



The impact of economic growth, tourism, natural resources, technological innovation on carbon dioxide emission: evidence from BRICS countries

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Abstract

The main objective of this manuscript was to investigate the relationships among economic development, tourism, the use of natural resources, technical advancement, and carbon dioxide emissions in the BRICS group of nations. Data from the panel was gathered from 1995 to 2018. Modern methodology tools including the CS-ARDL tests, Westerlund cointegration tests, and panel data unit root tests have been used in this study. Results of the models show that all the variables were transformed to the first difference to make it stationary. The Westerlund model test results suggest that dependent and independent variables have robust cointegration. Results of the CS-ARDL models reveal that all the variables signed, and significance are aligned with the economic theory. It indicates that except for tourism, the rest of the variables like technical innovation, natural resources, and economic growth have positive and significant effects on carbon dioxide emissions both in the short and long runs. Additionally, a 1% rise in economic growth, technical innovation, and natural resources over the long term would raise carbon dioxide emissions in the BRICS economies by 1.79%, 0.15%, and 0.10%, respectively. However, a 1% increase in tourism would result in a 0.39% decrease in carbon dioxide emissions among the nations in the panel data set. Therefore, the promotion of sustainable tourism and advancement in technological innovation is highly important in these countries, so the high impact of environmental degradation pressure may reduce to some extent. An in-addition comprehensive set of policies should be made on encouraging low-carbon transportation, promoting sustainable tourism certification, boosting local produce, reducing waste management, and provide education and awareness campaigns to tourists.

Keywords Economic growth · Tourism · Natural resources · Technological innovations · CS-ARDL

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Introduction

Over time, the economies of South Africa, Brazil, Russia, India, and China have experienced rapid growth. These nations are categorized as BRICS nations. These countries are ranked as having highly dense populations and high fast-growing per capita income economies. Nearly, the world's partial population is living and belongs to these countries. BRICS countries have responsibility for more than half of the world's gross domestic product (GDP) (Baloch et al. 2019). The BRICS countries become a great political and economic bloc in the world. China has a flourishing emerging economy; it has a GDP of 14 trillion, and a growth rate of above 6% annually by the year 2018. China has a population of 1.4 billion, and 9905.3 US dollars of GDP per capita income. Russia is another big player in the political and economic arena of the world. Russia is a former super-power of the world playing a great role in world politics

and envisioning the present and future policies of the world (Ahmed et al. 2020; Danish and Wang 2018).

Conference of the Parties (COP) is a committee that was created and signed the United Nations Framework Convention on Climate Change (UNFCCC). The COP27 summit of UNFCCC has taken decisions that all countries require to make an extra effort to address the climate crisis. A ground-breaking agreement was reached at COP27 to provide loss and damage funding for vulnerable nations that have been severely affected by floods, droughts, and other climate disasters. Countries reaffirmed their dedication to keeping the increase in global temperature to 1.5 °C above pre-industrial levels at COP27. The UN Climate Change will prioritize commitment to transparency from organizations and enterprises in 2023. Everything the world does to prevent climate change is driven by finance. Everything from mitigation to adaptation to loss and damage to climate technology needs enough money to work properly and produce the desired effects. This demonstrates that at least USD 4–6 trillion in investments are anticipated to be needed annually for the world to transition to a low-carbon economy. Delivering such finance will necessitate a rapid and thorough reform of the financial system, as well as institutional investors, commercial banks, governments, central banks, and other financial actors. Notably, governments committed to making the shift to development that is low in emissions and climate-resilient ambitious, just, and equitable. At COP27, they took things a step further by choosing to create a work program on “just transition,” which is meant to support and complement the urgently needed upscaling of mitigation ambition and implementation (UNFCCC 2023).

BRICS countries with expanding economic activities have used most of the natural resources to meet the market demand. These emerging economies consume more natural energy resources like crude oil, natural gas, and coal to meet the energy requirements for the mass production of the products (Baloch et al. 2019). As a result, over the last decades, they damage the atmosphere brutally and causes global warming and acid rain. Therefore, the life of the people disturbed on earth psychologically, economically, and physically. Moreover, to a greater extent, it is hard to live in the entire world specifically in these countries (Zakarya et al. 2015). The faster economic affairs in the country enhance faster GDP growth, and CO₂ emissions simultaneously, and this is due to the excessive use of fuel which causes many gases to emit into the atmosphere having unhealthy substances that pollute the air. Previous literature including Ali et al. (2021), Ahmad et al. (2022), Ullah et al. (2022), and Noor et al. (2023) have linked various operations of the economy such as energy consumption, technological innovation, globalization, and agricultural operation with environmental degradation. These macroeconomics variables show a substantial impact on expanding carbon emissions

in the various countries. Trade and investment are the two factors that are playing an important role in the economic growth and development of these countries (Lee 2013). BRICS countries experience a massive inflow of investments, mostly cross-border investment and more trade openness between these countries make them flourish at a high speed. Economic growth is essential for the socioeconomic expansion of the economies, and it must also be sustainable. BRICS countries are the signatories of the Kyoto Protocols which ensures and take climate change as a challenge for the countries to have sustainable growth. Economic growth is very important for emerging economies, but with that, it is also important to decrease the level of CO₂ emissions, which disrupts the climate (IPCC 2014). This disruption in the climate is known as climate change. The phenomenon of climate change is very important to address because green growth and sustainable development were considered high priorities in 2015. As a result, a summit was conducted in Paris and the entire contributors pledged that the minimization of devastating impacts of climate change should be considered on top priority due to robust economic activities pacifically in emerging countries like China, India, and Russia (Esso and Keho 2016). Further, South Africa has taken this issue very seriously and decided to minimize carbon emissions. It was targeted that at the end of 2020, South Africa would minimize carbon emissions by 34%. Moreover, the BRICS countries have consistently considered climate change phenomena their top property. Therefore, the 5th BRICS conference was called in the year 2013. The conference participant countries signed an agreement to fix the issues of climate change and to achieve economic development sustainably. It is pertinent to describe that the same agenda and goals already have been presented by the United Nations to achieve the objectives of sustainable development goals at the end of the year 2030 (Cowan et al. 2014).

