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Unveiling the Link between Macroeconomic Indicators and Carbon Emissions in BRICS Economies

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ABSTRACT

Carbon emissions have serious environmental and social effects, particularly in rising economies. Because of the issue of emissions and economic expansion, a better knowledge of the dynamic link between growth of economy & carbon emissions is required. This study explores the strong association between macroeconomic parameters &carbon emissions in Brazil, Russia, India, China, and South Africa (BRICS). The article employed a nonlinear panel quantile regression model using panel data spanning 2010 to 2023 to assess the impact of energy mix, prosperity, and digitalization on carbon emissions in BRICS countries. The data indicate that a higher energy mix ratio leads to lower carbon emissions.

KEYWORDS: *Carbon Emission Energy Mix, Economic Development, and BRICS.*

1. INTRODUCTION

The growing human population poses significant environmental issues, including climate change, resource depletion, & environmental degradation. To address these concerns & ensure a more sustainable future for present & future generations, it is critical to promote sustainable living practices and apply population control measures. Countries worldwide rely heavily on non-renewable energy sources, such as fossil fuels, to meet their energy needs. (Ullah et al., 2020; Zafar et al., 2020). However, as demand grows, so do carbon emissions from these sources. Non-renewable energy sources generate solid materials and gases that cannot be regenerated, causing pollution. As a result, meeting rising energy demand with cleaner and renewable resources would help reduce pollution from these sources.

Industrialization has shown to boost the global economy while jeopardizing environmental sustainability. Industrialization has an impact on the environment, including air pollution and global warming caused by carbon dioxide (CO_2) emissions (Tong et al., 2020). According to Azwar (2019), greater CO_2 emissions are linked to industrialization. This issue affects both wealthy and developing nations; Bashir et al. (2019) suggested that economies should prioritize sustaining economic growth while lowering environmental impact. BRICS has enormous natural richness &uses natural resources in economic activities to drive growth (Prawoto Basuki, 2020). Economic development must be balanced with environmental conservation & utilization of both renewable and non-renewable sources of energy. Several previous studies focused on economic advancement but overlooked ecological balance. Chontanawat (2020) identified a correlation and causation between CO2emissions, consumption of electricity, & ASEAN economic performance, signifying damages to the environment in ASEAN nations. Hdom & Fuinhas (2020) found that GDP, renewable, and hydropower all had a negative influence on Brazil's growing carbon emissions.

Azwar's (2019) study on Indonesia discovered that economic growth has a positive impact on CO_2 emissions, notably those from heating and cooling and power generation. Tong et al. (2020) investigated the causal connection within CO_2 emissions & GDP growth in the E7 countries (Brazil, India, Indonesia, Mexico, the People's Republic of China, Russia, & Turkey) and discovered no evidence of cointegration within energy use, carbon dioxide emissions, & economic growth in Indonesia, People's Republic of China, Mexico, or Turkey. According to research done in the British Isles by Shahbaz et al. (2020), electrical consumption and revenue growth contribute to habitat deterioration; however, CO_2 emissions may be lowered through R&D investment. Growth in the economy is best balanced with the efficiency of biodiversity in industries like manufacturing, because challenges ahead will become more serious as use of power production & conveyance expands.

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There is a positive relationship b/w economic development and carbon emissions, as developing countries frequently require more energy per person to support activities such as industrialization (Pata,2018; Ullah.,2020), urbanization (Pata & Caglar, 2021), economic development, tourism, & digital infrastructure among others (Ullah et al., 2021). As a result, these countries tend to have greater emission rates. For example, BRICS group,which includes Brazil, Russia, India, China, & South Africa, has exceeded the G7 countries in terms of purchasing power parity (PPP) GDP share (IMF,2023).By 2023, the difference had increased, with BRICS accounting for 32 percent of world GDP, compared to G7's 30%. Energy demand per capita kWh has increased in the BRICS countries, which have actively expanded the manufacturing sector, trade, and infrastructure to encourage stronger economic growth. For example, China's per capita energy consumption increased from 4914 kWh in 1980 to 9335 kWh in 2000, and is projected to reach 31,053 kWh by 2022. (see Figure 1). Similar increases in per capita energy consumption can be observed in countries such as India (3519 kWh in 2000 to 7143 kWh in 2023), Russia (49127 kWh in 2000 to 55,459 kWh in 2022), Brazil (13400 kWh in 2000 to 17,300 kWh in 2022), and South Africa (25322 kWh in 2000 to 22,351 kWh in 2022).

