



Economic performance and carbon emissions: revisiting the role of tourism and energy efficiency for BRICS economies

Adnan Alfaisal¹ · Tongshui Xia¹ · Kafeel Kafeel² · Sher Khan³

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Abstract

Increased demands for infrastructure, water, electricity, and different natural assets have triggered land erosion, climate change, and pollution increase and deterioration in biodiversity. The purpose of this research is to look at how economic performance, tourism, renewable energy, and energy efficiency affect carbon emissions in the emerging economies of BRICS during 1990–2021. Using panel estimation approaches, the empirical outcomes validate the longer-run equilibrium connection between the components of the model. Using a nonparametric estimator, the study found that economic performance is the significant driver of higher emissions levels in the sample countries. In contrast, tourism, energy efficiency, and renewable energy substantially reduce emissions levels and improve environmental sustainability. The estimated results have been found robust, and the feedback effect is found valid between repressors and carbon emissions. This study further suggests that investment in research and development, improvement in energy-efficient tools and equipment utilization, and enhanced renewable energy output are the key policy efforts for ensuring environmental sustainability.

Keywords Economic growth · BRICS economies · Energy efficiency · Tourism · Renewable electricity · Carbon emissions

✉ Tongshui Xia
tsxia@sina.com

✉ Sher Khan
sherkhan4477@gmail.com; khan41@uniba.sk

Adnan Alfaisal
adnanalfaisal66@gmail.com

Kafeel Kafeel
kafeelxtu@gmail.com

¹ Department of Management Science and Engineering, Shandong Normal University, Jinan, Shandong, China

² Business School, Xiangtan University, Xiangtan, Hunan, China

³ Faculty of Management, Institute of International Management, Comenius University, Bratislava, Slovakia

1 Introduction

The worldwide community has steadily considered the problem of air pollution in recent years—brought on by high carbon (CO₂) emissions (Azam et al., 2016). It is a matter of global environmental contamination that affects a wide range of aspects of living and social production. As a result, it will have an influence on both the current economic development route and how the economy will evolve in the future. Additionally, it will have an impact on how economic interests are distributed and how different nations choose their national policies. All nations exhibit the same stage features when seen in the context of global economic growth. A number of the major industrialized nations and regions have completed the industrialization process, which resulted in high energy utilization and significant CO₂ emissions (Akadiri & Adebayo, 2022). According to Youmani (2017), depending on the composition effect, economic expansion either favorably or adversely influences the natural chemistry of the environment. It was argued that industrial operations using less polluting technology lessen the harmful effects of economic activity on environmental sustainability and vice versa (see Brock & Taylor, 2005). Additionally, the tertiary industry, with its low energy usage and low-CO₂ emission, makes up the majority of the industry structure in developed countries. The industrial structure has evolved as a result of the economy's fast expansion. A number of advantages, including higher income, societal cohesion, and expanded employment, result from ongoing and significant economic expansion. However, certain regrettable negative characteristics, such as excessive energy waste and ecological damage, have sadly evolved alongside quick economic progress. The agricultural industry uses a variety of contemporary energy sources, some of which can produce highly harmful CO₂, as it transitions from an immense activity to energy-intensive farming. Kuznets (1995) anticipated the concept that as per capita income increases, wealth disparity reaches its peak and then diminishes in tandem with the law of diminishing returns. This theory was developed in an attempt to elucidate the debate over the question of whether economic expansion has an adverse effect on environmental quality. Economic expansion and the desire for a satisfying life force an increase in income. The key drivers of rising energy consumption have been identified as industrialization, globalization, exponential population growth, and shifts in lifestyles. Because of economic activity aimed at boosting gross domestic product (GDP), CO₂ emissions always rise in tandem with energy consumption (Apergis & Ozturk, 2015).

Because they provide more alluring prospects for travelers in both outward and incoming tourism, these countries have a bright future for economic growth and have enormous potential for tourism growth. Additionally, in order to increase their GDP to 37.7% by 2030, these nations are also increasing ICT-based activities. The collective GNP of Europe and the US (15 and 15.3%, respectively) is less than this economic worth (World Bank 17). Aside from the BRICS nation's continued economic growth, which cannot be ignored, tourism expansion also influences the quality of the environment (Dong et al., 2019).

The BRICS¹ nations have appeared as a prospective group among emerging nations that attracts the majority of visitors from industrialized nations. At the 2017 BRICS Xiamen Summit in China, tourism was a prominent topic of discussion. These nations are popular tourist attractions across the world and have strong growth rates. China is listed as a significant

¹ Where B: Brazil; R: Russia; I: India; C: China; and S: South Africa.

destination among BRICS nations, followed by South Africa, Russia, India, and Brazil. During 1990–2014, these countries increased from 11% of the global GDP to nearly. Owing to its growing long-term involvement in economic expansion and development, the significance of tourism arrivals has increased enormously. It boosts revenues through rising reserves of foreign currency, promoting investments in human capital and new infrastructure, as well as expanding competitiveness, encouraging growth in industry and employment generation, and thus raising income. Tourism that comes from abroad also generates beneficial economic effects, and as the country's economy develops, one might suggest that a rise in GDP might result in an enhanced tourism industry. The BRICS is five countries that are steadily developing, as per the Future Market Insights report in 2020 (Razzaq et al., 2021; Davis et al., 2018; Chien et al., 2021).