BRICS countries are compelled to invest in construction, mining, and production industries to meet the desired economic growth and development goals as the population of these countries increases. Industrialization and urbanization are the two more factors that impacted economic growth (Khan et al. 2020a, b). Urbanization and rising population increase the demands, and to meet this level of demands, industries are producing more products, and these products are being made with the exploitation of energy that comes from natural resources and the production of goods needs more amount of energy (Ulucak et al. 2020; Adedoyin et al. 2020). The burning of natural resources such as fuel is damaging the climate and causes climate change (Balsalobre-Lorente et al. 2019). So, this is against the principal stand of having green or sustainable growth (Muhammad et al. 2021). The CO₂ emissions are an important concern, and it should be for emerging economies specifically to take it as a challenge to get

sustainable socio-economic and environmental development policies (Nathaniel and Yalçiner 2021). Natural resources are used for energy purposes; one of them is oil which accounts for 40% of the energy purposes of the world, with that almost 94% of this being used in transport alone (Sun et al. 2021). It is clear that oil is an essential commodity needed for economic growth; thus, this is a big source of emissions of greenhouse gasses (GHGs). From them, the CO₂ is causing severe damage to the climate of the whole world (Shi et al. 2020).

Tourism is another factor that can contribute to economic growth (Aziz et al. 2020). Moreover, when a tourist visits an area, it can cause some activities. We are considering economic activities here; more economic activities, higher will be economic growth and economic development in that area or region (Banday and Ismail 2017). Tourism in BRICS countries has high prospects, and more revenue can be generated (Danish and Wang 2018). In 2015 on World Tourism Day, the celebrations had a theme “One Billion Tourists: One Billion Opportunities.” The theme exposes the perspective of one billion tourists. Traveling is becoming a great contributor to the global GDP; it accounts for nearly 10% of the global GDP. One billion tourists visited the tourist sites last year, showing a huge economic activity caused by tourists and representing 7% of global exports (Rasool et al. 2021). Developing countries are becoming emerging players in the tourism sector, gaining a greater chunk of the industry. Tourism is a potential factor for many emerging economies in the world; it is certainly becoming a great source to earn foreign exchange reserves; it also creates jobs, attracts investors, and increases income with the improved lifestyle of the people. Xiamen Summit 2017 of BRICS countries in China was focused on tourism specifically. Most of the tourists visit BRICS countries from developed countries. These countries having great economic growth in the last decades, and they develop many facilities to accommodate tourists (Pop 2014). The BRICS countries have ancient civilizations, in particular, India, and China has many ancient places recognized by UNESCO, while Russia, South Africa, and Brazil also have UNESCO sites, and also beach touring spots to attract tourists from around the world (Shi et al. 2020).

Technological innovation plays a key role in environmental degradation. The BRICS countries have a massive technological growth over the years, for example, China has an economic structure to increase productivity levels, for somehow this model was compromising the quality of the products that were being produced at that time. Contrary to that, China has taken some important steps in this regard like they cut short the production level to enhance product quality; they also make adjustments in industrial and economic structures to change factor-driven growth to innovation-driven growth. China has learned that sustainable economic growth can be achieved through total factor

improvement and involvement, and for that, they have taken steps to shift their economy from productivity to efficiency.

This study focuses on BRICS countries as these countries have close ties both economically and politically. In the past, this topic is researched by many researchers with a different set of factors/variables. This study focuses on the CO₂ emissions in BRICS due to tourism, technological innovation, and economic growth. Summarizing the aforementioned literature, we can all conclude that the prior study was ineffective at critically and in-depth analyzing the connection between CO₂ emissions and other considerable variables of the study. Moreover, different studies’ outcome shows conflicting results. For instance, the different ways that natural resources are extracted, the various administrative procedures, and the differences in the characteristics of each country could all be contributing factors to these contradicting conclusions. Technology must play a crucial part in the development of an appropriate environmental strategy that can successfully address the issue of climate change. As a result, the current study examines the short- and long-term relationships between natural resources, technological advancements, economic growth, tourism, and CO₂ emissions. Moreover, when applied to the context of the aforementioned topic, the literature fails to provide evidence of a connection between economic growth, tourism, natural resources, and technological innovation on carbon dioxide emission taking the case of BRICS countries. Hence, this study’s objective is to fill the required gap in the existing literature. Moreover, this study link must be examined from the environmental quality point of view as BRICS countries are more conscious of environmental concerns.

The order of the paper is organized into different parts: the first part is an introduction in which the topic; factors such as economic growth, tourism, and technological innovation; and their impact on CO₂ emissions are explained precisely. In the second part, a wide range of literature reviews are presented which cover every dynamic of these factors with each other and their outputs for the environment. The study’s methodology, findings, and discussion are covered in the third and fifth sections, respectively. Conclusions are the focus of the final section.

