Pol. J. Environ. Stud. Vol. XX, No. X (XXXX), 1–14
DOI:*10.15244/pjoes/195353* ONLINE PUBLICATION DATE:

Original research

Building a Green Future: The Impact of Global Value Chains and Economic Fitness on CO_2 Emissions in BRICS Nations

Tan Yang[1*], Yanyan Zhang[1], Haiqing Hu[1], Pomi Shahbaz[2]

[1]School of Economics and Management, Xi'an University of Technology, Xi'an, Shaanxi, 710054, China
[2]Department of Economics, Division of Management and Administrative Science, University of Education, Lahore, Pakistan

Received: 10 July 2024
Accepted: 28 October 2024

Abstract

Climate change is a major challenge hindering economic efforts to maintain a balance between economic growth and the environment. BRICS economies, a group of five emerging nations, are major emitters of CO_2 emissions that cause climate change. Their trade patterns and production structures also contribute to their CO_2 emissions. Therefore, the current study analyzed the individual and synergistic impact of gross value chains (GVCs) and economic fitness (EF) on CO_2 emissions in light of the Environmental Kuznets Curve (EKC) model. The data were cross-sectionally dependent and heterogeneous. Therefore, comprehensive econometric techniques, including panel-corrected standard error, feasible generalized least squares, and robust standard error methods, were applied to the panel of BRICS economies from 1995–2018. The findings of the study revealed i) the existence of the EKC hypothesis in BRICS economies; ii) the positive and significant individual impact of GVCs on CO_2 emissions while holding the EKC hypothesis; iii) the negative and significant individual impact of EF on CO_2 emissions; iv) the negative and significant synergistic impact of GVCs and EF (GVCs*EF) on CO_2 emissions in the presence of the EKC hypothesis. The most effective incentive policies, such as tax reductions and financial awards, encourage the local industries involved in GVCs to lower their emissions. Moreover, retrofitting the existing production infrastructure must be executed to increase the economic fitness level of economies, which lowers the positive cause of GVC emissions by fostering the adoption of clean and energy-efficient technologies.

Keywords: gross value chains, economic fitness, sustainable growth, green environment, clean energy technologies

*e-mail:yangtan0928@163.com

Introduction

Achieving sustainable development goals (SDGs) is a major concern of stakeholders worldwide. Therefore, nations are implementing effective initiatives to achieve their goals by 2030 [1]. However, the continuously changing climate significantly hinders economic efforts to maintain a balance between economic growth and the environment. For example, almost 30 gigatons of carbon are emitted into the atmosphere every year, causing climate change [2]. According to the World Meteorological Organization (WMO), a record emission of carbon will occur in 2022, despite emissions from fossil fuel consumption being reduced by 2022. BRICS is a group of five emerging economies: India, China, Brazil, South Africa, and Russia.

BRICS nations are well known worldwide because of their unique profile of abundant natural resources, high technological innovations, and low-cost labor [3]. Moreover, these nations have a major influence on the world because they collectively accommodate 3.2 billion people and primarily contribute (more than 50%) to global growth [4]. At the same time, these nations are major contributors of greenhouse gases (GHGs), as their emissions are almost 50% of the G20's emissions [2]. Moreover, the emissions of BRICS countries in terms of the percentage of GDP and emissions are almost four times greater than those of European Union and G7 countries. This observation emphasizes the dynamic relationship between economic growth and decarbonization [5]. The Earth's index for the BRICS nations collectively was -95% in 2019, which highlights a significant rise in their emission levels.

Among the BRICS nations, almost 85% of total emissions were generated only by China and India. Therefore, these nations are primarily responsible for polluting the environment [6]. Among these BRICS countries, China is the largest emitter of CO_2 after the USA. India and Russia are ranked 3rd and 4th, respectively, whereas South Africa and Brazil are ranked 13th and 14th, respectively, with almost 1% CO_2 emissions [7]. To reduce the emission level, BRICS executes emission plans, and South Africa and Brazil have promised to lower their emissions by 34 and 36–39%, respectively. Similarly, China and India also committed to reducing their emission level by 40–45% and 20–25% of the emission level of 2005, respectively. Moreover, Russia has pledged to lower emissions by 10–25% [4].

The continuous increase in GHG emissions and climate change are major problems faced by human society. However, gross value chains (GVCs) play a crucial role in various societal difficulties and environmental stressors [8]. In the 21st century, environmental safety groups worldwide have been working extensively to advocate international collaboration and design effective plans to lower emissions [9]. Therefore, economies have accelerated their emission reduction targets, and with the rise in economic globalization, global production networks around the world are integrated into the dispersion of global manufacturing systems. Developed nations have taken a crucial position in GVCs, reducing emissions by shifting their high-carbon industries to developing nations. Moreover, the nation strictly executes low-carbon import regulations, which increase barriers to value-added imports and exports. These hurdles are ongoing as the nation steadily follows low-carbon guidelines [10].

