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Unravelling the Trade- Environment Nexus in Emerging Economies: A Composite Index Approach within an Extended STIRPAT Framework

Neha Jain

neha.jain@jaipur.manipal.edu

Manipal University Jaipur

Manobal Kumar

Birla Institute of Technology and Science, Pilani

Geetilaxmi Mohapatra

Birla Institute of Technology and Science, Pilani

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Abstract

This study investigates the impact of trade on the Composite Environmental Sustainability Index (CESI) for emerging countries by applying STIRPAT (Stochastic Impact by Regression on Population, Affluence and Technology) approach over the period of 1990-2023. The research evaluates environmental sustainability via the CESI while addressing sustainable development goals (SDGs) such as SDG6 (clean water and sanitation), SDG7 (affordable and clean energy), SDG9 (Industry, innovation, and infrastructure), SDG11 (sustainable cities and communities), and SDG12 (responsible consumption and production). The study employs cross-section dependence tests, panel unit root tests, and quantile regression models to address the objectives of the study. Moreover, the study also utilized the Driscoll-Kraay standard errors technique to check the robustness of the results. The empirical analysis reveals that trade openness significantly enhances quality of environment. Institutional quality emerges as a consistently positive and significant determinant across all quantiles, underscoring its critical role in fostering sustainable development irrespective of initial environmental conditions. Conversely, innovation and globalization exhibit adverse effects on environmental sustainability. The novelty of the paper lies in the fact that environmental sustainability is measured by constructing a composite index (CESI) using seven critical indicators which is multidimensional in nature. The empirical results support the claim that trade supported with strong institutions and green innovation substantially impact a nation's ability to preserve its environment. It also recommends to policymakers that a balanced and integrated policy strategy is required to attain long-term environmental sustainability.

Keywords: Trade, Composite Index, Environmental sustainability, Emerging Economies, MMQR, Sustainable development

JEL codes: F41, Q01, Q37, Q5

1. Introduction

Sustainability is the primary focus of the growing internationalization of the global economy in the twenty first century (Yin et al. 2023). The 2030 Agenda is one of the initiatives taken to achieve sustainability which focuses on protecting the future of the planet and humans. Moreover, it also strengthens the three fundamental pillars of sustainable development, namely economic, social, and environmental (Nylund et al. 2022). Towards the goal, economies have started incorporating sustainable development goals (SDGs) into their national development plans, legislations, and institutional responsibilities (Jha et al. 2018). Nevertheless, environmental indicators have made the least progress out of the 17 SDGs (Arora & Mishra, 2019). Additionally, environmental sustainability is essential for a long-term sustainable future. Environmental sustainability involves a responsible relationship with the environment over the long run by maintaining environmental quality while preventing resource depletion or degradation. It also improves human welfare without unreasonably endangering the planet's life-supporting ecosystems (Arora, 2018).

However, measuring environmental sustainability is a complex task that requires inclusiveness of a wide array of factors of environment. Previous researchers have employed various proxies for environmental sustainability, for instance carbon dioxide emissions (CO_2) (N'dri et al. 2021; Ahmad et al. 2021; Dou et al. 2021; Chen et al. 2023), emissions of sulphur dioxide (SO_2) (Selden and Song, 1994), and particulate matter (PM 2.5). However, single indicators do not provide a complete picture of environmental sustainability. The available literature highlights the greater accuracy of composite environmental indices in capturing a country's environmental situation (Blanc et al. 2008; Jones et al. 2002; Chakraborty and Mukherjee, 2013). Among composite indicators, Ecological Footprints (EF) and EPI (Environmental Performance Index) have been widely used in previous research (Chakraborty and Mukherjee, 2013; Yilanci and Pata, 2020; Chen et al., 2022; Yilanci et al., 2022). The EPI utilizes trend analysis and performance benchmarks to evaluate significant environmental policy outcomes but falls short of incorporating crucial factors like water quality, water erosion, and waste management. EF does not account for oceans and underground resources such as water. The environmental sustainability index (ESI) was also constructed but criticized based on the contradiction between its terminology and actual measurement (Fischer et al., 2022, Jain and Mohapatra, 2023).

