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The Impact of Shipping Connectivity on Environmental Quality, Financial Development, and Economic Growth in RCEP Countries

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Abstract: This study investigates the relationship between shipping connectivity, environmental quality, financial development, and economic growth among 14 countries in the Regional Comprehensive Economic Partnership (RCEP) from 2006 to 2019. Using panel-corrected standard error, Dynamic Seemingly Unrelated Regression, and Driscoll-Kraay estimation methods, the analysis reveals that shipping connectivity significantly contributes to financial development and economic growth, while also exerting a negative impact on environmental quality. These findings underscore the dual role of shipping connectivity in fostering economic prosperity and increasing environmental challenges, highlighting the trade-offs between growth and sustainability. The study also emphasizes that as trade between RCEP countries grows, driven in part by the removal of customs tariffs, shipping activities—and consequently environmental pollution—will likely increase. To achieve sustainable development in the maritime sector, policymakers must devise strategies that maximize economic benefits while mitigating environmental harm. These strategies include promoting environmentally friendly green ports, adopting low-carbon and advanced technologies, and strengthening policies to control emissions and marine pollution. Collaboration among shipping companies, local governments, and environmental organizations is also essential.

Keywords: shipping connectivity; environmental sustainability; financial development; economic growth; Regional Comprehensive Economic Partnership; RCEP

1. Introduction

Global economic growth develops in parallel with energy demand and international trade. Maritime trade plays a key role in international trade with an increasing number of ships (Elgohary et al. 2015). The growth in global trade volume in 2022 was lower than expected, at 2.7%, with a decrease in the fourth quarter. The World Trade Organization predicts a 1.7% growth in merchandise trade volume in 2023, below the averages of 2.6% and 2.7% over the last 12 years, respectively (WTO 2023). In recent years, the global shipping industry has also been facing many challenges, such as increasing trade policy and geopolitical tensions. Consequently, changes are seen in maritime trade routes, and maritime trade volume decreased slightly by 0.4% in 2022. However, UNCTAD predicts that this rate will increase in the coming years (UNCTAD 2023).

Maritime trade is vital to the global economy as it accounts for more than 80% of global trade by volume and 70% by value. This rate remains even higher in most developing countries (UNCTAD 2021). Maritime connectivity has become an increasingly popular topic in the global economy due to its close relationship with maritime trade (Mishra et al. 2021). High maritime connectivity with low transport costs leads to further development of trade. Similarly, increased trade may enhance maritime

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connectivity and further reduce costs through economies of scale and the leverage of network effects (Hofmann et al. 2020).

The rapid globalization of economies has propelled maritime transport to the forefront of global trade, solidifying its position as the primary mode of transportation (Jiang et al. 2015). Shipping connectivity (SC) has become one of the determining factors of bilateral exports (Fugazza and Hoffmann, 2017). The Liner Shipping Connectivity Index (LSCI) was developed by UNCTAD in 2004 to assess and compare countries' roles in the global liner shipping network. This index includes five main factors: vessel quantity, container capacity, maximum ship size, service frequency, and the presence of container ship operators in a country's ports (UNCTAD 2017).

Liner shipping is one of the elements that facilitate the movement of goods worldwide (Del Rosal 2023). The Liner Shipping Connectivity Index shows a country's position within global maritime transport networks (Tovar and Wall 2022). A country's access to global markets largely depends on its transport connectivity and, in particular, the quality of its transport services (World Bank 2024). The connectivity level of the shipping network is an indicator of how well the ports in the network are connected to each other. Good connectivity values mean that goods are delivered smoothly between trading countries (Pan et al. 2022).

On the other hand, increasing trade and expanding shipping networks bring with them rising shipping emission values. Like every sector, the maritime sector must organize its activities according to the needs of a sustainable world and be sensitive to the environment (Hasanspahić et al. 2021). Sustainability is a reaction to the unsustainability of the characteristics of industrial society (Caradonna 2022). As a concept, sustainability includes three basic dimensions: economic, social, and environmental considerations, which are integral across various sectors, including maritime transportation (Lee et al. 2019).

In the global efforts to reduce greenhouse gases and CO_2, the decarbonization of the maritime sector holds an important place (Romano and Yang 2021). Approximately 3% of global greenhouse gas emissions come from shipping, and this rate has increased by 20% in the last decade (Wang and Wright 2021). Unless necessary measures are taken, emissions are projected to rise to 90-130% of 2008 levels by 2050 (IMO 2020). Table 1 shows selected countries' shipping carbon dioxide emission amounts (in tonnes) in 2012 and 2022.

Table 1. Shipping Carbon Dioxide Emissions of Countries in 2012 and 2022 (tonnes).

