ISSN: 2755-8339

Journal of Business Research and Reports

Research Article

Open Access

Digitalization and Environmental Sustainability: Evidence from Selected BRICS Economies

Menzi Mhlanga

Department of Economics and Business Sciences Nelson Mandela university, South Africa

ABSTRACT
Information and communication technology (ICT) has become a dominant tool for disseminating information and knowledge in the 21st century by enabling faster communication, making research easy, facilitating skill acquisition, making international collaborations much easier, and acting as a catalyst for business operations. However, the use of ICT has raised environmental concerns, due to the increased consumption of ICT. This study examined the effect of ICT on carbon emissions in selected BRICS economies between 2009 and 2022. To adopt the appropriate estimation techniques, panel unit tests (LLC and IPS) were conducted. The tests revealed a mixed sequence of integrations between the variables, i.e. I (0) and I (1). This necessitates the use of panel ARDL estimation techniques. Using the PMG (pooled mean group) estimator, the panel ARDL was selected as the appropriate model for this study. The FMOLS (fully modified ordinary least squares) and FE (Fixed effects) methods were also utilized in this study as part of the robustness assessment. The findings from the panel long-run ARDL reveal that ICT, national output, and financial development increase emissions, while innovation reduces them. Furthermore, the findings from FMOLS and FE confirm the results obtained from ARDL. Therefore, this study recommends using green technology to achieve net-zero emissions, reducing our digital carbon footprint on an individual and societal level, and scaling adaptation while reducing global emissions as a means of improving environmental sustainability within BRICS nations.

***Corresponding author**
Menzi Mhlanga, Department of Economics and Business Sciences Nelson Mandela university, South Africa.

Received: January 12, 2026; **Accepted:** January 19, 2026; **Published:** January 23, 2026

Keywords: ICT, Innovation, GDP, Financial Development and BRICS

Abbreviations
DOLS: Dynamic Ordinary Least Squares
IC Technology: Information and communication technology MG Mean Group **Estimator**
CS-ARDL: Cross-sectional Autoregressive Distributed Lag model
CH4: Methane
N2O: Nitrous oxide

Introduction
Information and communication technology (ICT) encompasses all technologies utilized to operate broadcast media, telecommunications, network-based control, and monitoring systems. ICT is pivotal in enhancing energy efficiency and productivity in the digital era. Furthermore, ICT has become a dominant tool for disseminating information and knowledge in the 21st century by enabling faster communication, making research easy, facilitating skill acquisition, making international collaborations much easier, and acting as a catalyst for business operations. However, the use of ICT has brought high environmental concerns, through increased consumption of ICT devices and infrastructure, such as the manufacturing processes involved in producing ICT equipment and data centers. Therefore, it is critical to examine the influence of ICT on CO_2 emissions in developing markets such as the BRICS nations (Brazil, Russia, India, China, and South Africa). This study enhances our understanding of how ICT influences carbon emissions in BRICS countries, identifying challenges, obstacles, and opportunities to propel these nations towards improved environmental sustainability [1-4].

Apart from commuting to curb carbon dioxide emissions to comply with the one point five degrees Celsius goal set by the Paris Agreement, the BRICS countries accounted for approximately 44% of global greenhouse gas emissions in 2021. Between 2000 and 2023, the average CO_2 emissions per capita for BRICS countries amounted to 276.20 metric tons, the highest being 1476.23, and the average energy mix (E M I X) (the ratio of renewable to non-renewable energy production) was 1.30, with the maximum ratio being 8.51. Evidence suggests that even though the relations between the BRICS countries are growing at rapid rates due to ICT, the components used within the production processes of ICT have an enormous effect on the rising CO_2 emissions. The United Nations has recognized the readiness of ICT in the BRICS nations in accordance with the Sustainable Development Gaols (SDGs); however, it has been concluded that these nations suffer from growing concerns arising from their prevailing economic growth trajectories [5-8].

BRICS nations have put strategies accompanied by their timelines and policies in place to improve IC technology and mitigate the release of greenhouse gases (GHG). This includes the net-zero GHG emissions (CH_4, N_2O, and CO_2) strategy, in which Brazil aims to accomplish net- zero emissions by 2050, Russia by 2060, India by 2070, China by 2060, and South Africa by 2050. Similarly, BRICS nations have recently agreed on specific actions to strengthen cybersecurity and promote the sharing of information to foster a more inclusive digital governance model and reduce dependence on foreign solutions. Furthermore, the nations launched the BRICS Digital Economy Partnership Framework in 2022, promoting cooperation on digital issues, such as e-commerce, data protection, and cybersecurity [9-11].

Yahyaoui emphasized that many researchers have concluded an invented U-shaped Environmental Kuznets Curve (EKC) correlation between income and specific indicators of ecological quality, which validates the assumption that national income results in high carbon in the short run and low carbon in the long run; as such there are few studies that have investigated the role of ICT on CO_2 using the ARDL model (together with the FMOLS and FE methods) and innovation, GDP, and financial development as control variables in the analysis. Therefore, this study aims to analyze the panel nexus between ICT and carbon emissions using the ARDL model together with specified robustness techniques. Thus, this study has the potential to provide recent and applicable policy recommendations to BRICS nations with the aim of fostering constructive

collaboration through ICT to reduce carbon dioxide emissions in these emerging economies. Since BRICS has recently expanded to become BRICS+, only five countries were selected for this study. Figure 1: Illustrates the Selected Countries [12].

Figure 1: Map of the Selected BRICS Countries. Source: BRICS (2018)

Literature Review

Theoretical Literature

This section provides an overview of various theories on the subject. A commonly known theory within the area is the EKC hypothesis invented by Simon Kuznets, which emphasizes that as income increases, the ecological footprint also increases to a point were growth decreases emissions. The review also includes other corresponding theories, such as the carbon curse hypothesis (2013) and theory of technology dominance (1998), to broaden our knowledge of the multifaceted correlation between the two phenomena. An empirical literature review that supports this study was conducted to obtain a more detailed understanding of the link between phenomena.

The Environmental Kuznets Curve (EKC) Hypothesis

The EKC was developed by Simon Kuznets, who initially analyzed the correlation between income inequality and national growth. Grossman and Krueger continued with Simon's findings when they assessed the correlation between national output and environmental declension, and named the association the EKC hypothesis. The EKC hypothesis claims an inverted U-shaped link between output and ecological degradation. Furthermore, the EKC emphasizes three stages of the curve: in the first stage, initially, the economy has a low ecological impact with low income per capita, eventually evolving towards increased economic performance and environmental impact; in the final stage, per capita income continues to grow while mitigating the ecological impact [13]. Within the context of this study, this theory initially asserts that BRICS nations have low economic performance, which will have less influence on the environment. However, as national growth and all its factors increase, the ecological footprint will also increase to a specific turning point, where economic growth will promote advancements in clean energy and improve environmental sustainability.