Regarding its effects on the environment, greater research has to be done on how quickly the tourist industry is growing in the BRICS nations. As per Aziz et al. (2020), continued overconsumption of natural resources for tourism will result in a higher level of environmental deterioration. Additionally, this will cause the depletion of natural resources and create environmental instability for future generations (s). British Petroleum estimates that BRICS countries produce 40% of the world's CO₂ emissions (Petroleum, 2018). The BRICS economies' elevated CO₂ and greenhouse gas emissions have resulted in dangerous environmental risks (Zhang et al., 2022; Sun et al., 2022; Davis et al., 2018). At all times, BRICS countries have encouraged strategies for achieving CO₂ neutrality goals, advancements in zero-emissions technological advances, enhanced power and infrastructural assets, regulated expansion of novel high-energy initiatives, and green financial investments. The BRICS countries have instituted governance programs to establish economic development frameworks. Though technical modernization has increased in the BRICS nation's development, there are a number of issues with inadequate technological development, high-tech infrastructure, and environmentally friendly industrial output. With an increase of 164.9% in 2019 compared to 2008, China has continued to see significant progress in terms of technology (Zhang et al., 2022). After the background, this research aims to examine the empirical connection between economic performance and the environment of the BRICS region. However, a number of empirical studies are available in this context. However, the present study adopts the extended dataset to explore the more comprehensive connections that exist between them. This study also purposes to analyze the role of tourism in environmental quality. Since the BRICS region is currently one the most visited spot across the globe for international tourists, therefore, their importance cannot be ignored in identifying the factors of environmental degradation in the BRICS region. Besides, this study also tends to examine the role energy efficiency and renewable electricity play in the quality of the environment. Since the developed and developing economies are already investigated in the literature. Still, the BRICS region remained out of focus in terms of such a lens, which needs appropriate evidence from the policy perspective. The study is further classified into the following sections: Sect. 2 provides a review of the literature and its summary, along with the gap. Section 3 outlines the conceptual framework and data and model specification. Section 4 discloses the estimation approaches and results and discussion for the empirical outcomes, respectively. Finally, Sect. 5 provides the concluding remarks along with the policy suggestions.

2 Review of literature

2.1 Studies on the impact of CO₂ emission and environmental degradation

Aye and Edoja (2017) stated that economic development was predicted to have an impact on CO₂ emissions. Global warming and indirect environmental deterioration are both believed to be caused by CO₂ emissions, which are classified as greenhouse gases. The authors disprove the idea that the efficiency of the environment will recover as wages rise and instead argue that if action is not taken to minimize CO₂ footprints, more CO₂ will be emitted into the atmosphere.

In this way, industrialization and development aggravate the effects on the environment. The slow environmental destruction and its components, such as the water, ecosystem, air, soil, animal, and habitat, as a result of unchecked human activity is known as environmental impact or degradation (Conservation Energy, CEF, 2016). It has been formally recognized that the degradation of the environment poses a serious threat to both humanity and nature (Aye & Edoja, 2017). According to Azam et al. (2016) investigation of environmental deterioration provided by carbon emissions on the profile of a few higher CO₂ emissions economies, there is a direct correlation between CO₂ emissions and economic development in BRICS. According to Pao and Tsai (2010) and Li and Ullah (2022), energy utilization has a significant positive influence on CO₂ emissions for BRICS nations in the longer-term equilibrium. Raza et al. (2021) carried on a nonlinear relationship between economic growth urbanization and environmental degradation. The researcher applied the newly proposed econometric method panel smooth transition regression (PSTR) framework with two schemes to annual panel data from 1995 to 2017. The results suggest that the relationship between tourism development and environmental pollution is nonlinear and system dependent. In addition, the findings showed that above the threshold level, the relationship is negative and significant, while below the threshold, tourism development has a positive and significant effect on environmental pollution. There is also an inverted U-shaped relationship between tourism development and environmental pollution, which means that at a certain point, an increase in tourism development increases environmental pollution, but after a certain point, an increase in tourism development reduces environmental pollution. Economic growth and urbanization also describe a nonlinear and system-dependent relationship with environmental degradation. Research contributes to policy and empirical knowledge.

Yang and Li (2017) identified that a significant quantity of GHG emissions, such as those of CO₂, NO₂, and methane, are to blame for environmental deterioration. According to Shahbaz et al. (2013), the consumption of wood as a fuel the fossil fuels used for daily activities, and the significant smoke emissions from manufacturing facilities all contribute to increased CO₂ emissions. Industries, as well as the economy as a whole, including agriculture and forestry, are negatively impacted by CO₂ emissions. Isik et al. (2019) looked into how real GDP, population, and the use of renewable and fossil energy affected carbon emissions.

Raza et al. (2017) contended on tourism development (TD) and environmental degradation in the USA. Using an empirical transformation framework, this study examines the empirical impact of TD on environmental degradation in a tourism volume economy (i.e., the USA). This new methodology allows time series to be carried at different time frequencies. In this study, they used maximum overlap discrete wavelet transform (MODWT), wavelet covariance, wavelet correlation, continuous wavelet power

spectrum, wavelet coherence spectrum, and wavelet-based Granger causality test to analyze the relationship between TD and CO₂ emissions in the USA using monthly data from 1996(1)–2015(3). The results show that TD has a positive effect on CE mainly in the short, medium, and long term. We find unidirectional effects of TD on CE in the short, medium, and long run in the USA.

According to Mendonç et al. (2020), the use of energy is a critical driver of development and advancement in the economy and has a direct impact on our basic well-being. As a result, public agenda tactics and the full course of economic growth are necessary for consolidating environmental sustainability and managing climatic stress. Energy consumption is naturally influenced by economic activity and technological advancements; however, even while energy is an essential contributor of economic expansion, the adverse effects on welfare may be handled by lowering vulnerability and encouraging the proper kind of growth. The association between our income and carbon emissions is emphasized, i.e., the more money we earn, the more CO₂ we emit. By looking back at the literature that has already been published, we can see that few studies have specifically examined the characteristics of BRICS countries. This knowledge vacuum served as the impetus for this study, which aimed to look into the link between real GDP and CO₂ emissions across BRICS countries in order to better understand a crucial aspect of climate change. Isik et al. (2019) looked into how real GDP, population, and the use of renewable and fossil energy affected carbon emissions.

CO₂ emission is an indicator of the degradation of the environment, and the desire for ecologically sound environments has led to research on CO₂ emission drivers. Several investigations that will be emphasized in this section have investigated various factors that exacerbate the destruction of the environment with varying effects, partially due to the depth of the study, the approach to analysis, and the choice of control factors. Ma et al. (2019) employ a nonparametric approach to the relationship between CO₂ emissions and energy use to conclude that economic growth is China's most significant predictor of CO₂ emissions. The above findings are identical to Lin and Raza's (2019) finding that Pakistan's energy consumption decreased CO₂ emissions from 1978 to 2017. Similarly, Shaheen et al. (2020) utilize the ARDL method to demonstrate that Pakistan's energy usage and GDP increased CO₂ emissions during 1972–2014.