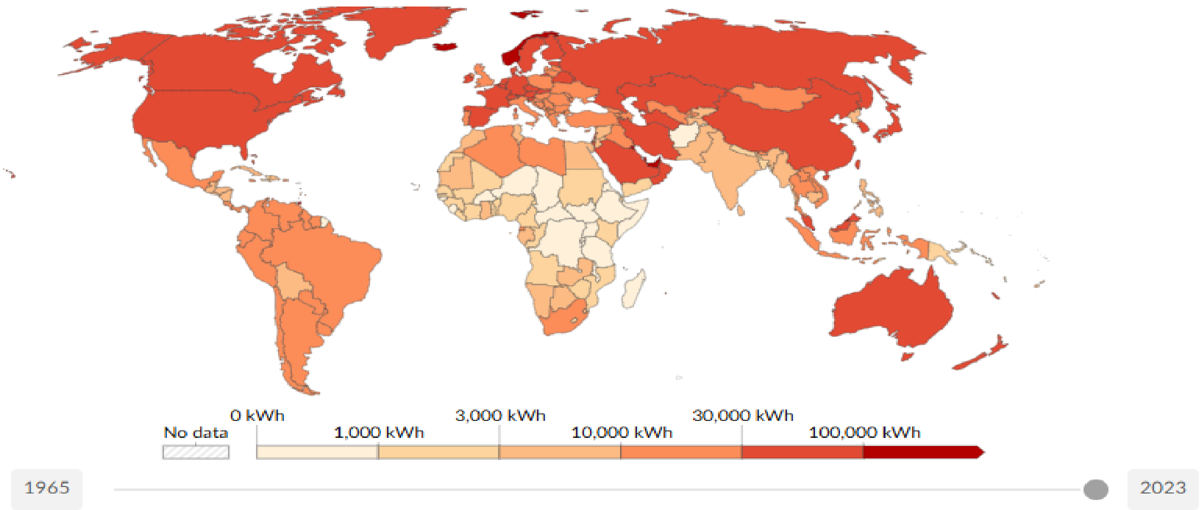

Figure 1: Per capita energy consumption- 1965-2023

Source: https://ourworldindata.org/energy-production-consumption

The bulk of world's primary energy demand is met by non-renewable sources of energy (see Figure 2), resulting in increased environmental damage such as carbon emissions.

