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Empirical linkages between ICT, tourism, and trade towards sustainable environment: evidence from BRICS countries

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ABSTRACT

There is a growing utilisation of information and communication technologies (ICT) in the recent digital era. Trade and tourism have also attained attention as determinants of environmental sustainability. Therefore, this study investigates linkages between ICT, tourism, trade, economic growth, and environmental sustainability in BRICS economies. Advanced panel estimation entitled cross-sectionally augmented autoregressive distributed lags (CS-ARDL) was applied from 1990 to 2019. Findings suggest the adverse effect of tourism, trade, and growth factors on environmental sustainability, whereas ICT helps promote a sustainable environment among the targeted economies. Likewise, the short-run results prove that economic growth and tourism are prone to ecological health, while trade possesses an insignificant influence on ecological sustainability. These results suggest the integration of ICT in trade and tourism sectors to mitigate their negative ecological consequences.

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1. Introduction

Information and communication technologies (ICT) sector has been on the rise with innovative extensions and up-gradation to improve the mode of life. ICT implementation has been an important factor in societal development over the past few decades (Faisal et al., 2020). Each country focuses on improving the ICT industry to keep pace with today's digital world, reducing regional boundaries, enhancing communication, easing business procedures, and improving economic growth in all sectors.

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Implementation of ICT provides several opportunities to developing and emerging economies for liable resources and knowledge management. This way, countries can interact with other world economies for improved business strategies and fruitful competition (Chen & Zhu, 2004). The ever-increasing importance of ICT has been developing globalisation, economic growth, and environmental quality (Khan et al., 2018). Emerging economies have been focussing on implementing ICTs to improve economic development and foreign direct investment (FDI) that mainly rely on ICT in this modern era of innovative technology. ICT is associated with several factors, including trade openness, economic development, technological innovation, energy utilisation, and foreign direct investment. However, all the given factors of ICT also impact the environmental quality. Industrialisation growth is also an important factor brought by ICT innovation, which enhances energy utilisation and thus impacts environmental quality. The level of environmental pollution increases with an increase in industrialisation that significantly impacts public health. ICT innovation has been stated as an essential factor in boosting economic growth in all sectors of developing and emerging nations. Effective implementation of ICT has set the foundation for emerging economies by enhancing global connectivity and utilising resources efficiently. Implementing ICTs also increases the competition in technology and innovation among countries striving to bring sustainable development (Sinha et al., 2020).

Since industrialisation, BRICS economies have been rapidly growing in products and services exports. BRICS countries have been providing knowledge- and ICT-based services to improve industrial production other than the traditional services and products. China, India, and Russia, among BRICS economies, have gained a 15% economic growth rate during the pre-crisis era; meanwhile, the world average growth rate has been 9% (Biryukova & Matiukhina, 2019). In addition, trade openness has not been undertaken in terms of product development by BRICS countries. In contrast, services exports have seen massive development in BRICS economies, contributing to internal and external trade structural development. Implementation of ICT directly impacts the economic sector through the penetration of information technology in remote areas. Increased investment in the ICT sector generates new job openings and enhances the social standards of life.

Along with the economic development, the tourism industry is also responsible in terms of higher energy demand in different tourism activities, including transport (75%), lodging (20%), and other services (5%) (Lemelin et al., 2010). This energy is generated through fossil fuel consumption or directly from electricity generation (Baloch et al., 2022; Chien et al., 2021; Gössling, 2013; Nawaz et al., 2021; Tsai et al., 2014). The tourism sector can also impact environmental production based on the energy production source, including renewable or non-renewable energy. Lin (2017) stated that different modes of transportation in the tourism industry directly impact the carbon emission level. Moreover, electricity consumption in hotel facilities is also accountable for direct or indirect over-utilisation of energy. These aspects pose serious implications for sustainable environmental development (Omran & Kamran, 2018; Ozturk et al., 2016). In the previous four decades, tourism has had a profoundly positive impact on global economic growth. This industry has emerged as a key driver of economic development for developing and developed countries. The tourism sector ranks 3rd for export income after the chemical and automation sector (Ullah et al., 2022). Considering these undesirable impacts on the tourism sector require the implementation of necessary policies by developed and developing countries to eliminate the adverse effects of tourism. Only a few research studies presently explore the correlation between the environment and tourism and their environmental impacts (Dogan & Turkekul, 2016).

According to Future market insights 2020, BRICS (Brazil, Russia, India, China, and South Africa) are the five progressively developing nations (Chien et al., 2021; Davis et al., 2018; Razzaq et al., 2021). These economies present a positive outlook of economic development and contain a huge potential for tourism development by providing more attractive opportunities to tourists in both outbound and inbound tourism. Moreover, the BRICS economies are also developing ICT-based economic activities to surge Gross Domestic Product to 37.7% by 2030. This economic value is more than the combined GNP of both US (15%) and Europe (15.3%) (World Bank 17). Tourism expansion also affects environmental quality other than the economic development of BRICS economies, which cannot be neglected (Dong et al., 2019). The rapid rise of the tourism sector in BRICS countries needs to be investigated further regarding its environmental impacts. Aziz et al. (2020) stated that the persistent over-consumption of natural resources for tourism would lead to environmental degradation at a higher level. This will also deplete the available natural resources and cause an insecure environment for coming generations. According to British Petroleum (BP), carbon emissions in BRICS economies reached 40% of global emissions (Petroleum, 2018). Such increased emissions of carbon and greenhouse gases in BRICS economies have brought detrimental environmental hazards (Davis et al., 2018; Sun et al., 2022; H. Zhang et al., 2021).