2.2 The nexus between CO₂ emissions, energy efficiency, and renewables

The study of Akram et al. (2022) analyzed the dynamic connection between renewable energy, energy efficiency, and pollution in Mexico, Indonesia, Nigeria, and Turkey (MINT) economies. Using various panel estimators for the period 1990–2014, the outcomes indicate that energy efficiency and renewable significantly reduce the level of emissions in the countries. Akadiri and Adebayo (2022) documented that the use of non-renewable energy is a substantial driver of economic prosperity in India. Whereas renewable energy sources via energy-efficient and energy-saving technologies could reduce environmental degradation. Since there are several factors, which could enhance the creation and consumption of renewable energy, among others, energy intensity, R&D expenditure, technological progress, and economic development are the significant factors of sustainable energy development, i.e., energy efficiency and renewable energy (Alola et al., 2023; Shahzad et al., 2021). In the case of the BRICS region, Adebayo et al. (2023) use CS-ARDL approach and conclude that renewable energy and technological progress could play a pivotal role in decreasing emissions and enhancing environmental

sustainability. Concerning the role of energy efficiency and renewable, there are numerous studies available in the literature that provide empirical evidence regarding their negative role in CO₂ emissions and consequently lead to environmental sustainability, see for instance, Khezri et al. (2022), Luan et al. (2022), Awan et al. (2022), Cai et al. (2022), and Ali et al. (2022) for different regions. Further, the current research of Qin et al. (2021a, 2021b) asserted that renewable electricity, along with financial inclusion and financial development, significantly limits CO₂ emissions.

2.3 Tourism and CO₂ emissions

In recent times, tourism has been regarded as among the substantial aspects of economic expansion in many regions. In this sense, the existing literature also focuses on its environmental consequences for several economies and regions. Further, the study of Razzaq et al. (2023) uses quantile regression and authenticates the tourism-led economic growth assumption in the top ten GDP countries. Besides, the results asserted that both tourism and economic development are significant drivers of environmental deterioration in the region. However, without any mitigation efforts, tourism could deplete around 40% of the global remaining CO₂ budget to 1.5 °C (Gössling et al., 2023). In terms of urban residential CO₂ emissions, Zhou et al. (2023) revealed that tourism agglomeration significantly enhances the urban residential CO₂ emissions level. Unlike the previous studies, Liu et al. (2022) asserted that tourism exhibit an indirect negative and direct positive impact on emissions, where both are highly significant in 70 economies. Apart from these studies, the existing literature provides mixed evidence for various economies including positive (Erdoğan et al., 2022; Ozturk et al., 2022; Raihan et al., 2022), negative (Rahaman et al., 2022; Razzaq et al., 2021; Tong et al., 2022), and asymmetric (Bekun et al., 2022; Wei & Ullah, 2022) influence of tourism on CO₂ emissions in different regions. Zaman et al. (2016) asserted on tourism development energy consumption and environmental Kuznet curves. The study used principal component analysis (PCA) to construct an index of tourism development, which is a combination of tourist arrivals, tourism income, and international tourists. The study examines the relationship between economic growth, carbon dioxide emissions, tourism development, energy demand, domestic investment, and health expenditure with the aim of testing the validity of the environmental Kuznets curve (EKC) hypothesis of three different world regions, including the East Asia & Pacific, European Union and high-income OECD and Non-OECD countries. The results confirm an inverted U-shaped relationship between carbon dioxide emissions and regional per capita income. The results further confirm the following cause–effect relationships: (i) carbon dioxide emissions caused by tourism, (ii) emissions caused by energy, (iii) investments—emissions, (iv) tourism based on economic growth, (v) tourism based on investments, and (vi) tourism development based on health in the region.

3 Research gap

Empirical research has mostly concentrated on the literature suggesting that tourism stimulates economic growth. The investigation will examine the possible relationships between economic expansion and international tourism, considering the corresponding importance of financial growth in the case of the BRICS nations in order to provide

additional support for the nexus. This study is unusual because it examines the nexus between tourists and CO₂ emissions conceptually and practically. Some recent and important literature discussed the influence of energy efficiency, renewable electricity output, and environmental pollution. The research gap was fulfilled in order to study CO₂ emissions from a unique perspective by considering GDP, energy efficiency, tourism, and renewable electricity.

3.1 Hypothesis

H1 There is a positive relationship between carbon emission and GDP.

H2 There is a negative relationship between carbon emission and energy efficiency.

H3 There is a positive or negative relationship between carbon emission and tourism.

H4 There is a negative relationship between carbon emission and renewable electricity (RELO).

4 Methodology

4.1 Theoretical framework and model construction

In the research investigations of the tourism–growth nexus conducted in the framework of BRICS countries, Danish and Wang (2018) determine the connection between global revenues from tourism and financial growth while limiting tourism funding and globalization. Banday and Ismail (2017) estimate the relationship between global tourism receipts and monetary expansion while adjusting for general labor, CO₂ emissions, and gross capital formation without using any boom model. In addition, Usmani et al. (2021) assess the relationship between the arrivals of tourists, worldwide tourism expenditures, and economic expansion while. Therefore, the policy repercussions of these investigations may not be expansionary. Therefore, we recommend utilizing a macroeconomic development strategy to revisit the issue. In macroeconomics, the neoclassical interpretation of long-run growth in money assumes that a rise in an economy's total output depends on uncontrolled population growth and the cost of technological trade (Swan, 1956; Solow, 1956, 1957). Subsequently, Schultz (1992) extended this neoclassical model by arguing that human resources are also an essential component of long-term economic growth. Further, Barro (1996) reported that the growth rates of economies are enhanced with life expectancy and the aid early schooling, lesser fertility, reduced governmental consumption, better maintenance of the rule of law, advanced terms of trade, and lower inflation. In addition, Barro (2003) found that long-term growth in the economy depends strongly on the investment and law ratio, specified in accordance with human capital and per capita GDP. In accordance with these different kinds of neoclassical methods, the total labor force, aggregate capital formation, and human development are significant determinants of long-term economic growth. Subsequently, the tourism-augmented model can be developed by incorporating tourism development indicators such as international tourist arrivals, global tourism receipts, and worldwide spending on tourism. Current research indicates that international tourist arrivals can have a substantial impact on long-term economic growth (Ren et al., 2019a,b; Hakan et al., 2015). Furthermore, international tourism receipts may contribute positively to long-term economic expansion (Boga & Erkisi, 2019; Azeez, 2019; Hüseyini et al., 2017; Govdeli & Direkci, 2017; Tang et al. 2018; Simundic et al. 2016).

