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Abstract: *The environmental consequences of digital transformation have become a rising concern for developing economies pursuing rapid economic growth. This study investigates whether ICT contributes to greener GDP growth by weakening the association between growth and carbon emissions in BRICS economies. Although ICT is increasingly viewed as a driver of efficiency, productivity, and green transformation, its environmental impact remains uncertain, as digital expansion may also increase electricity demand and CO₂ emissions. Using panel data from 1990 to 2024, the study applies the Driscoll-Kraay fixed effects model to account for CSD, autocorrelation, and heteroscedasticity issues, while the PCSE is used as a robustness check. The findings reveal that EC and trade enhance carbon emissions, while REN reduces them. Most importantly, the interaction term between GDP and ICT is negative and statistically significant, indicating that ICT weakens the positive interplay between growth and Carbon emissions. This study enriches the existing literature by combining the ICT–growth nexus with the energy–growth–emissions framework in BRICS economies. The findings suggest that ICT can support greener growth when digital development is combined with REN, energy efficiency, green innovation, and sustainable trade policies.*

Introduction

Achieving GDP growth without raising Carbon emissions has become one of the important environmental challenges for emerging economies. BRICS economies occupy a central position in the global debate on whether GDP growth can be made environmentally sustainable (Su et al., 2021). Their rapid industrialization, intensifying energy demand, expanding digital infrastructure, and growing contribution to global output have heightened concern about the environmental costs of development, especially through energy-related CO₂ emissions (Maryam et al., 2017). Because BRICS economies static depend on fossil fuels, economic expansion grows to rise emissions unless technological progress, REN, and efficiency-oriented structural change weaken the relation between growth and environmental

degradation (Fu et al., 2021; Mehta & Shah, 2024). In this context, ICT is important because it can support greener growth through digitalization, dematerialization, energy efficiency, and improved access to information and financial services (Usman et al., 2020). Though, ICT may also increase electricity demand for data centers, digital devices, broadband networks, and electronic infrastructure, making its environmental effect theoretically ambiguous (Usman et al., 2020).

Previous studies have considered the relationships among ICT, REN, green technology, economic growth, EC and CO₂-emissions from various empirical perspectives. Studies show that, across BRICS, ICT reduces emissions when linked to mobile subscriptions, broadband diffusion, innovation, REN, and financial development (Huang et al., 2024; Su et al., 2021; Xing & Imran, 2025; Zafar et al., 2023). Other studies find that some ICT indicators reduce CO₂ emissions. In contrast, others, such as fixed telephone subscriptions or broadband expansion, may increase emissions depending on the energy source and technological maturity of the economy (Faisal et al., 2020; Dang et al., 2025; Appiah-Otoo et al., 2023; Ben Soltane, 2026; Alsaggaf, 2025;). Green innovation studies also suggest that environmental technologies and REN support green growth and reduce emissions (Wang et al., 2024; Jiang et al., 2022; Danish & Ulucak, 2020; Safdar et al., 2026; Sun et al., 2022; Habiba et al., 2022; Tan & Cao, 2023). Research on REN in the BRICS further shows that it can support GDP growth while lowering CO₂ emissions in the long run (Fu et al., 2021).

However, these studies have limitations because existing evidence remains mixed, fragmented, and sensitive to ICT measurement, country group, estimation technique, and the inclusion of energy variables. Some studies confirm that ICT improved environmental quality through efficiency gains and reduced physical movement (Ullah et al., 2023; Zafar et al., 2025; Usman et al., 2020), while others show that ICT increases electricity consumption and may intensify emissions when the electricity mix remains fossil-fuel dependent (Lee & Brahmasrene, 2014; Zafar et al., 2026; Su et al., 2021). Several studies also examine ICT and emissions without fully integrating the growth–energy–emissions channel, although EC is a key mechanism through which GDP growth becomes environmentally damaging (Khan et al., 2023). Moreover, ICT itself makes the growth process greener in EC and CO₂ emissions (Jiang et al., 2022; Tan & Cao, 2023).

Therefore, the central argument is that ICT can subsidize to green-growth only if its productivity and efficiency effects outweigh its direct and indirect energy demand effects (Jiang et al., 2022; Su et al., 2021). In this sense, the study does not treat ICT as inherently green; rather, it explores whether ICT helps decouple GDP growth from CO₂-emissions in states where energy demand remains high and development strategies remain closely interconnected to industrial expansion (Zafar et al., 2025; Muhammad et al., 2025). By focusing on BRICS nations, the study addresses a group of emerging economies where the policy challenge is not merely to increase output, but to transform the quality of growth through cleaner energy, digital innovation, and lower carbon intensity (Ullah et al., 2023; Zhang et al., 2022; Tang et al., 2023).