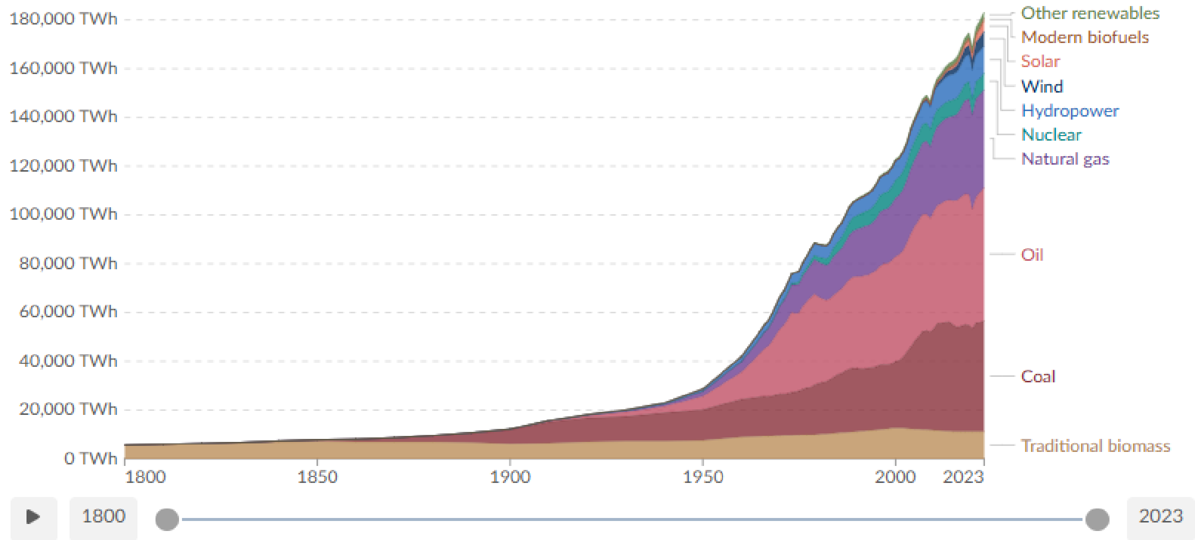

Figure 2: Global primary energy consumption by source from 1800 to 2023

Source: https://ourworldindata.org/energy-production-consumption

Demand for energy is rising in many nations throughout the world as people's incomes grow and communities expand. If increased demand is not offset by advancements in energy efficiency in other countries, global utilization of energy will climb year after year. Growing usage of energy complicates moving from fossil fuels to renewable power sources: new low-carbon energy must meet rising demand while simultaneously aiming to replace present fossil fuels in the energy mix. This interactive graphic shows how global energy use has evolved year after year. The change is indicated as a percentage of the previous year's consumption. For more than half a century, worldwide use of energy has increased virtually yearly. The exceptions are in early 1980s, 2009, following economic crisis, & 2020 due to the COVID-19pandemic. Global energy demand continues to climb, albeit it looks to be decreasing, averaging 1% to 2% annually.