Additionally, tourism expenditure may possess a positive long-term influence on the rate of economic expansion (Yazdi et al., 2017; Seghir et al., 2015). Therefore, we regarded these three variables to represent the economic expansion of the tourism zone. Additionally, to the indicators mentioned above, the latest research suggests the growth effect of tourism is dependent upon the enhancement of the economic environment in the destination nation as it strengthens the country's liquidity operation, promotes access to credit and other financial services, and boosts the efficiency of monetary transactions through decreasing the associated fee, which boosts the number of foreign visitors and their expenditures (Shahbaz et al., 2017; Khan et al., 2020). In the literature, the role of FDI inflows in the development of the tourism region has also been emphasized (Fauzel et al., 2017; Boora & Dhankar, 2017; Samimi et al., 2013; Tang et al., 2007; Selvanathan et al., 2012). Hence, we considered economic advancement indicators and foreign direct investment flow in the tourism-augmented development model. Following the preceding debates, we present the following enhanced neoclassical model of long-term economic growth for BRICS economies.

Keeping in mind the study objectives, this research initiated by specifying a baseline model with CO₂ (kt) emissions, whereas the variables (explanatory components) consist of the economic growth (gross domestic product: GDP constant US\$ 2015), energy efficiency [ENEF: GDP per unit of energy consumption (constant 2017 PPP \$ per kilogram of oil equivalent)], tourism [TOUR: foreign tourism, receipts for traveler passage items (current US\$)], and renewable electricity output (RELO: % of total electricity productivity). This research follows Razzaq et al. (2023) and constructed the below given regression model:

$$CO_{2it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 ENEF_{it} + \beta_3 TOUR_{it} + \beta_4 RELO_{it} + \varepsilon_{it} \quad (1)$$

In the above model, it could be distinguished that β_0 is the model's intercept, while $\beta_{1,2,3, \text{and } 4}$ are the slopes for regressors. The error term is depicted via ε , and the subscripts t and i represent time period and cross sections. Specifically, the cross sections include BRICS economies for the period of 1990–2021. For all the selected variables, the data have been obtained from the World Bank.²

4.2 Empirical strategy

This research's practical evaluation of data began with descriptive stats and normalcy indicators of the elements. This study estimates the median, mean, and range of the time series data, with the latter presenting the occurrences with the greatest and smallest values. This research examines the variable's standard deviation, which demonstrates the volatility of time series as a result of the vast variation in range statistics. Using the usual metrics of kurtosis and skewness, this research additionally examines the normalcy of the data. In distinction, the present study used the normalcy test developed by Jarque and Bera (1987), which accounts for excess kurtosis and skewness while keeping their zero values. The process for assessing normalcy statistics using the specified evaluation is as follows:

² To access data for the mentioned variables, visit: <https://databank.worldbank.org/source/world-development-indicators#>

$$JB = \frac{N}{6} \left(S^2 + \frac{(K-3)^2}{4} \right) \quad (2)$$

In order to examine the long-run coefficient, it is essential to apply some diagnostic tests, which could provide a path toward the employment of an appropriate empirical estimator. In this scenario, the present study investigates the cross-sectional dependence and cross-sectional heteroscedasticity in panel data. The presence of cross-sectional correlation may arise from various factors such as unobserved common events, spatial dependencies, or social network exchanges. Failing to account for cross-sectional dependence in panel data can result in significant ramifications (Wei et al., 2022). The presence of serial correlation in data results in a reduction of effectiveness for least squares and renders conclusions invalid due to the preexisting cross-sectional connection. In certain instances, it leads to incongruous estimation. Consequently, it is crucial to examine the cross-sectional dependence of panel residuals. The conventional statistical methods for multivariate analysis, such as the Lagrange multiplier (LM) and log-likelihood ratio tests, are appropriate for use. Specifically, this study uses the Breusch–Pagan LM, Pesaran scaled LM, and Pesaran CD test for cross-sectional dependence and likelihood ratio for slope heterogeneity.

Since the stationarity of data is one of the compulsory conditions for empirical analysis, therefore, this study employs "five" unit root evaluation methods: Levin et al. (2002), Breitung (2001), Im et al. (2003), ADF-Fisher (Maddala & Wu, 1999), and Phillips and Perron (1988). Each of these examinations is undertaken using both level and first-differenced data in order to conduct a comprehensive analysis of stationarity. According to the null supposition, preceding tests showed the existence of a unit root in series. On the other hand, if the statistical data meet its relevance thresholds of 1%, 5%, and 10%, the hypothesis is likely to be disproved.

After the unit root assessment, it is essential for the panel data analysis to examine the long-run equilibrium nexus between the considered variables. Westerlund (2007) created the error correction model (ECM) to evaluate the long-run cointegration in panel nations. Using group mean and panel statistics, the present test tackles the issue of slope heterogeneity cross-sectional dependency with precision. Common formulae for group mean statistics include $G_\tau = \frac{1}{N} \sum_{i=1}^N \frac{\hat{\alpha}_i}{S.E.\hat{\alpha}_i}$, and $G_a = \frac{1}{N} \sum_{i=1}^N \frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)}$, while $P_\tau = \frac{\hat{\alpha}}{S.E(\hat{\alpha})}$, and $P_a = T.\hat{\alpha}$ are employed for assessing the panel's forecasts.

Since the studied variables exhibited stationarity, a prerequisite for elasticity measurement, the long-run elasticity could be determined. Furthermore, the variables include elements of long-term equilibrium relationships. So, it is feasible to calculate the long-run estimates using an effective technique. This study applies the Method of Moment Quantile Regression (MMQR) estimation method developed by Sarkodie and Strezov (2018). This method is more effective than standard regression since it generates accurate predictions at a specified location and scale. In addition, this method is superior to previous estimation methods since it provides estimates for each quantile rather than the average effect. In addition, this technique tackles the endogeneity problem in an appropriate way, making it more suitable for studying long-run coefficients. Under specified assumptions, the following equation defines the location-scale variance $Q_y(\tau|R)$:

$$Y_{it} = \alpha_i + \beta R_{it} + (\gamma_i + \rho \hat{Z}_{it}) \mu_{it}, \quad (3)$$

In the previous equation, the probability expression $p(\gamma_i + \rho \hat{Z}_{it} > 0)$ is identical to one, whereas α, β, γ , and ρ indicate the expected outcomes of the current investigation.

