant negative effect on GRL performance.

H_5The adjustment speed of shortrun deviations and the longrun equilibrium relationships, as estimated via ARDL and DCC methodologies, are statistically significant.

4. Empirical Results

4.1 China

The stationarity of the variables was assessed after applying natural logarithmic transformations, using the Augmented Dickey Fuller (ADF) unit root test with lag lengths selected by the Schwarz Information Criterion and the Bartlett kernel based Phillips Perron (PP) test. Results from both tests indicate that none of the variables is integrated of order two I(2) level.

Variables	**ADF**		**PP**	
	Intercept	**Intercept and trend**	**Intercept**	**Intercept and trend**
China GRL	-3.90	-3.88	-3.90	-3.99
China FDI	-14.28	-13.38	-16.40	-16.98
China GDP	-3.42	-3.48	-3.42	-3.62

China REC	-6.94	-6.94	-6.95	-7.06
China TCO2	-5.22	-5.28	-5.22	-5.28

Table 2: Unit Root Test

Within the bounds testing framework of Pesaran et al. (2001), the computed F-statistic of 5.98 exceeds the upper critical values at the 1%, 5%, and 10% significance levels. Consequently, the null hypothesis of no long-run relationship is rejected. These results imply that the specified macroeconomic and environmental variables co-move in the long run, exhibiting a stable cointegrating relationship. In particular, this finding demonstrates a statistically significant and enduring long-run linkage between China's green logistics performance and its foreign direct investment, renewable energy consumption, economic growth, and carbon emissions (Table 3).

Test Statistic	Value	Signif.	I(0)	I(1)
Fstatistic	5.98	10%	2.2	3.09
		5%	2.56	3.49

Table 3: ARDL Model Long-Run Cointegration (Pesaran Bounds) Test Results for China

The explanatory power of the selected ARDL(1,0,0,2,2) model is exceptionally high, as evidenced by an adjusted R^2 of 0.99. The Breusch–Godfrey LM test yields a p value of 0.076, indicating no significant autocorrelation in the residuals. The Breusch–Pagan–Godfrey test of heteroskedasticity, with a p value of 0.31, confirms the assumption of constant variance. The Ramsey RESET test returns a p value of 0.48, demonstrating that the linear functional form is adequate. Finally, both the CUSUM and CUSUM of Squares stability tests produce statistics that remain within the critical bounds, indicating that the model parameters have remained structurally stable over the estimation period.

Adjusted Rsquared	0.99
BreuschGodfrey LM Test	0.076
Heteroskedasticity Test: BreuschPaganGodfrey	0.31
Ramsey RESET Test	0.48
Cusum of Squares	Stable
Cusum of Squares	Stable

Table 4: Diagnostic Test Results

Longrun ARDL estimation results reveal that GDP exerts a very strong influence on green logistics performance, with an estimated elasticity of 0.92 ($p < 0.001$), implying that a 1 % increase in GDP is associated with an approximately 0.92 % rise in GRL in the long run. Although the coefficient on renewable energy consumption is negative, it is not statistically significant ($p = 0.44$), suggesting a limited longterm effect. In contrast, transportrelated CO_2 emissions have a highly significant adverse impact: a coefficient of –1.01 ($p < 0.001$) indicates that higher emissions substantially undermine sustainable logistics capacity. The errorcorrection term, with a coefficient of –1.01 ($p < 0.001$), suggests that about 101.1 % of any deviation from

the longrun equilibrium is corrected within one period, reflecting a rapid adjustment mechanism. These findings underscore the critical importance of prioritizing sustainable economic growth and emission control policies to strengthen China's green logistics over the long term, while indicating that the contributions of renewable energy consumption and foreign direct investment merit further indepth investigation (Table 5).