BRICS countries have been actively developing strategies to achieve carbon neutrality goals, low emission technological development, improving energy and economic infrastructures, controlling the development of new high-energy projects, and promoting green financial investment. The BRICS countries have adopted governance activities to develop cooperation mechanisms for improved economic growth. Although technological innovation has been on the rise in BRICS countries, there are still several challenges of insufficient technological advancement, high-tech infrastructure, and green production at the industrial level. From the perspective of technological innovation, China has maintained a rapid development rate with a rise of 164.9% in 2019 compared to 2008. In contrast, other BRICS countries, including Brazil, Russia, and South Africa, have declined ICT implementation (H. Zhang et al., 2021). However, there is still a wide gap in the proper implementation of ICTs within all sectors. Investigation of the influence of innovation and GDP growth on carbon emissions is vital and of considerable practical importance, with countermeasures and ideas based on the current situation of the BRICS countries. Moreover, income disparity and unavailability of services between rural and urban areas prevail. Most of the available research concludes that technological innovation, productivity expansion, and carbon dioxide emissions are all correlated, but their conclusions may differ in results.It is important to explore the cointegration between the environment and tourism in developing economies such as BRICS countries. Still, less consideration of the given variables has been provided. Recently, BRICS economies have adopted policies to curb carbon emissions through tourism development and green energy production. However, the given variables have not been discussed for BRICS economies. The current study presents useful insights to generate links between ICT, tourism, and economic growth impacting environmental quality.

In the next phases of this current study, we structure the remaining of our research. Section 2 gives a review of the literature. Section 3 designates the data and methodology employed in this research; Section 4 presents the findings and discusses it, and Section 5 concludes with policy recommendations.

2. Literature review

The rising implementation of information and communication technology (ICT) and its interrelationship with other factors such as economy, environment, and sustainable development have gained much importance among researchers (Khan et al., 2022). ICT access index has been on the rise in BRICS economies, with a maximum score of 72.8 for Russia (Vipr & Somayajula, 2022). ICT access involves different aspects such as internet availability, affordability of digital means, the neutrality of ICT usage, and progress in the digital economy.

Chien et al. (2021) determines the effect of ICT on carbon emissions by employing the Environmental Kuznets curve (EKC) hypothesis for BRICS economies. The Quantile Regression approach is used, which provides the relationship between ICT and carbon emissions across varying quantiles. Empirical findings of the study reveal that ICT significantly reduces carbon emissions for lower emission quantiles only by confirming the existence of the EKC curve for the given variables. It is further stated that ICT's impact on carbon emissions is found to be lowest in lower quantiles and highest in higher quantiles of emissions. The DH-panel causality test is also implemented to determine the bidirectional cointegration between the given variables. It states that policy implications for ICT development from the government affect the carbon emission rate in BRICS countries. The environmental implications of ICTs cannot be ignored in this era of digitalisation. The empirical research of Zhang et al. (2019) explores the part of ICT in carbon dioxide emissions across varying regions between the period between 1990 and 2015. The study employs different methods, including the ordinary least squares, robust long-term panel data approximation, and Driscoll–Kraay regression, to determine the interrelationship between ICT and carbon emissions. Findings of the study reveal that ICTs reduce carbon emissions across middle- and higher-income economies. In contrast to this, increase in ICT implementation increases carbon emissions in lower-income countries. They also implement the EKC curve hypothesis to prove the cointegration between given variables. The findings state that significant ICT policies have brought environmental sustainability to different regions.

Nguyen et al. (2020) investigate the role of ICT on the level of carbon emissions and economic growth in terms of %GDP for G-20 economies. The study follows the implications of the 21^{st} conference of parties to the climate convention (COP-26). Fetching the data from G-20 economies, the empirical research determines the correlation between ICT and carbon emissions for the past 15 years. The study findings reveal that increased spending on ICT impedes carbon dioxide emissions. Moreover, it states that the increased ICT level is a positive driving force minimising carbon emissions. The study also suggests that controlled consumption of resources through digital technologies will limit carbon emissions. Anser et al. (2021) provide a carbon analysis structure to determine how ICT can drive carbon emissions in different ICT subsectors. The research study determines the impacts of ICT on the level of carbon emission for European economies based on the data between 2000 and 2017. A fixed-effect panel regression model determines the functionality of ICT and carbon emissions within the agriculture sector. Moreover, Quantile Regression Model also confirms the presence of an inverted U-shaped curve between the given variables. Findings of the study exhibit that higher ICT implementation positively impacts the carbon emissions across European countries.

Lu (2018) investigates the impact of ICT on carbon emission by employing panel data between 1993 and 2013 in the context of Asian economies. The panel unit root test estimates the cross-sectional dependence to determine the cointegration between the given variables. Moreover, the Pedroni Panel Cointegration model also confirms the correlation between ICT and environmental emissions. Results of the empirical study indicate that a long-run equilibrium is present between ICT and carbon emissions nexus with GDP as a control variable. They further state that increased policies on ICT promotion are an important strategy by governmental departments to eliminate carbon emissions in different Asian economies. X. Chen et al. (2019) investigate the impact of ICT on the intensity of carbon emission. The study employs China's provincial data for the period 2001-2016. Quantile Regression Model is utilised to determine the benchmarking model for five different quantiles, including 0.1, 0.25, 0.5, 0.75, and 0.9. The empirical results suggest that increased use of digital resources significantly reduces carbon emissions through sustainable means of development and production in industrial sectors. Ulucak and Khan (2020) examine the correlation between ICT development and carbon emissions. The study utilises the Robust panel data estimation model for the data obtained from BRICS economies between 1990 and 2015. The empirical findings reveal that ICT positively impacts carbon emissions in BRICS economies. Research findings on the Nexus between ICT and carbon emissions show a need to establish new policies for combating environmental degradation, and improved levels of ICT implementation can significantly reduce carbon emissions in BRICS economies. Alternative energy sources need to be developed through innovative technologies as a part of carbon emission reduction policy.