The subscript i represents the fixed effect indicated by the finite elements α_i and γ_i with the notation $i = 1, 2, \dots, n$. However, the k -vector is R 's distinguishing characteristic, as represented by Z , whereas the “ i ” vector emphasizes its variability:

$$Z_i = Z_i(R), i = 1, 2, \dots, k, \quad (4)$$

where R_{it} is distributed independently and identically across time (t), while both t and i are consistent and orthogonal (Machado & Silva, 2019). So, the outside features and reserve are preserved. Using the above reasoning, the essential model of this research [Eq. (1)] may be stated as follows:

$$Q_y(\tau|R_{it}) = (\alpha_i + \gamma_i q(\tau)) + \beta R_{it} + \rho \dot{Z}_{it} q(\tau), \quad (5)$$

In this model's framework, R_{it} comprises the regressors *GDP*, *ENEF*, *TOUR*, and *RELO*. All elements have been transformed to the natural log—allow the estimates for presenting as percentage. Furthermore, R_{it} illustrates the quantile distribution of the regression coefficients, as depicted by Y_{it} , which represents CO_2 and is highly depending on its quantile location. In addition, the equation $-\alpha_i(\tau) \equiv \alpha_i + \gamma_i q(\tau)$ defines the vector component responsible for the persistent impact of quantiles on i . Despite this, the intercept remained uniform throughout all quantiles. Ultimately, $q(\tau)$ delivers the τ th quantile sample, which includes the values $Q^{0.25}$, $Q^{0.50}$, $Q^{0.75}$, and $Q^{0.90}$. As a consequence, the quantile equation used in the current study is shown below.

$$\min_q \sum_i \sum_t \theta_\tau(R_{it} - (\gamma_i + \rho \dot{Z}_{it})q) \quad (6)$$

The assessment formula is $\theta_\tau(A) = (\tau - 1)AI\{A \leq 0\} + TAI\{A > 0\}$.

In addition to examining the basic criteria, the consistency (robustness) of the model was also evaluated. Thus, the present research used the nonparametric robustness approach—Bootstrap Quantile Regression. The distribution of nonlinear data needs the adoption of such a strong approximation for the model's validity. This research takes into account four quantiles for robustness analysis: $Q^{0.25}$, $Q^{0.50}$, $Q^{0.75}$, and $Q^{0.90}$. Further, this investigation also explores the causal association between the variables via applying the pairwise Granger causality test. There has been a lot of interest in the Granger causality test. Since Granger first introduced the concept of causality in 1969, numerous methods have been proposed. The most generally utilized test is vector autoregression (VAR) models presented by Sims (1972). Other regression models, like VECM, GARCH, MGARCH, and a few nonlinear regression models, have likewise been utilized to test Granger causality from that point. In these circumstances, the cross-correlation functions (CCF)-based CCF-test methods are also utilized. To test Granger causality in mean, Haugh (1976) proposed an asymptotically two tests using residual cross correlations. Cheung and Ng (1996) broadened the tests proposed by Haugh (1976) to test causality in fluctuation. The Cheung and Ng (1996) test and the Granger (1969)-type test were included in Hong's (2001) test statistics as special cases. Since Granger causality tests are extremely valuable for examination of causal relationship, they have been generally applied in finance and economics. As of late, time-fluctuating Granger causality has drawn in much consideration from scientists, and a couple of new tests have been proposed. Aaltonen and Östermark (1997) utilized a moving Granger causality test (moving F -test) with a window length of 150 to look at time-shifting Granger causality between the Finnish and Japanese protections markets in the mid-1990s. To study the dynamics of inflation in the USA, Cogley and Sargent

Table 1 Descriptive statistics

	CO2	GDP	ENEF	TOUR	RELO
Mean	6.024753	12.06104	0.750844	7.098305	1.112468
Median	6.070105	12.07913	0.714800	7.051771	1.237763
Maximum	7.029677	13.19871	1.053798	8.210955	1.979573
Minimum	5.296446	11.25372	0.268686	6.299071	-1.074599
Std. Dev	0.482480	0.450133	0.183162	0.536354	0.676754
Skewn	0.415409	0.354919	0.146756	0.530748	-0.994813
Kurtos	2.211273	3.115210	2.426026	2.313139	3.331511
Jarque–Bera	8.748992	3.447619	2.770638	10.65702	27.12341
Probability	0.012594	0.178385	0.250244	0.004851	0.000001

(2001) developed a Bayesian VAR with time-varying parameters for inflation, unemployment, and interest rate. Cogley and Sargent (2005a, 2005b) looked at how monetary policy in the USA changed after World War II by developing a VAR with drifting coefficients and stochastic volatilities for quarterly inflation, nominal interest, and unemployment. A time-varying structural VAR, in which the innovations' coefficients and variance covariance matrix change over time, was proposed by Primiceri (2005). The dynamics of the relationship between unemployment and inflation in the USA were studied with the help of the model. Using quarterly US data, Christopoulos and León-Ledesma (2008) proposed a time-varying parameter VAR model (LSTAR-VAR) for studying the money–output relationship. This test is proposed by Dumitrescu and Hurlin's (2012), which is more operative in considering the issue of slope heterogeneity, imbalanced panel ($T \neq N$), and cross-sectional dependence.

5 Results and discussion

The empirical results of the data for selected economies are initiated from the summarization of the given information. The result of the descriptive stats is provided in Table 1, including the median, mean, and range stats. The computed results for the stated measures indicate positive values, which reveals the progressiveness of all variables across the selected time span. As a consequence, to the significant difference in the range statistics, the calculated result for the standard deviation indicates that RELO and TOUR are the most volatile variables during the selected time period. Comparatively, volatility in ENEF, GDP, and CO2 is found relatively lower than the latter. With reference to the empirical estimates of the normality indices, both the kurtosis and skewness indicates wide-ranging values than their critical values. However, to analyze the problem of data normalcy more comprehensively, the estimations offered by Jarque and Bera (1987) test reveals that CO2, TOUR, and RELO are significant to reject the null assumption of normal dispersion. Instead, it could be concluded that the issue of data asymmetry persists in the panel data, which could be dealt with the use of nonparametric panel estimators.