Literature review

Linking between CO₂ emissions and tourism

Tourism is nevertheless a big problem around the world. The developed infrastructure in developed and developing countries causes a huge influx of tourists to these countries. Tourists are always looking for well-developed tourist destinations with all facilities for traveling, living, and eating. Most countries are working on developing the

infrastructure; this causes multiple problems to tackle as well. The more tourist influx, the more environmental degradation, and pollution, due to GHG emissions (Aslan et al. 2020). Katircioglu et al. (2020) established a relationship between tourism and carbon emission in Cyprus. The results of their study reveal that tourism has a positive relationship with environmental degradation. Most of these GHG emissions are associated with the usage of fossil fuels. According to a report by UNDP, almost 75% of CO₂ emissions are globally associated with fuel consumption and increases the transportation means; the tourism industry itself has a positive impact on economic growth due to higher FDI inflow, infrastructure development (Ballia et al. 2018), and job creation, but with that, it also has a positive link with the environmental degradation. Tourism, GDP growth, and environmental deterioration are all significantly correlated (Muslija 2019). In the same pattern of study, Uzar (2019) provided the same argument in his study “The impact of tourism on CO₂ in Turkey” that tourism is an industry that is rapidly flourishing all over the world, despite the internal socio-political instability of any country; this increasing trend benefited the host economies in many ways, causes the foreign exchange reserves, investments, traveling industry, hospitality industry, and businesses of many kinds to establish, operate, and flourish at a high speed. There are lots of factors that influence people to go out and visit some places, cities, and regions of the world; one of them is religious tourism. Religion is a set of beliefs that a person has. Many things are considered sacred in religions, like cities. The Christians have Vatican City, Muslims have Makkah and Medina, Buddhists have Lhasa, Hindus have Varanasi, and Sikhs have Kartarpur. Every year Makkah hosts an annual pilgrimage called Hajj, and billions of pilgrims from around the world visit this city. Saudi Arabia earns billions from this event. This massive inflow of pilgrimage provides many benefits to the economy of Saudi Arabia; it also leads to infrastructure development over the years, and with all these positive things, this human traveler causes harm to the environment. Saudi Arabia burns fuel to accommodate travelers with transportation means. This burning of fuel causes air pollution because of GHG influx into the atmosphere (Ozturka and Altinoze 2021).

In 2017, the travel and tourism sector contributed \$8272.3 billion to the GDP, according to the World Travel and Tourism Council, and it is estimated that it would increase from 10.4% to 11.7% of the GDP by the year 2028 (Tian et al. 2020). This makes travel and tourism gain a share of \$12,450.1 billion in the space of a decade. With that travel and tourism industry created 313.22 million jobs in 2017, which is 9.9% of the overall employment (Ahmad et al. 2019).

Linking between CO₂ emissions and economic growth

Environmental deterioration is a serious problem that affects the entire world. In the case of MENA countries, previous researchers like Farhani and Rejeb (2012) examined the relations between energy use, economic growth, and CO₂ emissions. A total of 15 MENA nations were included in the panel data set, which was collected from 1997 to 2008. The study's findings imply that rising energy use and economic growth both increase carbon emissions. Energy must be employed for boosting industrial production to promote economic growth. Increased energy use directly contributes to worsening environmental conditions (Arouri et al. 2012). The overall increase in the production of the country has a direct relationship with environmental degradation. For the BRICS countries, Cowan et al. (2014) assess the links between macroeconomic factors and environmental degradation. From 1990 to 2010, they made use of the panel data set. The outcomes varied for each of the BRICS nations. As a result, it was impossible to develop a unified policy for these nations. To ensure sustainable economic growth and development, energy policy is crucial.

There are a lot of studies in the past which investigated economic growth concerning CO₂ emissions had been completed and assisted the policymaker to design a more sustainable policy for energy, resources, and pollution. Pollution has been a top-notch topic for environmental researchers in the past and present as well; they investigated many factors such as energy utilization, economic growth, and technological innovation concerning environmental degradation (Mardani et al. 2019). Moreover, to reduce the pressure of environmental degradation, the countries must utilize natural resources and energy resources in alternative and most probably use renewable energy resources. This would decrease the GHG emissions in the atmosphere and provide a viable environment for living organisms to a larger extent. In a similar vein, Su et al. (2021) examined the relationships between economic growth and environmental degradation in China from 1990 to 2018. The study's findings supported the notion that the nation's carbon emissions are a result of economic expansion. Additionally, the BRICS countries' rising economic trends have negatively impacted the climate to a greater extent, which is to blame for the deterioration of the environment and the disruption of the climate. Sharif et al. (2022) explored Brazil's economic growth and carbon emissions in the same vein of research. According to the study's findings, the country's carbon emissions increase as its economy grows.

Linking between CO₂ emissions and natural resources

The atmosphere is deteriorated by GHG emissions, according to prior literature. Macroeconomic variables like economic growth and foreign direct investment are seen in this context as being important drivers of increased atmospheric CO₂ emissions. Aziz et al. (2020) examined the effects of tourism and renewable energy on environmental degradation in a study with a similar design. Additionally, the study's findings imply that countries' natural resources are being exploited by overly vigorous economic activity. In the context of Pakistan, Hassan et al. (2018) examined the relationship between natural resources and ecological footprint. The study's findings demonstrate how natural resources support and shield the environment from further deterioration. Miyah et al. (2022) investigated the link between environmental change and the coronavirus epidemic in this line of research; they concluded that the coronavirus has improved the quality of air, water, and land fertility as most of the world was being into a lockdown situation. During the lockdown situation, the ecology of the world has been improved. In addition, Balsalobre-Lorente et al. (2018) examined the connection between natural resources and CO₂ emissions in the 5 European countries. The study's findings indicate that as more natural resources are accumulated, the quality of the ecosystem improves. Similarly to this, Bekun and Sarkodie (2019) looked at the connection between the 16 European countries' natural resources and carbon emissions. The study's findings indicate that the overuse of natural resources increases carbon emissions.

