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Modeling Disaggregate Globalization to Carbon Emissions in BRICS: A Panel Quantile Regression Analysis

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Abstract

This study analyzes the impact that economic, political, and social globalization has had on carbon dioxide emissions in BRICS countries from 1991 to 2022. An empirical analysis has been performed by using the panel ordinary least squares, fixed effects, fully modified ordinary least squares, dynamic ordinary least squares, and panel quantile regression methods. The findings show that both coal-based energy production and economic expansion are major contributors to carbon emissions in BRICS countries. This research substantiates that there is an inverted U-shaped relationship between carbon emissions and per capita income in these countries, which validates the environmental Kuznets curve (EKC) hypothesis. Also, coal-based energy production and economic development are seen to be significant in raising carbon emissions at lower quantiles, and their significance falls at higher quantiles, thus reinforcing the EKC hypothesis in BRICS. The results show a strong influence of both political as well as economic globalization on carbon emissions, whereas social globalization has an insignificant impact. The findings indicate that the influence of economic and political globalization on carbon emissions differed across the distribution of carbon emissions, with a higher effect in the lower to middle quantiles and a lower effect in the higher quantiles; this is consistent with the EKC theory. This type of impact by disaggregate globalization indicates that deeper regional cooperation and the empowerment of global institutions can depress global carbon emissions.

Keywords: carbon emissions; economic globalization; political globalization; social globalization

1. Introduction

Over the past few decades, the pursuit of accelerated economic growth and development has significantly increased carbon dioxide emissions. However, initiatives such as the United Nations' Millennium Development Goals (MDGs) and the ongoing sustainable development goals (SDGs) have played a fundamental role in addressing these challenges; now, developed and developing countries have more concerns about environmental degradation due to negative links to human health (Liu, Zhang, & Bae, 2015; Fei, Fang, & Wang, 2021). Therefore, it is crucial to investigate the extent and drivers of this rising degradation in the natural environment. Economic activities have been identified as significant reasons for environmental degradation (Heath & Gifford, 2006). Grossman and Krueger (1995) established a connection between environmental quality and growth; this study highlights that there is a need for sustainable economic development to lessen the adverse effect of economic activities on nature. Presently, numerous economists have tried to explore this relationship, with special reference to the environmental Kuznets curve hypothesis framework. In the initial phases of economic growth, carbon emissions increase slightly with a rise in income. However, once economies achieve a certain threshold of per capita income, carbon emissions begin to decline. This creates an inverted U-shaped association between environmental quality and economic growth.

In the last few years, policymakers have increased their interest in the factors contributing to environmental pollution, in particular, greenhouse gas (GHG) emissions and their effects on the quality of air (Wang, Wei, & Lin, 2021). This is particularly interesting regarding the work by Kraft and Kraft (1978), who investigated the bi-directional causality between energy use and economic development in the US and found that growth led to a greater consumption of energy. If there is more growth, more energy is needed, and more energy requires ever-increasing amounts of carbon dioxide emissions. Coal remains a primary production factor of energy, and coal consumption is the key factor of carbon emissions, producing more carbon compared to natural gases and oil (IPCC, 2014). Shen, Li, and Hasnaoui (2021) found that the consumption of coal is the biggest supplier of carbon emissions, but its role in stimulating the level of economic growth cannot be overlooked, specifically in developing economies like BRICS. Notably, BRICS has emerged as the world's largest coal user in recent years, with increased coal consumption contributing to the rise in emissions (Apergis & Payne, 2014). BRICS fulfills more than 50% of its energy demand from coal (Stern, 2004). This extensive use of fossil fuels for the production of energy also makes BRICS the major GHG emitter in the world, posing alarming environmental concerns (IPCC, 2014; Canton, 2021). Since BRICS countries keep on achieving more, controlling the destruction of mother nature while progressing economically is an arduous challenge the world has to contend with. As broadly described in Stern

(2004), if the EKC hypothesis is valid for BRICS ethnic groups, then the gross output in the beginning phases of growth would raise both growth and environmental deterioration, and the latter drops in mass carbon emissions over the later stages, creating an inverted U graph.