Therefore, this study uses the composite environmental sustainability index (CESI) to address most of the environment-related SDGs (see Table A1). CESI is composed of seven indicators, and the indicators have significant association with international trade. Growing interdependence between countries has led to sizeable greenhouse gas (GHG) emissions, carbon emissions, and air pollutants especially in emerging economies. Traditionally emissions are seen from the production perspective and ignored the impact of international trade and emissions led by consumption. Researchers have increasingly emphasized the urgency of addressing air pollution from the global perspective (Ma et al., 2021; Zhou et al., 2025). International trade and consumption patterns are also associated with water footprints. The concept of 'virtual water' proposed by Allan (1997) is an important tool for tackling

water related issues in the world. International trade with conservation of water can increase the global productivity of freshwater resource allocation through virtual water trade method. It helps in protecting the environment and achieving the sustainable growth of water resources (Kopnova, 2017; Hekmatnia et al., 2024). The revenue from natural resource extraction has significant link with globalization through its influence on financial development and economic growth. Export dependent nations often experience slow economic growth due to unequal allocation of natural resource revenue across the economy. A country's capacity to discover new markets and broaden the variety of items it exports may also be hampered by this imbalance. Since resource exploitation has a significant impact on the emerging economies, it is imperative to comprehend the relationship between trade and natural resource rent (Pang et al., 2022; Arslan et al., 2022; Wang & Razzaq, 2022; Huang and He, 2023). Moreover, research on developing economies reveals that, although trade may initially lead to an increase in energy consumption, it ultimately suppresses energy intensity as long as green trade and technology transfers are actively promoted.

Although international trade provides a growth impetus among countries through various channels, its implications on environmental sustainability are becoming a growing concern through increasing pollution and depleting natural resources. However, as trade has expanded, questions about its impacts on the environment and, more generally, about the ability of nature to withstand the environmental effects of economic activity have also been raised. Emerging economies have made impressive strides in enhancing their macroeconomic policies, which has assisted them in doubling per capita incomes since the turn of the century (Duttagupta and Pazarbasioglu, 2021). The degree of openness to international trade can be reflected by their growing proportion in international trade. According to a report by ADB (Jha et al., 2018), most emerging Asian countries fall short of involving all citizens in the process of development, and ensuring environmental sustainability will take decades. A significant portion of the population is subject to the effects of air pollution, limited access to water resources, escalating land degradation, and a limited adoption of renewable energy sources. As economies continued to grow and develop in the recent decades, environmental degradation has become a "common concern" (Shrinkhal 2019).

The paper uses environmental sustainability rather than ecological pollution which is a broader concept. To date, there has been no empirical investigation that has examined the causal link between international trade and environmental sustainability using the composite indicators approach for emerging countries. Against this backdrop, the current study targets to investigate the influence of trade openness (TR), institutional quality (IQ), innovation, globalization index and other control variables on environmental sustainability measured by CESI in 20[1] emerging economies from 1990 to 2023 using

[1] Based on the classification provided by the IMF World Economic Outlook in 2021, a total of 20 economies have been identified as emerging economies. The study incorporates countries, namely Argentina, Brazil, Chile, China, Columbia, Egypt, Hungary, India, Indonesia, Iran, Malaysia, Mexico, the Philippines, Poland, Russia, Saudi Arabia, South Africa, Thailand, and Turkey (Duttagupta and Pazarbasioglu, 2021). The United Arab Emirates has been excluded from this analysis due to a lack of available data.

the modified version of STIRPAT model. The STIRPAT (Stochastic Impact by Regression on Population, Affluence and Technology) model is mostly used framework in environmental economics. It is the stochastic, statistical evolution of the foundational I = PAT identity (Environmental Impact = Population × Affluence × Technology) (Fan et al., 2006). Moreover, the present research aims to address some critical research questions. For instance, is trade openness good or bad for environmental sustainability? Can international trade and environmental policies be combined to maximize benefits and minimize environmental costs? To address these questions, the present study utilizes a new approach (composite index) to measure environmental sustainability. The novel contribution of the study is also evident in assessing the effect of IQ and innovations on environmental sustainability while suggesting policy implications to optimize economic integration and its cost to the environment in emerging economies.

The subsequent sections of this paper are arranged in the following manner. Section 2 of the paper provides a comprehensive analysis of the existing literature, which is divided into two separate sub-sections. Subsection 2.1 provides a clear exposition of the theoretical framework, whereas Section 2.2 presents an extensive overview of empirical research conducted in this field. Section 3 of this study is devoted to a comprehensive examination of the data and methodology utilised in this research paper. Additionally, Section 4 thoroughly examines and discusses the empirical findings. Section 5 of the paper serves as a comprehensive summary of the study with a particular focus on potential policy implications.