Linking between CO₂ emissions and technological innovation

Members of the BRICS nations are the emerging market, developing at a rapid speed in the last 3 to 5 decades. China is one of the important countries in this collaboration and for the overall world as well. China has experienced great industrial, economic, and financial gains in the last decades. The industrial boom leads to massive infrastructure development which needs more fuel, and this consequently increases the amount of carbon emissions. British petroleum's recent report in 2019 declared that the CO₂ emissions of the world show an upward trend. As of 2013, the CO₂ emissions were figured out 25,715.7 million tons, and 33,890.8 million tons were recorded in 2018. This data reveals that a 31.79% increase has been recorded in the elevation of CO₂ emissions. This abundance of greenhouse gases in the ecosystem increases the risk of global warming, which consequently melts the glaciers, rising sea level, and desertification of land. Resultantly, the more CO₂ emissions, the more will be social and environmental problems (Zhao et al. 2021).

Saqib et al. (2023a) examine the relationship between energy and environmental degradation taking the case of European countries. It was depicted that renewable energy has a negative and energy consumption has a positive impact on environmental degradation. This may be due to the shifting from fossil fuels to renewable energy sources like solar, wind, hydro, and geothermal, which help reduce carbon emissions associated with energy production.

The world considers China as the main contributor to the eradication of the ecosystem of different regions of the world, in particular, Central Asia and South-East Asian regions. China is under the so-called "New Normal" situation; they are thinking to overhaul its political, social, and corporate structures to mitigate the adverse impacts of CO₂ emissions. To further this notion, Yu and Du (2019) analyzed the context of China and the linkages between technological innovation and CO₂ emissions. Their study's findings indicate that the country's carbon emissions are rising as a result of technological advancements. The risk of environmental deterioration is increased by the rising trend of CO₂ emissions brought on by industrial expansion, as also explored by Wen et al. (2020). They looked into how technology advancements affected CO₂ emissions in the Chinese building sector. The results of their study presented that technical innovative equipment and the technical personnel in the construction industry are source provisions of carbon emissions. Additionally, the outcomes demonstrate that modern technological equipment has a beneficial effect on reducing environmental damage. Saqib (2022) examined the linking between technological innovation and environmental quality taking the case of G-7 countries. It was concluded that technological innovations improve environmental quality.

Renewable energy is not only a source of getting an abundance of energy in simple and economic ways but also it makes security and energy policy independent from external influence. Technological innovation would facilitate the transition of energy production from traditional means to more renewable ones. Khan et al. (2023) studied that demand for energy consumption has increased in South Asia countries. Therefore, energy consumption leads to environmental degradation in the South Asian countries. Saqib et al. (2022) have studied the relationship between technological innovation and carbon emissions, taking the case of emerging seven countries. The results show that technological innovation and modernization improve environmental quality. Furthermore, in this context, Saqib et al. (2023b) investigated the relationship between technological innovation and environmental sustainability. Their results concluded that technological innovation reduces environmental degradation. Lin and Zhu (2019) assert that technological innovation actively contributes to environmental stability and produce environmental deterioration and climatic change. The results of

their research imply that technological advancements in the energy sector cause CO₂ emissions. According to Adebayo et al. (2021), businesses and the government should spend more money on R&D to find ways to generate energy from renewable sources and employ tools to reduce CO₂ emissions. Similar to other research, Brazil's economic growth increases CO₂ emissions because of the country's increased energy needs. Ahmed and Jahanzeb (2020) investigated the effect of technological advancement on CO₂ emissions in Brazil. The authors of the study concluded that increased exports and economic expansion are beneficial for technical innovation. Because of this, there would be a decrease in CO₂ emissions as technology advanced.

Materials and methods

Data and variables

This study focuses on the effect of economic growth, tourism, natural resources, and technological innovation on CO₂ emissions in BRICS member countries. The panel data set was employed between 1995 and 2018. All of the study's variables and all of the grouped nations' panel data sets were from the World Bank's database. The CO₂ emissions, expressed in metric tonnes per person, serve as the study's dependent variable. The independent variables, like economic growth, were calculated using the economic growth per capita constant 2010 USD. Tourism and natural resources were taken as a number of arrivals and percent of GDP. The last variable technological innovation was taken as patent applications in these countries. Table 1 contains a detailed overview of the variables.

This study adopted modern econometric methods to perform the analysis. Therefore, we performed the cross-sectional dependency test of Pesaran (2021) followed by the heterogeneity test of Pesaran and Yamagata (2008). The cross-sectional dependence analysis has the potential to overcome biased estimates or meaningless results. This

study is focusing on BRICS countries which have diversified cultures in many aspects such as the social, political, and economic environment.

Moreover, these countries are emerging markets and have greater potential to cater to the consumer market. In addition to that, these countries used fossil fuels in exponential amounts to meet the expectations of consumers. Over the years these countries saw an upward trend in technological innovation and tourism as well. Further, these countries have signed multiple agreements for their mutual interest. Therefore, in these circumstances, the cross-sectional dependency (CD) test is mandatory to overcome the biases (Chien et al. 2021; Dogan and Seker 2016 2016). As a result, we used the following Pesaran (2021) equation to examine whether CD is present or not.

$$CD = \sqrt{\frac{2T}{N(N-1)} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij} \right)} \sim N(0, 1)_{i,j} \quad (1)$$

$$CD = 1, 2, 3, 4, \dots, 0.15 \dots N.$$

$$M = \sqrt{\frac{2T}{N(N-1)} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij} \right) \frac{(T-K)\widehat{\rho}_{2_{ij}} - E(T-K)\widehat{\rho}_{2_{ij}}}{\text{Var}(T-K)\widehat{\rho}_{2_{ij}}}} \quad (2)$$

where $\widehat{\rho}_{2_{ij}}$ displays the sample estimates for the residual pairwise correlation coefficient derived using the OLS-ordinary least squares method. The null hypothesis must be rejected in favor of the alternative when CD is valid.