In the panel estimation procedure, it is crucial to apply some diagnostic assessments including the cross-sectional dependence and the heteroscedasticity. This research applies the residual cross-sectional dependence test and panel cross-sectional heteroscedasticity

Table 2 Cross-sectional dependence

Residual cross-sectional dependency			
Tests	Stats	df	Proba
B-P L.M	87.92021***	10	0.0000
Pesaran scaled L.M	17.42349***		0.0000
Pesaran C.D	8.473164***		0.0000
Panel cross-sectional heteroskedasticity L.R			
	Valu		Proba
Likelihood ratio	149.2760***		0.0000
L.R test summary			
Restricted Log.L	114.6540		
Unrestricted Log.L	189.2920		

*, **, and *** mean significance at 10%, 5%, and 1% levels, respectively

Table 3 Unit root

Test	CO2	ENEF	GDP	RELO	TOUR
<i>Unit Root Summary I (0)</i>					
Levin, Lin, and Chu t*	0.73789	0.14301	0.34473	-2.12202**	3.38717
Breitung t-stat	1.98841	1.03261	0.76285	-1.05932	3.11820
Im, Pesaran, and Shin W-stat	1.62615	0.91591	0.34935	-2.49860***	20.5539
ADF—Fisher Chi-square	7.96578	6.97309	11.0027	25.4864***	3.38717
PP—Fisher Chi-square	4.16155	14.3046	7.29869	25.1456***	3.11820**
<i>Unit Root Summary I (1)</i>					
Levin, Lin, and Chu t*	-2.20017**	-1.87925**	-2.05318**	-	4.21531
Breitung t-stat	-3.09909***	-3.22589***	-1.42380*	-	1.69663
Im, Pesaran, and Shin W-stat	-2.50365***	-3.85863***	-2.25350**	-	-1.75434**
ADF—Fisher Chi-square	24.1518***	32.5446***	20.9138**	-	22.5270**
PP—Fisher Chi-square	49.8500***	141.143***	40.3483***	-	160.375***

*, **, and *** mean significance at 10%, 5%, and 1% levels, respectively

test. The observed outcomes for both the estimators are reported in Table 2. The projected outcomes for both the estimators revealed significant statistics, hence rejecting the null assumptions of cross-sectional independence and homoscedasticity in the panel data at 1% level of significance. Thus, the study concluded that the cross-sectional dependence exists in the BRICS economies and also panel cross sections hold the properties of heteroscedasticity.

Similar to the above diagnostic tests, it is also critical to inspect the data stationarity as the estimation of the information must adopt stationary series of the panel. In this respect, the current study uses five-unit root testing approach, and the outcomes are portrayed in Table 3. It can be observed from the results that all the components, except for RELO, are insignificant at I(0), while the latter is significant (1%). Similarly, the stationarity of CO2, ENEF, GDP, and TOUR are tested on I(1). At this juncture, the predicted values of all the

Table 4 Cointegration

Statistic	Value	Z-value	P-value
Gt	-7.240***	-11.439	0.000
Ga	-13.046	-0.996	0.160
Pt	-15.170***	-9.121	0.000
Pa	-12.896**	-2.074	0.019

*, **, and *** mean significance at 10%, 5%, and 1% levels, respectively

Table 5 Quantile results—MMQR

Var	Loc	Scal	Quant			
			Q ^{0.25}	Q ^{0.50}	Q ^{0.75}	Q ^{0.90}
GDP	1.219*** [0.064]	0.070** [0.033]	1.157*** [0.069]	1.215*** [0.065]	1.290*** [0.074]	1.332*** [0.085]
TOUR	-0.196*** [0.050]	-0.050* [0.026]	-0.151*** [0.054]	-0.193*** [0.050]	-0.247*** [0.058]	-0.277*** [0.066]
RELO	-0.160*** [0.025]	-0.020 [0.013]	-0.142*** [0.027]	-0.159*** [0.025]	-0.180*** [0.029]	-0.193*** [0.034]
ENEf	-1.574*** [0.089]	-0.003 [0.047]	-1.571*** [0.097]	-1.573*** [0.089]	-1.576*** [0.103]	-1.578*** [0.120]
Constant	-5.929*** [0.439]	-0.366 [0.230]	-5.602*** [0.474]	-5.908*** [0.442]	-6.299*** [0.509]	-6.519*** [0.583]

*, **, and *** mean significance at 10%, 5%, and 1% levels, respectively

tests for the mentioned variables are found higher in absolute than their respective critical values—lead to neglect the null assumption. Hence, these tests concluded the validity of the variable's stationarity, which permits the current research to investigate the cointegration between variables.

Table 4 presents the empirical estimates of the long-run balance association between variables obtained via Westerlund (2007) ECM. In this specific measure, the ECM is assumed to be zero as a null hypothesis. However, the results asserted that both the group (G_t) and panel (P_t and P_a) are significant at 5% and 1% levels, which rejected the null hypothesis. Therefore, it may be concluded from the negative and significant values that there is an equilibrium relationship between exist between the model's components mentioned earlier.

After the validity of the stationarity and persistence of cointegration, this study contemplates the subject of data's nonlinearity. Following the stated problem, this study employs the novel MMQR technique which effectively tackles non-normality and endogeneity issues. The projections of MMQR are reported in Table 5. Specifically, this study uses four quantiles (Q_{0.25}, Q_{0.50}, Q_{0.75}, and Q_{0.90}), while the estimator provides statistics for the scale as well as location. Results of the test emphasized that GDP is the only crucial factor that increased environmental deterioration in the BRICS region, where a percentage increase in the GDP increases the CO₂ emissions level by 1.157–1.332% across quantiles. These estimates are statistically significant (1% level). Due to upsurge in the economic activities, the level of income for general population increases, which boosts the consumption level.