Rank	Country	2012 Emissions	2022 Emissions	Rate of Change (%)
1	China	43,493,613	102,317,721	135.25
2	Japan	99,628,524	101,254,900	1.63
3	Greece	69,330,862	95,968,419	38.42
4	USA	43,859,245	45,656,717	4.10
5	China, Hong Kong	18,822,466	39,060,933	107.52
6	Germany	86,588,074	37,040,384	-57.22
7	Singapore	19,806,355	32,522,147	64.20
8	South Korea	24,324,282	28,736,060	18.14
9	Denmark	23,473,417	28,007,662	19.32
10	Norway	25,748,700	26,496,768	2.91
21	Indonesia	4,930,297	10,830,329	119.67
28	Malaysia	6,020,028	5,548,442	-7.83
29	Vietnam	2,098,899	5,296,530	152.35

Table 1 was prepared by UNCTAD ((UNCTAD 2023) for 29 countries, seven of which are the Regional Comprehensive Economic Partnership (RCEP) countries. The increase in shipping carbon dioxide emissions in China, Indonesia and Vietnam, which are members of RCEP, is particularly striking. On November 15, 2020, RCEP was signed, marking the world's largest free trade agreement. The agreement involved ten ASEAN countries along with New Zealand, Japan, South Korea, China, and Australia (Shimizu 2021). In the first phase, the RCEP agreement entered into force for ten member

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countries on 1 January 2022 (RCEP 2022), and then the process was completed for the remaining five countries (South Korea, Myanmar, Malaysia and Indonesia) (RCEP 2023). This agreement holds significance, representing around one-third of the global population, 30% of the world's GDP, and 28% of global trade (Armstrong and Drysdale 2022). On the other hand, within the scope of the RCEP agreement, customs tariffs applied to more than 90% of the member countries' goods will be gradually eliminated over the next 36 years (Zhu and Huang 2023).

Therefore, the carbon emissions resulting from the shipping trade of RCEP countries are considerable. The main purpose of this study is to examine the relationship between the Liner Shipping Connectivity Index, environmental quality, economic growth (EG), and financial development (FD). In other words, it aims to determine the impact of shipping connectivity on environmental quality, economic growth, and financial development. In this context, data for the 2006–2019 period from 14 RCEP countries were used in the study. In the empirical analyses, the Westerlund and Edgerton (2007) bootstrap methods were employed for cointegration relationships; Panel-Corrected Standard Errors, Dynamic Seemingly Unrelated Regression, and Driscoll-Kraay methods were used for long-term coefficients; and the Dumitrescu-Hurlin (2012) bootstrap methods were utilized for causality relationships.

This study is expected to contribute to the literature in three different aspects: 1) Expansion of Environmental Literature. Only one study examining the relationship between shipping connectivity and environmental quality has been conducted by Ayesu (2023) on African countries. This study investigates the relationship from the perspective of RCEP countries, allowing for the expansion of the environmental literature. 2) First Empirical Findings on SC's Impact on FD and EG. This study is important as it reveals the first empirical findings on the impact of shipping connectivity on financial development and economic growth. 3) Policy Development for Reducing Carbon Footprint. The research results may contribute to the development of policies and practices to reduce the carbon footprint of the maritime industry. Additionally, the findings may help RCEP countries balance sustainability and economic growth when developing maritime trade policies. In summary, the findings of this study may provide strategically important information for decision-makers, policymakers, and industry stakeholders in various areas such as regional development, environmental sustainability, economic integration, social development, and regional cooperation.

The upcoming sections of this study are structured as follows: Following this introduction, a concise review of the literature is provided in Section 2. Section 3 elucidates the dataset and models utilised in the research. Section 4 elaborates on the empirical methodology, while Section 5 delves into the analyses and discusses the empirical findings. Ultimately, the findings are evaluated, and recommendations for future studies are put forth in the conclusions section.

2. Literature Review

There is a strong connection between shipping transport, global trade, global supply chains, economic growth and development (Fratila et al. 2021). Bouazza et al. (2023) conducted a descriptive analysis using the Liner Connectivity Index database to determine the region most connected to Morocco. They concluded that Morocco has strong bilateral ties with Europe and Asia. Then, they identified 15 factors under six topics related to the development of a robust bilateral connection. The analysis results show that EG, logistics, and maritime factors have a strong and positive impact on bilateral connectivity. Alnıpak et al. (2023) developed models to evaluate the logistics performance of 32 European countries and determine the factors affecting Logistics Performance Indexes (LPIs). Twelve variables were determined for the analysis, and data for 2010–2018 were collected. The findings show that three factors—LSCI, GDP, and commercial service imports—are more effective on LPI. Rizkallah (2023) aimed to investigate the direct and indirect impact of logistics investments on EG. The study used panel data for the 2007–2016 period of six Arab countries and the 2007–2018 period of 31 OECD countries. The analysis employed a product of coefficients approach alongside bootstrapping methodology. Findings reveal a discernible relationship between logistics investment and EG in OECD nations, but this relationship appears less evident in Arab countries.