Variable	**Coefficient**	**tStatistic**	**Prob.**
CHINA_GDP	0.924	1.381	0.00
CHINA_REC	-0.0059	-0.785	0.44
CHINA_TCO2	-1.0156	-3.570	0.00
CHINAFDI	0.0036	0.507	0.61
C	1.09	3.066	0.00
CointEq(1)	-1.011	-2.170	0.00

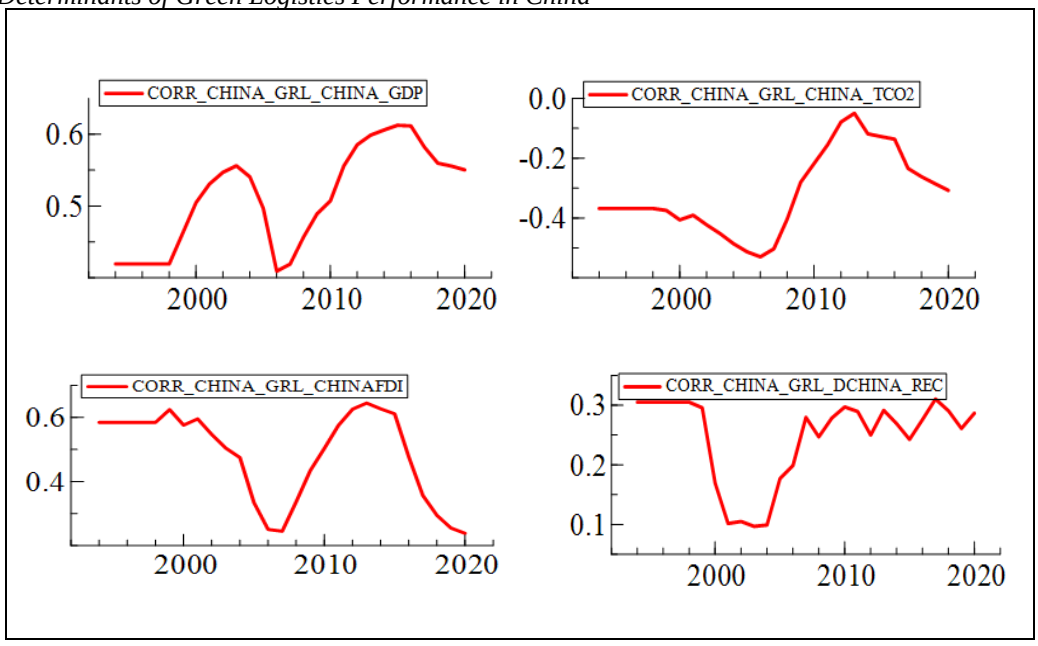
Tablo 5: The Hypothesis Concerning GRL For China

In the DCC model, it is essential that the series are stationary at the I(0) level; therefore, the first differences of the series are taken to achieve stationarity. Accordingly, the dynamic conditional correlations are estimated based on variations in the variables. Table 6 presents the DCC model results for China, focusing on the relationships among GRL, FDI, GDP, REC, and TCO_2. Based on Table 6, $((\alpha = 0.15) + (\beta = 0.55) < 1)$ and $\alpha \geq 0, \beta \geq 0$. The coefficient estimates reveal that the alpha parameter is statistically insignificant, while the beta parameter is significantly positive. This suggests that the conditional variance of the error terms is influenced more by their past variances than by the past squared residuals.

	CHINA GRL
Variables	**Coefficients**
α	0.15
β	0.55

Table 6. Estimated Parameters of the Conditional Dynamic Correlation (DCC) Model

Graphic 1 illustrates the time-varying dynamic conditional correlations among China's GRL, GDP TCO_2, FDI, REC, variables based on model 1. This section provides an interpretation of the evolving correlation patterns observed throughout the study period.



Graphic 1: Dynamic Conditional Correlation between Variables for China

The first part of Graph 1 illustrates the conditional correlation between green logistics performance (GRL) and economic growth (GDP). The correlation remained at a low level until the early 2000s, but began to strengthen markedly thereafter, exhibiting a positive trend. Notably, during the period following 2010, the correlation coefficient reached levels as high as 0.7. This finding suggests that China's economic growth process has directly supported green logistics activities, indicating that economic expansion has contributed to increased investment in environmentally friendly logistics practices. However, the slight decline observed after 2015 may imply a weakening of the influence of economic growth on GRL or a shift in sectoral priorities over time.

The last part of Graph 1 illustrates the conditional correlation between green logistics performance (GRL) and carbon dioxide emissions due to transport (TCO_2). The correlation between TCO_2 and GRL was negative prior to 2000 but became positive after 2005. It is the shift in the correlation coefficient that reflects the establishment of an immediate connection between emission increase and green logistics activity. It may be a sign that the rise in transport-related carbon dioxide emissions incentivized the enhanced demand for green logistics practice in China and stimulated the more enthusiastic response towards the initiatives on green logistics. Particularly after 2010, the strengthening of the positive correlation is evidence of the parallel development of carbon management initiatives and environment-friendly policies in the logistics sector.