Scholars, such as Leal and Marques, opposed the EKC, noting that it does not consider other components. Scholars argue that (1) the EKC overlooks the effect of imported goods consumption on the environment by focusing only on production. Consequently, ecological improvements from technical advancements will be offset, and economic growth will impair the environment, leading to environmental degradation. By doing so, the notion goes against the change in consumer behavior that occurs with an increase in income, which is a fundamental assumption of the EKC; (2) the EKC does not consider the relocation of polluting industries and the resulting emissions that could distort the carbon dioxide emissions trajectory over the national growth path; (3) the ecological damage incurred in the first stage of the EKC might be not repairable and the growth path traced by the U-shape is not efficient. Therefore, scholars have proposed that energy transition, climate finance, and technological innovation could improve EKC assessment. That said, the EKC can be compared with carbon curse theory and the theory of technology dominance. Both theories highlight the importance of improving the technology to curb carbon dioxide emissions.

The Carbon Curse Hypothesis

Friedrichs and Inderwildi developed the carbon curse hypothesis, asserting a direct correlation between fossil fuel endowments and carbon dioxide emissions. The hypothesis is based on the resource curse, a well-known notion linking resource abundance with social, political, and economic outcomes. As such, the carbon curse hypothesis broadens this concept to include the adverse environmental effects, such as CO_2 emissions [14,15]. Moreover, posits that the carbon curse emphasizes that fossil fuel-rich countries tend to have higher carbon dioxide emissions than resource-poor nations, as economic growth, and energy production lead to heavy reliance on fossil fuel resources. Within BRICS nations, the carbon curse hypothesis states that countries with large fossil resources will depend primarily on them for most of their energy production and economic growth. The heavy reliance on these resources will lead to high emissions of greenhouse gases that degrade the environment. According to a report by Maguire, China, India, and Russia recorded a sharp increase in power emissions within the first quarter of 2024, while South Africa and Brazil had low emissions. In this regard, the hypothesis could emphasize that these countries might have large fossil fuel resources. A study by Khan et al, which further supports the carbon curse hypothesis, found that, based on data from 41 countries, carbon emissions were higher in countries that heavily relied on fossil fuels, such as coal, natural gas, and oil, than those that relied less on fossil fuels [14].

Theory of Technology Dominance (TTD)

The theory proposed Arnold and Sutton [16]. The theoretical framework aims to help us better understand the influence of technology on organizations and society. Furthermore, this notion posits that technological advancements can dominate organizational behavior, decision making, and performance [17]. Within this study, this theory emphasizes that the rising use of ICT and technological advances in BRICS nations may lead to countries being more data-driven and making decisions based on the data, even though some data may be subject to data bias and errors. In simple terms, this means that if nations are more data-driven, the actual rate of their greenhouse gas emissions might not be adequately represented. One limitation of this theory is that it does not specify how technology can shape organizations and society. Many scholars have argued that the theory should be integrated withother theories, such as resource dependence theory, to enhance our understanding of the influence of technology on organizations and society, and CO_2 emissions [16].

Empirical Literature

SU et el. examined the rates of technological innovation, technology adaptation, and CO_2 within BRICS. Their research utilized the environmental Kuznets curve to quantify nations' information and communication technology (ICT) and innovation, linking it to each country's rate of information technology adoption. Their study found that two of three technology innovation instruments, broadband subscriptions and fixed telephone, raise carbon dioxide emissions. Additionally, their study revealed that mobile cellular subscriptions lower carbon emissions in the BRICS nations. These results are particularly significant as they highlight the specific ICT components that impact carbon emissions [14,18]. examined the role of IC technology, renewable energy consumption, and innovation on carbon emissions in BRICS nations from 1990 to 2019. The research utilized panel estimation methods. The study's outcomes reveal that two IC technology indicators, mobile cell phone subscriptions, negatively impact CO_2, national output, and financial development. The results also indicate that innovation and renewable energy consumption significantly decrease the rate of CO_2 emissions in the presence of ICT indicators. At the same time, trade openness and telephone subscriptions increase the rate of CO_2 emissions. Similarly, these findings are paramount, as they specify the role of trade openness in raising emissions, while emphasizing that investing in technology innovation and renewable energy can reduce emissions. explored the implications of Internet surveillance (IS), information and communication technology (ICT), and national growth for BRICS economies between 2000 and 2019. Their study utilized dynamic optics in econometric methods (Pedroni panel cointegration and DOLS). Their research has revealed a positive link between carbon, IS, and ICT. Their findings are closely aligned with the expectations of this study, as they emphasize the long-term impact of IC technology on national growth in these nations in the long run [5]. investigated the influence of diffusion and structural change in information and communication technologies (ICT) on carbon emissions, focusing on their interactions within BRICS countries. By including estimators such as GDP and renewable and non-renewable energy, their study utilized the PMG-ARDL approach to analyze the effect of IC technology on carbon dioxide emissions within the BRICS nations between 2000 and 2021. Using the PMG (pooled mean group) estimator, their study revealed that GDP and non-renewable energy significantly increase carbon emissions, while renewable energy significantly reduces them.

Chen et al. analyzed the influence of financial development, IC technologies, and national growth on carbon emissions by simultaneously testing the EKC within the BRICS. The regression analysis confirmed that the independent variables examined varied. These findings indicate that monetary development and national output lead to CO_2 emissions. Simultaneously, ICT significantly reduces CO_2 emissions only at lower emission quantiles. Furthermore, the findings confirm the presence of the EKC hypothesis [19]. examined the correlation between information and communication technologies (ICT), environmental sustainability, national growth, trade, and tourism within BRICS economies between 1990 and 2019. Their study used CSARDL. The findings suggest an adverse effect of economic growth factors, trade, and tourism on environmental sustainability, whereas ICT promotes ecological sustainability in the economy. The findings are particularly significant, showing that, although some economic growth factors result in high carbon emissions, ICT reduces the carbon footprint. This finding is of the utmost importance, as many studies have suggested that ICT contributes to high emissions. Furthermore [20]. investigated how boosting the trade of ICT goods impacts energy transition and carbon (CO_2) emissions within the BRICS nations between 2000 and 2017. Their study utilized the DOL Sapproach to analyze the long-term role of ICT trade on the demand for renewable energy and CO_2 emissions. Their research revealed that the rising trade in ICT goods promotes the demand for renewable energy and decreases ecological pollution within the countries. Research has also noted that foreign direct investment (FDI) significantly decreases CO_2 emissions, and national growth raises the level of ecological pollution within the nations. This finding closely aligns with the study's objectives and expectations, as it proves the presence of the invented-U EKC curve between national growth and ecological degradation while highlighting the role of FDI in emissions. Similarly, Zhu, Xu, Xiqiang, Sibt-e-Ali, Waqas, Ullah and Anwar examined renewable energy consumption, IC technology, research, and development (R&D), and natural resources rent on carbon emissions between 1998 and 2021. The CS-ARDL method was used in this study. The outcomes revealed that natural resources, urbanization and national growth raise the ecological pollution, while on the other hand, digitalization, renewable energy consumption, and R&D expenditures align with ecological sustainability.