After fuels and chemicals, tourism has become the world's 3rd largest export sector. Over the past few years, there has been a huge surge in international tourism, which makes up 7% of the world's total exports (Rasool et al., 2021). Tourism and hospitality activities have fuelled the economic development of more than two dozen countries. As a result, most countries have recognised that tourism and hospitality are key growth drivers for their economies. Xuefeng et al. (2021) provide fresh insights into the dynamic relationship between tourism growth and carbon emissions in the United States. The analysis made in the research study employs a unique 'Morlet's Wavelet' model.

Moreover, the study utilises coherence techniques for the dataset from 2001to 2017. Empirical findings of the study reveal strong but inconsistent interrelation between the given variables based on lag associations. Long-term positive impacts are estimated between tourism development and carbon emissions. The research findings can assist policymakers in developing strategies for tourism development towards a sustainable future. Sun et al. (2021) investigate the pathway towards sustainable development while observing the impacts of tourism on carbon dioxide emissions in Malaysia. The study employs the Quantile autoregressive distributed lag model on the data between 1970 and 2018. Granger causality test is also implemented to determine the asymmetric and dynamic correlation between tourism development and carbon emissions. Empirical results of the study show a steady-state equilibrium between both variables in the long-run. The study reveals that tourism significantly contributes towards a sustainable environment while mitigating carbon emissions across high emissions quantiles. The presence of bidirectional causality is also observed between the given variables.

Khan and Ahmad (2021) examine the role of tourism in carbon emission levels by employing the GMM and DOLS models for high-income countries in Europe and developing economies of Asia based on the data between 2000 to 2020. Empirical results of the study indicate that tourism has a close linkage with carbon dioxide emissions. Moreover, increased tourism plays an essential role in rising emission levels in developed and developing countries. The study also provides useful implications for sustainable development through enhanced GDP in the tourism sector for developed economies. Yue et al. (2021) examine the correlation between tourism and carbon dioxide emissions. The impact of tourism is determined in decreasing the carbon emissions in Thailand by employing the Bootstrap ARDL approach. The study also utilises the conventional ARDL bound test to enhance the F- and T-test power, which provides various advantages in developing dynamic models with the variable explanation. The study's empirical findings show that tourism leads towards environmental sustainability with reduced carbon emissions.

Tourism development is taken as an effective way towards realising regional sustainability. Thus, it is important to explore the impact of tourism in alleviating carbon emissions. Tong et al. (2022) employ the structural equation modelling (SEM) to reflect the impact of the tourism economy and enhanced GDP on carbon emissions for China. An empirical study reveals that improved tourism significantly reduces carbon emissions through direct impact in China. The indirect tourism development is negative and stronger than the direct effect. Multiple considerations are presented in the research work for tourism impact on reduced carbon emissions. The study implies that enhanced tourism leads to environmental regulations, ultimately reducing carbon emissions through efficient policies.

Moreover, spatial heterogeneity is also estimated in the formation process of the carbon reduction impact of the improved tourism sector. Isaeva et al. (2022) investigate the causality relation between tourism and carbon emissions using the sample data for the period 1995-to 2014 in the case of developing countries. The empirical research employs Kao and Pedroni Tests to estimate the cointegration between the given variables. The Granger causality test demonstrates a bidirectional linkage between tourism and carbon emissions. It further states that an improved tourism department brings economic growth and an increase in %GDP that ultimately minimises carbon dioxide emissions.

Trade openness and economic coordination between BRICS economies are the major concerns in economic and sustainable development strategy. Trade openness improves the international competitiveness level for BRICS countries, globally accounting for 12.7% in the services sector, 17.3% in goods, and 21% in GDP. Long- and short-term strategies need to be implemented for trade development in BRICS economies that significantly impact the carbon emission levels (Yarygina & Zhiglyaeva, 2021). Khan et al. (2021) provide the association between Trade (TRD), GDP, and carbon emissions for emerging countries like Bangladesh. The research utilises the panel data between 1980 and 2016 to determine the cointegration between TRD and carbon emissions. The study employs the ARDL approach to ascertain the long-term and short-term correlation between the variables. The study results reveal that economic development through increased trade has a significant long-term impact on environmental sustainability. It further suggests policies for governmental organisations to devise strategies for enhanced TRD at the international level for reduced carbon emissions. Wang and Zhang (2021) explore the impact of TRD on decoupling carbon emission levels in terms of GDP growth. They investigate the heterogeneous effects of TRD on carbon emission levels using the datasets between 1990 and 2015 for developing nations. Empirical results show that improved TRD decreases carbon emissions in higher-income and middle-income economies. At the same time, in the case of low-income countries, it enhances the levels of carbon emissions. The TRD impact on carbon emissions indicates that trade openness has significantly positive impacts in decoupling economic development for rich economies, but negative impacts for poor economies.