This study contributes to the literature by bringing together three connected debates that are often studied separately: the ICT-growth and energy-nexus and the green innovation–REN nexus. First, it contributes to the ICT literature by evaluating whether digitalization supports greener economic performance rather than merely higher output (Lee & Brahmasrene, 2014; Alsaggaf, 2025; Ben Soltane, 2026; Usman et al., 2020). Second, it contributes to policy debates by clarifying that ICT can support green growth when combined with REN, green innovation, and environmentally oriented financial and industrial policies (Danish & Ulucak, 2020; Zafar et al., 2023; Su et al., 2021).

Literature Review

Previous literature has examined the relationships among ICT, economic growth, EC, REN, green innovation, and CO₂ emissions from various theoretical and empirical perspectives. ICT has improved communication, reduced transaction costs, strengthened market connectivity, supported e-commerce, and increased productivity; therefore, it has often been treated as an important driver of GDP growth (Sarangi & Pradhan, 2020; Usman et al., 2020; Criveanu, 2023; Su et al., 2021). Besides, ICT infrastructure had also required electricity-consuming systems such as communication networks, servers, data centers, broadband systems, and digital devices; therefore, ICT had sometimes increased energy demand and CO₂ emissions, especially when electricity generation depended heavily on fossil fuels (Lee & Brahmasurene, 2014; Usman et al., 2020). This mixed evidence showed that ICT had not automatically made GDP growth greener; rather, its environmental impact had depended on each economy's energy structure, technological maturity, and policy environment (Katal, 2023; Criveanu, 2023; Faisal et al., 2020). Therefore, it also affects the food security (Rehman et al., 2023).

Thus, Lee and Brahmasurene (2014) studied the ICT had positively affected GDP growth but also increased CO₂ emissions (Criveanu, 2023; Sarangi & Pradhan, 2020). This result suggested that digital development had supported economic expansion but had not reduced environmental pressure. Usman et al. (2020) analysed selected South Asian economies and found that ICT had positively effect on energy efficiency. Their findings indicated that ICT had produced environmental benefits by improving productivity and reducing energy intensity (Ulucak, 2020; Usman et al., 2021; Ullah et al., 2023). Therefore, Khan et al. (2022) examined BRICS economies. They argued that ICT had supported trade, financial development, innovation, foreign investment, and energy-sector efficiency, but its ultimate environmental impact depended on how it interacted (Alsaggaf, 2025; Su et al., 2021; Jiang et al., 2022). Another strand of literature has investigated the direct relationship between ICT and CO₂ emissions (Faisal et al. (2020). Their results implied that ICT initially increased emissions and greater ICT use helped reduce pollution (Ben et al., 2024; Fatima et al., 2023). Su et al. (2021) showed that fixed-telephone and broadband subscriptions increased CO₂ emissions in BRICS economies, whereas mobile cellular subscriptions reduced emissions (Haseeb et al., 2019) It showed that different ICT indicators had produced different environmental effects. Similarly, Khan et al. (2022) found that mobile cellular and fixed broadband subscriptions reduced CO₂ emissions, whereas fixed telephone subscriptions increased them. These findings suggested that the environmental impact of ICT depended on the type of ICT infrastructure and the energy required operating it (Briglaier et al., 2023; Malmodin et al., 2014; Riaz et al., 2024; Shahid et al., 2025). The ICT and CO₂ combine significantly affect the health activities of the people particular in developing economies (Abdulwahab et al., 2026; Ahmad et al., 2026; Gul et al., 2023).

Several studies have also examined the role of EC in linking GDP growth with environmental degradation (Osuntuyi & Lean, 2023; Zhang et al., 2023; Naseem et al., 2023; Saba et al., 2024; Safdar et al., 2026; Sun et al., 2022). Maryam et al. (2017) investigated CO₂ emissions, EC, and GDP growth in BRICS economies and found that GDP growth was closely associated with rising EC and emissions. Their study highlighted that BRICS economies had relied heavily on fossil fuels, increasing the environmental cost of economic development (Sarangi & Pradhan, 2020). Fu et al. (2021) examined REN, economic growth, and CO₂ emissions in BRICS economies and found evidence of a bidirectional relationship between REN and economic growth. They also showed that REN had helped reduce CO₂ emissions in the long run (Alsaggaf, 2025; Faisal et al., 2020). These studies suggested that ICT could not be evaluated separately from the energy system, as digitalization powered by fossil fuels could increase emissions, while digitalization supported by REN could promote greener growth (Osuntuyi & Lean, 2023). Besides, in

democratic states highly focus on reduce to climate change as compare to authoritarian (Khan et al., 2023).