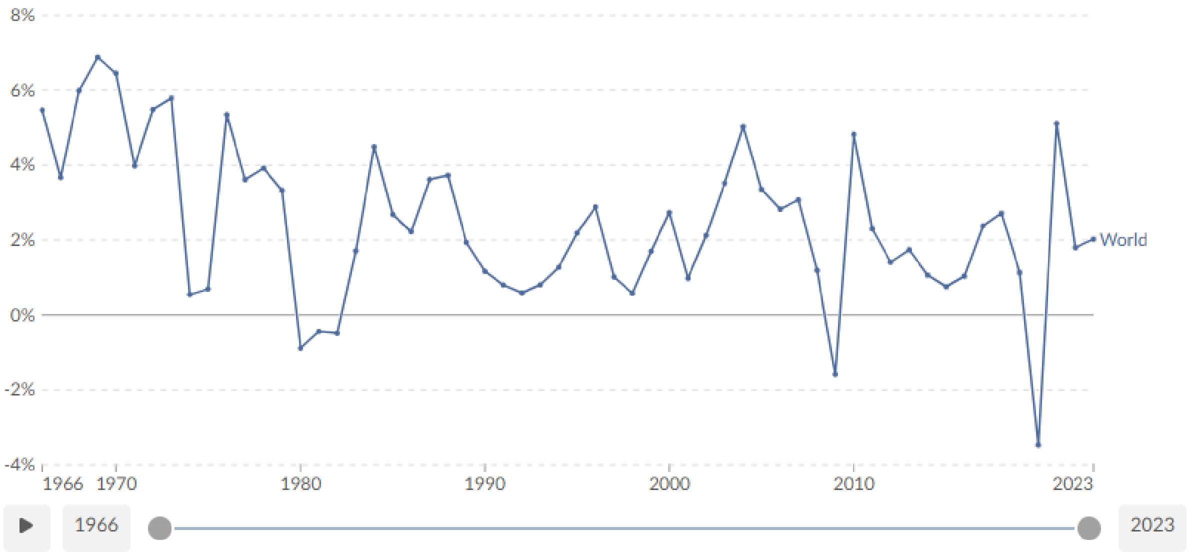

Figure 3: Annual change in primary energy consumption

The development of digital infrastructure and economic systems is critical to the country's growth (Dauda et al.,2021; Zhao). To steer investments into the economy and support economic development, it is critical to generate economic growth. Furthermore, a well-established economic system allows for the reallocation of economic resources to more ecologically friendly and greener initiatives (Zhao, Samour et 2023b). To connect developing countries to global economy & increase their economic potential, digital infrastructure, such as information & communication technology, has long been regarded as critical (Herman & Oliver,2023). Digitalization generates online shopping sites and worldwide supply chains that integrate small firms, low-skilled workers, and informal labourers with worldwide markets, encouraging economic growth while lowering carbon footprints (Herman & Oliver, 2023). This study investigates how the energy mix, economic development, & digitalization influence carbon emissions in the BRICS countries. This paper addresses a vital gap by presenting empirical facts and outlining the benefits and drawbacks of economic development, digitization, and energy mix.

2. LITERATUREREVIEW

Environmental degradation has been acknowledged as a major concern to both nature& humanity (Aye &Edoja, 2017). A number of factors influence a country's development pace, including population size, economic instability, & the availability of natural resources. Economic growth seeks to raise everyone's standard of life as well as nations' riches. Pollution, overexploitation, degradation, species extinction, & climate change are all potential consequences of growth in certain areas. As a result, the bulk of papers that looked at the association between growth in GDP and CO2 pollution discussed the difficulties in obtaining the "correct degree of expansion" that should be linked to goal of lowering CO2 emissions. Accepting that greenhouse gases are a proxy for decline in the environment, Azam (2016) argue that CO2 emissions help China, Japan, and the USA grow their economies.

Pao & Tsai (2010) &Li et al. (2022) demonstrate that consumption of energy has a long-term beneficial influence on CO2 emissions in BRICS countries. Several studies have examined association connecting emissions of CO2 as well as national economic growth; one such research is Yousefi-Sahzabiet al.(2011), who investigated problem in

Iran & found a statistically significant link b/w CO2 emissions & financial growth. Additionally, Bouznit & Pablo-Romero(2016) affirm similar results for the Algerian shape, whereas Osadume & College (2021)researchers investigated how various African countries' economic growth affects their CO2 emissions. Simon-Steinmann's growth rate model serves as foundational theoretical framework. The findings show that the independent component that was important (CO2) had a high degree of short-term cointegration, which positively influenced dependent variable of interest (GDP)growth across all samples. (Adu, Denkyirah, 2017). Industrial development &internationalization are viewed as drivers of GDP growth.

Adu & Denkyirah (2017) definition of industrialization as " economic engine for expansion and prosperity." Aye &Edoja (2017) proposed that growing GDP might be used as a credible prediction of future carbon emissions.CO2 emissions are thought to contribute to global warming&, as a result, environmental damage via their greenhouse effect. Rather than expecting more CO2 emissions as salaries grow, the authors suggest that this will happen unless actions are done to limit CO2 footprints. Environmental degradation challenges come gradually as the economy develops. Many researchers believe there is a substantial relationship between economic growth and carbon emissions (Selden and Song, 1994; Galeotti et al., 2009). Extensive research has started to focus on the link between GDP growth and carbon dioxide emissions, investigating the efficacy of an environmental Kuznets curve (EKC) in many nations & areas (Apergis,2016; Apergis 2017; Murshed, 2020). Scholars use Granger causality to draw various conclusions regarding relationship between GDP growth & energy usage. Granger causality tests show that in long run, there is unidirectional Granger causation from electricity use & pollution to GDP growth.