2. Literature Review

2.1 Theoretical Background

Strong trade ties between nations increase a nation's output and citizens' standards of living, thereby promoting economic growth and reducing poverty. (Tipping and Wolfe, 2016; Zafar et al., 2021). The growth of international trade and the development of global value chains raised a question about trade and its impact on environmental quality. Trade offers a double-edged sword that can have favourable and unfavourable effects on the same. On the one side, international trade provides a better opportunity to improve environmental management while also promoting economic development and societal well-being. Furthermore, trade facilitates access to new technologies that improve production efficiency by reducing the use of environmentally harmful inputs. For instance, the pollution halo hypothesis states that greener technologies, such as pollution abatement technologies and renewable energy techniques, can be transferred through foreign direct investment (FDI), which mitigates carbon emissions (Das, 2019; Nguyen-Thanh et al., 2022). On the other, increasing pollution and degrading natural resources are the direct negative environmental effects of trade expansion. Since environmental regulation varies between nations, trade openness could lead to specialization in pollution-intensive activities in countries – the so-called pollution haven hypothesis (OECD, 2021).

Numerous studies examine the relationship between the various macroeconomic factors and the environment in the literature. Certain studies examine the relationship between economic growth and the environment using the Environmental Kuznets Curve (EKC) hypothesis. On the other hand, some studies investigate the relationship between trade openness and the environment within the context of the EKC hypothesis, pollution haven hypothesis, and pollution halo hypothesis (Sibanda et al., 2023). As per the theory proposed by Grossman and Krueger (1993) and Copeland and Taylor (1994) distinguished three environmental impacts of internationalization. The scale effect is the first effect, which demonstrates that the increased output of a country may result in a rise in harmful emissions. The second effect is the composition effect, which affects the sectoral structure of markets when there is a shift in the ratio of cleaner to dirtier industries due to international trade. The third consequence is a technical one brought on by adopting eco-friendly technological advancements. As a result, combining these three effects will have an overall impact on the ecosystem (Appiah et al. 2022; Awad and Mallek, 2023).

2.2 Empirical Studies

Numerous scholars have conducted extensive investigations into the relationship between trade openness and environmental sustainability over an extended period, employing diverse indicators to measure environmental sustainability. Nonetheless, their results are mixed. Using data from 1965 to 2008, Shahbaz et al. (2013) studied the correlation between CO_2 emissions and trade in South Africa. The authors employed the autoregressive distributed lag (ARDL) model, and results reveal that in South Africa trade openness has a detrimental effect on CO_2 emissions, indicating that greater trade openness improves environmental sustainability. However, a study conducted in Tunisia by Mahmood et al. (2019) found that trade openness has positive impact on CO_2 emissions, suggesting that an increased trade openness contributes to enhanced environmental sustainability. Moreover, Hossain (2011) evaluated the relationship between trade openness and CO_2 emissions by employing data spanning from 1971 to 2007. The empirical findings found no indication of a causal relationship between trade openness and CO_2 emissions in newly industrialized countries. The research mentioned by Sun et al. (2019) and Dauda et al. (2021) offers contradictory results about the relationship between trade openness and CO_2 emissions. Mutascu (2018) evaluated the effects of trade openness and CO_2 emissions by analysing a dataset from 1963 to 2013. The study used wavelet methods to assess this linkage, including wavelet coherence, multiple wavelet coherence, and partial wavelet coherence. The findings of this study showed that there was little correlation between CO_2 emissions and trade openness. The findings of Sebri et al. (2014) for the BRICS countries and Cetin et al. (2018) for Turkey confirmed the relationship between CO_2 emissions and trade openness as beneficial. The study conducted by Rehman et al. (2021) examined the linkage between globalization, energy use, and trade on environmental sustainability using ecological footprints as an indicator in Pakistan. A linear ARDL model with limited information maximum likelihood and linear Gaussian model estimation is utilized for the annual data

from 1974-2017. The results show that in the long term, globalization, energy use, trade, and GDP growth are positively related to ecological footprints. Based on the analytical conclusions of this study, it is advisable for policymakers and authorities to persist in their efforts to strengthen interventions targeted at facilitating efficient trade strategies, fostering economic development, managing fuel consumption, and specifically mitigating carbon emissions. This would increase economic production, minimize ecosystem damage, and preserve sustainable settings. Orhan et al. (2021) investigated the association between CO_2 emissions and economic growth in India while accounting for energy use, agricultural production, and trade openness. The results of the study discloses that India's environmental sustainability in negatively impacted by increased energy use, agriculture, and trade openness.