The slope heterogeneity test was invented by Pesaran and Yamagata (2008). This test is being done to see if the countries in the chosen panel data set are homogeneous. Additionally, this test has a considerable advantage over the other heterogeneity tests, and it is regarded as innovative because it accepts the CD test (Khan et al. 2020a). Homogeneity issue is very critical in most of the panel data. However, this study considered that BRICS countries are likely to show viable differences such as socially, economically, and geographically. Therefore, the coefficient in the heterogeneity test would show significant differences. The mean slope heterogeneity test described by Pesaran and Yamagata (2008) is expressed in the form of the following equations:

$$\widehat{\Delta}_{SH} = N^{\frac{1}{2}} 2K^{-\frac{1}{2}} \left(\frac{1}{N} \widehat{S} - k \right) \quad (3)$$

$$\widehat{\Delta}_{ASH} = (N)^{\frac{1}{2}} \left(\frac{2k(T-k-1)}{T+1} \right)^{-\frac{1}{2}} \left(\frac{1}{N} \widehat{S} - k \right) \quad (4)$$

After CD and slope heterogeneity test of Pesaran (2007), we run a unit root test to check what kind of order in which the variables co-integrated. All the variables involved in this research take into account in this test. More importantly, the first-generation unit root result relies on the CD test.

Table 1 An overview of the variables

Variable	Abbreviations	Measurement	Source
Carbon dioxide emissions	CO ₂	Metric tons per capita	WDI
Economic growth	EG	Economic growth per capita (constant 2010 USD)	WDI
Tourism	TR	Number of arrivals	WDI
Natural resources	NR	Percent of GDP	WDI
Technological innovation	TI	Patent applications (resident + non-resident)	WDI

Therefore, the test results may be ambiguous or incorrect if CD is present in the panel data (Seker 2016). Moreover, to perform authentic results this study performs parametric and non-parametric tests. Accordingly, in the same situation, Khan et al. (2020a, b) suggested that parametric and non-parametric tests are very useful to tackle these kinds of problems. These tests would prevent data from being biased.

$$\Delta W_{i,t} = \phi_i + \phi_i Z_{i,t-1} + \phi_i \bar{Z}_{i,t-1} + \sum_{l=0}^p \phi_{il} \Delta \bar{W}_{t-1} + \sum_{l=0}^p \phi_{il} \Delta W_{i,t-1} + \mu_{it} \quad (5)$$

$$\widehat{CIPS} = N^{-1} \sum_{i=1}^n CADF_i \quad (6)$$

Westerlund cointegration test

Once it was confirmed that all the series in the panel data set are appropriate for co-integration tests, the Westerlund test was adopted. Accordingly, Westerlund's (2007) panel co-integration test was performed to examine the equilibrium association among the variables. Westerlund cointegration test employs among the variables to check if the cointegration exists or not before going for the estimation of long-run parameters. Westerlund's (2007) cointegration test is very reliable and gives accurate results, that is why we employ this test after CD, slope heterogeneity, and unit root tests. We also consider this test to run for the panel data because it is one of the great ways to deal dependency of all the cross-sections and it also helps to rectify the error terms of slope heterogeneity tests. The equation for this test is given as

$$\alpha_i(L) \Delta y_{it} = \delta_{1i} + \delta_{2i} t + \alpha_i y_{it-1} - \beta_i x_{it-1} + \lambda_i \left(\begin{matrix} L \\ L \end{matrix} \right) v_{it} + e_{it} \quad (7)$$

In the above equation, β_i is a coefficient for error correction and α_i is the vector for the co-integration association, whereas x and y are the variables to find the co-integration association.

$$G_a = \frac{1}{N} \sum_{i=1}^N \frac{T \alpha_i}{\alpha_i(1)} \quad (8)$$

$$P_i = \frac{\alpha}{SE(\alpha)} \quad (9)$$

$$\alpha = \frac{P_a}{T} \quad (10)$$

CS-ARDL test

After all, this study used the Chudik and Pesaran (2015) model known as augmented ARDL. It is the advanced version of augmented ARDL specifically used for panel data, termed the cross-sectional ARDL (CS-ARDL) model. This technique is very famous and Chudik (2013) proposed and established the CS-ARDL model. The short-run and long-run elasticities of the variables utilized in the panel data are directly provided by the CS-ARDL model. These outcomes were verified with the help of the AMG technique described as an augmented mean group (Eberhardt 2012). The directional flow of the variables was examined with the help of the Granger causality test developed by Dumitrescu and Hurlin (2012). The following is a detailed explanation of the study's methodology.

Empirically, to evaluate the relationship between economic growth, tourism, technological innovation, natural resources, and CO₂ emissions, CS-ARDL was utilized in this study. There are several methods or techniques to check and rectify the errors in the past presented by many economists. However, all these first-generation methods like FMOLS, DOLS, etc. (Al-Mulali, and Ozturk 2015), yielded biased and unreliable results due to the inconsistency that these models have provided the best results (Danish et al. 2020). The CR-ARDL model has a significant impact and works smoothened while facing the endogeneity and non-stationarity of the data (Chudik 2013). It is also used to control the issues of cross-section dependency, the slope of heterogeneity, and short- and long-run links between the data and more pertinently present efficient, reliable, genuine, and robust results. It is empirically represented as

$$CO_{2it} = \alpha_0 + \sum_{j=1}^p \gamma_{it} CO_{2i,t-j} PC + \sum_{j=1}^p \alpha_{it} X_{i,t-j} + \sum_{j=1}^3 v_{it} \bar{Z}_{i,t-j} + \mu_{it} \quad (11)$$

where $Z_t = (\Delta CO_{2t}, X'_t)'$, $X_{it} = (EG_{it} + TR_{it} + NR_{it} + TI_{it})'$, and X is a set of independent variables such as economic growth, tourism, natural resources, and technological innovations.