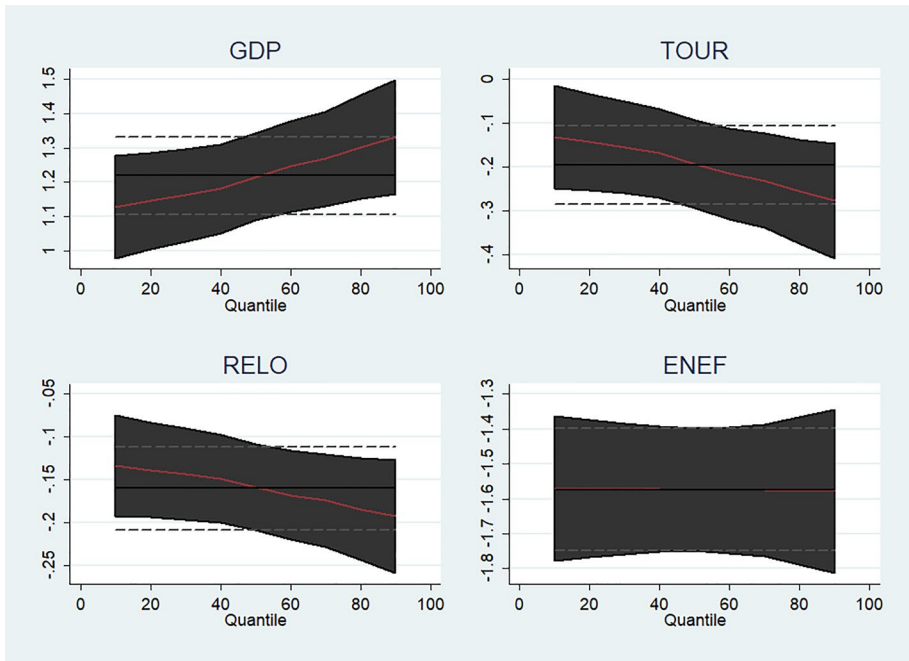


Fig. 1 Quantile (MMQR) estimates

Consequently, the increased demand for products and services, the energy demand further increase and its consumption although leads to enhance industrial production. Still, on the other hand, it also increases the CO₂ emissions level in the selected area. The results are found consistent to the empirical results of Edoja (2017), Azam et al. (2016), and Isik et al. (2019); Khan et al. (2019), Khan et al. (2021), Muhammad and Khan (2021), Muhammad et al. (2021). On the contrary, the empirical findings asserted that TOUR, RELO, and ENEF are the crucial factors of environmental sustainability in the BRICS countries during the selected period. Specifically, an increase in the TOUR, RELO, and ENEF significantly reduces the CO₂ emissions level by 0.151–0.277%, 0.142–0.193%, and 1.571–1.578%, respectively. The prime reason for the substantial negative influence of such variables is that renewable electricity output and energy efficiency promote renewable energy consumption and reduces CO₂ intensive products and services. Specifically, the energy efficiency is a procedure where the resources are utilized in a way to attain maximum output from them. Also, renewable electricity is currently replacing the traditional energy resources (fossil fuel), which are regarded as the major driver of CO₂ emissions and environmental deterioration. Since the BRICS economies are currently adopting renewables and energy-efficient instruments for increasing efficiency of the industrial sector. Therefore, the level of emissions is reduced as a consequent of the significant increase in these (ENEFF and RELO) indicators. Moreover, the tourism sector is mostly service oriented, where the incentives from such sector lead governments and organizations to implement appropriate environmental policies by creating nature reserves and other measures to protect biodiversity. The adverse influence of ENEFF, RELO, and TOUR are observed statistically significant (1% level) across quantiles, and consistent to the empirical results of Akram et al. (2022), Akadiri and Adebayo (2022), Alola et al. (2023), and Qin et al., (2021a, 2021b) for

Table 6 Robustness—BSQR

Var	Bootstrap Quant. Reg			
	Q ^{0.25}	Q ^{0.50}	Q ^{0.75}	Q ^{0.90}
GDP	0.959***	1.203***	1.030***	1.152***
TOUR	0.077	-0.232**	-0.075	-0.125***
RELO	-0.129**	-0.155**	-0.012	-0.047
ENEF	-1.150***	-1.848***	-1.122***	-1.112***
Constant	-5.184***	-5.291***	-4.905***	-5.944***

*, **, and *** mean significance at 10%, 5%, and 1% levels, respectively

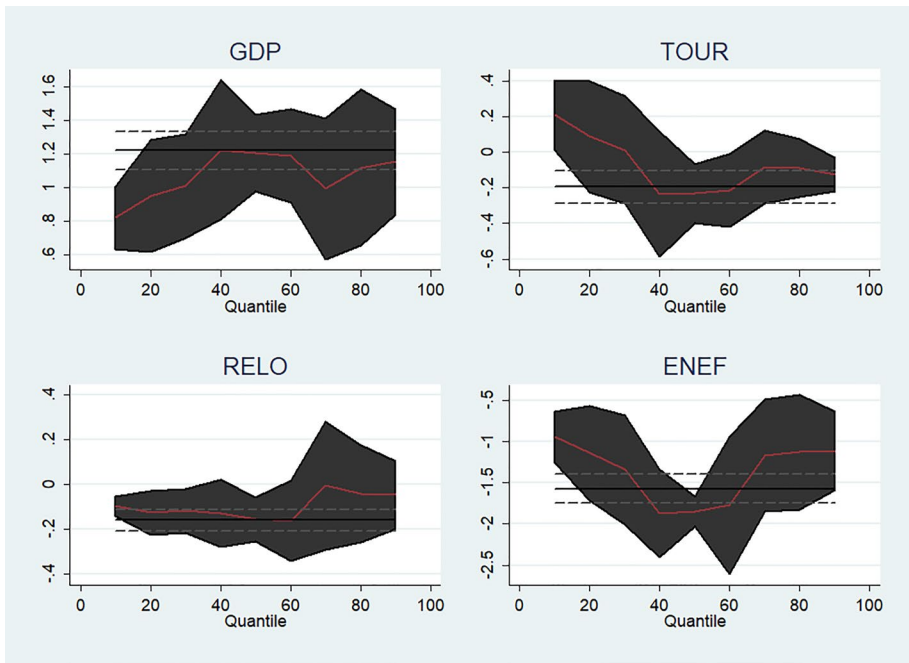


Fig. 2 Quantile regression coefficients

energy efficiency and renewable electricity, and Tong et al. (2022), Rahaman et al. (2022), Raza et al. (2021), and Razzaq et al. (2021) for tourism in different economies and regions. The significance results of scale and location further reveal the significance of the results, where the quantile estimates are portrayed in Fig. 1.