Baajike et al. (2022) investigated the impact of economic growth, trade liberalization, and financial development on the environmental quality in West African region during the period of 2005-2018. The finding derived from the empirical analysis indicate that trade liberalization has a detrimental impact on environmental sustainability. However, this negative effect can be mitigated by the presence of strong and effective institutions, as well as a well-regulated market. It also validates the EKC hypothesis within the ECOWAS sub-region. Andriamahery (2022) assessed the EKC hypothesis with the relationship between renewable energy, environmental innovation, environmental sustainability, and trade in India and Russia. He also employed per capita CO_2 emissions as a metric to assess environmental sustainability. Similarly, Pham et al. (2020), Longe et al. (2020), Boamah et al. (2020), Sun et al. (2020), and others studied the impact on the environment of trade openness.

Recently, Ali et al. (2020) addressed the effects of trade openness on environmental quality using ecological footprints in OIC (Organisation of Islamic Cooperation) countries. The positive effect of trade openness on ecological footprints is discovered by Dynamic Common Correlated Effect (DCCE) method. It is also suggested that green investment and technology, clean production, and improved institutions must be encouraged by OIC countries for better environmental quality and sustainable development. Lheonu et al. (2021) examine the association between international trade, urbanization, and CO_2 emissions in Sub-Saharan Africa (SSA) for the period 1990-2016. The study finds that trade encourages environmental sustainability in nations with the highest and lowest CO_2 emissions using panel quantile regression. Trade restrictions, however, ought to apply to nations with intermediate CO_2 emissions. Baek et al. (2009) used a co-integration approach to evaluate the ecological effects of globalisation on both developed and developing nations. The findings indicate that while income growth and trade tend to have negative effects on the environment in most developing nations, they tend to have positive effects in advanced nations. A causality test revealed that a divergence in trade and income growth in developed nations led to a deviation in ecological quality. Conversely, the opposite is true for emerging nations.

It raises fundamental questions about how trade and economic policies interact with environmental sustainability in developing nations and LDCs. It is observed from the above review of the literature that these studies widely employed CO_2 emissions; some used ecological footprints as an indicator of

the environment. It is challenging to find a significant number of studies that consider the composite index of environmental sustainability.

3. Data and Methodology

3.1 Construction of CESI

The paper attempts to examine the association between trade openness and environmental sustainability for emerging economies during 1990-2023. The dependent variable in the present study is CESI, a composite index. The previous literature depicts that a composite environmental index explains the present environmental situation more comprehensively than the individual indicators of the environment (Jones et al. 2002). Therefore, our own previous study (Jain and Mohapatra, 2023) constructs the CESI to measure the environmental sustainability using the seven critical indicators of environmental sustainability as suggested in the ADB report by Jha et al. (2018). The data for the indicators of CESI have been gathered from world development indicators (WDI), human progress, World Bank, and the international energy agency. To create the CESI, the study used Principal Component Analysis (PCA). The CESI scale goes from 1 to 6 with 1 denoting the poorest state of environmental sustainability and 6 denoting the best. The World Economic Forum (WEF), Yale Center for Environmental Law and Policy (YCELP), and Columbia University's Center for International Earth Science Information Network (CIESIN) collaborated to create the ESI. Because of the vocabulary used, it is not particularly obvious. For example, ESI was the previous name of EPI (Fischer et al., 2022). These two phrases, however, have different meanings and interpretations in the literature. The EPI tracks and contrasts countries based only on how well they perform according to environmental parameters. The ESI, on the other hand, evaluates how well countries are doing globally in terms of environmental sustainability for the benefit of both current and future generations. The study by Jain and Mohapatra (2023) provides a detailed description of the CESI indicators and the technique used.

3.2 Data and Model Specification

After constructing the CESI, the study intends to explore the link between trade and environmental sustainability. The theoretical foundation of this study is based on the STIRPAT model for analyzing ecological pollution indicators. Based on the York, Rosa and Dietz (2003) the STIRPAT baseline model is represented in Equation (1).

$$I_{it} = aP_{it}^{b}C_{it}^{c}T_{it}^{d}\varepsilon_{it} \quad (1)$$

Where, I represents ecological pollution, P is population size, A depicts affluence or financial structure, and T indicates technical indicators. The present study extends the STIRPAT model by including variables such as trade openness (TR), economic growth (GDP), foreign direct investment (FDI), technological innovations (IN), urbanization (URB), institutional quality index (IQI), Globalization Index (GI). Hence, the empirical model analysed in the present study is as follows:

$$CESI_{it} = \alpha_1 + \beta_1 TR_{it} + \beta_2 GDP_{it} + \beta_3 FDI_{it} + \beta_4 IN_{it} + \beta_5 URB_{it} + \beta_6 IQI_{it} + \beta_7 GI_{it} + \varepsilon_{it} \quad (2)$$