Use multiple model hypotheses to reassess the energy-led growth paradigm. A causal Granger model containing 3 or four variables is more likely to support premise than one containing only two. Furthermore, affluent & developing countries are more likely to endorse energy-led growth idea than less advanced or poorer ones. There are several factors that influence carbon emissions. Scholars performed lots of research and discovered numerous key reasons. Banerjee & Murshed (2020)confirmed polluting paradise theory by analyzing sectional dependency across national teams from 2005 to 2015 & calculated a long-term stable link b/w net export emissions & real GDP. Foreign Direct Investment, Trade Liberalisation, Energy, the act of buying, and Growing Economic Activity. Murshed (2020) concluded that ICT trade in South Asia reduces emission of greenhouse gases by proactively boosting renewable energy consumption, expanding share of energy from renewable sources, lowering energy intensity, fostering cleaner cooking fuels, subsequently boosting renewable energy usage, improving energy conservation, & improving cleaner fuel avenues. Furthermore, environmental policies have a significant influence. Environmentally, pricing policies in G7countries have the ability to reduce domestic electricity consumption and, consequently, emissions of carbon dioxide over time.

In case of China, Ma (2021) conclude that provincial expansion & development of the third sector are to blame for the country's declining carbon dioxide production trend. The study's findings also suggest that pollution fines, R&D investment, technical innovation, & the usage of renewable energy all help to reduce carbon dioxide emissions. Positive effects on grain agricultural output are going to boost carbon dioxide emission levels in the long run; adverse effects on forestry will have little or no effect on China's carbon dioxide greenhouse gases; &negative impact on livestock farming will only rise carbon dioxide pollutants in short term.

2.1 Economic development & carbon emissions

Rapid growth of finance & technology has undoubtedly resulted in a significant increase in energy consumption in both developed and emerging countries. While it is undeniable that energy consumption is intimately linked to economic progress, it must also be acknowledged that it contributes significantly to environmental degradation (Ibrahim & Ajide, 2021). Extensive research confirms a broad consensus: economic development has a negative influence on environment (Le 2020; Ozturk and Ullah,2022;Zhaoand Ozturk, 2023a). In contrast, a significant body of research supports the argument that economic development can actually reduce environmental degradation. Tamazian et al., 2009. A study by (Zhao, Ozturk, et al.,2023a) looks at economic growth& its impact on carbon emissions. The researchers used stock market value to GDP ratio to conduct their analysis. Economic development can be measured in a variety of ways, including economic development scale, which incorporates variables such as stock market performance, liquidity, & credit availability. Previous research discovered that economic development, as measured by stock market turnover, stock market capitalization, total credit, & private sector credit, reduces carbon emissions. Furthermore, Nasreen et al. (2017) have demonstrated that business growth benefits environmental quality. They also observed that economic stability has a one-way causal link with carbon emissions. Efficient economic systems may provide low-interest funding for alternative energy sources as well as environmental projects. These low-cost financing options have the potential to minimize excess resource & energy consumption by promoting innovation in indigenous energy-demanding sectors (Khan2020; Tao et al.,2023).Several studies have produced conflicting findings about the causal connection in economic advancement and carbon emissions. For example, Raihan (2023) discovered that economic development raises carbon emissions. Furthermore, Shahbaz (2016)used NARDL model to study asymmetrical implications of economic progress on carbon emissions, discovering that both stock marketand bank-based economic development measures degrade state of environment (Maji et al.,2017; Sunday Adebayo et al.,2023). Furthermore, data from emerging countries (such as India & China) indicates that increased economic growth is linked to higher carbon emissions.