Methodology

Model Specification

The specification below was augmented, building on the works of Su et al. Khan et al. and Naseem et al. [7,18]. However, the primary model specification was adopted from Wen et al. who explored the effect of IC technology on carbon emissions in developing markets [21]. The study formally specified the model of their research as equation 1 below, based on the main goal of the investigation, which was to explore the link between IC technology and carbon emissions in developing markets:

$$ce_{it} = \theta_0 + \theta_1 ict_{it} + \theta_2 y_{it} + \theta_3 glo_{it} + \theta_4 ur_{it} + u_{it} \quad (1)$$

where $ceit$ is carbon dioxide emissions, is a proxy for ecological sustainability, and is a dependent variable for the model. $ictit$ is IC technology represented by the digitalization of the economy and is the independent variable of the model. yit is income, $gloit$ is globalization, and $urit$ is urbanization. The variables were used as control variables in the model. uit is the error term. To achieve the objectives of this study, the primary argumentative model was subject to modifications that included innovation and financial development. The new model specification excludes globalization and urbanization in the specification, as specified in Equation 2 below:

$$ce_{it} = \theta_0 + \theta_1 ict_{it} + \theta_2 ino_{it} + \theta_3 y_{it} + \theta_4 fnd_{it} + u_{it} \qquad (2)$$

where θ_0 to θ_4 are the coefficients of the estimators and u_t is the stochastic error term. ce_t is the carbon dioxide emissions at time (t) and is the dependent variable. ict_t is the information and communication technology at time (t), the primary independent variable. ino_t, y_t and fnd_t are innovation, income, and financial development at time (t) respectively. The i index represents the specific country. All variables are control variables, except for innovation, which is a mediator variable. It is thus expected that $\theta 1$,$\theta 2$ and $\theta 4 < 0$ whereas $\theta 3 > 0$.

Data Sources and Expected Priori

This study examined five BRICS nations: Brazil, Russia, India, China, and South Africa ($N = 5$). This study utilized annual cross-sectional data from 2009 to 2023. The research period is particularly important as it includes the year 2009, which marked the formation of BRICS and other historical and economic events within the nations. The data was obtained from the World Bank. The World Bank is a widely recognized, accredited, and reputable secondary source, making it suitable for this investigation. The variables used in this study include carbon dioxide emissions (ce) proxied by carbon dioxide (CO_2) emissions (total), excluding LULUCF (Mt. CO_2e).

Information and communication technology (ict) is the primary independent variable proxied by ICT goods exports (% of total goods exports). Innovation (ino) is a mediator variable proxied by R&D expenditures (% of GDP). Income (y), measured by gross domestic product, is also a control variable proxied by GDP per capita (constant 2015 US$). Finally, financial development is a control variable proxied by domestic credit to the private sector (as a percentage of GDP). Combined, these variables form the basis of the analytical framework for examining the correlation between IC technology and CO_2 within BRICS nations. Table 1 presents the variables' symbols, measurements, and data sources.

Table 1: Description of Data and Variables

Variable name	Symbol	Status	Expected priori	Measurement	Database source
Carbon dioxide emissions	ce	Dependent variable	N/A	Carbon dioxide (CO2) emissions (total) excluding LULUCF (Mt CO2e)	Worldbank
Information and communication technology	ict	Independent variable	negative	ICT goods exports (% of total goods exports)	Worldbank
Innovation	ino	Mediator variable	Negative	Research and development expenditure (% of GDP)	Worldbank
Income	y	Control variable	Positive	GDP per capita (constant 2015 US$)	Worldbank
Financial development	fnd	Control variable	Negative	Domestic credit to private sector (% of GDP	Worldbank

Estimation Techniques

The study employed two panel unit root tests to ascertain the sequence of integration among the estimators. These include the LLC and IPS tests. The study also used the PMG estimator to analyze the short and long-run correlations among the estimators. The FMOLS and FE methods were employed to assess the robustness of the selected model.

Panel Unit Root Tests and Cointegration

The study conducted the Levin, Lin & Chu (LLC) and Im, Pesaran and Shin (IPS) tests to evaluate the sequence of integration of the variables. Scholars have proposed that the LLC (2002) test is useful as it tests the null hypothesis over a homogeneous alternative to which every series in the panel is stationary with the same speed of reversion, while the Pesaran and Shin test the null hypothesis of the unit root against the alternative to which at least one series in the panel is stationary [22]. In this study, both tests were used to examine the sequence of integration within the variables, where the LLC serves as the first unit root test and the IPS as a confirmatory test. The LLC test can be expressed as the following model:

$$y_{jt} = d_{jt} + \alpha y_{j,t-1} + \sum_{i-1}^{kj} \psi ji \Delta y_{j,t-1} + u_{jt} \qquad (3)$$

Where α is obliged to be similar for each series in the panel, the null hypothesis holds that $\alpha = 1$, and the alternative hypothesis holds that $\alpha < 1$. For every series j, j = 1, … N,.$djt = \beta j' z_t$ is a set of predetermined regressors that allow for time trends and heterogeneous intercepts. The first lagged difference terms of k_j are included to report the serial correlation. The error terms are assumed to be contemporarily uncorrelated, $E(uit\ ujt) = 0$ for $i \neq$ j. Furthermore, the research utilized Pedroni cointegration and Kao tests to investigate the cointegration between IC technology and carbon emissions within the selected BRICS nations. The primary purpose of Pedroni cointegration and Kao assessments is to examine the existence of long-term correlations [23]. The Kao test serves as a confirmatory test to confirm the outcomes of the Pedroni test. The null hypothesis is that no cointegration exists. The study also utilized the ARDL model because the stationarity (mixed order of integration) of the series allowed it to be carried out. Finally, robustness tests were conducted, including FE, FMOLS, and normality tests.