Many governments have been trying to attain carbon emission and carbon neutrality targets after the Paris Agreement. China is one of the largest economy and carbon emitters globally. To reduce the carbon emission rate, the role of TRD is discussed in the research study of Liu et al. (2021), along with the control impact of GDP. The analysis introduces the TRD level based on the panel data between 1995 and 2017 as a determinant of sustainable development in China. They utilise the advanced panel method such as the cross-sectional dependency test to determine the cointegration between the given factors. The study suggests that increased TRD and GDP positively impact the carbon emission rate.

In contrast, foreign trade is negatively associated with carbon emission levels. Adebayo et al. (2021) examine the association between international TRD and carbon emissions. The asymmetric impact of TRD growth on consumption-based carbon dioxide emissions is provided for MINT economies (Mexico, Indonesia, Nigeria, and Turkey). The research study utilises a non-linear ARDL model to assess the cointegration between the given variables based on the data between 1990 and 2018. The non-linear ARDL approach validates a long-run cointegration between TRD, GDP, and environmental sustainability. Empirical findings of the study reveal that positive shock in TRD development enhances carbon emissions, while a negative shift in TRD does not significantly affect carbon emission.

Adebayo et al. (2022) aim to determine the correlation between TRD and carbon emission and GDP growth for Sweden by employing the data between 1965 and 2019. The study implements the Quantile-on Quantile (QQ) model to assess the cointegration between the given variables. Outcomes of the study reveal that TRD negatively impacts carbon emission levels at lower and medium quantiles. Moreover, the study applies Quantile Regression (QR) model to check the robustness of given variables. Findings of the QR model also validate the research outcomes obtained from the QQ approach given in the research study. Li et al. (2021) determine the effect of structural variations on emission levels from TRD development while considering the control effect of GDP. The study employs a fully-modified ordinary least squares approach and a Granger causality test to estimate the TRD growth levels for different countries based on the data between 1990 and 2015. Results of the empirical research show that improved TRD structure has positive impacts on carbon dioxide emissions. Granger causality test also verifies the presence of bidirectional relationship between the given variables. The given model includes the GDP as a control variable that has a complementary impact on carbon dioxide emissions. The GDP of BRICS economies makes 43% of the world GDP, while US and Europe together make 36% of the global GDP.

The impact of GDP on carbon emissions is analysed for ASEAN countries (Bieth, 2021). Aslam et al. (2021) explore the nexus between GDP and carbon emissions for the Chinese economy and TRD. The study evaluates the Environmental Kuznets Curve (EKC) for the given variables. Research estimates that the GDP per capita reduces carbon emissions in a long-term effect. It further states that a bidirectional relationship is found between GDP growth and carbon emissions. The given research study will likely open ways for analysing the cointegration between ICT, TRD, Tourism, GDP, and carbon emissions to propose strategies for improved economic growth and a sustainable environment in BRICS countries. Z. Zhang et al. (2021) also provide the control impact of GDP on carbon emissions by determining low-emission energy production. China's panel data is employed for 2000-2017 to establish a link between given variables. Empirical findings of the study show that with a 1% increase in the ratio of low-emission energy production, the GDP increased by 0.16%, which decreased the carbon emission rate by 0.848% for China. In addition, low-carbon economic growth with enhanced GDP rate can be attained through low carbon energy production.

Manta et al. (2020) estimate the impact of GDP growth on carbon emissions for Central and Eastern European economies based on the panel data between 2000 and 2017. The study employs the EKC theory along with the Granger causality estimation. It determines the direction of causality with a complementary effect of GDP growth on carbon emissions. It is further stated that bidirectional causality exists between economic growth, GDP, and carbon emissions. Thus, increased financial development will bring improved GDP, ultimately affecting the carbon emission rate. The study's findings reveal that economic development and GDP growth will increase the carbon emission rate in the short run. Osadume (2021) investigates the impact of economic growth and GDP on carbon emissions for selected Western African nations employing the data from 1980 to 2019. The study uses 'Simon-Steinmann's' model to determine economic growth that affects the GDP, which significantly impacts the carbon emission rate. The research findings reveal that GDP growth positively impacts carbon emissions in the short run. It further states that a 1% increase in GDP will bring 3.11% rise in carbon emission rate. Governments should devise policies to curb carbon emissions through innovative means of sustainable production that will ultimately decrease energy consumption and carbon emissions.

3. Research methodology

In the initial step, current research considers the implication of the cross-sectional dependence (CD) test, which helps justify the consideration of the unit root test. More specifically, the importance of CD is linked to various factors like macroeconomic changes, residual interdependency, and many others (Westerlund, 2007). However, suppose there is no consideration of the CD test in the initial step. In that case, the findings at later stages will generate biased output, leading to misleading justification and implications. Therefore, this study applies the Pesaran (2015) test for inspecting the CD, followed by stationarity. For this purpose, the current study applies Pesaran's (2007) test for examining the second-generation unit root properties followed by Bai and Carrion-I-Silvestre (2009) test, which is the third generation in nature andcan significantly deal with the structural breaks and slope heterogeneity. Therefore, Pesaran (2007) and Bai and Carrion-I-Silvestre (2009) tests are applied based on the stated justification.