With continuously growing BRICS economies, the major concern is the environmental implications of international trade. Therefore, international trade with this group of five nations plays a crucial role in low-carbon global development. To lower the emission level, it is necessary to understand the emissions and value-added flows in trade between BRICS and non-BRICS countries, as well as among BRICS nations. This may help lower the emissions of the BRICS nations by promoting international cooperation. These countries experience unbalanced trade benefits and high emissions levels. Moreover, the downstream position of BRICS countries in GVCs incurs high environmental costs and low trade benefits [11].

With growing concerns about international trade and climate change, local and international institutions have strongly advocated environmentally oriented goods and services to lower global emissions around the world. Economies continuously adopt environment-friendly policies that promote the production of sustainable and climate-neutral goods and control unsustainable products in the market. Therefore, sustainable and environmentally friendly products are attainable through diversified production, called "diversified products", which are energy efficient and also contribute to environmental preservation [7]. Researchers have focused on the factors that affect CO_2 emissions, considering the BRICS and NON-BRICS economies. For example. Various studies have examined the impact of foreign direct investment [12], trade [13], urbanization [14, 15], and globalization [16] on CO_2 emissions in BRICS economies. Similarly, the impact of globalization [17], energy consumption [18], foreign direct investment [19], innovation [20], and ICT [21] on environmental degradation has been explored. However, international trade is currently a crucial factor that affects CO_2 emissions. As trade fosters economic growth, it also influences emissions through different channels, including technique, scale, and composition effects. These channels determine the increasing or decreasing effects of trade on CO_2 emissions [7]. In terms of analyzing the impact of trade on emissions, few studies have used trade volume (scale effect) as a proxy variable for trade [22]. Other studies have used export product diversification as a proxy variable for trade. Currently, product diversification plays a crucial role in environmental preservation and is a superior measure for export product diversification [23]. Moreover, economic fitness is superior to product diversification in economic fitness [7].

Economic fitness (EFI) describes an economy's ability to produce diversified and complex goods that compete in the global market. As the economic fitness (EF) of an economy increases, it may experience long-term economic growth and strengthen its competitive position in the global market. As BRICS economies are major emitters of GHGs, they require a transformation of production systems to produce less pollution-intensive products [24]. To reduce CO_2 emissions, EF is an important element [7].

Based on the aforementioned discussion, it is urgent to examine the current status of CO_2 emissions in BRICS economies using two crucial aspects: participation in GVCs and the EFI. Therefore, we chose the BRICS nations to analyze the individual and synergistic impact of GVCs and EFI on CO_2 emissions using the environmental Kuznets curve (EKC) hypothesis. This study contributes to the literature in many ways; for example, it examines the individual and synergistic impact of GVCs and EFI on CO_2 emissions in BRICS countries in light of the EKC. Additionally, to the best of our knowledge, the current study is the first to use GVCs and EFI simultaneously to analyze their impact on EKC trajectories in BRICS nations. Therefore, this study may provide comprehensive insights for policymakers to understand the complex dynamics of GVCs, EFI, and CO_2 emissions in the BRICS countries.

Literature Review

The emergence of multinational companies, globalization, and vertical production have transformed the nature of international trade [25], which has made the production and marketing of products more complex. This transformation has changed the global production structure and has fragmented production across different countries. This transformation generates a global commodity chain or value chain. After the rejection of neoclassical assumptions steadily led to a transformation in trade theory, researchers are considering production networks emerging around the globe in international trade [26].

In 1995, Gereffi and Korzeniewicz [27] focused on the production networks. Subsequently, studies began to extensively focus on outsourcing, vertical specialization, disintegration of products, and production fragmentation across the nation [28]. In 2005, Gereffi et al. [25] made an important contribution to the literature by developing a theoretical framework that emphasizes governing patterns in GVCs. The concept of GVCs can be traced back to 1970 when labor mobility and international production were flexible, and in the manufacturing sector, multi-stage vertical production was happening across different countries [26]. Therefore, two-thirds of world trade occurred in the form of GVCs in 2018. Emerging economies such as China and India play important roles in international trade through GVCs [29], and the participation of emerging economies in GVCs has facilitated their engagement in global trade. They experienced rapid economic growth, employment, and increasing income [30].

GVCs participation has various environmental implications in terms of CO_2 emissions and energy consumption. Chiou et al. [31] emphasize that teamwork with supply chain partners promotes the production of environmentally friendly goods. This enables firms to create strong market positions for their competitors by maintaining high-quality products. Thus, firms engaged in supply chain activities may lead to more efficient resource use, strengthening their market reputation and position. GVCs are also sources of the essential information necessary to improve the environment, especially for companies working in relational networks. These companies may gain the latest knowledge and advanced technologies through GVCs, which further helps foster their adoption of environmental practices. Thus, firms participating in GVCs share knowledge and environment-oriented practices. This approach reduces the environmental implications by fostering the implementation of sustainable practices [32]. Wang et al. [33] claimed that the participation of GVCs fostered green growth in the long run by lowering CO_2 emissions. Moreover, they find that an increase in GVC participation increases CO_2 emissions, while this decreases as GDP increases. Jouanjean et al. [34] have demonstrated that GVC participation has differentiated impacts on the environment in terms of CO_2 emissions across the different nations and sectors. Meng et al. [35] have performed only a correlation analysis between GVCs and CO_2 emissions without conducting any empirical analysis. Yao et al. [36] also supported the beneficial impact of GVCs participation on emissions. They found that countries with high GVC participation were more energy efficient and had low emissions. Wang et al. [37] used the panel of 62 countries and found the inverted U-shaped relationship between GVCs participation and per capita CO_2 emission, and they referred to this relationship between GVCs participation and CO_2 emission to the combined outcomes of four different effects, such as scale, technique spillover, competition, and composition effects.