Pooled Mean Group (PMG) Estimator

This study employs the PMG estimator to estimate the ARDL model. The PMG estimator allows for short-run and error variances to be determined as cross-section specific. Within the context of this study, this estimator was used to examine the short and long-term correlations between information and communication technology and carbon dioxide emissions for each country. To estimate the ARDL (p, q, q, … , q) model, the following equations were augmented, building upon the work of Pesaran, Shin, and Smith:

$$y_{it} = \sum_{j=1}^{p} \beta_{ij}\, y_{i,t-j} + \sum_{j=0}^{q} \alpha'_{ij}\, x_{i,t-j} + u_i + \varepsilon_{it,} \qquad (3.1)$$

Where x_{it} (K X 1) is the vector for the explanatory regressors for $_i$, u_i stands for the fixed effects, the coefficients of the lagged dependent parameters, β_{ij} are scalers, and α'_{ij} are K X 1 coefficient vectors. The reconfiguration of Eq. (3.1) is as follows:

$$\Delta y_{it} = \Phi_i\, y_{i,t-1} + \theta'_i\, x_{it} + \sum_{j=1}^{p-1} \beta^*_{ij}\, \Delta y_{it-j} + \sum_{j=0}^{q-1} \alpha^{*t}_{ij}\, \Delta x_{i,t-j} + u_i + \varepsilon_{it}, \qquad (3.2)$$

i = 1,2, … , N, and t = 1,2,…,T, where $\Phi_i = -(1 - \sum_{j=1}^{p} \beta_{ij}), \theta_i = \sum_{j=0}^{q} \alpha_{ij}$,

$$\beta^*_{ij} = -\sum_{m=j+1}^{p} \beta_{im}, j = 1,2, \dots, p-1, \text{ and } \alpha^*_{ij} = -\sum_{m=j+1}^{q} \alpha_{im,}\ j = 1,2, \dots, q-1 \qquad (3.3)$$

Moreover, when sequential observations are assembled for each group, Equation (3.2) is subject to the following modifications:

$$\Delta y_i = \Phi_i\, y_{i-1} + X_i\, \theta_i + \sum_{j=1}^{p-1} \beta^*_{ij}\, \Delta y_{i-j} + \sum_{j=0}^{q-1} \Delta X_{i-j}\, \alpha^*_{ij} + u_i\, l + \varepsilon_{i,} \qquad (3.4)$$

i = 1,2, … , N, where $y_i = (y_{i1}, \dots, y_{iT})'$ is a T X 1 vector of the observations on the dependent variable of the i-th group, $Xi = (x_{i1}, \dots, x_{iT})'$ which is a T X K matrix of observations on theegressors that change across groups and time intervals, $l = (1, \dots, 1)'$ which is a T X 1 vector of the ones, $yi,-j$ and $Xi,-j$ are period lagged j values of yi and $X_i, \Delta y_i = y_i - y_i, \Delta X_i = X_i - X_{I,-1}, \Delta y_i, -j$ and $\Delta X_i, -j$ are period lagged j values of Δy_i and ΔX_i, $\varepsilon_i = (\varepsilon_{i1}, \dots, \varepsilon_{iT})'$. However, the PMG was selected as a suitable estimator because it offers various advantages. This includes the assumption of long slope homogeneity, changes in short-term coefficients, and error variances [23].

Robustness Tests (Fully Modified Least Squares (FMOLS) and Fixed Effects (FE) Methods

To explore the correlation between ICT and carbon emissions, this study employs two robustness test methods to ensure the reliability and accuracy of the selected model. These include FMOLS and FE methods. As it is essential to assess the sensitivity of long-term parameters from the ARDL, the FMOLS adopts the semi-parametric approach to estimate long-run parameters, offers consistent parameters in small sample sizes, and subdues the difficulties of serial correlation, omitted variable bias, and endogeneity [24]. The FMOLS estimator is defined as follows:

$$O^\wedge FME = (\sum_{t=1}^{T} Z_t\, Z'_t)^{-1} (\sum_{t=1}^{T} Z_t\, Y^+_t - T[\frac{\lambda^{+\prime}_{12}}{0}]) \qquad (3.5)$$

According to Priyankara, the specified terms in equation (3.5) correct serial correlation and endogeneity. The FMOLS estimator has a fully efficient normal mixture asymptotic distribution and is asymptotically unbiased. Furthermore, while standardized regression models offer biased estimates of causal effects, FE methods provide unbiased estimates. Thus, the FE method is suitable for this study. The equation below depicts the error component model that the FE estimation builds upon:

$$y_{it} = x_{it}\beta + \alpha_i + \varepsilon_{it} \qquad (3.6)$$

where y_{it} is the observed outcome at time (t), x_{it} is the 1 X K vector of covariates, which is measured simultaneously. α_i and ε_{it} are error terms of the model, which are split into two components. α_i represents the unobserved effects that capture time-constant heterogeneity and ε_{it} is an idiosyncratic error term that differs across subjects and over time. In conclusion, by employing FOMLS and FE robust estimators, this study aims to obtain unbiased and reliable findings. Finally, the normality test was utilized in this study using the Jarque-Bera test. The formula for estimating Jarque-Bera is represented by Equation (3.7) below:

$$JB = \frac{n}{6}.(S^2 + \frac{(K-3)^2}{4}) \qquad (3.7)$$

where the sample skewness $S = \hat{\mu}_3 / \hat{\mu}^{3/2}_2$ is an estimator of $\beta_1 = \mu_3/\mu^{3/2}{}_2$ and the sample kurtosis $K = \hat{\mu}_4 / \hat{\mu}^2_2$ is an estimator of $\beta_2 = \mu_4/\mu^2{}_2$ μ_2 and μ_3 are the theoretical 2nd and 3rd central moments, respectively, along with their estimates.

$$\hat{\mu}_j = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^j, j = 2,3,4 \qquad (3.8)$$

According to Browman and Shenton, we can conclude from equations (3.7) and (3.8) that the JB test is a sum of squares of two asymptotically independent standardized normal variables; hence, the test is asymptotically chi-squared distributed with two degrees of freedom. This implies that $H0$ must be rejected at level α if $JB \geq X^2 1-\alpha,2$. When examining the correlation between ICT and CO_2 in BRICS nations, the null hypothesis of the Jarque-Bera test holds that residuals comply with a normal distribution.

Empirical Results

Summary Statistics

Table 2 presents a synopsis of the statistical data depicting the variables examined in this study. According to the analysis, all variables in this investigation have positive mean coefficients, which means that they exhibit upward trends over the series. The data were closely centered on the average, as seen in the deviation, which was low. All variables had positive skewness, except for income (LGDP). Finally, all the variables are leptokurtic except for LGDP, which is mesokurtic. This is seen in the kurtosis of the variables, which is less than 3 and equal to 3.