Thus green innovation and environmental technologies and the role of environmental technologies in BRICS economies and found that environmental-related technologies had positively contributed to green growth (Jiang et al., 2022). They also showed that REN had supported green growth, while non-REN had harmed it (Khan et al., 2016; Ahmad et al., 2024). Jiang et al. (2022) analyzed consumption-based CO₂ emissions in BRICS economies and found that environment-related technologies had reduced emissions, while coal consumption and GDP growth had increased them (Habiba et al., 2022; Hilty et al., 2009; Huang et al., 2024). Tan and Cao (2023) examined G7 and BRICS economies. They found that individual green technologies had not always produced a significant emission-reducing effect, but the interaction of different green technology indicators had helped lower CO₂ emissions. These findings showed that green innovation strengthened the possibility of greener growth when combined with technology diffusion, international cooperation, and REN development (Latif et al., 2023; Lee & Brahmasrene, 2014; Mehta & Shah, 2024; Safar et al., 2022; Khan et al., 2023). Some studies have linked ICT to trade, tourism, financial development, and broader structural transformation. Zafar et al. (2023) examined ICT had promoted environmental sustainability, while tourism, trade, and GDP growth had increased environmental pressure (Muhammad et al., 2025; Katal et al., 2023). The ICT had reduced the ecological burden of trade and tourism when integrated into these sectors. Latif et al. (2023) investigated the relationships among ICT, financial development, and ecological quality in BRICS economies and found that ICT and financial development interacted to shape environmental outcomes. Recent studies on emerging economies have provided additional evidence that ICT and green technologies have affected emissions conditionally rather than uniformly. Iqbal et al. (2024) examined green technological innovation, ICT, REN, and CO₂ emissions in emerging economies. They found that green technological innovation, REN, and structural change had reduced emissions, while GDP growth had increased them (Lee & Brahmasrene, 2014; Mehta & Shah, 2024; Muhammad et al., 2025). This showed that economic expansion remained environmentally harmful unless supported by technological improvements and policy interventions. Naseem et al. (2023) examined ICT and GDP growth in BRICS economies and found that ICT reduced CO₂ emissions, whereas GDP growth and agricultural production increased emissions. Their findings reinforced the argument that ICT had improved environmental quality by boosting efficiency and driving structural transformation (Criveanu, 2023; Katal et al., 2023; Faisal et al., 2020).

Thus, the literature showed that ICT had the potential to make GDP growth greener, but this effect had not been automatic. ICT has supported greener growth by reducing energy intensity, improving production efficiency, encouraging dematerialization, supporting the integration of REN, and complementing green innovation (Usman et al., 2020; Danish & Ulucak, 2020). However, ICT had failed to support greener growth when digital expansion increased electricity demand, relied on fossil-fuel-based energy, or accelerated production and consumption faster than efficiency gains could reduce emissions (Lee & Brahmasrene, 2014; Su et al., 2021). Therefore, previous literature justified the need for further investigation into whether ICT had made GDP growth greener in BRICS economies by jointly considering economic growth, EC, and CO₂ emissions.

Methodology

This study uses an annual balanced panel dataset for BRICS economies, including Brazil, Russia, India, China, and South Africa, over the period 1990 to 2024. The purpose of the study is to analyze whether ICT helps to make growth greener by reducing the effect of growth on Carbon emissions. The variable

descriptions, data sources, and their measurements are displayed in Table 1.

Table 1: Variable Description

Variable	symbol	Measurement	Source
CO ₂ emissions	lnCO2	“CO ₂ emissions per capita”	WDI
Economic growth	lnGDP	“GDP per capita, constant 2015 US\$”	
ICT development	lnICT	“Individuals using the Internet, % of population”	
ICT–growth interaction	lnGDP*lnICT	“author’s calculation”	
Energy Consumption	lnEC	“kg of oil equivalent per capita”	
Renewable Energy Consumption	lnREN	“% of total final EC”	
Trade openness	lnTrade	“% of GDP”	

Model Specification

The Baseline Model

$$CO2 = f(GDP, ICT, EC, REN, Trade)$$

The log-linear econometric model is specified as:

$$lnCO2_{it} = \beta_0 + \beta_1 lnGDP_{it} + \beta_2 lnICT_{it} + \beta_3 lnEC_{it} + \beta_4 lnREN_{it} + \beta_5 lnTrade_{it} + \varepsilon_{it}$$

To explore whether ICT makes GDP growth greener, the interaction term among growth and ICT is added.

$$lnCO2_{it} = \beta_0 + \beta_1 lnGDP_{it} + \beta_2 ICT_{it} + \beta_3 (lnGDP_{it} \times lnICT_{it})_{it} + \beta_4 lnEC_{it} + \beta_5 lnREN_{it} + \beta_6 lnTrade_{it} + \varepsilon_{it}$$

Where *i* denote country, *t* represents time, β represents the estimated coefficients and ε_{it} the error term.