There are extensive studies of the impact of trade on the environment, mostly focusing on the scale effect of trade. This effect has been studied using imports or exports as a proxy variable for trade, which only explains trade volume [38, 39]. On the other hand, many studies have explained the impact of trade on the environment using different indicators of trade, such as export product diversification (EPD), export product quality (EPQ), export product concentration (EPC), and import product diversification (IPD) [7]. Therefore, trade has different impacts on the environment in various ways, such as scale, technology spillover, and composition effects. Cadot et al. [40] have described the U-shaped relationship between EPD and economic development. They demonstrated that as developing nations experience economic growth, their export product basket expands until their income reaches \$22500–25000. However, developed nations concentrate on sophisticated and complex products that use low energy and contribute to environmental preservation [41]. Therefore, diversified product production helps maintain revenue, generates new skills, and fosters the adoption of new production techniques [42, 43]. Considering the environmental implications of economic activities, many studies have focused on the economic complexity index (ECI) proposed by Hidalgo and Hausmann [44]. ECI is an important element of economic growth, which is measured based on the pervasiveness and diversity of goods. It also demonstrates the capabilities of a nation's production system to produce sophisticated manufactured goods [45].

Several studies, such as those by Ikram et al. [46], Li et al. [47], and Doğan et al. [48], comprehensively explored the dynamic relationship between economic complexity and environmental degradation. Can and Gozgor [49] found that economic complexity negatively affects air pollutants in developed nations. Yilanci and Pata [50] used the Fourier ARDL method to explore the impact of economic complexity on the ecological footprint of China. They found that economic complexity positively affected CO_2 emissions. Many studies have also described an inverted U-shaped relationship between economic complexity and CO_2 emissions [51, 52]. ECO is extensively used as a proxy variable for economic activities but has been largely criticized because of its linear computation approach [53, 54]. Therefore, the EF index was proposed by Tacchella et al. [55] and is computed based on a nonlinear fixed-point iteration, which considers both the economic complexity and production capabilities of a nation.

Based on the aforementioned discussion, it is observed that BRICS nations are rapidly growing economies owing to their economic activities, and they majorly contribute to global CO_2 emissions. Therefore, understanding the impact of GVCs and EF in a single framework drives an understanding of the dynamic relationship between BRICS nations' EF, GVCs, and CO_2 emissions. Moreover, owing to the continuously changing economic and industrial structure and its impact on the production structure, trade, and adoption of technological innovations, GVCs primarily integrate the BRICS nations' trade framework. Similarly, EF describes the BRICS nations' capabilities to produce sophisticated and diverse globally competitive products, which are considered to have a positive impact on environmental preservation. Considering these points, the current study extends the literature by focusing on the individual and synergistic impacts of GVCs and EF on environmental degradation in BRICS nations, which is lacking in the existing literature.

Materials and Methods

Model Specification

Following Majeed and Mazhar [56] and Destek et al. [57], this study developed the following basic model for analyzing the EKC hypothesis in BRICS economies:

$$CO_{2,\,it} = f(GDP_{it},\, GDP^2_{it})$$

In this study, the dependent variable was CO_2 emissions. Two main variables were integrated into the model. The first is GVCs, which play a crucial role in determining a nation's environmental performance. Moreover, GVCs enhance access to advanced knowledge and technology across the borders. Therefore, according to Cai et al. [58], GVCs were used as the first main independent variable. The second EF, which determines the capabilities of a country to produce diversified and globally competitive products, is also expected to have a strong impact on the BRICS economies' CO_2 emissions along with GVCs. Thus, EF was integrated as the second-most important independent variable in the model. Additionally, gross fixed capital formation (GFCF) and renewable energy consumption (RE) are included as independent variables in the model. The inclusion of GFCF and RE along with GVCs and EF is expected to provide comprehensive insights into the EKC in the BRICS economies. Model-1 was developed to describe the theoretical model used in this study.

$$lnCO_{2\,it} = f(GDP_{it},\, GDP^2_{it},\, GVC_{it},\, EF_{it},\, GFCF_{it},\, RE_{it}) \quad \text{Model-1}$$