The third part of Graph 1 illustrates the conditional correlation between green logistics performance (GRL) and foreign direct investment (FDI). The positive and high correlation between FDI and GRL existed between 1995 and 2005; however, the correlation dropped significantly after 2005. In 2015, the correlation dropped to nearly zero. Foreign direct investments initially appeared to have a complementary role in enhancing green logistics performance in China. Over time, however, this influence decreased. This decrease can be either

because the foreign investments' priority was directed towards other industries or because there was a diminishing congruence of foreign investment operations and environmental sustainability objectives.

The fourth part of Graph 1 depicts the conditional correlation between green logistics performance (GRL) and changes in renewable energy consumption (REC). Initially, the correlation exhibited a negative trend, with a notable mismatch between GRL and REC changes particularly evident during the 2000–2005 period. However, after 2005, the correlation shifted towards a positive trajectory, and following 2010, a more stable positive relationship emerged. This development suggests that increases in renewable energy consumption have gradually begun to more effectively support green logistics performance. While the early stages of the energy transition had a limited direct impact on the logistics sector, over time, energy policies and logistics practices appear to have become increasingly integrated.

4.2 India

The stationarity properties of the variables were assessed after applying natural logarithmic transformations, using the Augmented Dickey–Fuller (ADF) unit root testwith lag lengths selected by the Schwarz Information Criterion and the Bartlett kernel based Phillips Perron (PP) test. Both tests confirm that all series are at most integrated of order one, and none are integrated of order two I(2). (Table 7).

Variables	**ADF**		**PP**	
	Intercept	**Intercept and trend**	**Intercept**	**Intercept and trend**
India GRL	-4.11	-4.15	-4.11	-4.14
India FDI	-4.69	-5.02	-4.70	-5.02
India GDP	-4.84	-4.71	-4.38	-4.42
India REC	-5.54	-6.07	-5.54	-6.07
India TCO2	-8.84	-8.98	-8.69	-8.88

Table 7. Unit Root Test

Within the Pesaran bounds testing framework, the computed F-statistic of 7.85 exceeds the upper critical values at the 1 %, 5 %, and 10 % significance levels. Consequently, the null hypothesis of no long-run relationship is rejected, indicating that the specified macroeconomic and environmental variables co-move in the long run and share a stable cointegrating relationship. In particular, this finding demonstrates a statistically significant and enduring long-run linkage between India's green logistics performance (India GRL) and its foreign direct investment (India FDI), renewable energy consumption (India REC), economic growth (India GDP), and transport-related CO_2 emissions (India TCO_2). The presence of cointegration among these series implies that India's GRL performance evolves in close conjunction with FDI inflows, REC levels, GDP growth, and CO_2 emissions. Moreover, this result facilitates formal testing of the long-run coefficients and the error-correction mechanism (ECM), thereby enabling quantitative assessment of adjustment speeds toward equilibrium and the permanent impact of each independent variable on India GRL (Table 8).

Test Statistic	Value	Signif.	I(0)	I(1)
Fstatistic	7.85	10%	2.2	3.09
		5%	2.56	3.49

Table 8. ARDL Model Long-Run Cointegration (Pesaran Bounds) Test Results for India

The explanatory power of the selected ARDL(4,2,3,2,3) specification is exceptionally high, as evidenced by an adjusted R^2 of 0.99. The Breusch–Godfrey LM test yields a p value of 0.40, indicating no significant autocorrelation in the residuals. Similarly, the Breusch–Pagan–Godfrey heteroskedasticity test, with a p value of 0.78, confirms the assumption of constant variance. The Ramsey RESET test returns a p value of 0.12, demonstrating that the linear functional form is adequate. Finally, both the CUSUM and CUSUM of Squares tests remain within their critical bounds, verifying that the model parameters have remained structurally stable throughout the estimation period. Collectively, these diagnostic results attest that the ARDL model is well suited for drawing reliable inferences about longrun equilibrium relationships (Table 9).