The checking of stationarity properties of the data leads to examining the heterogeneity in the slope through a modified version of Swamy's test (1970). Both null and alternative hypotheses are discussed in more detail under the discussion part of the study. Because of CD's presence in the data, it is not suitable to apply the conventional tests. For this reason, we apply Bai and Carrion-I-Silvestre (2009) and Westerlund and Edgerton (2008) tests for investigating the cointegration properties. Moreover, Westerlund and Edgerton (2008) help ensure reliable estimation with slope heterogeneity while incorporating the structural breaks.

In addition, it is observed from the current literature that the presence of CD in the data may lead to biased findings if ignore the unobserved factors associated with the explanatory variables in the model. With CD and slope heterogeneity identification, the most appropriate test for examining both long-run and short-run relationships is Cross Sectional ARDL (CS-ARDL). More specifically, thedependent variable is carbon emission (kt), while ICT, TOUR, and TRD and explanatory variables. Finally, GDP is also added as a control variable. The traditional way to reflect the association between these variables is provided in Eq. (1).

$$\mathrm{CEKT}_{,i,t} = f\ (\mathrm{ICT}_{i,t},\ \mathrm{TOUR}_{i,t},\ \mathrm{TRD}_{i,t}, \mathrm{GDP}_{i,t}) \tag{1}$$

The term cross-sections are covered through i, whereas the time duration from 1990 to 2019 is presented through t.

Equation (2) shows the regression form of Eq. (1).

$$\mathrm{CEKT} = \beta_{1it} + \beta_{2it}\mathrm{ICT}_{it} + \beta_{3it}TOUR + \beta_{4it}TRD_{it} + \beta_{4it}GDP_{it} + \alpha_i + \delta_{it} \tag{2}$$

Table 1. Details of variables.

Variable title/Abbreviation	Measurement	Data source
Information and Communication Technology (ICT)	Fixed telephone subscriptions (per 100 people)	WDI, World Bank Group
Tourism (TOUR)	International tourism, number of arrivals	WDI, World Bank Group
Trade (TRD)	% of GDP	WDI, World Bank Group
Gross Domestic Product (GDP)	Current USD	WDI, World Bank Group
Carbon Dioxide Emission (CEKT)	CO2 emissions (kt)	WDI, World Bank Group

Source: Author's Source.

$$W_{i,t} = \sum_{i=0}^{pw} \varphi_{i,t} W_{i,t-1} + \sum_{i=0}^{pz} \gamma_{i,t} Z_{i,t-1} + \varepsilon_{i,t} \tag{3}$$

The autoregressive distributed lag (ARDL) model is defined as Eq. (3). However, Eq. (3) was used for each cross-section average repressor and extended into Eq. (4). The cross-section average reduced the CSD effects.

$$W_{it} = \sum_{i=0}^{pw} \varphi_{i,t} W_{i,t-1} + \sum_{i=0}^{pz} \gamma_{i,t} Z_{i,t-1} + \sum_{i=0}^{px} \alpha_i \overline{X}_{t-1} + \varepsilon_{i,t} \tag{4}$$

where

$$\overline{X}_{t-1} = (\overline{W}_{i,t-1}, \overline{Z}_{i,t-1})$$

where W_{it} is used to reflect the main dependent variable of interest and $\overline{Z}_{i,t-1}$ covers the rest of the study variables. Meanwhile, the average for both dependent and independent variables has been taken through $\overline{X}_{t-1}$ so that the issue of CD could be handled in a batter way. Besides, P_w, P_z, and P_x demonstrates the lagged variables. Additionally, long-run coefficients are estimated through a short run with the help of CS-ARDL estimation long-run coefficients.

Table 1 shows the details, including the measurement and data source of the variables used in the above model.

4. Discussion of findings

Initially, descriptive results are provided in Table 2, which shows that GDP has the highest mean value with a score of 11.99 and a standard deviation of 0.477. The reason for showing the highest mean score is that GDP is measured in terms of current USD over the study duration for all the BRICS countries. Meanwhile, TOUR stands at the second position in reflecting the mean value of 7.145 after taking the natural log of total international arrivals in a given time. Carbon emission has reflected a mean value of 6.04 calculated after the natural log of carbon emission in kt over the past few decades. Finally, trade (%GDP) reflects a mean value of 1.603, followed by ICT. Additionally, none of the study variables reflects a standard deviation above 0.60, where the lowest value is 0.154, as linked with the TRD.

The variance inflation factor (VIF) results are in Table 3, where CEKT, TOUR, GDP, and TRD have provided their relative scores of 4.53, 4.02, 2.91, and 1.96,

Table 2. Descriptive statistics.

Variables	Mean	SD	Min	Max
ICT	1.032	.383	.094	1.502
TOUR	7.145	.537	6.299	8.211
TRD	1.603	.154	1.194	1.841
GDP	11.997	.477	11.111	13.155
CEKT	6.046	.476	5.383	7.013

ICT: Information and Communication Technology, TOUR: Tourism, TRD: Trade, GDP: gross domestic product, CEKT: carbon emission (kt).
Source: Author's Source.

Table 3. Variance inflation factor.

Variables	VIF	1/VIF
CEKT	4.537	0.224
TOUR	4.021	0.249
GDP	2.912	0.343
TRD	1.962	0.519
Mean VIF	3.358	-

Information and Communication Technology, TOUR: Tourism, TRD: trade, GDP: gross domestic product, CEKT: carbon emission (kt).
Source: Author's Source.

Table 4. Results of cross-sectional dependence test.