To eliminate heteroscedasticity and data fluctuation, variables were transformed using the natural logarithm [59]. This transformation is superior to a simple linear model specification, leading to reliable and robust estimates [60]. The model-2 depicts the transformation of variables:

$$lnCO_{2,\,it} = \alpha_{it} + \delta_1 lnGDP_{it} + \delta_2 lnGDP^2_{it} + \delta_3 lnGVC_{it} + \delta_4 lnEF_{it} + \delta_5 lnGFCF_{it} + \delta_6 lnRE_{it} + e_{it} \quad \text{Model-2}$$

where α_{it} and, δ_1, $\delta_2 \ldots \delta_7$ are unknown parameters to be estimated and e_{it} is the error term. Moreover, i depicts the cross-sectional identifier, and t represents the time period from 1995–2018. Model-2 was further decomposed into various models. Model-3 was used to confirm the existence of the EKC in light of GFCF and RE. Model-4 describes the existence of the EKC when the GVCs are added to the analysis. The inclusion of EF is presented in model-5 to analyze the existence of the EKC hypothesis in BRICS economies. Model-6 is developed to examine the EKC while adding both GVCs and EF in the same framework. Model-7 highlights the synergistic impact of GVCs and EF (GVCs×EF).

$$lnCO_{2\,it} = \alpha_{it} + \delta_1 lnGDP_{it} + \delta_2 lnGDP^2_{it} + \delta_4 lnGFCF_{it} + \delta_5 lnRE_{it} + e_{it} \quad \text{Model-3}$$

$$lnCO_{2\,it} = \alpha_{it} + \delta_1 lnGDP_{it} + \delta_2 lnGDP^2_{it} + \delta_3 lnGVC_{it} + \delta_4 lnGFCF_{it} + \delta_5 lnRE_{it} + e_{it} \quad \text{Model-4}$$

$$lnCO_{2\,it} = \alpha_{it} + \delta_1 lnGDP_{it} + \delta_2 lnGDP^2_{it} + \delta_3 lnEF_{it} + \delta_4 lnGFCF_{it} + \delta_5 lnRE_{it} + e_{it} \quad \text{Model-5}$$

$$lnCO_{2\,it} = \alpha_{it} + \delta_1 lnGDP_{it} + \delta_2 lnGDP^2_{it} + \delta_3 lnGVC_{it} + \delta_4 lnEF_{it} + \delta_5 lnGFCF_{it} + \delta_6 lnRE_{it} + e_{it} \quad \text{Model-6}$$

$$lnCO_{2\,it} = cnGDP_{it} + \delta_2 lnGDP^2_{it} + \delta_3 lnGVC_{it} + \delta_4 lnEF_{it} + \delta_5 lnGVC \times lnEF_{it} + \delta_6 lnGFCF_{it} + \delta_7 lnRE_{it} + e_{it} \quad \text{Model-7}$$

The coefficients of GDP and GDP^2 (δ_1 and δ_2) signify the nature of the relationship between economic growth

Table 1. Variable of the study and their sources.

Variables	Description	Source
GVCs	Gross value chains	Eora-MRIO
EF	Economic fitness	WDI
GDP per capita	Gross domestic product	WDI
CO2 emission	Carbon dioxide emission	WDI
GFCF	Foreign direct investment	WDI
RE	Renewable energy consumption	WDI

WDI=World Development Indicators

and CO_2 emissions, confirming the existence of the EKC in the BRICS economies. Therefore, the signs and values describe the relationship between economic growth and CO_2 emissions and confirm the existence or absence of the EKC. Therefore, if both coefficients (δ_1 and δ_2) possess zero values, indicating no relationship between the variables, this describes the relationship between the GDP and CO_2 emissions. If δ_1 is greater than 0 and significant, while δ_2 is equal to 0, it describes a significant positive relationship between GDP and CO_2 emissions, whereas the square of GDP does not have an impact on CO_2 emissions. This implies an increasing relationship between GDP and CO_2, meaning that higher GDP is associated with higher CO_2 emissions. The negative values of δ_1 and δ_2 are 0, indicating a negative impact of economic growth (GDP) on CO_2 emissions, whereas the square of GDP does not have a significant impact on CO_2 emissions. This finding emphasizes a consistent decrease in emissions as economic growth increases. If the value of is positive (>0) or negative (<0), an inverted U-shaped relationship exists between the variables. This implies that the first emission increases as the GDP increases and reaches a specific point in GDP, which turns into an inverse relationship between economic growth and emissions. However, the U-shaped relationship requires a negative value of δ_1 and a positive value of δ_2.

Data

This study used a panel of BRICS economies. Table 1 presents the data sources and their descriptions. CO_2 emissions were measured in metric tons per capita, and GDP per capita (Current US$) was used to analyze the existence of the EKC. GFCF is in current US$, and RE is the percentage of total energy consumption. Data regarding all variables were obtained from the World Development Indicators (WDI). For GVCs, we used the Eora-MRIO (Multi-Regional Input-Output) dataset.

Econometric Approach

The empirical assessment of data was conducted using descriptive analysis, including standard deviation, skewness, kurtosis, and Jarque and Bera tests. The standard deviation signifies the volatility of each variable, and skewness and kurtosis describe the distributional quality of the variables. Jarque and Bera [61] analyzed the normalcy of the variables.