Adjusted Rsquared	0.99
BreuschGodfrey LM Test	0.40
Heteroskedasticity Test: BreuschPaganGodfrey	0.78
Ramsey RESET Test	0.12
Cusum of Squares	Stable
Cusum of Squares	Stable

Table 9. Diagnostic Test Results

Longrun ARDL estimates reveal that foreign direct investment exerts a positive and statistically significant effect on India's green logistics performance ($p = 0.0085$). Gross domestic product demonstrates a very strong influence, with an elasticity of 0.966 ($p < 0.001$), indicating that a 1 % increase in GDP is associated with an approximately 0.97 % rise in green logistics performance over the long term. Although the coefficient on renewable energy consumption is negative, it does not attain statistical significance ($p = 0.11$), suggesting only a limited longrun effect. In contrast, transportrelated CO_2 emissions have a highly significant adverse impact (coefficient = –1.0064, $p < 0.001$), implying that higher emissions substantially erode sustainable logistics capacity. The errorcorrection term, with a coefficient of –1.686 ($p < 0.001$), indicates that approximately 168.7 % of any disequilibrium is corrected within one period, reflecting a rapid adjustment back to the longrun equilibrium. These findings underscore the imperative of prioritizing FDI incentives, sustainable economic growth, and emissioncontrol policies to bolster India's green logistics in the long run, while highlighting the need for further investigation into the role of renewable energy consumption (Table 10).

Dependent Variable: India GRL			
Variable	Coefficient	tStatistic	Prob.
INDIA_FDI	0.000	3.463	0.008
INDIA_GDP	0.966	8.0.2	0.00
INDIA_REC	-0.001	-1.778	0.11

INDIA_TCO2	-1.006	-6.519	0.00
C	1.042	4.357	0.00
CointEq(1)	-1.686	-1.152	0.00

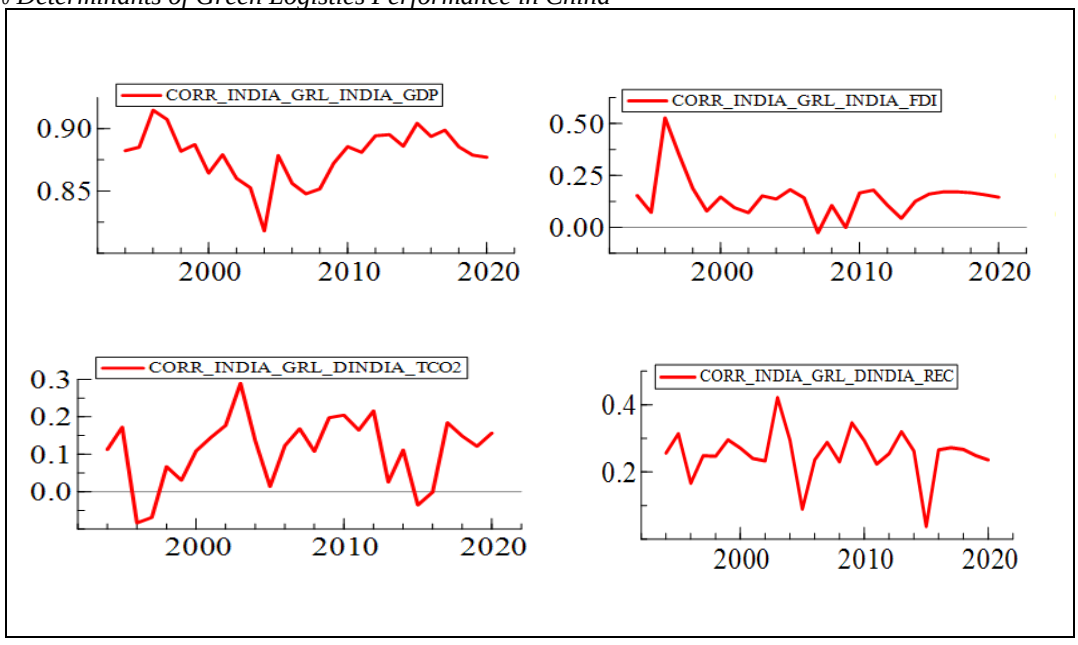
Tablo 10. The Hypothesis Concerning GRL For India

In the DCC model, it is essential that the series are stationary at the I(0) level; therefore, the first differences of the series are taken to achieve stationarity. Accordingly, the dynamic conditional correlations are estimated based on variations in the variables. Table 11 presents the DCC model results for India, focusing on the relationships among GRL, FDI, GDP, REC, and TCO_2. Based on Table 11, $((\alpha = 0.09) + (\beta = 0.21) < 1)$ and $\alpha \geq 0, \beta \geq 0$. The coefficient estimates reveal that the alpha parameter is statistically insignificant, while the beta parameter is significantly positive. This suggests that the conditional variance of the error terms is influenced more by their past variances than by the past squared residuals.