Variable	t-Statistics (sig.)
ICT	18.520*** (0.000)
TOUR	28.207*** (0.000)
TRD	23.207*** (0.000)
GDP	31.806*** (0.000)
CEKT	21.527*** (0.000)

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, ICT: Information and Communication technology, TOUR: Tourism, TRD: trade, GDP: gross domestic product, CEKT: carbon emission (kt).
Source: Author's Source.

respectively. It implies that none of these variables has crossed the threshold level of 5. Similarly, tolerance values as measured through 1/VIF have also provided evidence that all the values are above 0.10; therefore, there is no evidence for a higher correlation between them. Finally, the Mean VIF is 3.358, which covers that the overall trend is less than five.

Before applying the advanced Panel estimations, it is imperative to examine the various properties of the study variables based on the data curation. In this regard, the first step reflects the investigation of cross-sectional dependence. Various studies have proposed a significant need to examine whether cross-sectional dependence exists in the study data (De Hoyos & Sarafidis, 2006; Sarafidis & Wansbeek, 2012). Examining whether the cross-sectional dependence exists, t-statistics with significance provide enough evidence. The results in Table 4 report that for ICT, TOUR, TRD, GDP, and carbon emission (kt), the values of T-statistics are highly significant at 1%, confirming the presence of CD.

This study analysis discusses the study variables' unit root properties, both with and without a structural break. In Table 5, the results show that the null hypothesis failed to reject at level I(0) and was accordingly accepted. It offers an absence of stationarity at the level while considering the presence of CD in the data. Similarly, we apply the unit root test of Bai and Carrion-I-Silvestre (2009), as shown in Table 6. The results failed to reject the null hypothesis. However, data has become stationarity,

Table 5. Results of unit root test with & without structural break (Pesaran, 2007).

	Level I(0)		First difference I(1)	
Variables	CIPS	M-CIPS	CIPS	M-CIPS
ICT	−4.520***	−7.207**	–	–
TOUR	−3.205***	−6.504**	–	–
TRD	−4.205***	−6.107**	–	–
GDP	−3.108***	−4.159*	–	–
CEKT	−4.159***	−7.510**	–	–

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, ICT: Information and Communication technology, TOUR: Tourism, TRD: trade, GDP: gross domestic product, CEKT: carbon emission (kt).
Source: Author's Source.

Table 6. Results of Unit root test (Bai and Carrion-I-Silvestre, 2009).

Variables	Z	P_m	p	Z	P_m	p
ICT	0.210	0.810	21.527	−3.938***	8.159***	69.522***
TOUR	0.159	0.721	18.415	−5.204***	8.159***	71.205***
TRD	0.215	0.750	25.578	−4.207***	11.205***	68.504***
GDP	0.319	0.818	19.852	−3.504***	7.527***	76.015***
CEKT	0.305	0.667	20.159	−4.851***	8.636***	72.352***

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, ICT: Information and Communication technology, TOUR: Tourism, TRD: trade, GDP: gross domestic product, CEKT: carbon emission (kt).
Source: Author's Source.

Table 7. Slope heterogeneity.

DV: CEKT	t-statistics (Sig.)
Δ tilde	33.205*** (0.000)
Δ tilde Adjusted	30.570*** (0.000)

Note: ***, ** & * explain the significance at 1%, 5% and 10% respectively, whereas the values are in parentheses contains p-values.
Source: Author's Source.

as per Pesaran (2007). Therefore, based on such findings, a first-order difference was taken for the Bai et al. (2009) test. The results claim that there is a presence of stationarity or no unit root where CD exists in the study data. Therefore, the study variables are found to be stationary.

After checking for the stationarity properties, slope heterogeneity has been tested, and the results are provided in Table 7. The findings have been covered through a modified version of the Swamy (1970) test, which Pesaran and Yamagata (2008) reviewed. As stated in the earlier studies, checking for slope heterogeneity is very important as neglecting this step will provide unreliable results at later stages. This way, the following null, and alternative hypotheses have been developed and tested empirically.

H0: there is no presence of slope heterogeneity
H1: There is a presence of slope heterogeneity

The result indicates that both Δ tilde and Δ tilde Adjusted have reflected significant t-statistics at 1% level of significance. Therefore, it is inferred that H1 is accepted, which supports the presence of slope heterogeneity.

The subsequent step is based on investigating the cointegration properties of the data, for which Westerlund and Edgerton (2008) have suggested panel cointegration

Table 8. Results of Westerlund and Edgerton (2008) panel cointegration analysis.

Dependent variable: CEKT	No break	Mean shift	Regime shift
$Z_{\varphi}(N)$	−3.874***	−4.620***	−2.997***
Sig.	(0.000)	(0.000)	(0.000)
$Z_{\tau}(N)$	−3.736***	−3.628***	−2.917***
Sig.	(0.000)	(0.000)	(0.000)

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, ICT: Information and Communication Technology, TOUR: Tourism, TRD: Trade, GDP: gross domestic product, CEKT: carbon emission, whereas the values in parentheses contain *p*-values.
Source: Author's Source.

Table 9. Results of Bai and Carrion-I-Silvestre's (2009) cointegration analysis.

DV: CEKT	No deterministic specification	With constant	With trend
Full Sample	−5.205***	−4.638***	−3.625***
Brazil	−5.159***	−4.205***	−5.159***
Russia	−8.178***	−8.357***	−7.510***
India	−6.204***	−5.227***	6.117***
China	−6.357***	−4.207***	−6.357***
South Africa	−6.007***	−6.357***	−6.638***

Note: Critical Value (C) at 1%*** with constant is −2.32, −2.18 and with the trend is −2.92 and −2.82.
Source: Author's Source.