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Li et al. (2023) conducted a comprehensive study on the ramifications of the Panama Canal's expansion on regional EG. Their findings underscored the significant role of improved port connectivity and expanded infrastructure in stimulating EG at the regional level. On the other hand, Adenigbo et al. (2023) delved into the intricate relationship between maritime trade and EG in Nigeria. Over the period spanning 1970 to 2020, they examined four key variables. Through cointegration tests, they identified both short- and long-term causality relationships among imports, exports, exchange rates, and GDP. Notably, their study highlighted the pivotal role of imports in Nigeria's EG trajectory, emphasizing the enduring impact of imports and exchange rates on GDP dynamics in the long run. Şeker (2020) studied the impact of the Liner Shipping Connectivity Index and economic grwoth on exports in European countries and Turkey, finding a positive effect on exports. Liang and Liu (2020) examined port infrastructure connectivity, logistics performance, and trade on the EG of 32 countries, suggesting that improvements may promote trade and growth.

Liner shipping is one of the most important transportation systems that enable the movement of goods around the world. The LSCI score is an indicator of how well a country is connected to global shipping networks. However, a higher LSCI score also means that the country may cause more environmental damage due to increased CO_2 emissions from liner shipping. Ayesu (2023) examined the environmental impact of shipping-related emissions in Africa using regression analysis. The study analyzed data from 31 countries from 2006–2016 and concluded that shipping in Africa increases short- and long-term emissions. Guo et al. (2023) investigated the nexus between maritime energy consumption, maritime trade, and greenhouse gas emissions using time series data for 2005–2017 for eight Northern European countries. Using the extended environmental Kuznets curve model, they examined the relationship between container throughput, LSCI, and trade openness. The findings show that increases in energy consumption led to higher marine greenhouse gas emissions in all eight countries, but this increase was more significant in Denmark, Norway, and Sweden.

Chua et al. (2023) aimed to investigate the impact of the Emission Trading System (ETS) on the fleet distribution decisions of liner shipping companies. In this context, they developed a short-term fleet planning model that accounts for CO_2 emissions for a transportation company. The findings show that regional ETS practices are not sufficient due to carbon leakage. Lu et al. (2023) developed an approach to measure global maritime container shipping emissions and estimate CO_2 emissions for 2015–2020. The study determined that container traffic at Asian ports constitutes approximately 55% of total global shipping emissions. Although energy efficiency improvement activities reduce emissions, the growth impact of trade plays a dominant role in increasing maritime emissions.

Becker et al. (2021) examined Asian and European countries in terms of the relationship between connectivity and sustainability within the scope of the Asia-Europe Meeting (ASEM). For this purpose, two indices were developed in the study: connectivity and sustainability. They determined significant differences between European and Asian countries in terms of connectivity and sustainability indices. Wang et al. (2021) developed various models using trans-Arctic routes for shipping due to climate change and ice retreat. In this context, the liner shipping bilateral connectivity index was created to determine port pairs where ships may head to trans-Arctic routes. The study sample includes 522,691 shipping transactions. The analysis indicated that only 20 movements would reduce shipping costs and greenhouse gas emissions.

Numerous studies in the literature have explored various aspects of the Regional Comprehensive Economic Partnership. However, research focusing on economic growth, logistics, financial development, and environmental implications within the RCEP framework still needs to be completed. Hence, this study aims to fill this gap in the literature. Sikder et al. (2024) investigated factors influencing logistics sector performance and CO_2 emissions across 16 countries, including RCEP and the South Asian Association for Regional Cooperation (SAARC) nations. Utilising 11 variables related to the environment, logistics, and the economy spanning from 2007 to 2018, the study revealed that economic growth, foreign direct investment inflows, and international trade positively impact logistics performance. Tian et al. (2022) initially evaluated the economic impacts of RCEP and then estimated the resulting CO_2 emissions. Their findings suggested that complete tariff elimination among RCEP members might lead to a 3.1% annual increase in global CO_2 emissions.

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Meanwhile, Fan et al. (2022) developed the green Logistics Performance Index (LPI) using the entropy method based on the traditional LPI.

Furthermore, their study analyzed the influence of RCEP countries' green logistics practices on China's exports. Fan et al. (2023) also presented three policy scenarios for carbon pricing under the RCEP agreement. Their findings indicated potential increases in RCEP's GDP, energy consumption, and CO_2 emissions due to trade liberalization. Finally, Tu et al. (2022) explored the impact of economic growth, energy consumption, renewable electricity generation, and energy efficiency on emissions across 12 RCEP countries. By analyzing panel data from 1990 to 2020, they concluded that economic growth and energy consumption contribute to emissions growth.