Trade openness (TR) is measured by the trade of goods and services as a percent of GDP. Various control variables are also included in the model specifications. GDP per capita (GDP) is the indicator of income. FDI inflow (FDI) is taken as the indicator of investment flows, expressing the importance of investment. Globalization Index (GI) measures the economic, social and political dimensions of globalization. It measures the degree of globalization in countries in long run. It ranges between 1 to 100. Higher the value of globalization index, higher will be the degree of globalization (Gygli et al. 2019; Dreher, 2006). Innovation (IN) is considered here and measured by patent applications (Muhammad et al., 2020). This variable has been employed as a crucial measure in numerous investigations. According to specific research, innovation lowers carbon emissions. URB is the urban population which is a significant indicator in influencing environmental sustainability. Transformation of all the variables is done in their logarithmic form to rule out the possibility of heterogeneity occurrences. Authors have constructed the Index of CESI. Table 1 presents the variables and their description in detail.

Table 1: Description of Variables

Variables	Description	Symbol	Data source
Environmental sustainability	Index	CESI	Authors' Calculation
Trade openness	Trade (% of GDP)	TR	WDI, World Bank
Economic Growth	GDP per capita (current US$)	GDP	
Investment flows	Foreign direct investment, net inflow (% of GDP)	FDI	
Technological innovations	Patent applications	IN	
Urbanization	Urban population	URB	
Institutional quality index	Index	IQI	World Governance Indicators, World Bank
Globalization index	KOF Globalization Index	GI	Gygli et al. (2019)

Source: Authors' Compilation

3.3 Estimation Methods

Before performing a panel data analysis, a cross-section dependence test (CSD) is required. Ignoring the CSD in panel data can result into incorrect and biased inferences. Therefore, the CSD test is performed to check the CSD in the models employed. The next step in methodological procedure is to test for stationarity. Second-generation panel unit-root test such as the Cross-section Im-Pesaran-Shin (Im et al., 2003) test (CIPS), and Cross-section Augmented Dickey-Fuller (CADF) test are utilized to test the unit root properties of the variables. The null hypothesis of these tests is that each panel includes a unit root. The presumption that all panels have the same value of rho is one of the main limitations of the Levin-Lin-Chu, Harris-Tzavalis, and Breitung tests. Pesaran (2007) created the CADF test by

combining the conventional ADF regression model with the lagged cross-sectional average and its first difference. Panel cointegration tests are employed after the unit root test. Establishing stability among the parameters requires an understanding of the existence of cointegration in panel data, which has significant consequences for forecasting and policy research. Kao (1999), Pedroni (2004) and Westerlund (2007) cointegration tests are used to assess the long run relationship between the variables.

Furthermore, to estimate the impact of independent variables on dependent variable our primary approach is quantile regression (QR). To reduce the challenges with panel data assessment, the QR technique can help identify the heterogeneous impact and distribution across different quantiles Jahanger et al. (2023). Therefore, a new and innovative MMQR technique proposed by Machado and Silva (2019) was used in the study. The MMQR is especially useful for assessing the impact of variables on various regions of the distribution since it examines the conditional quantile of the explained indicator. Additionally, MMQR makes it easier to identify heterogeneity and time-varying dynamics by taking into account both time-specific and individual effects when evaluating panel data (Fatima et al. 2024). The MMQR approach is similarly successful in models with endogenous explanatory indicators, according to Jahanger et al. (2023). Equation (3) shows the generic linear formula for this method:

$$Q_y\left(\frac{\tau}{X_{it}}\right) = \left(\pi_i + \theta_i q(\tau)\right) + X'_{i,t}\,\beta + Z'_{i,t} y q(\tau) \tag{3}$$

Where, X_{it} represents all the regressors, Q_y indicates the quantile assessment of dependent variable with the conditional distribution. The scaler coefficient calculated through the fixed effect (τ) each cross-section (i) is represented by $X_{it} = \left(\pi_i + \theta_i q(\tau)\right)$. Nevertheless, the q(τ) identifies the estimated quantile, for instance (τth), which helps compensate for the optimization of the function as presented in Equation (4):

$$Min_q \sum_i \sum_t \rho_\tau \left(A - (\lambda_i + Z'_{it} y)\right) q \tag{4}$$

To test for the robustness of the results, the study employs Driscoll-Kraay standard errors (DKSE) approach. The approach controls for CSD and serial correlation. The non-parametric regression method under consideration exhibits enhanced efficiency when applied to datasets with large time dimensions. This is primarily attributed to its inherent flexibility and its ability to operate without any underlying assumptions. Furthermore, it should be noted that the DK approach has the capability to generate estimates for both balanced and unbalanced panel datasets. This is particularly advantageous when dealing with datasets that contain missing values, as the DK approach has been shown to be more efficient in such cases (Park et al., 2018).