$$CO_{2it} = \varphi_0 + \varphi_1 \Delta EG_{it} + \varphi_2 \Delta TR_{it} + \varphi_3 \Delta NR_{it} + \varphi_4 \Delta TI_{it} + \sum_{t=2}^T P_t (AD_t) + \mu_{it} \quad (12)$$

where j denotes the dummy time parameters and AD_t stands for the first difference $T-1$ period dummies. The following step is changed to the variable, illuminating the typical dynamic process as follows:

$$CO_{2it} = \varphi_0 + \varphi_1 \Delta EG_{it} + \varphi_2 \Delta TR_{it} + \varphi_3 \Delta NR_{it} + \varphi_4 \Delta TI_{it} + d_1(\lambda_t) + \mu_{it} \quad (13)$$

$$CO_{2it} - \lambda_t = \varphi_0 + \varphi_1 \Delta EG_{it} + \varphi_2 \Delta TR_{it} + \varphi_3 \Delta NR_{it} + \varphi_4 \Delta TI_{it} + \mu_{it} \quad (14)$$

Table 2 Results of cross-sectional dependence analysis

Variable	Test statistics (<i>P</i> -values)
CO ₂	10.23*** (0.00)
EG	11.99*** (0.00)
TR	11.98*** (0.00)
NR	11.18*** (0.00)
TI	11.95*** (0.00)

*** explains the level of significance at 1%, whereas the values in parentheses contain *P*-values

The average values of the group-specific models are established in the study after the regression model of the group-specific variables has first been reformed with ϕt .

Results

The econometrics results are provided in this part of the paper. The BRICS countries due to globalization and trade liberalization become more dependent on each other. Any change in condition in one country has a negative or positive impact on other countries. So, it is important to run a CD test of Pesaran (2021) to negate the possibility of any biased results (Khan et al. 2020a; Westerlund 2007). Table 2 shows the cross-sectional dependence analysis and the results reveal that a variation does exist in the coefficient of the variables. These results suggest that CD is valid and shows the cross-sectional dependency of one country over another. The presence of cross-sectional dependency means any change in one country either in economic growth, tourism, natural resources, and technological innovation on ecological footprint, and has a ripple effect on each other.

In Table 3, the results of the heterogeneity test are displayed. The heterogeneity test's findings support the panel data's presence of heterogeneity. So, the slope would vary across the countries due to the heterogeneous behavior of the panel data. It indicates that a change in any factor in one country would not specifically cause a change in other countries for the same variable. Further, if the results of the heterogeneity test were not heterogeneous, then we would assume that there is a severe issue of homogeneity does exist in the panel data. These results would be considered

Table 3 Slope heterogeneity test results

Test	Value	<i>P</i> -value
$\tilde{\Delta}$	1.69*	0.09
$\tilde{\Delta}_{adjusted}$	1.96**	0.04

The symbols ** and * indicate the significance levels at 5 and 10%, respectively

Table 4 Results of unit root tests

Variable	CIPS		CADF	
	Level	First difference	Level	First difference
CO ₂	−1.68	−3.38***	−2.027	3.651***
EG	−2.38	−3.48***	−2.033	−3.388***
TR	−2.64	−4.69***	−2.882	−3.151***
NR	−2.20	−4.44**	−2.234	−3.455***
TI	−2.80	−5.18***	−1.273	−2.748***

The symbols *** and ** indicate the significance levels at 1 and 5%, respectively

biased and erroneous estimations, more specifically uncertain outcomes (Alam et al. 2018). In addition, we include the updated second-generation unit root tests like CADF and CIPS if the CD and heterogeneous results dominate in the panel data analysis.

The study conducted CIPS and CADF second-generation unit root testing at the level and first difference after the heterogeneity tests. Table 4 displays the findings from the CIPS and CADF tests. Additionally, the CIPS and CADF tests would verify the outcomes of panel data due to their implications for CD and heterogeneity tests. The fundamental benefit of these tests is that they strictly avoid the occurrence of misleading estimations (Ulucak and Bilgili 2018). Therefore, adopting the second generation of unit root tests using CIPS and CADF is hence more authentic. This procedure would reveal that the data series has stationarity. Furthermore, in comparison, CIPS results are more reliable and imperative than CADF in the occurrence of CD and heterogeneity analysis. All of the variables were non-stationary before the first difference was taken, according to the findings of the unit root tests conducted on the CIPS and CADF. As a result, all variables at first difference had integrated of order $I \sim (1)$ and were significant at a 1% level of significance. Additionally, mixed integration softened the path for both the CS-ARDL and Westerlund's (2007) cointegration approaches due to the stationarity of the variables at the level and first difference.

Table 5 displays the result of the Westerlund test panel cointegration. The cointegration test's illustrative results are provided by the statistical and panel groups (Gt, Ga) and (Pt,

Table 5 Westerlund cointegration test results

Statistic	Value	Z-value	<i>P</i> -value	Robust <i>P</i> -value
G_t	−3.75***	3.99	0.09	0.00
G_a	−0.15	3.41	1.00	0.81
P_t	−4.67***	−0.31	0.06	0.00
P_a	−0.90	2.32	0.99	0.59

The symbol *** indicates the significance level at 1%

Pa). The findings show that the dependent and independent variables in the research study indeed have a long-term cointegration nexus. As a result, the null hypothesis is rejected in favor of the alternative hypothesis. After establishing a cointegration between the dependent variable and independent factors, this study proceeded with its panel data analysis. As a result, the analysis of the study used the CS-ARDL test after performing the stationarity and cointegration tests to determine the short- and long-term relationships between economic growth, tourism, natural resources, technological innovation, and CO₂ emissions.