Several studies have investigated various aspects of maritime transportation and economic development in the existing literature. These include examining the influence of logistics investments on EG (Rizkallah 2023), assessing the effects of port connectivity enhancements on regional EG (Li et al. 2023), and analyzing the impact of maritime trade on overall EG dynamics (Adenigbo et al. 2023). Furthermore, studies have explored the interplay between port infrastructure connectivity, logistics efficiency, and trade patterns in driving EG (Liang and Liu 2020), as well as investigating the environmental repercussions of shipping emissions (Ayesu 2023) and the complex relationship between maritime energy consumption, trade activities, and greenhouse gas emissions (Guo et al. 2023). Additionally, Tian et al. (2022) delved into the economic ramifications of the RCEP agreement and estimated associated CO_2 emissions, while Tu et al. (2022) analyzed the influence of EG, energy consumption, renewable energy generation, and energy efficiency on emissions within RCEP member countries. Moreover, Sikder et al. (2024) aimed to assess both the operational performance of the logistics sector and the determinants of CO_2 emissions across 16 countries, including those within the RCEP framework.

To summarize, while numerous studies have examined various aspects related to maritime transportation and economic development, there is a scarcity of research focusing on the combined effects of shipping connectivity on environmental quality, economic growth, and financial development within the RCEP framework. The environmental repercussions of shipping emissions, particularly in RCEP countries, require further exploration. This study aims to fill this gap providing valuable insights for policymakers and industry stakeholders.

3. Materials and Models

The primary objective of this study is to investigate the relationship between shipping connectivity and environmental quality, economic growth, and financial development. To achieve this, we utilize data from 2006 to 2019 for 14 member countries of the Regional Comprehensive Economic Partnership: Australia, Brunei, Cambodia, China, Indonesia, Japan, Malaysia, Myanmar, New Zealand, the Philippines, Singapore, South Korea, Thailand, and Vietnam.

The Liner Shipping Connectivity Index has been employed to measure shipping connectivity. This index is used in the maritime transportation sector and aims to assess the strength and effectiveness of maritime transportation networks and connections. It is commonly used to evaluate the connectivity between ports, shipping routes, and maritime transportation infrastructure. In many studies, this index has been utilized to measure SC (Lin et al. 2020; Mishra et al. 2021; Tovar and Wall 2022; Merk and Teodoro 2022; Jarumaneeroj et al. 2023).

Carbon emissions have been used to measure environmental quality (Ullah et al. 2023a; Jóźwik et al. 2023a; Saadaoui et al. 2023; Ullah et al. 2024). Other variables used in the study include financial development and economic growth. All variables in the model have been transformed into logarithms. Three models incorporating the dependent and independent variables mentioned above have been developed. The study outlines the variables utilized, as detailed in Table 2.

$$CO_{2i,t} = \beta_0 + \beta_1 LINEAR_{i,t} + \beta_2 FD_{i,t} + \beta_3 GDP + \varepsilon_{i,t} \quad (1)$$

$$FD_{i,t} = \beta_0 + \beta_1 LINEAR_{i,t} + \beta_2 GDP_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$GDP_{i,t} = \beta_0 + \beta_1 LINEAR_{i,t} + \beta_2 FD_{i,t} + \varepsilon_{i,t} \quad (3)$$

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Table 2. Data description.

Variable(s)	Abbrev.	Unit measurement	Source
Carbon emissions	CO_2	CO_2 emissions (metric tons per capita)	WDI
Shipping connectivity	LSCI	Liner Shipping Connectivity Index	UNCTAD
Financial Development	FD	Financial development index	IMF
Economic Growth	GDP	GDP per capita (constant 2010 US$)	WDI

Note: UNCTAD rebranded to UN Trade and Development.

4. Empirical Procedure

In the study, cross-sectional dependence (CD) was assessed using the Breusch-Pagan LM test (1980), Pesaran's scaled LM test (CD_{LM}), Pesaran's CD test (2004), and the Bias-Corrected Scaled LM test (LM_{adj}) (2008). These tests correspond to Equations 4, 5, 6, and 7, respectively.