The slope coefficient heterogeneity was assessed using the delta and adjusted-delta slope heterogeneity tests proposed by Pesaran and Yamagata [62].

$$\hat{\Delta} = \sqrt{N(2k)^{-1}}(N^{-1}S' - K)$$

$$Adj.\hat{\Delta} = \sqrt{N}\sqrt{\frac{T+1}{2K(T-K-1)}}\ (N^{-1}S' - 2K)$$

Before using the panel data analysis, the cross-sectional dependency (CSD) was executed. The conventional estimation methods do not assume cross-sectional dependency, which may provide inaccurate and biased results. Therefore, before estimating the long-run coefficient, the CD test proposed by Pesaran [63] was used.

$$CD = \sqrt{\frac{2T}{N(N-1)}}\ \Sigma_{i=0}^{N-1} \Sigma_{j=i+1}^{N-1} \hat{\rho}_{ij}^2$$

Where T shows the time period, N is the total number of countries and ρ_{ij} depicts the cross-sectional correlation between the residual of countries i and j.

To estimate the coefficient value, it is important to verify the stationarity of variables. The 1st generation unit root tests are inefficient because they cannot address the CSD. Therefore, 2nd generation unit root tests like the CADF and CIPS tests [64] were used to test the stationarity. The below equation presents the CADF statistics to test the stationarity.

$$\Delta Y_{it} = \alpha_i + b_i Y_{i,\,t-1} + c_i Y_{t-1} + c_i \Delta Y_t + \omega_{it}$$

where ω_{it} describes the error term and Δ shows the difference operator. Pesaran CIPS is based on the CADF, as given in the following Equation:

Table 2. Descriptive analysis.

Variables	Mean	Median	Maximum	Minimum	Standard Deviation	Skewness	Kurtosis	Jarque-Bera
$LnCO_2$	1.33	1.63	2.48	-0.27	0.88	-0.24	1.60	10.99*
Ln GDP	8.10	8.24	9.68	5.92	1.01	-0.52	2.22	8.41*
LnGVC	18.11	18.01	20.68	16.31	1.17	0.49	2.59	5.61*
LnEF	0.80	0.52	3.50	-0.72	1.07	1.20	4.18	35.98*
LnGFCF	26.13	26.28	29.41	23.62	1.34	0.41	2.88	3.42
LnRE	2.81	2.87	3.90	1.16	0.97	-0.49	-1.19	7.58*

Note: * shows significance level at 1%.

Table 3. Slope heterogeneity test.

Statistics	Test value	p-value
$\hat{\Delta}$	10.301*	0.036
Adj. $\hat{\Delta}$	12.240*	0.008

Note: * shows significance level at 1%.

Table 4. Panel unit root and cross-section dependency test.

Variables	CIPS		CADF		CD
	At level	1st difference	At level	1st difference	
$lnCO_2$	-2.306***	-2.937*	-1.670	-3.922*	11.62*
lnGDP	-2.088	-4.194*	-2.843	-4.109*	13.99*
lnGVC	-1.735	-5.259*	-2.712	-5.433*	15.42*
lnEF	-2.507*	-4.943*	-3.113**	-4.915*	-2.06**
lnGFCF	-1.565	-4.028*	-2.392	-3.976*	14.07*
lnRE	-2.055	-3.696*	-2.587	-3.537*	6.42*

Note: *, **, and *** shows significance level at 1%, 5% and 10%.

$$CIPS = \frac{1}{N} \Sigma_{i=1}^{N} CADF_i$$

After examining the integration levels of the variables, they were tested for cointegration. For this purpose, we applied Westerlund [65] panel cointegration tests. This Westerlund test includes two statistics: group (GT, Ga) and panel (Pt, Pa) statistics. Rejection of the null hypothesis demonstrates the existence of cointegration.

Panel Estimates

The panel-corrected standard error (PCSE) method was used to estimate unknown estimates. Beck and Katz [66] provide robust estimates in the presence of heteroscedasticity and contemporaneous correlation. Moreover, when T is larger than N, the estimates of the variance-covariance matrix of the error are more reliable, which endorses the application of PCSE. For the robustness check, we applied two more techniques, including feasible generalized least squares (FGLS) and Driscoll and Kraay [67] robust standard errors (DK-RSE). AS FGLS is applied when the error term is not independent across observations to measure the coefficients of the linear regression model. It counts the covariance structure of the error term and is very useful when cross-section dependency exists. In contrast, DK-RSE adjusts the standard error of the parameters and provides more robust outcomes in the presence of serial correlation and heteroskedasticity [68].

Results

Table 2 presents the descriptive analysis of the variables. The findings regarding skewness and kurtosis depict

Table 5. Westerlund cointegration test.

Models	Gt	Ga	Pt	Pa
Model-3	-3.652*	-2.536*	-2.665*	-2.356*
Model-4	-2.783*	-3.081*	-3.067*	-2.981*
Model-5	-4.072*	-5.738*	-4.701*	-3.892*
Model-6	-3.562*	-4.832*	-2.743*	-3.088*
Model-7	-2.879*	-3.283*	-4.044*	-3.806*

Note: * shows significance level at 1%.

Table 6. Exploring the existence of EKC hypothesis in BRICS economies.