The Dumitrescu-Hurlin panel causality test (DH) is used in the study to examine the causal relationship between the variables. The method is specifically used for panel analysis, where the observations are

gathered from different countries over time in contrast to traditional causality models. The DH causality test helps us to determine the causal relationship and the flow of causality between two indicators. The linear functional form for the DH test is presented in equation (5):

$$y_{it} = \varphi_i T + \sum_{k=1}^{\rho} z_i^k y_{i,t-k} + \sum_{k=1}^{\rho} X_i^j T_{i,t-k} + \delta_{i,t} \quad (5)$$

Here, k indicates the lag length and the autoregressive aspect of the regressors is denoted with z (i,j).

4. Empirical Results and Discussion

The result of cross-section dependence test is reported in Table 2. The result of all the tests suggests rejecting the null hypothesis of cross-section independence. Thus, there is the existence of CSD in the data at 1% significance level. To test the stationarity of the variables, CADF and CIPS test is employed to account for the heterogeneity and CSD. The result observed from the tests indicates that all the variables are integrated of order (1) as shown in Table 3.

Table 2: Cross-sectional dependence test

Test	Statistic
Pesaran CD	10***
Bias-Corrected CD	2.73***
Weighted CD	3.19***
Weighted CD (power)	533.29***

Source: Authors' Computation; Note: *** p<0.01

To test the long-run association between the variables, the Kao test developed by Kao (1999), Pedroni test developed by Pedroni (2004), and Westerlund cointegration developed by Westerlund (2007) test is employed. The results in Table 4 indicates that unadjusted Dickey-Fuller and unadjusted modified Dickey-Fuller statistics are significant at 10 percent level while using Kao test. When using Pedroni test, modified Phillip-Perron and ADF statistics is significant. Variance ratio under Westerlund test is also significant at 10 percent level. Overall, it implies that there is a valid cointegration among the variables used in the study.

Table 3: Stationarity Test

Variable	CIPS		CADF	
	I(0)	I(1)	I(0)	I(1)
CESI	-1.690	-4.564***	-1.567	-2.374***
TR	-2.025	-4.973***	-1.874	-3.147***
IN	-2.307**	-5.230***	-1.915	-2.878***
GDP	-2.192*	-4.003***	-2.153**	-2.768***
FDI	-3.122***	-5.570***	-2.111*	-3.781***
URB	-2.654***	-2.663***	-2.057*	-2.243**
IQI	-1.736	-3.903***	-1.598	-2.417***
GI	-2.230**	-5.031***	-1.939	-3.304***

Source: Authors' Computation; Note: *** p<0.01, ** p<0.05, *p<0.10

Table 4: Cointegration Tests

Test	
Kao Test	**Statistic**
Modified Dickey-Fuller	0.968
Dickey-Fuller	1.147
Augmented Dickey-Fuller	0.651
Unadjusted Dickey-Fuller	1.353*
Un. Modified Dickey-Fuller	1.511*
Pedroni Test	
Phillips-Perron	-2.319**
Modified Phillips-Perron	3.652***
Augmented Dickey-Fuller	-1.215
Westerlund Test	
Variance ratio	-0.384*

Source: Authors' Computation; Note: *** p<0.01, ** p<0.05, *p<0.10

After testing for cointegration, the results of method of moments – quantile regression (MMQR) are shown in Table 5. The results are presented at the 25th, 50th and 75th quantiles capturing heterogeneity across countries with varied level of environmental performance. The results show the effect of trade openness on environmental sustainability (CESI). It indicates that effect of trade openness (TR) is positive and significant, implying that as countries increase trade openness, the quality of environment improves. The magnitude rises at higher quantiles indicating that countries with better environment quality benefit more from trade. Trade will facilitate technological diffusion, access to greener technology, and raise environmental regulations in emerging economies particularly in nations with institutional capabilities. It implies that when quality of institutions is improved, trade can help enhance the environment. It is also supported by our findings in Table 5 that institutional quality index (IQI) depicts statistically significant and positive association with CESI. It suggests that institutional quality matters in improving the quality of environment and sustainable development. The finding emphasizes that regardless of the current state of environmental quality, institutional strength continuously improves environmental outcomes.