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^{\,2} \quad (4)$$

$$CD_{LM} = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T\hat{\rho}_{ij}^{\,2}-1\right) \quad (5)$$

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=1+1}^{N}\hat{\rho}_{ij}\right) \quad (6)$$

$$LM_{adj} = \left(\frac{2}{N(N-1)}\right)^{1/2}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^{2}\frac{(T-K-1)\hat{\rho}_{ij}-\hat{\mu}_{Tij}}{v_{Tij}} \sim N(0,1) \quad (7)$$

Afterward, the Δ tests calculated by Pesaran et al. (2008) and further developed by Blomquist and Westerlund (2013) for slope homogeneity were employed. The homogeneity test based on the Δ test, including its HAC (Heteroskedasticity and Autocorrelation Consistent) version, is depicted in Equations 8, 9, 10, and 11.

$$\Delta_{HAC} = \sqrt{N}\left(\frac{N^{-1}S_{HAC}-k}{\sqrt{2k}}\right) \quad (8)$$

$$S_{HAC} = \sum_{i=1}^{N}T(\hat{\beta}_i-\hat{\beta})'\left(\hat{O}_{iT}V_{iT}^{-1}\hat{O}_{iT}\right)(\hat{\beta}_i-\hat{\beta}) \quad (9)$$

$$\hat{\beta} = \left(\sum_{i=1}^{N}T\hat{O}_{iT}V_{iT}^{-1}\hat{O}_{iT}\right)^{-1}\sum_{i=1}^{N}\hat{O}_{iT}\hat{V}_{iT}^{-1}X_i'M_T y_i \quad (10)$$

$$\hat{V}_{iT} = \hat{\Gamma}_i(0)+\sum_{j=1}^{T-1}K\left(\frac{j}{M_{iT}}\right)\left[\hat{\Gamma}_i(j)+\hat{\Gamma}_i(j)'\right] \quad (11)$$

To assess panel stationarity, we conducted the Cross-Sectionally Augmented IPS (CIPS) test, a second-generation panel unit root test outlined in Equations 12–16.

$$\Delta y_{it} = \alpha_i+\beta_i y_{i,t-1}+u_{it} \quad (12)$$

$$u_{it} = \gamma f_t+\varepsilon_{it} \quad (13)$$

$$\Delta y_{it} = \alpha_i+\rho_i y_{i,t-1}+d_0\bar{y}_{t-1}+d_1\Delta\bar{y}_t+\varepsilon_{it} \quad (14)$$

$$\Delta y_{i,t} = \alpha_i+\rho_i y_{i,t-1}+c_i\bar{y}_{t-1}+\sum_{j=0}^{p}d_{i,j}\,\Delta\bar{y}_{t-j}+\sum_{j=0}^{p}\beta_{i,j}\,\Delta y_{i,t-j}+\mu_{i,t} \quad (15)$$

$$CIPS = \frac{1}{N}\sum_{i=1}^{N}CADF_i \quad (16)$$

Subsequently, the Panel LM bootstrap cointegration test by Westerlund and Edgerton (2007) was employed. The equations for the panel cointegration test are presented in Equations 17, 18, and 19.

$$y_{it} = \alpha_i+x_{it}'\beta_{it}+Z_{it} \quad (17)$$

$$\boldsymbol{Z_{it} = \mu_{it}+V_{it}\,V_{it} = \sum_{j=1}^{t}\eta_{ij}} \quad (18)$$

$$\boldsymbol{LM_N^+ = \frac{1}{NT^2}\sum_{i=1}^{N}\sum_{t=1}^{t}\hat{\omega}_i^{-2}\,S_{it}^2} \quad (19)$$

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Next, we estimated the long-term coefficients using the Panel-Corrected Standard Errors (PCSE) estimator proposed by Beck and Katz (1995) to correct for standard errors. The PCSE model is represented in Equations 20, 21, and 22.

$$y_{it} = x_{it}\beta + \varepsilon_{it} \quad (20)$$

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \end{bmatrix} = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_m \end{bmatrix} \beta + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_m \end{bmatrix} \quad (21)$$

$$\sum[\varepsilon\varepsilon'] = \Omega = \begin{bmatrix} \sigma_{11}I_{11} & \sigma_{12}I_{12} & \cdots & \sigma_{1m}I_{1m} \\ \sigma_{21}I_{21} & \sigma_{22}I_{22} & \cdots & \sigma_{2m}I_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{m1}I_{m1} & \sigma_{m2}I_{m2} & \cdots & \sigma_{mm}I_{mm} \end{bmatrix} \quad (22)$$

Then, following the PCSE estimation, we estimated the second set of long-term coefficients using Seemingly Unrelated Regressions (SUR). Based on the results of Monte Carlo simulations conducted by Mark, Ogaki, and Sul (2005), it can be asserted that this estimation method is effective in cases of high cross-sectional dependence (CD) and heterogeneity among cross-sections. The SUR model, comprising MM equations, is shown in Equations 23, 24, 25, and 26.

$$\begin{aligned} y_1 &= x_1\beta_1 + u_1 \\ y_2 &= x_2\beta_2 + u_2 \\ &\vdots \\ y_M &= x_M\beta_M + u_M \end{aligned} \quad (23)$$