	PCSE		DK-SEE		FGLS	
Model-3	Coefficient	p-values	Coefficient	p-values	Coefficient	p-values
Constant	-5.945*	0.00	-5.953*	0.00	-5.932*	0.00
GDP	2.21*	0.00	2.209*	0.00	2.23*	0.00
GDP^2	-0.12*	0.00	-0.127	0.00	-0.131*	0.00
GFCF	-0.004	0.619	-0.0048*	-0.40	-0.005	0.772
RE	-0.72	0.00	-0.726*	0.00	-0.75*	0.00
Wald chi^2/F-statistics	9170.61	0.00	2461.75	0.00	1614.08	0.00
R^2	0.93		0.93			
No. of group	5		5		5	
No. of obs.	120		120		120	

Note: * shows significance level at 1%.

the deviation from the normal distribution. The Jarque and Bera test shows that the null hypothesis is rejected, meaning that the variables are nonlinear.

Table 3 describes the findings of the slope heterogeneity test. The test values signify that both $\hat{\Delta}$ and $Adj.\hat{\Delta}$ are significant, and it demonstrates the rejection of the null hypothesis, which concludes the slope heterogeneity.

The stationarity of the variables was explored using the two-panel unit root test, including the CIP and panel CADF tests. Table 4 shows the findings of both the at-level and 1st-difference methods. The findings signify that in the 1st-difference method, the series stabilizes at the 1% significance level. This confirms that all the variables show integration at the I (1) level.

The findings of the CD test provide a p-value of less than 1%, which strongly rejects the null hypothesis of no cross-section dependency among the variables. Therefore, it signifies the alternative hypothesis, which states that cross-section dependency exists among all the variables of the study. This empirical examination shows that a change in one country has a strong effect on the other countries within the panel.

Table 5 presents the results of the Westerlund cointegration test. The findings signify significant long-run cointegration between the dependent and independent variables in all the models specified in the study.

Table 6 presents the findings of the PCSE, DK-SEE, and FGLS. All methods provide strong and robust evidence of the existing EKC in the BRICS economy panel. The coefficient of GDP per capita δ_1 is positive and significant (2.21), indicating that an increase in GDP per capita increases CO_2 emissions. The negative and significant coefficient of the GDP square δ_2 implies diminishing CO_2 emissions. The signs and significance levels of both the coefficients demonstrate the existence of the EKC hypothesis in the panel of BRICS economies. For robustness, the findings of the DK-SEE and FGLS also signify outcomes similar to those two of the PCSE estimators.

Individual and Interaction Effect of GVCs and EF in BRICS Economies through EKC Hypothesis

Table 7 shows the impact of GVCs and EF in BRICS economies through the EKC hypothesis.

Model-4: The findings of Model-4 endorse the existence of the EKC again after the integration of GVC in the model. The individual impact of GVCs (β = 0.339) on emissions

Table 7. Individual and interaction effect of GVCs and EF in BRICS economies through EKC hypothesis.

Models	PCSE	DK-SEE	FGLS
Model-4			
Constant	-3.458*	-3.458*	-3.446*
GDP	1.754*	1.748*	1.755*
GDP^2	-0.100*	-0.100*	-0.101*
GVC	0.339*	0.337*	0.332*
Control variables	Yes	Yes	Yes
Wald chi^2/F-statistics	6738.16*	1111.97*	2117.61*
R^2	0.946	0.939	
No. of group	5	5	5
No. of obs.	120	120	120
Model-5			
Constant	-0.635	-0.636	-0.633
GDP	1.813*	1.814*	1.809*
GDP^2	-0.096*	-0.095*	-0.096*
EF	-0.242*	-0.243*	-0.239*
Control variables	Yes	Yes	Yes
Wald chi^2/F-statistics	12327.63*	2725.37*	2401.43*
R^2	0.95	0.95	
No. of group	5	5	5
No. of obs.	120	120	120
Model-6			
Constant	2.019**	2.018	2.017***
GDP	1.339*	1.338*	1.337*
GDP^2	-0.068*	-0.069*	-0.068*
GVC	0.348*	0.347*	0.349*
EF	-0.247*	-0.246*	-0.25*
Control variables	Yes	Yes	Yes
Wald chi^2/F-statistics	5598.09*	3467.18*	3727.71*
R^2	0.968	0.968	
No. of group	5	5	5
No. of obs.	120	120	120
Model-7			
Constant	4.09*	4.08*	4.091*
GDP	0.87*	0.873**	0.872*
GDP^2	-0.0423**	-0.043*	-0.041*
GVC	0.288*	0.289*	0.288*

→

Models	PCSE	DK-SEE	FGLS
EF	-1.11*	-1.11*	-1.113*
GVC*EF	-0.067*	-0.068*	-0.066*
Control variables	Yes	Yes	Yes
Wald chi^2/F-statistics	6443.30*	8877.26*	4154.00*
R^2	0.97	0.97	
No. of group	5	5	5
No. of obs.	120	120	120

Note: *, **, and *** shows significance level at 1%, 5% and 10%.

in light of the EKC is positive and significant in the case of the BRICS economies. In addition, all the models provide robust evidence for the PCSE estimators. This positive impact can be explained by several factors. As the BRICS economies enter the global market through GVCs, they may increase their economic activities, leading to higher production and trade volumes. This increase in economic activity due to GVCs may consume more energy and demand more natural resources. In this way, industries expand to fulfill global demand, which may contribute to higher emissions.