Table 10. Long-run CS-ARDL results.

DV: CEKT	Beta value	t-Statistics	Sig./Insig.
ICT	−0.274***	−4.527	Sig.
TOUR	0.527***	3.527	Sig.
TRD	0.301***	5.207	Sig.
GDP	0.617***	4.637	Sig.
CSD-Statistics	–	0.018	Insig.

Note: ***Critical Value (CV) at 1%.
Source: Author's Source.

tests. This test helps to examine whether the study data contains cointegration properties. The results are reported in Table 8. More specifically, both null and alternative hypotheses are suggested. The former indicates no cointegration properties in the data with the presence of cross-sectional dependence. However, H1 rejects it and claims that there is a cointegration in the data. The results in Table 8 have rejected the Ho for all three stages (no break, mean shift, and regime shift), which means cointegration with CD is present in the data.

Bai and Carrion-I-Silvestre (2009) suggest that the cointegration may vary across the panel and countrywide. Thus, the entire sample and the stated individual economies are reported in Table 9, which shows highly significant test statistics with a 1% significance, confirming a cointegrated relationship between the sampled economies in our study.

Based on the above initial tests, it is inferred that the testing for the long run and the short run relationship between the variables is quite obvious. More specifically, the long-run results with the help of CS-ARDL estimation have been provided below (Table 10).

- As per the results, the coefficient for ICT is highly significant and negative (i.e., coefficient = 0-.274, t-statistics=-4.527, *p*-value = 0.000). It confirms that more advancement in information and communication technologies would help reduce carbon emissions, specifically in all the BRICS economies. This impact is observed

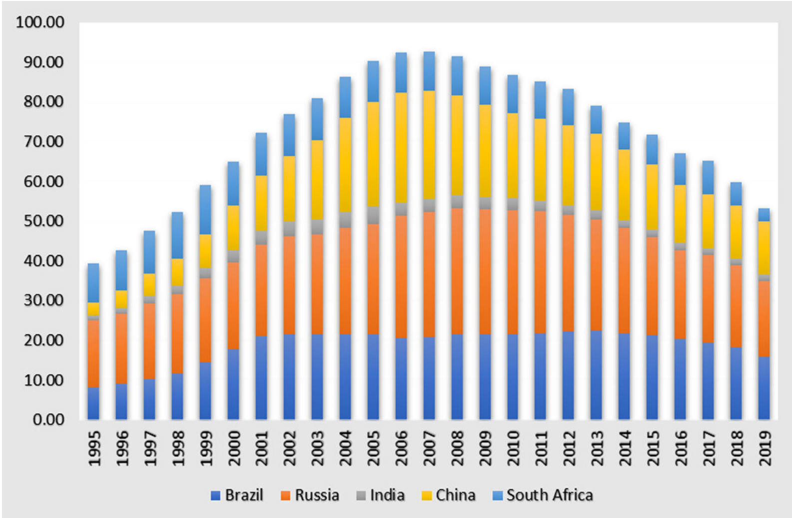

Figure 1. ICT among BRICS economies.
Source: Data from WDI.

in the long run, which means that batter attention to ICT and related advancement is a good sign for the government to control the adverse environmental consequences. Figure 1 shows that over the past couple of decades, from 1995 to 2019, there has been a good trend in terms of ICT among the sample economies. This is indeed a good indication. Meanwhile, the results show that a 1% change in ICT leads to a decline of 27.4% in carbon emission value; hence, environmental degradation would be improved accordingly.

- Additionally, the review of both theory and empirical findings regarding the impact of ICT on carbon emission reflects mixed output. For example, Moyer and Hughes (2012) examine whether ICTs development contributes to carbon emission. Authors suggest that ICTs negatively impact carbon emission, specifically over 50 years. However, the net impact of such technologies on carbon emission is limited. Amri (2018), however, confirms that from the context of Tanzania, the effect of ICT on carbon emission was insignificant from 1975 to 2014. Zhou et al. (2019) also explored the relationship between ICT and carbon emission in China while considering different sectors. It is stated that the ICT sector is not environmental-friendly. Therefore, the authors have suggested an integrated CO2 management strategy specifically for the ICT sector. However, contrary to these results, Haini (2021) infers that ICT is negative for CO2 emission in the ASEAN region.
- The relationship between tourism and CEKT is also explored in the long run. It reports a positive and significant coefficient. More deeply, it shows an upward shift of 52.7% in carbon emission because of a 1% change in tourism in the BRICS region. This is because a higher level of international arrivals of tourists is undoubtedly beneficial for economic growth. However, at the same time, various tourism-related activities like using transportation and energy sources cause more emissions in the natural environment. The coefficient of 0.527 is significant at 1%,

with the t-statistics of 3.527 (above a threshold level of 1.96). The literature review confirms that more arrival of tourists in any region is directly linked with environmental pollution until the government and related departments introduce some sustainable tourism practices. Like the relationship between ICT and carbon emission, the literature supports the relationship between TOUR and CEKT, also justified through mixed results. Khan and Ahmad (2021) take a sample of both developed and developing economies to check the impact of tourism, energy consumption, and foreign investment on carbon emission. The results confirm that more tourism is responsible for more carbon emissions and vice versa. Mishra et al. (2020) also justify the nexus between tourism and carbon emission, whereas Sun et al. (2021) state that tourism and transportation in the Malaysian economy help reduce carbon emissions because of sustainable practices. Papavasileiou and Tzouvanas (2021) focussed on tourism while exploring the carbon Kuznets curve. Their study provides a new contribution to the existing literature while claiming an inverted U-shaped relationship between economic and carbon performance with the presence of tourism.