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_M \end{bmatrix} = \begin{bmatrix} X_1 & 0 & \cdots & 0 \\ 0 & X_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & X_M \end{bmatrix} + \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_M \end{bmatrix} + \begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_M \end{bmatrix} \quad (24)$$

$$\sum = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1M} \\ \sigma_{21} & \sigma_{22} & \cdots & \sigma_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{M1} & \sigma_{M2} & \cdots & \sigma_{MM} \end{bmatrix} \quad (25)$$

$$\hat{\beta} = [x'\Omega^{-1}x]^{-1}x'\Omega^{-1}y = [x'(\Sigma^{-1} \otimes I)x]^{-1}x'(\Sigma^{-1} \otimes I)y \quad (26)$$

To assess the consistency of the models estimated with the SUR estimator, we conducted tests using the Panel-Corrected Standard Errors and Driscoll-Kraay estimators, which are developed as alternatives to address issues of cross-sectional dependence and heteroskedasticity. Finally, we employed the causality test proposed by Dumitrescu and Hurlin (2012) to examine the causality between variables X and Y, which is particularly applicable for heterogeneous panels and cases of cross-sectional dependence.

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \beta_{ik}\, y_{i,t-k} + \sum_{k=1}^{K} \gamma_{i,k}\, X_{i,t-k} + \varepsilon_{it} \quad (27)$$

5. Results

5.1. Descriptive Statistics and Correlation Matrix Outcomes

Table 3 presents the descriptive statistics of the variables utilized in the study. The findings reveal that the average CO_2 emissions per capita among RCEP countries are estimated to be 6.72 metric tons. The average value for the Liner Shipping Connectivity Index is calculated to be 49.92. Among the RCEP countries from 2006 to 2019, China has the highest LSCI, whereas Brunei has the lowest. The variations in LSCI and GDP suggest that while some countries have highly developed maritime infrastructure and strong economies, others are less connected and have lower economic output.

Table 3. Descriptive statistics.

Variable	Mean	Std.dev	Min	Max
CO_2	6.726	5.608	0.150	20.575
LSCI	49.922	38.907	3.4	158.6
FD	0.521	0.252	0.08	0.96
GDP	19773.67	20125.55	301.582	68198.42

Note: the number of observations 196.

The correlation analysis between the variables employed in the study is depicted in Table 4. The results show a positive correlation (r = 0.14) between shipping connectivity and CO_2 emissions. This indicates that CO_2 emissions also tend to increase as shipping connectivity increases, although the relationship is relatively weak. Furthermore, a robust and positive correlation between economic growth, financial development, and CO_2 emissions is evident. As countries experience higher levels of economic activity and financial development, CO_2 emissions also increase.

Table 4. Correlation matrix.

Variable	CO_2	LSCI	FD	GDP
CO_2	1.000			
LSCI	0.147	1.000		
FD	0.596	0.587	1.000	
GDP	0.767	0.153	0.654	1.000

These correlation coefficients provide initial insights into the relationships among the variables. The positive correlations between CO_2 emissions and both GDP and FD indicate that economic and financial growth may be linked to higher emissions. The moderate correlation between LSCI and FD suggests that improvements in shipping connectivity might be associated with financial sector development. However, it's important to note that correlation does not imply causation, and further analysis is necessary to understand the nature and direction of these relationships.

5.2. Preliminary Statistical Tests

In this section, we present the results of the preliminary statistical tests conducted to ensure the validity and reliability of our econometric models. These tests include assessments of cross-sectional dependence, slope homogeneity, and unit root properties of the data series.

Table 5 presents the results of the cross-sectional dependence tests for the variables. According to the test results, all variables are statistically significant at the 1% level ($p < 0.05$). This means the null hypothesis of 'no cross-sectional dependence' is rejected for all variables, affirming the presence of cross-sectional dependence across all series.

Table 5. Cross-Sectional Dependence (CSD) test results.

Test	CO_2	LSCI	FD	GDP
Breush-Pagan LM	242.41***	145.23***	341.21***	144.96***
Pesaran scaled LM	54.74***	65.16***	34.22***	95.78***
Bias-corrected scaled LM	31.92***	23.03***	19.18***	41.72***
Pesaran CD	9.58***	14.75***	15.75***	25.64***

Note: *** indicates statistical significance at the 1% level ($p < 0.01$).

Table 6 presents the results of the slope homogeneity test using the Δ test statistics calculated by Blomquist and Westerlund (2013). The null hypothesis (H_0) of slope homogeneity is rejected in all models, indicating the presence of slope heterogeneity among the cross-sections in the study's models.

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Table 6. Test of slope homogeneity.

	Model 1	Model 2	Model 3
$\tilde{\Delta}$	11.46***	13.52***	7.82***
$\tilde{\Delta}_{adj}$	8.74***	9.94***	6.87***

Note: *** indicates statistical significance at the 1% level (p < 0.01).

Table 7 investigates the stationarity of the variables. The results indicate that at the level, only GDP is stationary at the 5% significance level, and at the first difference, all variables are stationary at the 1% significance level. This means the null hypothesis H_0 stating that "the series contains a unit root" is rejected for all variables at their first differences, confirming that they are integrated of order one, I(1).