Model-5: the findings of model-5 also signify the significant negative impact of EF (β = -0.242) on emissions in light of the EKC hypothesis in BRICS economies. EF depicts the BRICS economies' capability to produce diversified and globally competitive products, which enables them to experience rapid industrialization and diversification. High-EF economies may be less dependent on polluting industries and more likely to adopt energy-intensive and advanced technologies rapidly, which lowers emissions.

Model-6: The findings regarding model-6 still present a positive and significant impact of GVCs (β = 0.348) and a negative impact of EF (β = -0.247) on emissions through the lens of the EKC in BRICS economies.

Model-7: When the individual and synergistic impacts of GVCs and EF were integrated into Model-7, the findings were especially interesting. GVCs (β = 0.288) still have a positive and significant impact when the EKC hypothesis is valid, whereas EF (β = -1.11) has a negative and significant impact on emissions. The positive impact intensity of GVCs is reduced, and the negative impact of EF is increased in Model-7. Additionally, the synergistic impact of GVCs and EF (GVCs×EF) was also significant and negative. GVCs contribute positively to CO_2 emissions due to the rise in production volume and industrialization efforts, while EF may promote the adoption of cleaner and advanced technologies that generate contradictory outcomes individually. When they interact with each other, EF may counteract the emission effects of the GVCs. Their interaction effect indicates that the variables may contribute differently to emission changes, but their synergistic effect leads to unexpected negative outcomes. This may be explained by the fact that economies with high EF may implement emission reduction measures more stringently to foster efficiency and environmental practices through GVCs. This may result in a greater emission reduction impact despite the initial impact of each variable.

Discussion

In the era of ongoing globalization, emerging new economic activities in the form of changing production structures [69] and trade patterns around the world may have serious concerns regarding climate change [70]. Globally, the research community has continuously focused on climate change and trade. However, there is still potential to explore the environmental implications of modern trade patterns. Similarly, continuous innovation in the production process also matters in climate change scenarios. Therefore, economies undertake various steps toward lowering CO_2 emissions, which is a major cause of climate change. In this context, economies have changed their trade patterns and stopped producing goods at a single production site. Currently, the production of traded goods is fragmented across different locations around the world, and economies add value until the final goods are produced for further export for final consumption [30]. This is called GVCs. Along with these value-added activities, economies also have the capability to produce diversified and complex goods that can compete globally (known as EF) [71], but these capabilities vary across economies. These two broad activities describe the trade pattern and signify the production structure. Therefore, both are important for analyzing their environmental implications in the case of BRICS economies. BRICS economies are major contributors to CO_2 emissions worldwide [2], and at the same time, they also experience rapid economic growth along with high fixed capital formation and energy consumption.

The current study aimed to explore the individual and synergistic impact of GVCs and EF on CO_2 emissions through the lens of the EKC hypothesis in the BRICS economies along with GFCF and RE consumption. DK-RSE and FGLS provide robust evidence for PCSE estimators. The models have confirmed the existence of the EKC in the case of BRIC economies, which demonstrates that CO_2 emissions are increasing with the rise in economic growth (GDP per capita), and after reaching a certain level of GDP per capita, emissions start to decrease with the rise in economic growth. Our findings are in line with those of Hasan et al. [72], who investigated RE consumption, financial development, trade openness, and fossil fuel consumption. Similarly, Sarwat et al. [73] confirmed the existence of the EKC in BRICS nations while exploring the impact of RE, natural resources, and globalization on CO_2 emissions. Balsalobre-Lorente et al. [74] explored the influence of RE and economic complexity on CO_2 emissions in light of the EKC hypothesis in BRICS economies. There are also many other studies that consider different aspects of economies to analyze the existence of the EKC hypothesis in BRICS nations [6, 75, 76].