Empirical strategies

This study follows a step-wise empirical strategy. First, CSD and SH tests are used to classify panel-data issues. Second, the 2nd-generation unit root test is used to examine the stationarity of the study variables. Based on diagnostic test results indicating the presence of CSD and heteroscedasticity, the study used the DK model for the main empirical analysis. Finally, PCSE is used to evaluate robustness and confirm the consistency of the main model. Figure 1 displays the graphical procedure of empirical strategies.

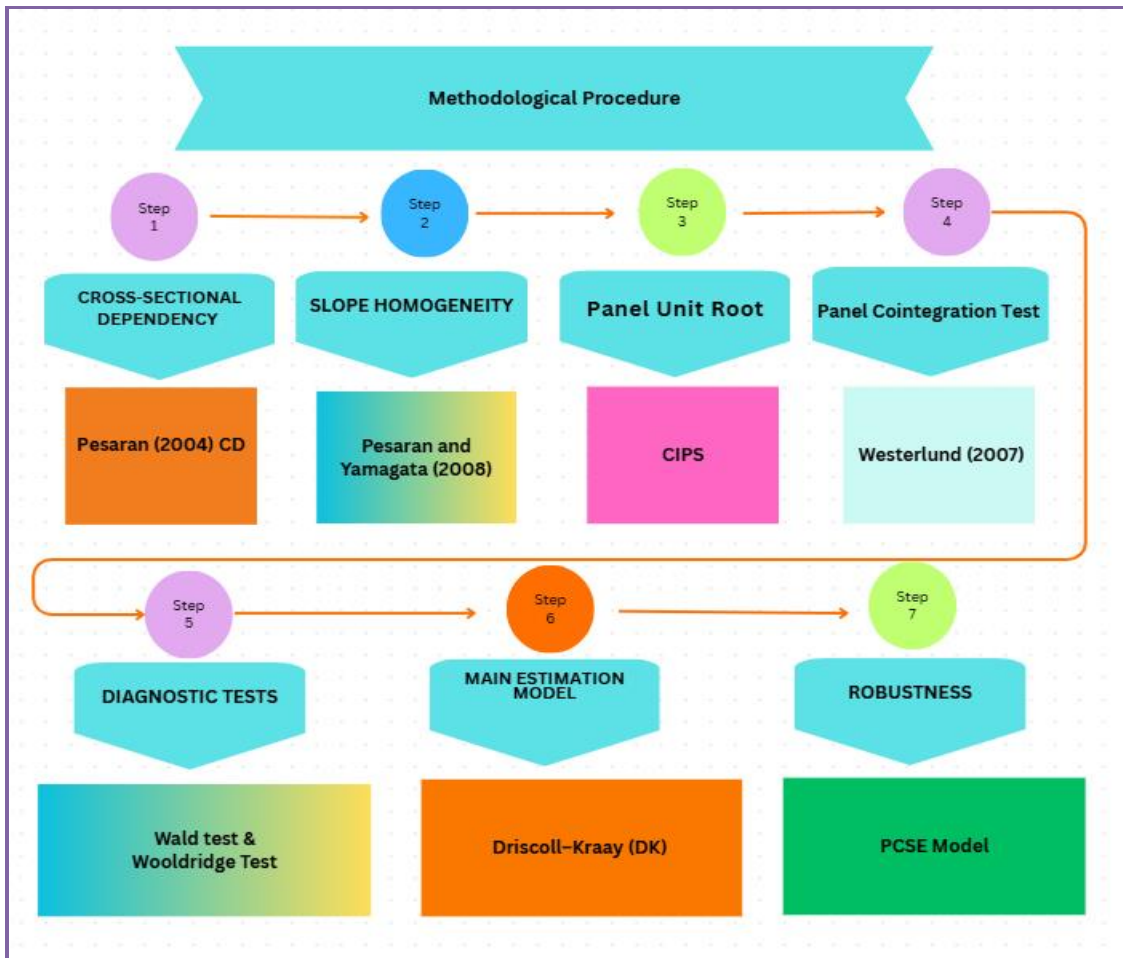


Figure 1. Step-wise Methodological Procedure

Cross-Sectional Dependence (CSD) Test

The CSD is tested using the Pesaran CS test because BRICS economies may be affected by common stocks such as technology diffusion, trade changes, energy prices.

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

H_0 : NO CSD, and H_1 : CSD Exists

Slope Heterogeneity test

The Pesaran-Yamagata test is used to check whether slope coefficient differ among BRICS economies.