- TRD reflects a significantly positive impact on carbon emission in BRICS, which means that more emission is due to more trade in the regional economies. More specifically, because of TRD, a change of 30.1% is found in CEKT over the study duration. The reason is that trade and other related activities are highly linked with the utilisation of transportation and most of the traditional energy sources through which more carbon emissions would be recorded in nature. This relationship is also justified in the literature that TRD and CEKT have their direct linkage. Shahzad et al. (2017) stated that 1% increase in the value of trade is causing an upwards shift of 24.7% in carbon emission from the context of Pakistan. At the same time, unidirectional causality also exists between both. Contrary to the stated findings, Zhang and Zhang (2018) examine that trade is negatively linked to carbon emission in China.
- The last variable under long-run analysis is economic growth via GDP, for which the coefficient is the highest among all. A change of 61.7% in carbon emission was found because of GDP during the selected time duration. Moreover, this impact is highly significant where the coefficient's p-value is less than 0.0000. Therefore, there is no doubt that more GDP means more environmental emissions. Various studies state that more production of goods and services in any economy is based on the consumption of a major part of the energy from traditional sources like fossil fuels.
- Additionally, with more consumption, Zhang et al. (2014) claim that GDP as a growth factor is directly responsible for curbing the Carbon emission intensity in the Chinese economy, whereas Lotfalipour et al. (2010) confirm the presence of unidirectional causality between GDP and carbon emission. Nawaz et al. (2021) apply the quantile regression estimation technique for BRICS and OECD countries. It is confirmed that positive nexus exists between GDP and carbon emission in the selected economies.
- Lastly, Table 11 reports the short-run results. Similar to long-run outcoes, the ICT is causing a reduction in carbon emission but with a different beta coefficient,

Table 11. Short-run CS-ARDL results.

Variables	Beta value	t-Statistics	Sig./Insig
DV: CEKT			
ICT	−0.51***	−3.508	Sig.
TOUR	0.116***	6.207	Sig.
TRD	0.019	1.523	Insig.
GDP	0.138***	3.928	Sig.
ECT(−1)	−0.227***	−6.357	Sig.

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, ICT: Information and Communication technology, TOUR: Tourism, TRD: trade, GDP: gross domestic product, CEKT: carbon emission.
Source: Author's Source.

significant at 1%. On the other side, tourism and economic growth confirm the same results for creating more emissions with the coefficient scores of 11.6% and13.8%. Meanwhile, there is no role of trade in the short run for creating more emissions in the BRICS economies. Besides, the error correction term (ECT-1) also justifies the convergence towards steady state equilibrium with 22.7% annual adjutment rate.

5. Conclusion

Although, the importance of ICT has been widely accepted in the recent era, however, still its regional investigation while considering different proxies is yet a big literature gap. Big trade growth has been observed among BRICS members, specifically in ICT services, where trade volume in two of the major economies (China and Russia) has grown to 21 million USD. Such a phenomenal relationship has caused a robust growth output during 2015 with 42.7 billion USD, which covers 87.1% of the Russian export to BRICS economies. Moreover, there is a growing trend of tourism, economic growth, and trade among BRICS economies, for which environmental concerns are nothing new in the literature. This relationship confirms the lack of attention towards sustainable business and environmental practices, exclusively in BRICS countries. Finally, an outstanding growth in international tourism has been found among the stated economies before COVID-19, hence more degradation due to the utilisation of conventional energy sources in different recreational activities. This study investigates the impact of ICTs development, trade, economic growth, and tourism in BRICS to determine whether such factors are creating environmental pollution or not.

Data has been collected from 1990 to 2019, whereas advanced Panel estimations entitled CS-ARDL have been applied. The key econometric model has been examined in the long run and short run durations. The results show that ICT is helping to reduce carbon emissions over the past three decades. In contrast, tourism, economic growth, and trade are responsible for putting adverse pressure on the natural environment of BRICS countries. Similar evidence is found in the short run except for the impact of trade on carbon emission, which was positively insignificant, meaning that trade is not responsible for environmental degradation in the short run. The negative effects of ICT on CEKT reflect that more focus on such developments would generate better results in the coming duration to protect the environment. However, the positive impact of tourism, trade, and economic growth on CEKT states that these macroeconomic dynamics are not associated with the sustainability dynamics in BRICS economies. Hence growth, trade, and tourism are not sustainable. In terms of practical implications, our results benefit government officials and stakeholders like environmentalists, community members, and international tourists to play their responsible role in controlling environmental pollution. For example, it is accepted as a prime obligation for the governments in BRICS countries to promote sustainable tourism practices with less dependency on traditional energy sources.

Moreover, governments in these countries may also promote sustainable tourism while giving tourists some financial and non-financial incentives to protect nature through less environmental pollution. Additionally, the linkage of ICT developments with ecological innovations and technologies is another suggestion to achieve sustainable results both in the long run and short run. In the final term, there is a great need to convert both trade and economic growth into green practices to play their role as a panacea for the natural environment of BRICS economies. However, this research is limited in sample selection, cross-country comparison, and considering only one proxy for environmental pollution. Future studies are highly suggested to address these limitations through some strong policy suggestions would be established.

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