Table 2: Descriptive Statistics

	LCO2	LICT	LINO	LGDP	LFND
Mean	7.372923	0.518999	0.053640	8.671503	4.371114
Median	7.471396	0.009950	0.069908	8.989250	4.139804
Maximum	9.443166	3.389462	0.938123	9.354954	5.226860
Minimum	5.954441	-1.514128	-0.506834	7.051944	3.730468
Std. Dev.	1.203838	1.568154	0.426541	0.677160	0.474901
Skewness	0.462974	0.930030	0.515097	-1.355276	0.337885
Kurtosis	1.922887	2.443849	2.138812	3.349743	1.488899
Jarque-Bera	5.464201	10.20805	4.882975	20.22967	7.421078
Probability	0.065082	0.006072	0.087031	0.000040	0.024464
Sum	479.2400	33.73494	3.486602	563.6477	284.1224
Sum Sq. Dev	92.75043	157.3829	11.64398	29.34688	14.43397
Observations	65	65	65	65	65

Please note: Authors' Drawings. Source: Eviews 10. (*10%, **5% & ***1% significance level).

Correlation Test

Table 3 presents the results of the correlation analysis. Studies utilize the correlation analysis to explore the degree of association, multicollinearity and collinearity among variables used in a particular study; as such, a high level of multicollinearity (when the variance inflation factors (VIF)≥ 5) becomes possible when $R \geq 0.9$ or ≤ -0.9 which is considered high-level multicollinearity [25]. However, some scholars argue that, in many instances, it is safe to ignore multicollinearity when variables with high VIFs are only control variables [26]. Within the context of the correlation analysis [27]. supports this notion, as he emphasizes in his book titled "Practical Business Statistics" that multicollinearity may or may not be an issue, depending on the extent of multicollinearity and the purpose of the analysis. From the results in Table 3, the values range between 0.796118 and -0.020520. Thus, it is safe to assume that there is no multicollinearity in the variables of the study. With that being said,

Table 3: Correlation Test

	LCO2	LICT	LINO	LGDP	LFND
LCO2	1.000000	0.796118	0.692941	-0.020520	0.329182
LICT	0.796118	1.000000	0.642947	-0.007819	0.725011
LINO	0.692941	0.642947	1.000000	0.554839	0.424230
LGDP	-0.020520	-0.007819	0.554839	1.000000	0.318523
LFND	0.329182	0.424230	0.424230	0.318523	1.000000

Please note: Authors' Drawings. Source: Eviews 10. (*10%, **5% & ***1% significance level).

a strong-positive link between Carbon (La strong-positive link between Carbon (LCO_2)) and IC technology (LICT) are present, with a magnitude of 0.796118. Another strong positive correlation exists between La strong-positive link between Carbon (LCO_2) and innovation (LINO) with a magnitude of 0.692941. Furthermore, a magnitude of -0.020520 between LCO_2 and gross domestic product (LGDP) indicates a weak negative link among the variables. Finally, a positive weak link between LCO_2 and financial development (LFND) was present, with a magnitude of 0.329182.

Panel Unit Root Tests

Table 4 presents the outcomes obtained from the formal panel unit root tests. These include the LLC, and the IPS tests. All the variables [28,29].

Table 4: LLC and IPS Test

VARIABLE	Levin, Lin, and Chu		Im, Pesaran and Shin	
	Statistic	Prob.**	Statistic	Prob.**
LCO2	-3.15540	0.0008***	-2.30587	0.0106**
LICT	-1.45563	0.0727*	-1.77283	0.0381**
LINO	-2.02075	0.0217**	-1.78387	0.0372**
LGDP	-1.99846	0.0228**	-3.99561	0.0000***
LFND	-1.89145	0.0293**	-1.81276	0.0349**

Please note: Authors' Drawings. Source: Eviews 10. (*10%, **5% & ***1% significance level).

under the LLC test are stationary after the first differencing (order of integration I (1)) except for income (LGDP) and financial development (LFND), which are stationary at levels (order of integration I (0)). The IPS test confirms the same outcomes as the LLC test except that LFND is stationary at I (0) in the LLC test and at I (1) in the IPS test. Nevertheless, the derived analysis from the panel unit root tests indicated the series is a combination of both I (0) and I (1) order of integration. Therefore, it is imperative to use panel cointegration techniques.

Panel Cointegration Tests

This study the Johansen cointegration test to assess the long-term correlation between information and communication technologies and carbon dioxide emissions. The Johansen cointegration test is specifically designed for multivariate systems because of its potential to uncover cointegration [30]. Pedroni and Kao tests were adopted to assess possible long-term links. Table 5 and 6 present the test results. It is thus evident

Table 5: Cointegration Test (Pedroni's)

	Statistic	Prob.	Statistic	Prob.
LCO2	-0.423160	0.6639	-0.412862	0.6601
LICT	1.839156	0.9671	1.953149	0.9746
LINO	-2.996479	0.0014	-3.008505	0.0013***
LGDP	-0.861754	0.1944	-1.054273	0.1459
Alternative hypothesis: individual AR coefs. (Between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	2.792492	0.9974		
Group PP-Statistic	-3.782337	0.0001***		
Group ADF-Statistic	-0.623025	0.2666		

Please note: Authors' drawings. Source: Eviews 10. (*10%, **5% & ***1% significance level).

Table 6: Kao Residual Cointegration Test

	t-Statistic	Prob.
ADF	-1.616847	0.0530**

Note: Authors' Drawings. Source: Eviews 10. (*10%, **5% & ***1% significance level).

that cointegration exists among the variables. This is depicted by the p-values, which is less than the five percent level. The Kao residual cointegration test, also confirming the outcomes of Pedroni. This was observed in the probability value of 0.0530. Therefore, we can conclude that the findings from the panel cointegration tests are statistically significant, enabling us to perform long and short-run regressions.

Regression Analysis

Since the purpose of this the investigation aimed to analyze the correlation between IC technology and carbon emissions in specific BRICS economies, the study included a mediator variable and two control variables to achieve this objective. These included innovation (ino), income (y), and financial development (fnd). The various estimation techniques discussed above were applied. Finally, several symptomatic assessments were conducted to evaluate the strength of the selected model.

Table 7: Pooled Mean Group (PMG) Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LICT	0.051771	0.005573	9.289250	0.0000***
LINO	-1.750268	0.143354	-12.20940	0.0000***
LGDP	0.172508	0.067180	2.567840	0.0153**
LFND	0.404033	0.098772	4.090574	0.0003***

Note: Authors' Drawings. Source: Eviews 10. (*10%, **5% & ***1% significance level).

Long-Run Results

Because PMG raises the coherence of the outcomes when compared to MG, this study determined its estimates using the estimator after cointegration was confirmed. These findings have been discussed in the preceding sections.