Once the long-run coefficients are obtained via MMQR approach, this investigation employs the nonparametric BSQR method to test the authenticity of the study model. Empirical results of BSQR estimator are reported in Table 6. Similar to the MMQR approximation, the BSQR is also analyzed on four quantiles. From the results, it is observed that the influence of GDP is positive and statistically significant (1%). In contrast, the influence of TOUR, RELO, and ENEF are found negative and significant at 5%

Table 7 Causality test

Null hypotheses	Pairwise Dumitrescu–Hurlin panel causality		
	W-Stats	Zbar-Stats	Prob
GDP \neq CO2	7.93006***	6.18093	0.0000
CO2 \neq GDP	9.80928***	12.0876	0.0000
ENEf1 \neq CO2	4.90418***	5.29782	0.000
CO2 \neq ENEf1	5.34969***	5.91450	3.E–09
TOUR1 \neq CO2	8.56264***	7.67234	0.0000
CO2 \neq TOUR1	7.29248***	8.60377	0.0000
RELO \neq CO2	5.81717***	6.56160	5.E–11
CO2 \neq RELO	4.77177***	5.11452	3.E–07

*, **, and *** mean significance at 10%, 5%, and 1% levels, respectively

and 1% levels. Apart from the difference in the coefficient values of MMQR and BSQR, the level of significance as well as direction of the impact is found similar, which validates the empirical results of the MMQR. The quantile statistics of the BSQR are portrayed here in Fig. 2.

Since both the nonparametric (MMQR and BSQR) approaches revealed only the coefficient level as well as specific influence of regressor(s) on the CO2 emissions while lacking the causal connection between the study variables. In this respect, this research employs the pairwise panel granger causality assessment projected by Dumitrescu and Hurlin (2012). The results of the stated estimator are described in Table 7, which asserted that the figures are highly substantial at 1% level. Due the lowest probability values, it can be concluded that there exists bidirectional causal connection between the variables. As a result of the two-way causal nexus, this study concludes that any sort of policy alteration in any of the regressors could cause changes in the environmental degradation and vice versa—validates the feedback effect between variables.

6 Conclusion and policy implications

Climate exchange is a first-rate challenge for growing international locations as the BRICS, which can be uncovered to a better hazard of this phenomenon. Climate exchange concerning the BRICS international locations have led to the formulation of the worldwide plan of action on climate alternate, which lists several missions that are variation and mitigation in nature. As a part of the worldwide mitigation efforts, the BRICS international locations registered with the UNFCCC then make voluntary efforts to lessen their emissions intensity of its GDP by way of 2020 in comparison with 2005 stages even they pursue the course of inclusive boom. Therefore, it is miles vital to higher recognize the causes of emissions greenhouse gas emissions in those nations so that the emissions may be addressed, and the sustainability of monetary development can be assured. This takes a look at examined a number of the possible elements that improved carbon emissions in BRICS international locations. A panel version becomes used taking the period 1990–2021. To reap the aim of this investigation, this research analyzes the influencing factors of CO2 emissions, where the prime motive is the exploration of the nexus between tourism

and emissions. Using panel diagnostic approaches, the study validates the stationarity of each variable including CO₂, GDP, TOUR, ENEF, and RELO. Besides, the cointegration association further strengthens the stance of identifying the long-run coefficients for each variable. As a result of the non-normality of data's dispersion, this research uses the MMQR approach and found that GDP is the leading factor of environmental degradation in the region. On the other hand, tourism, energy efficiency, and renewable electricity are the significant factors of environmental sustainability in the BRICS region. Such estimated results are found robust via BSQR approach. Further, the bidirectional causal connection strengthens the argument regarding the importance of these variables in attaining environmental recovery. Based on the empirical results, this study recommends policies that could increase environmental sustainability via limiting CO₂ emissions in the region. In terms of its implications for policy, this study implies that nations might successfully execute environmental legislation by granting authority to a lower level of government. Therefore, it is vital to clarify roles at various levels of government in order to perform the energy-saving functions of fiscal expenditures. Specifically, the applicability of the findings imply that GDP performs a progressive role in enhancing emissions via further expanding the industrial sector. Therefore, these economies must target increased energy efficiency, improvement of renewable power resources, and investment in latest technologies, in order to attain low-CO₂ strength. BRICS countries must use renewable energy sources for attaining environmental protection. The policies in question place a high priority on the substitution of fuels, the integration of renewable and nuclear energy sources into the power sector, and the advancement of more energy-efficient technology. Renewable energy sources such as biomass, hydropower, wind power, solar, and geothermal are frequently utilized to mitigate the environmental impact. In order to reduce their ecological footprint, the BRICS nations should prioritize these sources. Moreover, the tourism plays a considerable part in the economic as well as environmental sustainability. Therefore, these economies may focus the tourism sector via replacing air travels with greener alternative and subsidizing environmentally friendly hotels. Companies should pay attention to CO₂ emission and plays their role in the betterment of economy; this will enhance financial performance of the company. Regulatory body such as Security and Exchange Commission of Pakistan should formulate such a regulation in which companies are required to implement certain range of CO₂ emission. Alongside CO₂ emission, green tourism should be promoted in order to enhance the economy. Except electricity renewable energy, more forms of renewable energy should be encouraged and implanted.

Firstly, the research reveals that BRICS nations, which include Brazil, Russia, India, China, and South Africa, have experienced substantial economic growth in recent years. However, this growth has been accompanied by a significant increase in carbon emissions, highlighting the challenge of decoupling economic development from environmental degradation. The study underscores the pressing need for sustainable development strategies that prioritize decarbonization. Secondly, the role of tourism as a contributing factor to carbon emissions is examined. The research finds that the tourism sector plays a substantial role in the carbon footprint of BRICS economies due to its energy-intensive nature.

This finding calls for policies that encourage eco-friendly tourism practices and promote the use of renewable energy sources within the tourism industry. Lastly, the study emphasizes the importance of energy efficiency measures in mitigating carbon emissions. Improved energy efficiency not only reduces environmental impact but can also enhance economic performance by lowering energy costs. BRICS countries can leverage energy-efficient technologies and practices to achieve their economic goals while reducing their

carbon footprint. In conclusion, the research underscores the interconnectedness of economic performance, carbon emissions, tourism, and energy efficiency for BRICS economies. To achieve sustainable growth, policymakers must prioritize strategies that promote green development, decarbonization, and efficient resource utilization.

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Data availability Data from the corresponding author will be available upon reasonable request.

Declarations

Ethical standards The research protocol was approved by the Institutional Review Committee School of Management, Shandong Normal University.

Ethical approval This article does not contain any studies with animal performed by author.

Consent to participate All authors are agreed.

Consent for publication All authors agreed to publish this paper.

Conflict of interest The authors declare that they have no conflict of interest.

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