2.2 Energy consumption & carbon emissions

The relationship b/w energy consumption & other factors can be efficiently classified into studies that focus on individual countries vs those that analyze regions or groupings of nations. These analyses have investigated groups such as OECD, BRICS, G7, and the European Union to assess overall energy demand (Villanthenkodath, 2023; Voumik et al., 2023; Yadav, 2024; Yasin et al., 2024) or specific energy types, such as coal, natural gas (Kan et al.,2019), or renewable energy sources. To get the findings, a variety of strategies have been regularly used, including autoregressive distributed lag (Tukhtamurodov et al.,2024), pool mean group models. References include Sharma et al. (2021), Temiz Dinç and Akdoğan (2019), and Adebayo and Samour (2023). Research has continuously shown a link between the type of energy utilized (renewable or non-renewable) & carbon emissions (Iqbal et al.,2023). Studies on industrialized nations, such as the G7 and OECD, indicate that relying on nonrenewable energy sources increases carbon emissions, while shifting to renewable energy reduces emissions (Şanlı et al.,2023). These studies used energy production with non-renewable versus renewable energy in econometric models such as autoregressive distributed lag (ARDL).Şanlı et al. (2023) cite Dumitrescu and Hurlin's causality and Toda and Yamamoto's causality. Similar studies on groups of developing countries, such as BRICS nations, found a strong relationship b/w energy consumption by source (renewable versus non-renewable) and carbon emissions (Banday & Aneja,2020; Dogan et al.,2017; Gogoi & Hussain,2024; Mandim by, 2024). For example, found negative link b/w renewable energy consumption& carbon emissions in BRICS nations, demonstrating that increasing renewable energy sources considerably reduces carbon emissions. Similarly, (Karakurt & Aydin,2023) & (Iqbal 2023) discovered that non-renewable energy use is positively connected with carbon emissions, emphasizing necessity for a shift to renewable energy to reduce environmental effects.

3. METHODOLOGY

3.1 Data & Sample:

The study employed secondary panel data acquired online from World Bank Group portal & central bank websites of selected study nations between 2010 and 2023. This study's panel sample comprises BRICS nations (Brazil, Russia, India, China, & South Africa).

3.2 Variables

Dependent variable:

CO2 emissions: Carbon emissions per capita

Independent variable

Energy mix: Ratio of renewable & non-renewable energy generation

Economic development: Average stock traded to GDP ratio

Digitalization: Average population to internet user ratio

3.3 Econometric techniques

This study employs a nonlinear panel quantile regression (NPQR) approach to investigate asymmetric impact of macroeconomic variables—such as energy mix, economic development, and digitalization—on carbon emissions across different emission levels. Unlike traditional mean-based regressions, quantile regression captures heterogeneous effects of explanatory variables across the distribution of dependent variable, offering a more nuanced understanding of how these factors influence both low and high emitters differently. The nonlinear specification accounts for potential asymmetric relationships by decomposing each key independent variable into its positive (e.g., $EMIX^+$, ED^+, $DIGI^+$) and negative ($EMIX^-$, ED^-, $DIGI^-$) components. This enables the model to distinctly measure the differing marginal impacts of increases and decreases in each variable on carbon emissions.

4. RESULT AND DISCUSSION

Table 1 summarizes descriptive information for the BRICS countries' energy mix, digitalization, economic progress, and carbon emissions. From 2010 to 2023, the BRICS countries' average carbon emissions per capita (CO2) were 276.20 metric tons, with the highest being 1476.23. The average energy mix ($EMUX$) (i.e., ratio of renewable & non-renewable energy generation) is 1.30, while maximum ratio is 8.51. In BRICS nations, the average stock traded to GDP ratio (ED) is 94.56, while the average population to internet user ratio ($DIGI$) is 58.8%. The Jarque-Bera (JB) statistics estimates indicate that all of variables are not normally distributed. Based on pair wise correlation estimates, Table 2 shows that carbon emissions, energy mix, economic progress, and digitalization are all inversely related.

Table 1: Descriptive statistics & pair wise correlation

	$CO2$	$EMIX$	ED	$DIGI$	Y
Mean	276.21	1.31	94.55	58.81	5757.72
Median	109.13	0.18	66.01	12.11	6096.54
Maximum	1476.24	8.52	322.72	36.31	11437.46
Minimum	−90.72	0.01	17.56	15.18	748.73
Std. Dev.	399.84	2.27	76.15	8.96	3022.15
Skewness	1.623	1.723	1.456	2.054	−0.246
Kurtosis	4.454	4.521	4.036	5.865	1.835
Jarque-Bera	54.287***	60.827***	40.945***	107.685***	6.855**
Pairwise Correlation					
CO2	—				
EMIX	−0.366***	—-			
ED	−0.218**	−0.312	—		
DIGI	−0.784***	0.287	0.221***	—	
Y	0.115**	0.342**	0.136**	0.326**	—

Note- *, **, and ***indicate significance at 1%, 5%, & 10% levels, respectively.