Panel Long-Run ARDL Outcomes

The outcome of the long-run analysis is shown in Table 7. Nevertheless, the findings suggest that a unit increase in information and communication technology (LICT) is linked to a 0.051771 increase in carbon dioxide emissions (LCO_2). A probability of 0.0000 makes the outcome statistically significant at the 1% level. Raheem, Tiwari, and Balsalobre-Lorente supported this finding, as their study revealed that IC technology has a positive long-run influence on CO_2 emissions [31,32]. find that investing in research and development (R&D) reduces CO_2 emissions. These findings help us better comprehend the negative correlation between innovation (LINO) and CO_2, where a unit rise in innovation leads to a decline in CO_2 emissions by a magnitude of -1.750268. Moreover, a probability of 0.0000 makes the outcome statistically significant at the 1% level.

Furthermore, the analysis suggests the presence of a positive relationship between income (LGDP) and CO_2 emissions with a magnitude of 0.172508. The link between these variables suggests that a boost in national income results in a reduction in carbon emissions. These outcomes are related to the findings of Chen and Huang [33]. who reveal a positive long-run link between emissions, electric power consumption, energy use, and GDP. Khan and Ozturk explain the positive correlation between monetary expansion (LFND) and CO_2, as depicted in Table 6. These findings support the role of pollution in inhibiting financial development. Hence, in this study's long-run analysis, it can be noted that a unit increase in financial development (LFND) results in a 0.0003 increase in CO_2.

Short-Run Results

The results of the analysis and the ECM are presented in Table 8. Disequilibrium is not restored to its original state each year at a 27% speed of adjustment. This is because the t-statistic of ECM is -0.857017 (which is less than the critical value of than 2) and the probability is 0.3980 (which is above the 5% significance level), making the outcome statistically insignificant. Nevertheless, supported this study's short-run correlation between IC technology (LICT) and carbon dioxide emissions (LCO_2), as they also found a statistically insignificant link [34].

Table 8: Short-Run Results and the Error Correction Model (ECM)

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
ECM	-0.271206	0.316454	-0.857017	0.3980
D(LICT)	0.002126	0.037323	0.056956	0.9549
D(LINO)	0.386449	0.429463	0.899842	0.3751
D(LGDP)	1.106494	0.334790	3.305039	0.0024***
D(LFND)	0.015211	0.177596	0.085649	0.9323

Note: Authors' Drawings. Source: Eviews 10. (*10%, **5% & ***1% significance level).

between ICT and CO_2 emissions. Another insignificant correlation is seen between innovation (LINO) and CO_2 emissions, where the probability is which is larger than the 5% significance level. This is closely linked with the findings of Lin and Ma, who found that green technological innovation had the potential to reduce CO_2 emissions after 2010, but the effect was insignificant in Chinese cities before 2010. Moreover, a significant correlation exists between income (LGDP) and CO_2 emissions, where a unit increase in income results in an increase in carbon dioxide emissions by a magnitude of 1.106494. Given t-statistics of 3.305039 and a probability of 0.0024, the outcome is statistically significant at the 1% level. Additionally, this study obtained valuable insights from Jiang and Ma, who revealed that the monetary growth on carbon dioxide emissions effect was insignificant [35-40]. Their findings are paramount as they are closely related to the outcomes of this short-run analysis. Finally, the findings from FMOLS and FE

Table 9: Fully Modified Ordinary Least Squares (FMOLS) Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LICT	-0.054214	0.027068	-2.002868	0.0505**
LINO	-0.235577	0.124742	-1.888505	0.0647*
LGDP	0.435389	0.074721	5.826851	0.0000***
LFND	0.237677	0.117387	2.024730	0.0481**

To note: Authors' Drawings. Source: Eviews 10. (*10%, **5% & ***1% significance level).

Table 10: Fixed Effects (FE) Outcomes

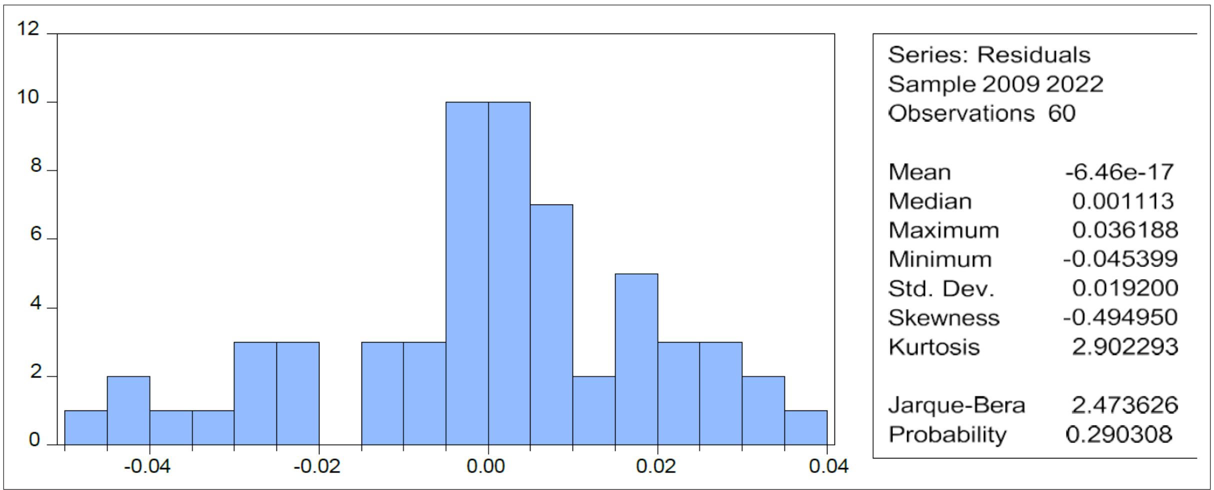
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LICT	-0.072468	0.015589	-4.648626	0.0000***
LINO	-0.185933	0.082646	-2.249758	0.0296**
LGDP	0.511239	0.053184	9.612695	0.0000***
LFND	0.210383	0.082472	2.550956	0.0144**

Note: Authors' Drawings. Source: Eviews 10. (*10%, **5% & ***1% significance level).

as shown in Tables 9 and 10 confirm the findings obtained from the panel ARDL. One notable difference is that the results obtained from FE and FMOLS reveal that both ICT and innovation have a negative influence on the release of CO_2. Khan, Weili, and Khan support this finding as they also found that ICT and innovation reduce CO_2 emissions [41-45].

Diagnostic Tests

The outcomes of the Jarque-Bera test are shown in Figure 2.



To Note: Drawing Obtained from Eviews.

Figure 2: Jarque-Bera Test

The test results were statistically significant. This is observed in the probability of 0.290308, which indicates the five percent level. The residuals are normally distributed.