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

H_0 : slope coefficients are homogeneous,
 H_1 : Slope coefficients are heterogeneous

Unit Root Test

Thus, CSD exists then used the 2nd-generation CIPS unit root test to check the stationarity.

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

H_0 : Unit Root and H_1 : Not Unit Root

Cointegration Test

The Westerlund (2007) test is used to investigate whether a long run relationship exist among the variables

$$\Delta y_{it} = a_i + \phi_i(y_{it-1} - \beta_i' x_{it-1}) + \epsilon_{it}$$

H_0 : No Cointegration and H_1 : Cointegration Exist

Driscoll-Kraay Fixed-Effects (DK-FE) Estimator

The DK-FE estimator is used as the main approach because it is robust to CSD heteroscedasticity, and autocorrelation

$$Var(\hat{\beta}_{DK}) = (X'X)^{-1} \hat{S}_{DK} (X'Y)^{-1}$$

PCSE Robustness Check

The PCSE approach is used as robustness check to confirm the consistency of the DK-findings.

$$Var(\hat{\beta}_{PCSE}) = (X'X)^{-1} X' \hat{\phi}_X (X'Y)^{-1}$$

If the interaction coefficient remains negative and significant, the main findings are considered robust.

Results and Discussion

This section reports the findings; descriptive statistics present the basic behavior of the data before the econometric analysis (Gul et al. 2023), which is presented in Table 2. The findings show that the variables exhibit sufficient variation across panels and years. ICT shows the highest variation, while trade shows the lowest. Figure 2 displays radar chart of descriptive statistic of all the study variables, presenting complete observation and variation across selected panel. The correlation matrix in Table 3 shows that all variables are positively correlated, except for REN, which shows a negative correlation, suggesting that REN is associated with lower emissions. Moreover, Table 4 reports SH test results, which indicate that both statistics are positive and statistically significant; indicating that slope Heterogeneity exists across the selected panel. Figure 3 displays the graphical representation of slope heterogeneity.

Table 2: Descriptive Statistic

Variables	Obs	Mean	SD	Min	Max
lnCO ₂	175	1.42	.905	-.365	2.801
lnGDP	175	8.345	.856	6.276	9.482
lnICT	175	2.486	1.656	0	4.598
lnEC	175	7.358	.802	5.779	8.69
lnREN	175	2.841	.968	1.163	3.97
lnTrade	175	3.649	.38	2.718	4.706