	India GRL
Variables	**Coefficients**
α	0.090
β	0.21

Table 11. Estimated Parameters of the Conditional Dynamic Correlation (DCC) Model for India

Graphic 2 illustrates the time-varying dynamic conditional correlations among India's GRL, GDP, FDI, REC, and TCO_2 variables based on model 2. This section provides an interpretation of the evolving correlation patterns observed throughout the study period.



Graphic 2: Dynamic Conditional Correlation between Variables

The first part of Graph 2 shows conditional correlation between green logistics performance (GRL) and economic growth (GDP) in India. Throughout the period under consideration, correlation always remained high and positive. During 1995-2020, the correlation coefficient fluctuated between 0.85 and 0.95, with an impressive strengthening being witnessed particularly post-2000. It signifies a high positive correlation, indicating that Indian economic growth has exercised a strong direct positive influence on green logistics activities. Economic growth has facilitated modernization of the logistics sector as well as instilling investment with environmental sensitivity objectives. However, there is a slight downward trend since 2015, which may suggest that economic growth has undergone structural transformation, leading to more profound effects across different sectors or reflecting a shift in the allocation of resources and sectoral priorities.

The second part of Graph 2 demonstrates the conditional relationship between green logistics performance (GRL) and foreign direct investment (FDI). A glimpse of the correlation between GRL and FDI for the duration of 1995–2020 reveals an overall weak and low positive relation. Although the correlation between GRL and FDI occasionally exhibits peaks between the years 1995 and 2000, the relation really declines after the year 2000 and gradually drifts toward zero. This trend suggests that foreign direct investment has not played a direct or effective part in encouraging green logistics performance in India. Foreign investments' tendency to focus on sectors such as manufacturing, technology, or services may have limited the extent to which they supported green logistics initiatives. Moreover, the domestic dynamics within India such as government policies and infrastructure investment also appear to have been more effective than foreign investment in driving the green logistics growth.

The third section of Graph 2 indicates conditional correlation between transport related carbon dioxide emissions (TCO_2) and green logistics performance (GRL). Overall, a weak positive trend can be observed between GRL changes and TCO_2. Following the year 1995, a trend of

fluctuation in the correlation is visible; however, if one takes a long-time perspective, one can observe a positive trend. This finding suggests that increased carbon emissions have not directly and forcefully prompted green logistics initiatives in India, but have instead served to increase awareness of the environment over time. The relatively consistent upward trend in observed correlation after 2010 indicates that solutions for carbon management have begun systematically being adopted by the logistics sector.

The fourth quadrant of Graph 2 shows the conditional correlation between renewable energy consumption change (REC) and green logistics performance (GRL). Throughout the time period under review here, the correlation was mostly positive in character; however, it was extremely volatile in character and lacked strong positive stability. Although moderate increases in the correlation were observed in the decade between 2000 and 2010, the trend in correlation started weakening from that point on. This would suggest that growth in the use of renewable energy in India has yet to have made a solid or stable impact on green logistics performance. It would also indicate that integration of processes of energy transition into the logistics sector has yet to increase significantly, and there is greater inclusive, cross sectoral coordination required in policies.

It is clearly observed that India's economic growth (GDP) has had a significant and strong impact on green logistics performance. In contrast, foreign direct investment (FDI) and changes in carbon dioxide emissions (TCO_2) appear to exert only a limited influence on green logistics, while changes in renewable energy consumption (REC), although occasionally supportive, have not provided a structural or consistent contribution. These findings indicate that the transformation of green logistics in India has been shaped largely by internal economic dynamics and public policy initiatives, whereas external capital inflows and energy transition processes have yet to become sufficiently effective drivers in this context.