Conclusion

Investigating the link between ICT and carbon dioxide emissions in selected BRICS economies was the main purpose of this research. To achieve this objective, the investigation conducted unit root tests to ascertain the unit root of the variables used in the investigation, which include ICT (primary independent variable), CO_2 emissions (dependent variable), innovation (Mediator variable), income (Control variable), and financial development (Control variable). The unit root analysis proved that the variables had a mixed order of integration (I (0) and I (1)), thus necessitating the use of panel ARDL techniques. The PMG estimator was chosen over the MG because it increased the efficiency of the parameters. The ARDL model was then conducted. The panel ARDL long-run test revealed that all variables had a positive effect on CO_2, except innovation, which had a negative effect on emissions. The findings from the short-run analysis suggested that all the variables had a positive and insignificant role in CO_2 emissions, except for income, which had a positive, significant effect within the selected BRICS nations. In addition to the panel ARDL techniques, this study also conducted several robustness tests, including the FE and FMOLS methods. Both FE and FMOLS confirmed the results obtained from the panel ARDL long-run test, except that ICT and innovation had a significantly negative influence on CO_2 emissions. Finally, a normality test was conducted. The test revealed that the residuals complied with a normal distribution [46-52].

Policy Implications and Recommendations

From the empirical findings, this investigation highlights the significant influence of ICT on CO_2 emissions within the selected BRICS nations, emphasizing the need for the selected countries to embark on a journey towards net-zero emissions by taking urgent climate action. Drawing from the findings of this study, sustainable and previously unexplored recommendations could propel the selected BRICS nations towards an improvement in environmental sustainability.

Using Technology to Achieve Net-Zero Emissions

The ARDL panel analysis shows that ICT results in an increase in CO_2. Thus, this study highly recommends that technology be used to achieve net zero emissions. This could be done by (1) utilizing IC technology instruments as substitutes to travel across all industries as a means of decreasing how much people travel within the technology sector, and (2) adopting high standards for buildings (i.e., High Passivhaus) and balancing supply and demand through the use of self- generation of energy, energy storage solutions, and smart appliances.

Reducing Our Digital Carbon Footprint

Building upon the results obtained from the long-run analysis, reducing our digital carbon footprint at the societal and individual levels is deemed imperative. This can be achieved by raising awareness about the use of ICT. As such, to decrease the carbon footprint, individuals should (1) use ICT products longer before upgrading, (2) reuse or recycle ICT equipment, (3) consume digital services on smaller devices, and (4) utilize ICT to help decrease carbon dioxide emissions.

Scaling Adaptation While Reducing Global Emissions

Businesses and companies within BRICS nations can achieve net-zero emissions at a rapid rate if they utilize digital technologies that have the potential to decarbonize firms. To achieve this, businesses must (1) invest and integrate new data frameworks through recognized strategies into their internal reporting structures. This ensures that data are shareable, assimilated, and available across value chains and with partnering entities within their operating environment. (2) Businesses must prioritize the development and inclusion of skills, and (3) businesses should foster sustainable digitalized operations within their enterprises as well as across value chains and industries.

Data Availability

Data will be made available upon request.

Statement of Conflict

There are no conflicts of interest regarding this research.

Declaration of Funding

There was no funding for this study.

References

1. UNESCO (2025) Information and communication technologies (ICT). Https://Uis.Unesco.Org/En/Glossary-Term/Information-and-Communication-Technologies-Ict.
2. Su CW, Xie Y, Shahab S, Faisal CMN, Hafeez M, et al. (2021) Towards Achieving Sustainable Development: Role of Technology Innovation, Technology Adoption and CO2 Emission for BRICS. International Journal of Environmental Research and Public Health 18: 277.
3. Onyema, Chiduzie M (2025) The role of ICT on the 21st century. Information and Communication Technology. https://slni.org/the-role-of-ict-in-the-21st-century/.
4. Kwakwa, Pual A, Adjei-Mantey K, Adusah-Poku F (2022) The effect of transport services and ICT on carbon dioxide emissions in South Africa. Environ Sci Pollut Res Int 30: 10457-104868.
5. Hasni R (2025) Structural change and CO2 emissions: Does information and communication technology matter in BRICS countries? Environmental Progress & Sustainable Energy/ Early View E14610. Doi.Org/10.1002/Ep.14610.
6. Mehta D, Shah Mohd A (2024) BRICS carbon emissions: Asymmetric Impact of energy mix, financial development, and digitalization. Sustainable Environment 10: 2418162.
7. Naseem S, Hu X, Shi J, Mohsin M, Jamil K (2023) Exploring the optical impact of information communication technology and economic growth on CO2 emission in BRICS countries. Optik https://www.sciencedirect.com/science/article/abs/pii/S0030402622015972.
8. Chien F, Anwar A, Hsu CC, Sharif A, Razzaq A, et al. (2021) The role of information and communication technology in encountering environmental degradation: Proposing an SDG framework for the BRICS countries. Technology in Society 65: 101587.
9. Owojori OM, Anwana E (2025) Climate governance in the BRICS: pathways toward netzero emissions. Discover Sustainability 6: 359.
10. Molina L (2025) BRICS strengthens cooperation on security. BRICS Brazil 2025. Brics.Br/En/News/Brics-Strengthens-Cooperation-on-Cybersecurity Accessed: 05 May 2025.
11. Ayodele O, Petla V (2024) Leveraging the BRICS Digital partnership for collaborative digital Governance. Journal for BRICS Studies 3: 2-7.
12. Yahyaoui I (2024) Does the Interaction Between ICT Diffusion and Economic Growth Reduce CO2 Emissions? An ARDL Approach. Journal of the Knowledge Economy 15: 661-681.
13. Wagner M, Boons F (2009) Assessing the relationship between economic growth and ecological performance: Distinguishing system levels and the role of innovation: Ecological Economics 68: 1908-1914.
14. Khan K, Zhang J, Gul F, Li T (2022) The carbon curse Understanding the relationship between resource abundance and emissions. The Extractive Industries and Society 11: 101119.
15. Tee Jia H (2025) hinrich foundation. Carbon dioxide emissions: A resource wealth paradox. Hinrichfoundation https://www.hinrichfoundation.com/research/infographics/carbon-dioxide-emissions.
16. Hampton C (2005) Determinants of reliance: An empirical test of the theory of technology dominance. International Journal of Accounting Information Systems 6: 217-240.
17. Theory Hub (2025) Theory of technology Dominance. https://open.ncl.ac.uk/academic-theories/13/theory-of-technology-dominance/.
18. Zafar Syed Z, Zhilin Q, Mabrouk F, Ramirez-Asis E, Alzoubi Haitham M, et.al. (2022) Empirical linkages between ICT, tourism, and trade towards sustainable environment: Evidence from BRICS countries. Economic Research Ekonomska Istrazivanya 36: 2-23
19. Yakubu I N, Kapusuzoglu A, Ceylan NB (2022) ICT Trade and Energy Transition in the BRICS Economies. In H. Dinçer & S. Yüksel (Eds.), Sustainability in Energy Business and Finance: Approaches and Developments in the Energy Market 13-24.
20. Wen J, Khalid S, Mahmood H, Alam K, Zakaria M (2025) Examining the Influence of ICT on Carbon Emissions in

Emerging Economies. Structural Change and Economic Dynamics 74 353-360.