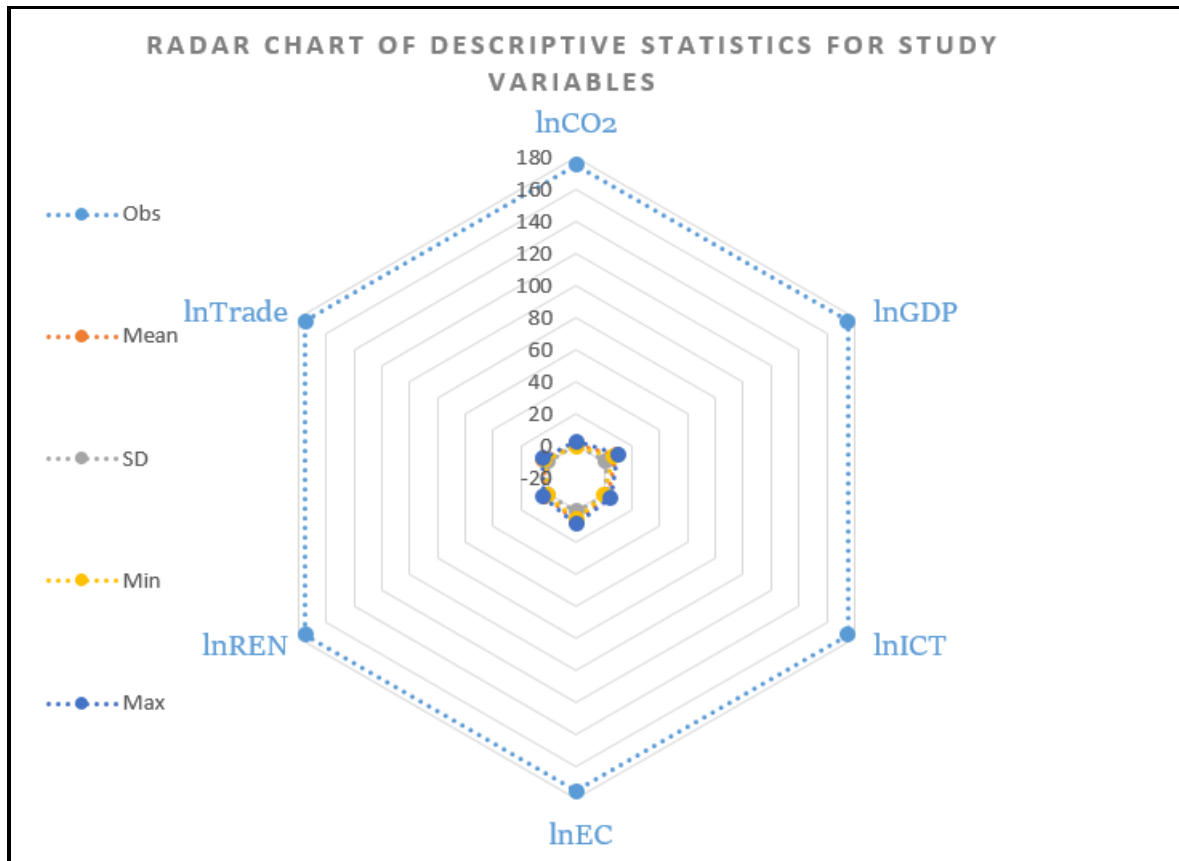


Figure 2: Radar Chart

Table 2: Matrix of Correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1)lnCO ₂	1.000					
(2) lnGDP	0.689	1.000				
(3)lnICT	0.332	0.537	1.000			
(4)lnEC	0.759	0.607	0.370	1.000		
(5)lnREN	-0.716	-0.489	-0.269	-0.684	1.000	
(6)lnTrade	0.659	0.201	0.258	0.527	-0.683	1.000