Due to the interdependence of international markets, globalization is also considered one of the main factors affecting the sustainability of the environment (Kivinen, Kotilainen, & Kumpula, 2020; Yan & Sriboonchitta, 2024). At low levels of income, individuals can afford a higher unsustainable environment, but when the consumption pattern is raised at the threshold level, the lower unsustainability of the environment is preferred (Dinda, 2004). This is true for economies which are trading with each other. As globalization increases the competition among the economies, higher economic benefits are attached to global warming over the depletion of natural resources, loss of biodiversity, diminishing layers of ozone, desertification, and massive deforestation (Kivinen, Kotilainen, & Kumpula, 2020; Pachauri et al., 2014; Nili & Asadi, 2024). These global environmental deteriorations are making globalization a significant threat to environmental sustainability. Globalization is a process that promotes integration, internationalization, and interdependence. Since the 1990s, globalization in BRICS nations has brought both negative as well as positive impacts. While increased economic growth, trade, and international investment have yielded significant benefits, globalization has also exacerbated economic disparities, creating divisions among regions, sectors, and social groups, resulting in distinct winners and losers. The adverse effects of trade openness include concerns about environmental degradation and carbon emissions (Raza, Raza, & Shahbaz, 2020; Khalil & Abdul, 2025). In response, BRICS governments have shown serious concern about combating greenhouse gas emissions; for this, some alternative sources of energy production have been introduced, and various measures to control pollution at the local, state, and national levels have been implemented (Wang, Wei, & Lin, 2021; Al Rasasi, 2025).

Economic globalization concerns the integration of economies in the world economic system with the help of trade, capital flows, and investments. The literature has approved the link between carbon emissions and economic globalization. Different indices have been proposed to estimate the level of economic globalization, which include not only the actual flow of trade and investment, but also trade barriers, tariff rates, and capital controls (Dreher, Gaston, & Martens, 2008). Different studies have linked political globalization with environmental governance (Falkner, 2003; Marks & Hooghe, 2003). This is because the diffusion of policies related to the environment and regulations across countries can lead to more effective governance related to the environment (Biermann & Siebenhüner, 2009; Kumar & Wu, 2025). In addition, the participation of countries in international environmental agreements further strengthens the adoption of stronger environmental standards (Bhagwati, 2004). Social globalization also has implications for environmental awareness and cooperation on environmental issues. Numerous studies have shown that social globalization, as measured by indicators such as the number of radios, use of the internet, and international tourism can lead to the promotion and spread of information related to norms and standards of the environment among nations (Giorguli-Saucedo, García-Guerrero, & Masferrer, 2023; Alvi & Mudassar, 2025). The increased exchange of people and ideas across borders can help to raise awareness about the issues of the environment and further promote the adoption of more sustainable practices (Hartmann & Vachon, 2018). Additionally, social globalization can facilitate cross-border collaboration and knowledge sharing on environmental issues, which can lead to more effective environmental governance (Liu, Zhang, & Bae, 2015; Hanvoravongchai & Paweenawat, 2025). BRICS nations have a substantial contribution to global CO2 emissions, accounting for over 40% of the world's total emissions. Additionally, BRICS nations exhibit diverse stages of economic development and environmental policies, making them an ideal case for analyzing the complex relationship between disaggregate globalization and carbon emissions. Thus, our study is going to explore the impact of economic, political, and social globalization on CO2 emissions in BRICS nations. As this kind of study is currently rare in the literature, this research is expected to make a valuable contribution to this area of inquiry.