The findings of the CS-ARDL model are shown in Table 6. The ECT term means the speed of adjustment is negatively significant. This suggests that ECT in long-run equilibrium will move at 0.80 speed of adjustment. These findings demonstrate both the short- and long-term relationships between all of these variables. Economic growth's short-term coefficient value is 3.17, with a standard deviation of 1.59. It indicates that a 1% increase in economic growth would result in a 3.17% increase in CO₂. The coefficient for natural resources and technological innovation shows similar trends, but tourism has a negative coefficient of 0.70. This suggests that a 1% increase in natural resources and technological innovation would enhance 0.56 and 0.14% CO₂ emissions, respectively, in the BRICS countries. The only variable that exhibits a short-term negative trend is tourism. These results suggest that positive change in tourism will decrease CO₂ emissions. Nevertheless, tourism shows consistent results in the long run of CS-ARDL analysis. This indicates that, over time, tourism also lowers CO₂ emissions. Additionally, the BRICS economies' 0.39% CO₂ emissions would decrease with a 1% rise in tourism. The analysis demonstrates that economic growth has a

positive influence on CO₂ emissions in both the short and long terms. In the long run, the CS-ARDL models predict that a 1% rise in economic growth will result in a 1.9% increase in CO₂ emissions. Additionally, according to the BRICS economies, the coefficients of natural resource and technical innovation indicate a positive impact on CO₂ emissions. This implies that, in the long run of the panel data estimation, 1% increase in natural resource and technical innovation would raise 0.15 and 0.10% CO₂ emissions, respectively.

The robustness tests including “the augmented mean group (AMG), and the common correlated effects mean group (CCEMG)” results are presented in Table 7. The coefficients of AMG and CCEMG of 0.078 and 0.085% show a positive correlation between economic growth and carbon emissions. On the other hand, tourism and carbon emissions have a negative correlation, with values of 1.770%, 0.931% AMG, and CCEMG, respectively. Moreover, natural resources and carbon emissions have a positive association both in AMG and CCEMG with coefficient values of 2.940% and 1.850%, respectively. The technological innovations have a negative correlation with the carbon emissions with values of 0.029% and 0.032%, AMG and CCEMG, respectively. The results of the robustness evaluation have confirmed the conclusions made by the CS-ARDL model. Additionally, Voumik et al. (2023) used the CS-ARDL approach to examine the relationships between variables over short and long terms and the AMG and CCEMG methods to assess the validity of their conclusions.

Discussions

The findings of this study shed light on the relationship between CO₂ emissions and economic growth in the BRICS countries. These results are heterogeneous as all the countries' conditions are different in socioeconomic as well as in the geographical environment. Moreover, it is much unblemished that economic growth is the main driving force to enhance CO₂ emissions. The findings of this study demonstrate that rising CO₂ emissions in the BRICS economies are a result of economic expansion. These findings

Table 6 Results of the CS-ARDL test

Variables	Coefficient	Standard error	Significance level
Short run			
$\Delta \ln EG_t$	3.17***	1.59	0.00
$\Delta \ln TR_t$	-0.70***	1.68	0.00
$\Delta \ln NR_t$	0.56***	0.56	0.00
$\Delta \ln TI_t$	0.14***	0.14	0.00
Long run			
$\ln EG_t$	1.79***	1.15	0.00
$\ln TR_t$	-0.39***	0.34	0.00
$\ln NR_t$	0.15***	0.06	0.00
$\ln TI_t$	0.10***	0.12	0.00
ECM	-0.80***		0.00

The symbol *** indicates the significance level at 1%

Table 7 Robustness tests

Variable	AMG	CCEMG
$\ln EG$	0.078**	0.085***
$\ln TR$	-1.770***	-0.931***
$\ln NR$	2.940**	1.850**
$\ln TI$	-0.029***	-0.032***

The symbol *** and ** indicates the significance level at 1% and 5% respectively

support those of Uddin et al. (2019), Ahmed et al. (2020), and Destek and Sinha (2020). This result suggests that the intensification of fast developments in the economies like BRICS countries enhances their national growth. Within the previous two decades, this phenomenon has tremendously enhanced economic growth which turns to the deterioration of the environment. The analysis's findings also imply that there is a positive relationship between CO₂ emissions and natural resources. These findings are in line with those made by earlier researchers Hassan et al. (2019) for Pakistan and Ahmed et al. (2020) for China. The findings of this study, on the other hand, are found to conflict with those of Danish et al. (2020) and Zafar et al. (2019), which demonstrate that environmental degradation may be controlled with the appropriate use of natural resources. However, most of the fast-growing economies exploit their natural resources very rapidly. Further, the fast-growing economies produce a plentiful quantity of coal to fulfill their energy demand. Therefore, fast-growing economies put extra pressure on environmental degradation. Furthermore, Hilmawan and Clark (2019) observe that as natural resource availability grows, so does the country's economic performance, which validates the nature and importance of the link in the context of Indonesia.