Table 3: Slope Heterogeneity (SH) Test

Test	Statistic	p-value
Delta	13.935***	0.000
Adj. Delta	15.580***	0.000

*** $p < .01$, ** $p < .05$, * $p < .1$

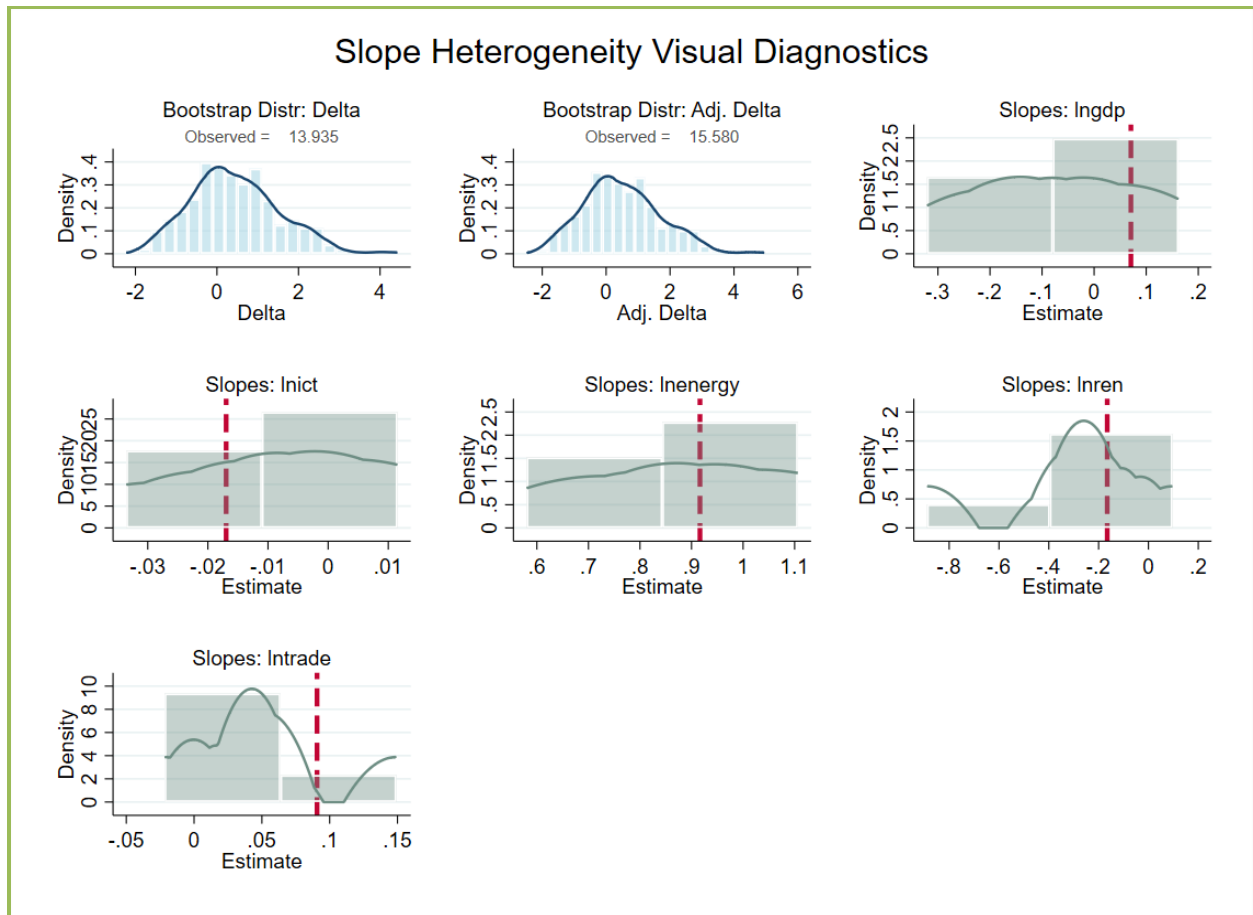


Figure 3: Slope Heterogeneity

Furthermore, Table 4 display CD test results, which indicate that all variables have significant CD statistics at the 1 percent level. This means the selected panel is interconnected, and shocks in one country may affect others. To confirm CSD using the 2nd generation CIPS test which is reported in Table 5. The results indicate that some variables are stationary at the level, while others are not, and that others are stationary after the first differencing. Therefore, the study variables exhibit mixed integration orders. Moreover, Table 6 reports the 2nd generation cointegration test results, which indicate the long-run interplay among the selected variables is justified.

Table 4: Pesaran's (CD) test of CSD

Variables	CD Statistic	p-value	Decision
lnCO ₂	5.517***	0.000	CSD Exists
lnGDP	5.869***	0.000	
lnICT	9.129***	0.000	
lnEC	5.907***	0.000	
lnREN	10.103***	0.000	
lnTrade	6.928***	0.000	

*** $p < .01$,

Table 5: Second Generation Unit Root Test

Variables	At-level	At 1st-diff	Decision
lnCO ₂	-1.801	-3.313***	Mixed Order of Integration
lnGDP	-2.652***	-3.614***	
lnICT	-0.185	-2.989***	
lnEC	-1.873	-4.340***	
lnREN	-3.011**	-4.556***	
lnTrade	-2.545***	-5.442***	
Critical value; 10% = -2.21, 5% = -2.33, 1% = -2.55.			

*** $p < .01$, ** $p < .05$,

Table 6: Cointegration Test

Statistic	value	p-value
<i>Gt</i>	-1.751	0.007***
<i>Ga</i>	-5.318	0.994
<i>Pt</i>	-3.900	0.016**
<i>Pa</i>	-5.396	0.865

The diagnostic tests for heteroscedasticity and autocorrelation are presented in Table 7. The Wald test is significant at the 1% level, and the null hypothesis is rejected, implying heteroscedasticity. The Wooldridge test is significant at the 10% level and provides weak evidence of first-order autocorrelation. The results indicate that the standard errors may be biased if the model is estimated using ordinary FE. This study uses the Driscoll–Kraay fixed-effects estimator, given the presence of CSD, heteroscedasticity, and weak autocorrelation. This estimator is appropriate for panel data with these econometric problems and yields good standard errors.

Table 7: Diagnostic Test Results

Test	Statistic	p-value	Decision
Wald Test	chi2 (5) = 49.76	0.000	Reject H0
Wooldridge Test	F= 7.064	0.0565	H0 reject at 10%

The DK-FE results are shown in Table 8, the without interaction shows that ICT has a negative effect on CO₂ emissions. The results support by Khan et al. (2022), who concluded that ICT indicators can help reduce CO₂ emissions in BRICS economies. Parallel, same results suggested that the digital economy can contribute to environmental quality by lowering CO₂ emissions in BRICS economies (Dong et al. (2025). EC has a positive and highly significant coefficient in both models. These results imply that the more energy is used, the more CO₂ is emitted in the BRICS economies. This is not surprising as BRICS economies are large emerging economies with high industrial activity and high energy demand. The results of Erkiş et al. (2025) sustained in BRICS economies. In both models, REN has a negative effect on CO₂-emissions. This indicates that REN consumption helps reduce environmental degradation (Khan et al. 2022). It is also supported by Wen, et al. (2025), who highlighted the importance of REN for reducing emissions and supporting sustainable energy policies in BRICS economies. The coefficient on trade

openness is positive and significant, indicating that greater trade openness is associated with higher CO₂ emissions. This could be because trade expansion in BRICS economies is frequently associated with industrial production, exports, transportation, and energy-intensive production. This result aligns with Saba et al. (2024), who found that trade openness can increase CO₂ emissions in BRICS economies.

The study found the key results in the interaction model. The interaction term (lnGDP × lnICT) shows a negative, statistically significant impact on carbon emissions. The results indicate that ICT development weakens the positive relationship between GDP and Carbon emissions. In other words, as ICT development advances, environmental costs decrease while GDP growth increases. Therefore, the findings support the main argument of this study, namely that ICT helps make Growth greener in the selected panel. These results align with Khan et al. (2022) and Mehta et al. (2024), who found that ICT-related interactions reduce Carbon emissions and that the digital economy enhances environmental quality.