Moreover, an increase in GDP would increase the quality of environment but the magnitude reduces from lower quantile to higher quantile of the distribution. The findings also indicate that innovations (IN) have negative and significant impact on environmental sustainability. It suggests that as countries innovate the quality of environment deteriorates but the magnitude reduces. Innovations are crucial for sustainable development, but it also has detrimental impact on society and environment in terms of pollution and resource consumption (Nill and Kemp, 2009; Kuzma et al., 2020). This concept is illustrated by well-known Environmental Kuznets Curve (EKC) which suggests a non-linear relationship between economic growth and environmental degradation. It suggests that pollution increases in the early stages of development and it starts declining in more advanced stages (Weber et al., 2025). Since with the increase in income households demand better quality of environment and

sustainable future. Green innovations will lead to improvement in environmental quality and make the environment sustainable. Furthermore, the impact of globalization index (GI) is significantly negative indicating that as the globalization increases, environmental quality deteriorates with increase in magnitude from lower quantiles to higher quantiles. Globalization may increase economic integration, but it can also increase resource exploitation, production pressures and environmental degradation in emerging economies that are more connected to international markets. This raises concern related to pollution haven hypothesis particularly in areas with lax environmental controls.

The effect of urbanization on CESI in positive and significant at higher quantiles. Rapid urbanization may initially pressurize resources and infrastructure. However, urbanization may encourage cleaner energy access, efficient public services, and economies of scale in pollution control in comparatively better-performing emerging economies, thus improving environment quality. Foreign direct investment has insignificant impact on CESI across all quantiles suggesting that FDI inflows are environmental neutral on average in emerging economies. It can possibly a mix of pollution intensive and cleaner investment strategies. The insignificant effect suggests FDI alone does not guarantee environmental sustainability without targeted environmental screening and regulation.

Table 5: Results of long-term coefficients (MMRQ)

Variable	.25	Std. Error	.50	Std. Error	.75	Std. Error
TR	.032*	.018	.038***	.013	.045**	.017
IN	-.023***	.005	-.022***	.003	-.021***	.005
GDP	.147***	.016	.134***	.012	.120***	.164
FDI	.00000227	.0002	.00004	.0001	.00009	.0002
URB	.007	.024	.049***	.019	.095***	.024
IQI	.141***	.037	.141***	.027	.139***	.036
GI	-.002	.058	-.077*	.043	-.160***	.056

Table 5a: Diagnostic test

Test	
Modified Wald test (Heteroskedasticity test)	2625.21***
Wooldridge test (Serial Correlation test)	95.686***
Variance Inflation Factor (Multicollinearity test)	2.47
Slope Heterogeneity	
Δ	24.725***
adj.Δ	28.834***

Source: Authors' Computation; Note: *** p<0.01, ** p<0.05, *p<0.10

4.1 Robustness Check

The robustness of the study is estimated using the Driscoll-Kraay standard error (1998) test (DKSE test). Cross-sectional dependence and serial correlation are taken into considerations within the lags selected by this method. The findings of the test are presented in Table 6 and are similar to the results of MMQR method. It is found that trade openness, institutional quality index, and GDP still have the

positive and significant effect on CESI. Additionally, innovation and globalization index negatively impact the CESI. Urbanization has positive and significant impact while FDI has insignificant impact on CESI. Thus, the findings confirm the validity of the results of the MMQR technique.

Table 6: Robustness test (Driscoll-Kraay Standard Error Test)

Variable	Statistics	Std. Error
TR	0.039*	0.019
IN	-0.022***	0.005
GDP	0.133***	0.016
FDI	0.000	0.000
URB	0.053**	0.025
IQI	0.140***	0.036
GI	-0.083**	0.032
Constant	*-0.676**	*0.389*
R-squared	*.3066*	
F-test	*54.50****	

Table 6a: Model Specification test for DKSE

Test	Statistics
F test	195.78***
BP-LM test	5101.39***
Hausman test	29.14***
Decision	Fixed Effect

Source: Authors' Computation; Note: *** p<0.01, ** p<0.05, *p<0.10

The causality analysis is shown in Table 7. The study employs Dumitrescu-Hurlin causality (2012) test. According to the results, a bidirectional causality exists between CESI and trade, innovation, GDP, urbanization and IQI. This implies that any change in one of the variables will also lead to change in the other series. Moreover, there is unidirectional causality flow from GI to CESI.