Table 7. CIPS unit root test results.

Variable	Level	First Difference
CO_2	-1.21	-3.85***
LSCI	-1.45	-3.85***
FD	-1.36	-4.38***
GDP	-2.73**	-5.64***

Note: ** indicates statistical significance at the 5% level (p < 0.05); *** indicates statistical significance at the 1% level (p < 0.01).

5.3. Long-Run Coefficients and Causality Test Results

This section presents the results of the long-run coefficients and the causality relationships among the variables studied. In Table 8, the Westerlund and Edgerton (2007) LM Bootstrap cointegration test is employed to determine the long-run cointegration relationship between the variables, accounting for cross-sectional dependence. This test is particularly suitable for panels with potential cross-sectional correlations among units. For the model evaluating LSCI, FD, and GDP's impact on CO2, with a Bootstrap-p value exceeding 0.10, the null hypothesis H_0 is accepted, suggesting a cointegration relationship among the series.

Table 8. Westerlund-Edgerton's LM Bootstrap Cointegration Test Results.

Models	Test	LM Statistics	Asymptotic-p Value	Boostrap-p Value
Model 1	LMN^T	13.26	0.0000	0.821
Model 2	LMN^T	16.51	0.0000	0.873
Model 3	LMN^T	11.33	0.0000	0.782

Note: *** indicates statistical significance at the 1% level (p < 0.01).

Table 9 presents the results from three different estimators: Panel-Corrected Standard Errors, Dynamic Seemingly Unrelated Regression, and Driscoll-Kraay. Using these estimators, the study investigated the effects of: i) shipping connectivity on carbon emissions, ii) shipping connectivity on financial development, and iii) shipping connectivity on economicg growth. Nine separate regression results were obtained using three different methods across three models.

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Table 9. Findings of long-run elasticity estimates.

	Model 1			Model 2			Model 3		
Method	PCSE	SUR	D-K	PCSE	SUR	D-K	PCSE	SUR	D-K
Depended Var.	CO_2	CO_2	CO_2	FD	FD	FD	GDP	GDP	GDP
LSCI	4.15***	2.51**	2.47**	32.99***	12.03***	22.57***	13.14***	5.71***	9.71***
	(0.13)	(-0.13)	-(0.13)	(0.03)	(0.03)	(0.03)	(182.5)	(182.5)	(182.5)
FD	8.23***	3.10***	11.17***	-	-	-	25.46***	13.93***	22.33***
	(5.39)	(5.39)	(5.39)				(688.9)	(688.9)	(688.9)
GDP	12.95***	9.74***	11.13***	21.02***	13.93***	18.63***	-	-	-
	(0.01)	(0.01)	(0.01)	(7.22)	(7.22)	(7.22)			
Constant	9.89***	1.19*	8.47***	33.19***	11.63***	33.46***	-11.71***	-3.02***	-20.52***
	(1.13)	(1.13)	(1.13)	(0.21)	(0.21)	(0.21)	(-689.9)	(-689.9)	(-689.9)
Observations	196	196	196	196	196	196	196	196	196
R-squared	0.6078	0.6078	0.6078	0.6707	0.6707	0.6707	0.5092	0.5092	0.5092
No. of groups	14	14	14	14	14	14	14	14	14

Note: Standard errors are in parentheses. *, **, *** denote significance at the 10%, 5%, and 1% levels, respectively.

For Model 1, all estimations using the PCSE, SUR, and D-K methods are statistically significant. The results indicate that increased SC within RCEP countries is associated with higher per capita carbon emissions, suggesting a positive relationship between the two. These findings are consistent with those reported by Ayesu (2023) and Guo et al. (2023). Similarly, increasing SC has a positive impact on EG and FD, aligning with the findings of Bouazza et al. (2023), Şeker (2020), and Liang and Liu (2020).

Additionally, an increase in EG has been found to harm the environment. Economic growth leads to increased energy demand and greater use of fossil fuels, potentially resulting in higher greenhouse gas emissions. This observation aligns with the findings of Shahbaz et al. (2023) and Ullah et al. (2024). Furthermore, it has been determined that an increase in FD adversely affects environmental sustainability. This phenomenon can be attributed to FD's association with increased income, greater consumption of natural resources, and increased energy demand that often accompanies EG. The literature supports these results (Jóźwik et al. 2023b; Ullah et al. 2023b; Shahbaz et al. 2023).

In Model 2, the impact of maritime transportation connectivity on FD, the results indicate that an increase in maritime transportation connectivity in RCEP countries accelerates FD across all estimators. This phenomenon is associated with the increase in international trade and the strengthening of commercial relationships. The growth in foreign trade can support EG and stimulate FD. Additionally, the enhancement of maritime transportation connectivity can contribute to the expansion of international investments and commercial activities. This, in turn, may encourage financial institutions and investors to invest in sectors such as port infrastructure and maritime transportation.