21. Lopez C (2003) Panel Unit Root Tests with GLS-Detrending with an Application to Purchasing Power Parity. University of Cincinnati. Https://Uh.Edu/~cmlopez2/Th3_8_10_03.Pdf.
22. Qoko A, Sibanda K, Senzangakhona P (2024) Health capital and economic performance in selected SouthernAfrican development Community (SADC) countries. GENERAL & APPLIED ECONOMICS 12: 1-17.
23. Priyankara E (2018) The Long-run Effect of Services Exports on Total Factor Productivity Growth in Sri Lanka: Based on ARDL, FMOLS, CCR, and DOLS Approaches. International Journal of Academic Research in Business and Social Sciences 8: 240-258.
24. Senthilnathan S (2019) Usefulness of Correlation Analysis. SSRN Electronic Journal https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3416918.
25. Allison P (2012) When Can You Safely Ignore Multicollinearity? Https://Statisticalhorizons.Com/Multicollinearity/.
26. In A. F. Siegel (Ed.) (2012) Appendix D - Statistical Tables. Practical Business Statistics https://doi.org/10.1016/B978-0-12-385208-3.00032-8.
27. Levin A, Lin CF, Chu CSJ (2002) Unit root tests in panel data: asymptotic and finite- sample properties. Journal of Econometrics 108: 1-24.
28. Im KS, Pesaran MH, Shin Y (2003) Testing for unit roots in heterogeneous panels. Journal of Econometrics 115: 53-74.
29. Poh CW, Tan R (1997) Performance of Johansen's Cointegration Test. In East Asian Economic Issues 402414.
30. Raheem ID, Tiwari AK, Balsalobre-Lorente D (2020) The role of ICT and financial development in CO2 emissions and economic growth. Environmental Science and Pollution Research 27: 1912-1922.
31. Fernández Y, Fernández López MA, Olmedillas Blanco B (2018) Innovation for sustainability: The impact of R&D spending on CO2 emissions. Journal of Cleaner Production 172: 3459-3467.
32. Chen JH, Huang YF (2013) The Study of the Relationship between Carbon Dioxide (CO2) Emission and Economic Growth. Ournal of International and Global Economic Studies 6: 45-61.
33. Appiah-Otoo I, Acheampong AO, Song N, Chen X (2023) The impact of information and communication technology (ICT) on carbon dioxide emissions: Evidence from heterogeneous ICT countries. Energy & Environment 34: 3080-3102.
34. Danya D, Tranfield D (2009) Producing a systematic review. In D. A. Buchanan & A. Bryman (Eds.), Sage handbook of organizational research methods 671-689.
35. Dong R, Song J, Jiang T, Baloch MA (2025) Environmental Sustainability across BRICS Economies: The Dynamics among the Digital Economy, Education, and CO2 Emissions. Journal of the Knowledge Economy 16: 4125-4145.
36. Hipolito P, Marques, Antonio C (2025) The evolution of the environmental Kuznets curve hypothesis assessment: National. National Centre for Biotechnology 8: 11521.
37. Manual A (2019) Index. In B. Özcan & I. Öztürk (Eds.), Environmental Kuznets Curve (EKC) 145-149.
38. Nnaji Kennady K, Ogboghro Vincent I (2024) Finance, economic growth, ICT, renewable energy and environmental Quality in BRICS and non-BRICS emerging Markets. Research Square https://Doi.Org/10.21203/Rs.3.Rs-4489702/V1.
39. Saba CS, Djemo CRT, Ngepah N (2024) The crucial roles of ICT, renewable energy sources, industrialization, and institutional quality in achieving environmental sustainability in BRICS. Environmental Science and Pollution Research 31: 35083-35114.
40. Sahoo M, Bhujabal P, Islam MK (2024) Empowering BRICS economies: The crucial role of green finance, information and communication technology and innovation in sustainable development. Sustainable Development 36: 7292-7308.
41. Su CW, Xie Y, Shahab S, Faisal Muhammad N, Hafeez M, et al. (2021) Towards achieving sustainable development: Role of technology innovation, technology adaptation and CO2 emissions for BRICS. Int. J. Environ.Res.Public Health 18: 277.
42. Sun Y, Ajaz T, Razzaq A (2022) How infrastructure development and technical efficiency change caused resources consumption in BRICS countries: Analysis based on energy, transport, ICT, and financial infrastructure indices. Resources Policy 79: 102942.
43. Tranfield D, Denyer D, Smart P (2003) Towards a methodology for developing evidence- informed management knowledge by means of systematic review. Supply Chain Manag Int 14: 207-222.
44. UNESCO (2009) Guide to measuring information and communication technologies (ICTs) in education https://unesdoc.unesco.org/ark:/48223/pf0000186547.
45. Wilding R, Wagner B (2012) Supply chain risk management: a new methodology for a systematic literature review. Supply Chain Manag Int.J 17: 403-418.
46. Bowman KO, Shenton LR (1975) Omnibus test contours for departures from normality based on√ b 1 and b 2. Biometrika 62: 243-250.
47. BRICS (2018) What is BRICS? Https://Www.Brics2018.Org.Za/.
48. ERICSSON (2025) A quick guide to your digital carbon footprint. Https://Www.Ericsson.Com/En/Reports-and-Papers/Industrylab/Reports/a-Quick-Guide-to-Your- Digital-Carbon-Footprint.
49. Kılıç E, Kutlu E (2017) What is Pooled Mean Group (PMG). In Handbook of Research on Unemployment and Labor Market Sustainability in the Era of Globalization https://labordoc.ilo.org/discovery/fulldisplay/alma994965886302676/41ILO_INST:41ILO_V1.
50. Lin B, Ma R (2022) Green technology innovations, urban innovation environment and CO2 emission reduction in China: Fresh evidence from a partially linear functional-coefficient panel model. Technological Forecasting and Social Change 176: 121434.
51. Pesaran Hashem M Shin Y, Smith Ron P (2004) Pooled Mean Group Estimation of Dynamic Heterogenous Panels. Journal of the American Statistical Association 94: 2-6.
52. YetaM (2019) How to reduce your digital carbon footprint. Https://Sustainableict.Blog.Gov.Uk/2019/10/14/How-to-Reduce-Your-Digital-Carbon-Footprint/.