Conclusion & implications

This study investigates the most important macroeconomic and environmental drivers of Green Logistics (GRL) performance in India and China, namely gross domestic product (GDP), foreign direct investment (FDI), renewable energy consumption (REC), and transportrelated CO_2 emissions (TCO_2)based on data for the period 1992–2020 to cover long and shortrun dynamics. Unitroot tests (ADF and PP) confirmed that all series were integrated of order zero or one I(0) or I(1), none of them being I(2), thereby satisfying the required conditions for the robust application of the ARDL bounds testing procedure and the errorcorrection model (ECM).

The result of the ARDL bounds test indicates a long-run cointegration between the macro-environmental variables of both countries because the F-statistic is larger than the upper critical values at the 1%, 5%, and 10% significance levels. Additionally, the error-correction term coefficients are around 101.1% for China and 168.7% for India, indicating that there is a quick adjustment mechanism that corrects short-run disequilibria to the long-run equilibrium.

The results indicate that economic growth and transport related carbon dioxide emissions constitute the primary determinants of Green Logistics (GRL) performance in both China and India. In contrast, the longrun impact of foreign direct investment (FDI) is statistically significant only in India; the insignificance of the FDI coefficient in the Chinese context suggests that China's logistics infrastructure remains largely financed by domestic resources and stateled projects. In India, however, the positive and significant effect of FDI underscores the pivotal role of international capital flows in establishing modern logistics distribution hubs and

accelerating the adoption of green technologies.

The lack of longrun significance of renewable energy consumption (REC) in both countries suggests that existing incentive schemes and technologyadaptation processes have not yet fully translated into the expected energyefficiency gains within the logistics sector. This underscores the need for more aggressive R&D support, regulatory reforms, and the redesign of market frameworks in both China and India to effectively integrate greenenergy applications into logistics operations.

The pronounced negative impact of transport-related CO_2 emissions (TCO_2) on GRL performance highlights the urgent need for both markets to accelerate the shift toward low-carbon transport modalities and to implement stringent emission-control policies. Prioritizing the expansion of rail networks and electric road-freight infrastructure over high-emission transport alternatives will not only strengthen environmental sustainability but also yield long-term cost efficiencies in logistics.

In conclusion, in China, policies emphasizing economic expansion and stringent emission controlsand in India, a holistic strategy that additionally incorporates foreign direct investmentemerge as the most effective levers for enhancing Green Logistics (GRL) performance. The observed stagnation in the integration of renewable energy into logistics operations underscores the need for comprehensive cost–benefit analyses and pilot-scale implementations in future research. By adopting such measures, it will be possible to establish a competitive and sustainable logistics framework that aligns with economic growth objectives while concurrently reducing the carbon footprint of both domestic and global supply chains.

It should be noted that while the DCC model captures the short term dynamic conditional correlations between variables, the ARDL model reveals the long term equilibrium relationships. Therefore, fluctuations observed in the DCC model reflect short term co-movements between variables, whereas the ARDL findings point to more persistent and stable long term associations. When the findings are evaluated holistically, it is observed that although the short term relationships between green logistics and its determinants namely FDI, GDP, REC, and TCO_2 for India exhibit variability over time, the strong positive effects of GDP and FDI and the significant negative impact of transport related CO_2 emissions remain consistent in the long run. This distinction clearly highlights the need to develop policies in the green logistics sector that are responsive both to short term fluctuations and to long term sustainability goals. Overall, the findings for China indicate that economic growth (GDP) has had a strong and persistent supportive impact on green logistics performance (GRL). Similarly, increases in carbon emissions (TCO_2) have emerged as a trigger for green logistics activities. However, the influence of foreign direct investment (FDI) on GRL has weakened over time, while changes in renewable energy consumption (REC), initially characterized by inconsistency, have gradually developed a more positive relationship with GRL. These results suggest that China's green logistics strategies have been shaped by both internal growth dynamics and external environmental pressures, whereas the role of external capital inflows (FDI) has diminished over time. Furthermore, the evolution of energy policies appears to have enhanced the role of renewable energy consumption in supporting green logistics performance.

The analysis is confined to prepandemic data through 2020; the effects of COVID19 on logistics dynamics should be examined in subsequent studies. Moreover, extending the framework to include sectorspecific submodels and paneldata methodologies is recommended to broaden the scope and enhance the robustness of future research.

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