The findings of the models signify the positive and significant individual impact of GVCs on CO_2 emissions while holding the EKC hypothesis in BRICS economies. Higher GVCs foster production activities, increase the trade volume of an economy, and raise the industrial volume, which demands high energy consumption leading to high CO_2 emissions. After a certain point, an increase in GVCs and the economic growth of BRICS nations may foster the adoption of modern, clean, and energy-efficient technologies that may lower CO_2 emissions. Liu et al. [10] have analyzed the threshold effect of GVCs on CO_2 emissions in BRICS economies and also found the impact of GVC on CO_2 emissions on both the negative and positive sides. In the case of the Asia–Pacific region, Wu et al. [77] also found a positive impact of GVCs on CO_2 emissions without considering the EKC hypothesis. BRICS economies are involved in manufacturing goods in GVCs, which are highly resource intensive [78, 79]. Therefore, their huge raw material extraction and heavy industrial processes have increased CO_2 emissions in BRICS economies [80, 81]. Moreover, Dünhaupt and Herr [82] stated that most developing nations like China join GVCs and extensively export finished goods in their early stages of development, which majorly causes high CO_2 emissions. The model outcomes reveal that EF has a significant negative impact on CO_2 emissions through the EKC hypothesis in BRICS economies. This implies that a country with a high EF may have significantly lower CO_2 emissions. Economically fit nations are more likely to adopt advanced and clean technologies, invest more in R&D activities, and be more reluctant to enforce environmental regulations to reduce CO_2 emissions. The EF of the BRICS economies improves, and their level of diversified, complex, and globally competitive production increases, which enhances their economic growth. After reaching a high level of GDP per capita, BRICS economies may adopt more advanced technologies in their production process of diversified products, which further lowers their CO_2 emissions. Our findings are consistent with those reported by UL-Haq et al. [7]. They found a negative impact of EF on CO_2 emissions, while they found an N-shaped relationship between EF and CO_2 emissions in the BRICS economies. Moreover, Çınar et al. [45] found a negative relationship between EF and emissions in the USA. Moreover, our findings match those of various studies focusing on the export complexity index (ECI), which describes diversity in production and the capabilities of a nation to produce sophisticated products, and the CO_2-GDP nexus. For example, Can and Gozgor [49] found a negative impact of the ECI on CO_2 emissions while validating the EKC in France. Moreover, Neagu [51] reported that the ECI has an inverted U-shaped relationship with CO_2 emissions in six European countries.

The results regarding the interaction impact of GVCs and EF (GVCs*EF) on CO_2 emissions in BRICS economies are interesting. Although GVCs have positive individuals and EF has negative individual impacts on CO_2 emissions, the negative coefficient of GVCs*EF implies that BRICS economies with high GVCs and EF experience low CO_2 emissions. This can be explained by the various interaction factors of economies. BRICS economies with high GVC participation increase their manufacturing activities [83] and expand their industry [84] in the early stages of development (pre-turning points), which increases CO_2 emissions by consuming more energy. However, improving EF may lower the increasing effect of GVC integration in BRICS economies. After reaching a certain turning point (post-turning point), a higher EF played a crucial role in lowering CO_2 emissions. At this point, high EF, along with high economic growth, the adoption of advanced, clean, and energy-intensive technologies, and more effective environmental regulations, outweigh the emissions caused by GVC.

Conclusions

A continuously changing climate hinders the efforts of economies to maintain a balance between economic growth and the environment. Therefore, around the world, it is mainly concentrated on undertaking effective initiatives to lower emissions levels. BRICS, a group of five emerging economies, has a unique profile of natural resources and is rapidly growing, with major contributions to global CO_2 emissions. The international trade of BRICS economies also plays a crucial role in CO_2 emissions, and their participation in GVCs may play an important role in resolving various societal difficulties and environmental stressors. Moreover, with continuously rising international trade and climate change, economies have begun to prefer the production of sustainable and nature-friendly products. It is attainable only through diversified production, which is known as diversified product. In this regard, EF describes an economy's ability to produce diversified and complex globally competitive products, which may accelerate long-term economic growth with low CO_2 emissions. Therefore, the current study aims to explore the individual and synergistic impacts of GVCs and EF on CO_2 emissions in light of the EKC hypothesis in BRICS economies. The robust findings of the three econometric models reveal important findings, which may provide comprehensive insights for the policymaker to develop effective policies to foster long-term green economic growth.

The findings confirm the existence of the EKC hypothesis in the case of BRICS economies, which implies that the economies experience high CO_2 emissions with an increase in GDP per capita, and after a certain turning point, CO_2 emissions start to decline with the rise in GDP per capita. The findings reveal the positive individual impact of GVCs and the negative individual impact of EF on CO_2 emissions through the EKC. Moreover, the synergistic impact of GVCs and EF (GVCs*EF) on CO_2 emissions is negative in BRICS economies. Therefore, it is concluded that the individually high participation in GVCs of BRICS economies increases CO_2 emissions owing to the rapidly expanding economic and manufacturing activities that consume more natural resources and energy. On the other hand, the negative impact of EF on CO_2 emissions means that economically fit economies produce more diversified and sophisticated goods with low CO_2 emissions. The negative interaction impact on CO_2 emissions implies that at the early stages of development (pre-turning point), high GVCs may increase emissions for the aforementioned reason, and EF may start to mitigate some of its positive impact on CO_2 emissions. In the later stages of development (post-turning points), EF, along with high economic growth, significantly lowers the impact of GVCs on CO_2 emissions by fostering the adoption of advanced and clean technologies in production activities.

Based on these fruitful findings, the BRICS economies must focus on the most effective incentive policies that encourage the local industries involved in GVCs to lower their emission levels. This might be possible through tax reductions or financial awards for firms investing in environmentally friendly technologies. Similarly, the strict implementation of environmental regulations encourages firms to integrate sustainability criteria into their value-added chain by purchasing raw materials from authentic environmentally responsible suppliers, along with the low waste of material during the production process. Moreover, they should develop a mechanism to promote the retrofitting of the existing production infrastructure with efficient energy technologies and practices.

Conflict of Interest

The authors declare no conflict of interest.

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