Upon examination of the results of Model 3, a robust and positive relationship between maritime transportation connectivity and EG is observed across all estimators. In other words, an increase in maritime transportation connectivity correlates with an acceleration in the rate of EG. This can be attributed to the strengthened connections in maritime transportation, leading to enhanced efficiency of ports and maritime transport services. These findings align with the results of Li et al. (2023) and Adenigbo et al. (2023).

The results of the Dumitrescu-Hurlin panel causality test are presented in Table 10. They highlight the significant roles of maritime transportation connectivity and financial development in influencing CO_2 emissions among RCEP countries. For example, there is a unidirectional causality from LSCI to CO_2 emissions, implying that improvements in shipping connectivity lead to increased carbon emissions. Otherwise, the bidirectional causality between GDP and LSCI suggests that economic growth and maritime transportation connectivity enhance each other. Simirarly, the bidirectional causality between GDP and FD underscores the close relationship between economic performance and the development of the financial sector. The findings emphasize the importance of considering these factors in policy formulations aimed at promoting sustainable economic growth while mitigating environmental impacts.

Table 10. Dumitrescu-Hurlin panel causality test results.

	W-bar	Z-bar	P-values
$CO \nrightarrow LSCI$	1.551	0.521	0.601
$LSCI \nrightarrow CO$	2.628	2.382	0.017
$CO \nrightarrow$ GDP	2.193	1.629	0.103
$GDP \nrightarrow CO$	2.302	1.818	0.069
$CO \nrightarrow FD$	1.863	1.060	0.288
$FD \nrightarrow CO$	2.925	2.896	0.003
$FD \nrightarrow LSCI$	2.899	3.012	0.002
$LSCI \nrightarrow FD$	3.109	4.401	0.000
$GDP \nrightarrow LSCI$	3.356	4.715	0.000
$LSCI \nrightarrow GDP$	3.751	5.515	0.000
$GDP \nrightarrow FD$	2.674	3.252	0.000

$FD \nrightarrow GDP$	2.203	2.972	0.003

Note: the maximum lag length is taken as 1.

6. Conclusions

Shipping plays a pivotal role in international trade and economies by providing a cost-effective method for transporting large cargo volumes. However, it also contributes significantly to greenhouse gas emissions, primarily through the burning of fossil fuels, leading to adverse effects on climate change and environmental quality. This study explores the connection between the Liner Shipping Connectivity Index and environmental quality, economic growth, and financial development within the Regional Comprehensive Economic Partnership countries. Given their significant share in global trade, understanding these relationships is crucial.

The analysis results show that shipping connectivity has positive effects on financial development and economic growth but has a negative effect on environmental quality. Furthermore, the gradual removal of customs tariffs applied to goods among member countries within the scope of the RCEP agreement implies that trade between these countries will increase further. Consequently, the increase in trade will lead to heightened shipping activities, which will escalate environmental pollution and marine emissions. Therefore, countries need policies and practices aimed at sustainable development alongside increasing maritime trade. Governments should plan to promote environmentally friendly green ports. Low-carbon and advanced technologies should be applied to reduce shipping emissions in maritime trade. Authorities need to tighten policies and increase controls to reduce or prevent environmental pollution and shipping emissions. In this context, industry stakeholders should encourage cooperation among shipping companies, local governments, and environmental organizations.

Based on the findings of the study, to enhance environmental sustainability in the maritime sector, green maritime practices such as replacing ship fuels with cleaner and low-carbon alternatives, improving waste management, and reducing the environmental impacts of maritime activities should be encouraged. Investment and innovation efforts should be supported for the development and adoption of environmentally friendly technologies. Research and development efforts and investments should be increased in areas such as maritime technologies based on renewable energy sources and carbon reduction solutions. Additionally, RCEP countries must set stringent environmental regulations and standards to reduce environmental impacts in the maritime sector, such as reducing shipping emissions, preventing marine pollution, and protecting biodiversity. It is important for RCEP countries to align their trade policies with environmental sustainability principles and create trade policies that encourage trade in environmentally friendly products and ensure compliance with environmental standards. These recommendations may help RCEP countries achieve a balance between environmental sustainability, financial development, and economic growth.

This study has some limitations. Firstly, the findings should be evaluated within the framework of the variables used in the study and in terms of RCEP countries. In future studies, similar research may be conducted for different country groups. Finally, the environmental impacts of maritime activities may be examined in more detail, especially their impact on CO_2 emissions, water pollution, and marine biodiversity. Such research may contribute to a better understanding of the maritime industry in terms of environmental sustainability.

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