The second-generation unit root test results show that$CO2$, $EMUX$, E0$\boldsymbol{P}$, $\boldsymbol{PUSU}$, &Y are all stationary at I level (refer to Table 2). Table 3 shows the panel cointegration test results from Pedroni (1999) & Westerlund (2007). These findings suggest that calculated statistics are significant and that variables are cointegrated in long run.

Table 2: Second-generation unit root test

Variables	CADF	CIPS
$\boldsymbol{CO}2$	−0.043	−0.065
$\Delta\boldsymbol{CO}2$	−3.737*	−3.858*
$\boldsymbol{EMIX}$	2.396	2.346
$\Delta\boldsymbol{EMIX}$	−3.956*	−3.857*

E$\boldsymbol{D}$	−2.485	−2.355
ΔE$\boldsymbol{D}$	−6.595*	−7.604*
$\boldsymbol{DIGI}$	−2.595	−2.634
$\Delta\boldsymbol{DIGI}$	−2.978*	−2.982*
$\boldsymbol{Y}$	1.911	2.044
$\Delta\boldsymbol{Y}$	−2.135*	−1.865*

Note: *, **, &***indicate significance at1%, 5 percent, &ten percent levels, respectively. CADF denotes cross-sectional Fisher ADF; CIPS denotes cross-sectional Im, Pesaran, & Shin test

Table 3: Panel cointegration test

Panel: Pedroni Cointegration Common AR coefficients (within-dimension)		
	Statistic	**Weighted Statistic**
P_v	−0.252*	−0.363*
P_{rho}	0.921***	1.617**
P_{pp}	−1.368*	−0.933*
P_{ADF}	0.676*	2.318*
Group: Pedroni Cointegration Individual AR coefficients (b/w-dimension)		
	Statistic	
G_{rho}	2.457*	
G_{pp}	−1.698*	
G_{ADF}	2.938*	
Wester lund (2007) Cointegration		
Variance Ratio	1.9756*	

Note- *, **, and ***indicate significance at 1 %, 5%, & 10% levels, respectively. P_v, P_{rho}, P_{pp}, and P_{ADF} denote panel statistics, and G_{rho}, G_{pp}, and G_{ADF} denote group statistics.

The study employs nonlinear panel quantile regression to assess impacts of $EMUX$, E$\boldsymbol{P}$, $\boldsymbol{PUSU}$, &Y on the carbon emissions ($CO2$) of BRICS countries falling between the 10th and 90th quantiles. This analysis is carried out following the establishment of the long-term connection (see Table 3). Table 4 shows panel quantile regression estimates for panel data of BRICS countries from 2010 to 2023.

Table 4: Nonlinear panel quantile regression estimates (Dependent Variable: Carbon emissions)

Quantiles	$\boldsymbol{EMIX^{+}_{it}}$	$\boldsymbol{EMIX^{-}_{it}}$	E$\boldsymbol{D^{+}_{it}}$	E$\boldsymbol{D^{-}_{it}}$	$\boldsymbol{DIGI^{+}_{it}}$	$\boldsymbol{DIGI^{-}_{it}}$	$\boldsymbol{Y}$	Constant
VL	−1.416*	1.713*	−0.636*	0.442*	−0.545**	0.714**	0.076*	6.363*
Scale	−0.007	0.004	−0.003	0.011	−0.003	0.001	0.006	0.027
q(10)	−0.202**	0.335**	−0.453**	0.185**	−0.481*	0.098*	0.054*	4.805*
q(20)	−0.365*	0.367*	−0.627*	0.466*	−0.546*	0.301*	0.032**	4.197*
q(30)	−0.481*	1.353**	−0.672*	0.466*	−0.442**	0.403*	0.035**	5.054*