Finally, Table 9 displays the PCSE robustness model results. The interaction term remains negative and continues to have a significant impact on carbon emissions, confirming that the main DK results are valid and reliable. Moreover, other variables, such as EC, have positive effects on carbon emissions, whereas REN has a negative effect; trade openness remains positive and has a significant impact. Therefore, the PCSE findings support the main model. Collectively, the findings indicate that ICT development plays the crucial moderating role in the growth-emissions nexus. Although EC and GDP growth can enhance environmental pressure, ICT helps to reduce the GDP growth effect on Carbon emissions. So, BRICS economies can make GDP growth greener by expanding ICT development, enhancing energy-efficient technologies, improving RNE utilization, and encouraging clean technologies in trade and production.

Table 8: Driscoll-Kraay Fixed Effect Regression Results

Variables	Model without Interaction		Model With Interaction	
	Coefficient	SE	Coefficient	SE
lnGDP	0.033	0.046	0.059	0.049
lnICT	-0.017***	0.005	0.096**	0.039
lnGDP*lnICT	-	-	-0.013***	0.005
lnEC	0.993***	0.082	0.993***	0.079
lnREN	-0.172***	0.024	-0.164***	0.023
lnTrade	0.080***	0.019	0.065***	0.008
Constant	-5.921***	0.245	-6.103***	0.254

*** $p < .01$, ** $p < .05$, * $p < .1$

Table 9: Panel Corrected Standard Error (PCSEs) Model

Robustness Model		
Variables	Coefficient	SE
lnGDP	0.055	0.045
lnICT	0.083**	0.035
lnGDP*lnICT	-0.005***	0.003
lnEC	0.689***	0.071
lnREN	-0.297***	0.044
lnTrade	0.064***	0.019
Constant	-3.517***	0.421

*** $p < .01$, ** $p < .05$, * $p < .1$

Conclusion and Policy Recommendations

This study examined whether ICT promotes greener GDP growth in BRICS economies by analyzing the relationships among ICT development, economic growth, EC, REN, trade openness, and CO₂ emissions from 1990 to 2024. The main aim of this study to test whether ICT weakened the positive interplay between GDP growth and CO₂ emissions. To achieve this objective, the study followed a stepwise empirical strategy, including SH, CSD, 2nd-generation unit root tests, 2nd-generation cointegration tests, Driscoll–Kraay fixed-effects estimation, and PCSE robustness testing. The diagnostic results confirmed that the BRICS panel suffered from cross-sectional dependence, slope heterogeneity, heteroscedasticity, and weak autocorrelation. These findings indicate that BRICS economies are interconnected through energy markets, trade flows, technology diffusion, and common global shocks. The unit root results showed mixed integration orders, while the cointegration test confirmed a long-run relationship among the variables. Therefore, the Driscoll–Kraay fixed-effects estimator is appropriate because it is robust to these panel-data problems. The empirical results showed that EC had a positive and highly significant effect on CO₂ emissions, confirming that energy use remains the major driver of environmental degradation in BRICS economies. Since these economies still rely heavily on fossil fuels and energy-intensive production, higher EC continued to raise emissions. Renewable energy had a negative and significant effect on CO₂ emissions, showing that clean EC helped reduce environmental pressure. Trade openness had a positive and significant effect on emissions, suggesting that trade expansion in BRICS economies remained linked to industrial production, transport activity, and energy-intensive exports. The important finding was the negative, significant interaction term between GDP and ICT. This result showed that ICT weakened the positive relationship between GDP growth and CO₂ emissions. Therefore, ICT development helped make GDP growth greener in BRICS economies. However, the findings also suggested that ICT should not be treated as automatically green. ICT infrastructure may increase electricity demand, but when ICT development is combined with economic activity, it can reduce carbon intensity through efficiency gains, dematerialization, smart production, digital services, and better information flows.

Based on these findings, BRICS economies should adopt a digital-green growth strategy. First, governments should expand ICT infrastructure and promote digital technologies in production, transport, trade, finance, and public services. Second, ICT expansion should be supported by REN so that data centres, broadband networks, and digital industries do not increase demand for fossil-fuel-based electricity. Third, trade policy should be aligned with environmental policy by promoting green exports, clean logistics, and low-carbon production standards. Fifth, governments should support green innovation, smart grids, digital energy management, and ICT-based clean technologies. Finally, BRICS economies should regulate the environmental footprint of ICT itself through energy-efficiency standards, e-waste management, and green data-centre policies.

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