Moreover, the results of technological innovations and CO₂ emissions show a positive relationship. These results are consistent with the findings of the previous scholar's result (Santra 2017). The author discloses that technological innovation is the key contributing factor to CO₂ emission stimulation. However, the findings of Mensah et al. (2018) for ECD, Shahbaz et al. (2020) for China, and Cho and Sohn (2018) for a group of EU countries conflict with our findings. According to these researchers' findings, technological innovation is essential to generating and reducing CO₂ emissions. Lowering carbon emissions would lead to sustainable development, particularly in BRICS economies. Technological innovation helps in maximizing energy efficiency by producing minimum carbon emissions. Moreover, Khan and Ullah (2019) studied that economic, political, and social globalization enhances carbon emissions in the case of Pakistan. Saqib (2022) looked at the relationship between technical advancement and environmental quality using the G-7 as a case study. It was determined that technical advancements raise the standard of the environment. Furthermore, the results of tourism and CO₂ emissions show a negative relationship. The findings of Jiaqi et al. (2022) have been used to support these results. On the other hand, our results are conflicting with the study performed by Katircioglu et al. (2020). The authors of the study examined the association between tourism and carbon emissions in Cyprus. Their study's findings indicate that tourism and environmental degradation are positively connected. Saqib et al. (2022)

examined the connection between technical advancement and carbon emissions using the example of seven developing nations. The findings indicate that modernization and technological advancement enhance environmental quality. Additionally, Saqib et al. (2023b) looked into the connection between technical advancement and environmental sustainability in this context. According to their findings, technological innovation slows down environmental damage. Theoretical underpinnings of the study's findings clarify why carbon emissions rise with tourism-related arrivals and fall with tourism-related earnings. Two causes could be the basis for it: One of the key elements that have a significant impact on the global natural environment is international travel transportation. As the tourism industry develops, so do transportation services and the number of visitors arriving and departing. The majority of the CO₂ emissions associated with tourism are attributed to the aviation industry, with transportation services accounting for close to 95% of those emissions, according to Brida et al. (2020). The variety of infrastructural services, such as housing, dining, and lodging facilities, as well as ports, airports, communication networks, railroads, and roadways, expands along with the number of tourists. Infrastructure development and the growth of tourism attractions both significantly contribute to rising carbon emissions.

Conclusions and policy implications

The primary goal of this research study is to investigate the linkages between CO₂ emissions, economic growth, tourism, and other natural resources in the Brics countries. The panel data were utilized between 1995 and 2018. The panel data estimation models, including the CS-ARDL and Westerglund's (2007) cointegration test, were applied to panel unit root tests (CIPS and CADF) and were used to investigate the stationarity of the data. The panel unit root test findings imply that none of the variables are stationary at levels for any of the variables. However, at the first difference, all the variables become stationary. The cointegration results show that there is a significant link between the dependent and independent variables. Moreover, the results of the panel data estimations are aligned with the economic theory. Achieving highly accelerating economic growth has widely affected the environment of most of the BRICS countries. Therefore, the result of the analysis confirms that economic growth is the main contributor to CO₂ emissions in the BRICS economies. Further, the over-exploitation of natural resources has drastically damaged the environment. The findings of this study confirmed that natural resources raise the concentration of CO₂ emissions in the panel data countries.

The study's findings have led to the following policy implication, which has been identified. The study's findings show that the BRICS countries' increased carbon emissions are a result of overusing their natural resources. To achieve sustainable development, it may be possible to implement a policy that prohibits the exploitation or overexploitation of natural resources and instead makes efficient use of those that already exist. Additionally, the efficient use of natural resources would rise with the development of technology. This study supports the idea that tourism reduces carbon emissions in the BRICS countries. Therefore, the promotion of sustainable tourism is highly important in these countries, so the high impact of environmental degradation pressure may reduce to some extent. Likewise, incentive-based sustainable tourism should be promoted. The incentive-based tourism would increase environmental sustainability in addition to economic growth. Secondly, in the context of a green economy, the relationships between tourism and technical advancement should be strengthened. The BRICS countries' environmental pollution would have diminished as a result. Because this study is solely focused on the BRICS economies and has a short panel data time range, it can be expanded to include other groups of countries. Therefore, a large panel data collection would be important for the next research. However, the study suggests that the government and policymakers create a framework for using natural resources in a better and more effective way, which can aid the nation's efforts to improve economic performance. Furthermore, the government needs to take a balanced approach to economic development and growth so that it may give priority to the industries that will ultimately lead to economic growth. To prevent waste and leakages that could result from the use of technology and incorporating innovations, resource extraction efficiency needs to be increased. Finally, for effective management, the governance structure needs to be enhanced, which will aid in better protecting and preserving natural resources.

Governments should allocate funding for research and development initiatives focused on technological innovations that can reduce carbon emissions specifically in the tourism sector. This can include support for projects related to renewable energy, energy-efficient transportation, sustainable infrastructure, and smart tourism solutions. Further, the governments can provide financial incentives, tax breaks, or grants to tourism businesses that adopt and implement sustainable technologies. This can encourage the adoption of energy-efficient systems, renewable energy sources, and low-carbon transportation options. Governments should facilitate collaboration between technology providers, tourism businesses, and research institutions to create innovation platforms. These platforms can encourage knowledge sharing, partnerships, and the co-creation of technological solutions that address

carbon emissions in the tourism industry. Governments can invest in capacity-building programs and training initiatives to enhance the technical skills and knowledge of tourism industry professionals. International cooperation: Governments can engage in international collaborations and partnerships to share best practices, exchange knowledge, and jointly address the carbon emission challenges in the tourism industry. This can include participating in global initiatives, sharing research findings, and coordinating efforts to develop common standards and guidelines. Governments can implement educational campaigns to raise awareness among tourists about the carbon footprint of their travel choices. Promoting responsible travel practices, eco-friendly accommodations, and low-carbon transportation options can encourage tourists to make more sustainable choices.

A few limitations apply to the current investigation. The factors in this study are investigated using quantitative time series data. However, qualitative information should be collected by interviewing domestic and international travelers who stayed at hotels in various tourist destinations to identify the common link among these aspects, particularly with determinants and tourism. This will present a fresh perspective on the tourism sector and aid in the collection of useful tourist recommendations, both of which will be helpful to policymakers when evolving policies for the industry.

Author contribution Arif Ullah designed, construct, and wrote the manuscript. Usman Mehmood conducted the analysis. Kashif Raza assisted in writing the manuscript.

Data availability Data are available on reasonable request from the corresponding author.

Materials availability Not required.

Declarations

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