2. Literature Review

Since the late 1980s, the emissions of greenhouse gases have been a significant source of apprehension for policymakers and economists. Numerous studies have examined the association between growth and greenhouse gas emissions, with some identifying an inverted U-shaped pattern (Galeotti, Lanza, & Pauli, 2006; Vollebergh & Kemfert, 2005; Heil & Selden, 2001), while others suggest an initially positive relationship that transitions into an N-shaped pattern (Friedl & Getzner, 2003; Spangenberg, 2001; Al-Masri & Ibrahim, 2025). The debate persists, with some scholars arguing that the EKC hypothesis may not be universally applicable (Perman & Stern, 2003; Shahbaz, Mutascu, & Azim, 2013). However, recent studies have documented instances where the EKC hypothesis holds in specific countries and regions. For instance, Shahbaz, Mutascu, and Azim (2013) provided evidence supporting the EKC hypothesis in Romania when energy consumption was included as a regressor for CO2 emissions. Tiwari, Shahbaz, and Hye (2013) also reported evidence of the EKC hypothesis for the Indian economy. Junyi (2006) found support for the EKC hypothesis in Chinese provinces.

Similarly, Song, Zhang, and Wang (2013) found support for the EKC hypothesis in China by using indicators of environmental pollution, i.e., waste gases, wastewater, and solid wastes. However, Yaguchi, Sonobe, and Otsuka (2007) found the EKC hypothesis to apply for Japan but not for China. Empirical evidence regarding the strength of the EKC hypothesis varies significantly across nations and regions. Further studies are needed to discover the intricate relationship between greenhouse gas emissions and economic growth in various contexts.

Globalization has been widely recognized as a vital force of economic growth and development, by providing avenues for technology transfer, division of labor, and investment opportunities. Its effects on greenhouse gases have also been extensively studied by economists by using various measures, i.e., trade, capital flows, and investments. Grossman and Krueger (1995) observed that trade liberalization significantly influences environmental degradation through scale effects. Copeland and Taylor (2004) have suggested that international trade is shaped by the relative availability of factor endowments in each economy, with trade's impact on environmental quality depending on comparative advantages as well as the extent of trade and the implementation of regulations related to the environment. Liddle (2001) and Antweiler, Copeland, and Taylor (2001) argued that trade liberalization can enhance environmental quality by facilitating technological advancements. However, Dean (2002) found that trade liberalization adversely affected environmental quality in China. Magani (2004) found that trade openness stimulates carbon emissions in developing countries. Similarly, McAusland (2008) found that trade has a positive relationship with the degradation of the environment. Shahbaz, Solarin, Mahmood, and Arouri (2013) found that the liberalization of trade boosted environmental degradation in Indonesia.

Recent studies have highlighted that globalization is a significant determinant in influencing environmental degradation. Chakraborty and Mukherjee (2020) found that globalization negatively affects the environment, as trade openness increases pollution in both developing and developed nations. Similarly, Yang, Jahanger, and Khan (2020) have concluded that globalization contributes to environmental degradation by fostering economic growth and industrialization. However, the impact of globalization on environmental quality remains a complex and multifaceted issue, necessitating further research and detailed analysis. While some studies suggest that globalization may improve environmental quality, others highlight its negative impact on the environment. Therefore, policymakers must consider the potential consequences of globalization on the quality of the environment and formulate appropriate policies to mitigate its adverse effects. Globalization has brought about both positive and negative effects on the economies of BRICS countries. While it has led to an increase in trade, growth, and investment, it has also caused concerns about environmental degradation. To mitigate negative effects, governments in BRICS countries have implemented measures to encourage clean energy technology and control pollution at various levels. Recently, Wang and Dong (2019) found that the liberalization of trade boosts CO2 emissions in China, and Li et al. (2021) found that the liberalization of trade is depressing environmental quality. Similarly, Zhang et al. (2021) mention that foreign direct investment encourages higher amounts of greenhouse gasses in China, while Peng, Mu, and Zhu (2021) reveal that FDI enhances both the quality of the environment and economic growth. These mixed findings underscore the multifaceted nature of globalization's impact on environmental quality, highlighting the need for nuanced analysis and strategic policymaking. Governments in BRICS nations should prioritize sustainable development goals and implement policies that mitigate globalization's contrary impacts on the environment while fostering economic growth.