Table 7: Dumitrescu & Hurlin Granger Causality Test

Variable	Z-bar	Decision
TR	10.178*** 1.999*	CESI ↔ Trade
IN	11.754*** 5.333***	CESI ↔ IN
GDP	11.102*** 2.907**	CESI ↔ GDP
FDI	-0.831 1.521	CESI ≠ FDI
URB	11.292*** 24.008***	CESI ↔ URB
IQI	9.692*** 9.846***	CESI ↔ IQI

GI	8.870*** -.844	CESI ← GI

Source: Authors' Computation; Note: *** p<0.01, ** p<0.05, *p<0.10

5. Conclusion and Policy Implications

Economic growth is a way to achieve development, which must be socially just and environmentally sustainable. International trade is an essential component of economic development. In recent decades, emerging market economies have grown at an unbelievable rate. However, current population and economic growth trends in many of these economies have increased pressure on their environment and natural resources. The purpose of the study is to examine the impact of trade on the environmental sustainability of emerging countries over the period 1990-2023. For the measurement of environmental sustainability, existing literature does not provide any comprehensive measure. Some studies use single indicators such as CO_2 emissions; others have used composite indices such as ecological footprints and EPI in the name of environmental sustainability and thus faced criticism. Therefore, using principal component analysis, the study constructs a CESI to evaluate environmental sustainability. The study then analytically examines the impact of trade on CESI including the various variables such as institutional quality, innovations, globalization index. Towards this, the MMQR model and the Driscoll-Kraay standard errors model are employed.

The findings of the empirical analysis can be used to infer few observations. Trade openness has a positive and significant impact on environmental sustainability. It also implies that countries with better environmental conditions benefit more from trade which is complemented by the quality of institutions. Institutional quality is a crucial variable in promoting environmental quality and sustainable development. Trade openness accompanied by good institutional quality can contribute to the efficient management of the environment by fostering economic development, social welfare, and growth. More importantly, free markets can provide access to new technologies that improve the efficiency of local industrial processes by reducing the need for inputs such as energy, water, and other harmful environmental variables. Similarly, industries may be incentivized to adopt stricter environmental standards by liberalizing trade and investment. A nation's export industry is more subject to environmental regulations imposed by its leading importers as it gets more integrated into the global economy.

On the other hand, innovation and globalization have a negative impact on environmental sustainability, suggesting that, in the absence of appropriate safeguards, technological development and international integration could worsen environmental deterioration. While foreign direct investment is environmentally neutral, indicating a balance between polluting and green investments, urbanization exhibits positive benefits at higher quantiles, showing efficiency improvements and enhanced infrastructure in more developed settings.

Therefore, some policy suggestions can be recommended to emerging countries to address environmental sustainability and SDGs. Policymakers should support trade openness in addition to

bolstering institutional frameworks, especially by making green technologies more accessible and enforcing environmental laws to maximize benefits of environment. Improving institutional quality need to be given top priority as a fundamental strategy for enhancing environmental results at every level of development. By encouraging green innovation and controlling pollution-intensive industrial practices, governments should also refocus innovation strategies on eco-friendly technologies. Since emerging countries rely primarily on foreign countries to fulfil their consumption and production demands and given the detrimental effects of globalization on the environment, stricter environmental regulations and international collaboration mechanisms are necessary to reduce the hazards connected with the pollution haven hypothesis. To maximize the environmental advantages of urbanization, urban planning policies should prioritize clean energy access, sustainable infrastructure, and effective public services. Furthermore, to guarantee that foreign investments support environmental objectives rather than being neutral, FDI laws must also include sustainability standards and environmental screening. All things considered, attaining long-term environmental sustainability requires a balanced and integrated policy strategy that synchronizes trade, innovation, and globalization with robust institutional governance.

Future research can build on this work in several directions. First, pooling emerging economies into a single panel assumes a reasonable degree of similarity across them, even though these countries differ widely in their income levels, resource endowments, trade structures, and environmental regulations. Averaged results may therefore hide country-specific dynamics. Researchers could split the sample by income group, region, or level of institutional development to see whether the trade-sustainability link differs across emerging economies. Second, since innovation and globalization show negative effects, future work could examine which kinds of innovation (green versus conventional) and which dimensions of globalization (economic, political, or social) are responsible. Finally, adding variables such as renewable energy use, environmental policy stringency, or green finance, and extending the analysis to country-level or sector-level case studies, would give policymakers more targeted evidence for pursuing the SDGs.

Data availability statement: The submission includes the refined and cleaned version of the dataset along with the command/codes used for the empirical analysis.

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