q(40)	−1.102*	1.362**	−0.538**	0.242**	−0.825*	0.695*	0.037**	5.125*
q(50)	−1.416*	1.713*	−0.675*	0.442*	−0.545**	0.714**	0.076*	6.363*
q(60)	−1.698*	1.765*	−0.633	0.268*	−0.683**	0.874**	0.073*	8.526*
q(70)	−1.631*	1.945*	−0.433*	0.121**	−0.596	0.905*	0.086*	9.678*
q(80)	−1.846*	2.328**	−0.325*	0.472*	−0.635*	0.925**	0.153*	8.463*
q(90)	−2.023*	2.583***	−0.706*	0.915*	−0.656**	0.965*	0.186*	9.156*

Source: Calculated using STATA 15

Table 4 presents the results of a nonlinear panel quantile regression where carbon emissions are the dependent variable, analyzed across various quantiles (from very low to high emitters). The independent variables include asymmetric components of the energy mix ($EMIX^{+}$ and $EMIX^{-}$), economic development (ED^{+} and ED^{-}), and digitalization ($DIGI^{+}$ and $DIGI^{-}$), along with a control variable (Y) and a constant. The quantile approach highlights how the impact of these variables varies across different levels of carbon emissions, rather than assuming a uniform effect. Notably, the coefficients of $EMIX^{+}$ and $EMIX^{-}$ are generally significant but in opposite directions, suggesting an asymmetric impact: increasing reliance on fossil fuels tends to reduce emissions in lower quantiles but has less clear effects at higher levels, while reducing fossil energy (i.e., switching to renewables) sometimes unexpectedly correlates with higher emissions—possibly reflecting transitional inefficiencies.

Further, the table shows that positive economic development (ED^{+}) typically reduces carbon emissions, especially at higher quantiles, implying that growth supported by cleaner technologies can mitigate environmental impact. Conversely, negative economic shocks (ED^{-}) increase emissions, perhaps due to the weakening of environmental safeguards during downturns. Digitalization also exhibits an asymmetrical effect: positive digital advancements ($DIGI^{+}$) consistently reduce emissions, especially among high emitters, while regressions in digital capacity ($DIGI^{-}$) raise emissions significantly. These findings emphasize importance of maintaining digital and clean-energy momentum, particularly for nations or firms with higher emission profiles. The results advocate for differentiated climate strategies, customized for varying emission levels and contextual dynamics.

5. CONCLUSION

This study intends to investigate relationship b/w emissions & macroeconomic indicators such as energy mix, economic development, digitalization, & national income in the BRICS countries. The study used a nonlinear panel quantile regression model, with paneldata spanning 2010 to 2023. The findings show that a higher energy mix ratio leads to fewer carbon emissions. The energy mix ratio calculates the proportion of energy produced by renewable sources vs non-renewable sources. Given the significant energy demands of developing countries to fund their expansion, a fast transition to renewable sources is not viable. The report emphasizes the potential for BRICS countries to implement policies that increase the energy mix ratio, which could dramatically reduce carbon emissions. According to studies, better economic growth might help BRICS nations reduce their carbon emissions by offering more affordable financing options for green energy initiatives. This may help to decrease insufficient resources and energy use by stimulating innovation in home energy-intensive areas. Furthermore, the report contends that the digitization of the economy might contribute to dematerialization, resulting in decreased carbon emissions in BRICS nations. Digitalization may boost the operational effectiveness of trade & commerce platforms by facilitating flow of information and optimizing manufacturing processes. The study also discovered a strong link b/w country GDP & carbon emissions. This study adds to existing research on the link b/w energy mix, economic growth in economy, digitalization, & carbon emissions. It gives fresh evidence from the BRICS countries, setting the path for future study on comparable and industrialized countries.

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