Recent studies have highlighted additional factors influencing environmental degradation, including military expenditure and its interactions with economic growth. Wu et al. (2023) analyzed the relationship between military spending, CO2 emissions, and economic growth in G7 nations, revealing a dual impact. Their findings suggest that military expenditure has a causal effect on environmental pollution, while economic growth exhibits a positive causal relationship with both pollution and military spending in most G7 countries. Similarly, Wu et al. (2022) investigated the relationship between globalization and environmental quality using the bootstrap autoregressive-distributed lag test with a Fourier function for the USA, China, and India. Their empirical results indicate heterogeneous effects of globalization on environmental quality, underscoring the complexity of globalization's environmental consequences across different national contexts. These findings further reinforce the argument that globalization and economic activities, including military expenditures, play a significant role in shaping environmental outcomes. Given these complexities, policymakers must adopt targeted strategies to balance economic growth, security needs, and environmental sustainability, particularly in emerging economies like BRICS.

In our attempt to evaluate the impacts of disaggregated globalization on the CO2 emissions in the BRICS states, we apply the KOF index of economic, political, and social globalization as developed by Dreher, Gaston, and Martens (2008). The KOF index considers various characteristics of globalization, i.e., trade, capital flows, trade restrictions, political ties, international organizations, and social factors. Economic globalization stresses international trade in services, capital, and goods; political globalization includes the worldwide transfer of public policies, whereas social globalization is concerned with the transnational flow of information, ideas, and people. Note that the Kuznets inverse 'U' relationship has been confirmed for many countries under this panel of research. Martinez-Zarzoso and Maruotti (2011) applied the KOF index to study the environmental effect of globalization on LAC economies. Table 1 provides a comprehensive summary of the literature review to identify the research gap. Likewise, using the KOF index of social, political, and economic globalization in BRICS economies, which has been reported to have contributed to the emission of CO_2, may add value to the literature. This study seeks to fill this gap in the literature by showing the relationship between disaggregated globalization and CO_2 emissions in BRICS states more thoroughly, using social, political, and economic dimensions of globalization. The outcomes of our study may help policymakers in BRICS countries to design effective policies to manage the environmental impacts of globalization.

Table 1. Summary of literature.

Dependent Variable: CO_2 Emissions							
Authors (Year)	**Time**	**Data**	**Case**	**Estimations**	**Results**	**Causality**	**EKC**
Oh & Lee (1996)	1970–1990	Time Series	Republic of Korea	Regression and Granger Causality	(+) energy consumption	CO2 emissions ↔ energy consumption	-
Zhang & Cheng (1997)	1953–1992	Time Series	China	Regression	(+) GDP, (+) industrial value added, (-) energy intensity	-	Inverted U-Shaped
Martinez-Zarzoso et al., (2004)	1975–1998	Panel	-	Pool mean group	(-) GDP, (-) trade openness, (+) renewable energy	-	Inverted U-Shaped
Halıcıoğlu (2004)	1970–2000	Time Series	Turkey	ARDL Model	(+) income, (-) energy prices, (+) exports	-	Inverted U-Shaped
Bhattacharya& Rafiq (2005)	1950–2000	Time Series	India	Johansen Cointegration	(+) economic growth	-	Inverted U-Shaped
Lee & Chang (2005)	1961–2001	Time Series	Taiwan	Multiple regression	(+) economic growth	-	Inverted U-Shaped
Wang & (2005)	1980–2002	Panel	China	Fixed-effects model	(+) GDP, (+) investment, (+) exports, (-) energy prices	-	Inverted U-Shaped
Soytas & Sari (2007)	1970–2002	Time Series	Turkey	ARDL	(+) Production, (+) capital	Production → CO_2 emissions, Capital → CO_2 emissions	Inverted U-shaped
Zhang et al., (2009)	1960–2005	Time Series	China	VAR model	(-) Energy consumption, (-) economic growth	Energy consumption ↔ CO_2 emissions, economic growth ↔ CO_2 emissions	Not U-shaped
Farhani et al., (2010)	1980–2005	Panel	MENA countries	Panel ARDL and causality tests	(+) Income, (-) Energy consumption, (-) Trade openness	Income ↔ CO_2 emissions, income → energy consumption	-
Gurgul & Lach (2010)	1960–2006	Panel	Poland	VAR model	(+) Coal consumption	-	-
Huang et al., (2010)	1960–2005	Panel	113 countries	Panel causality tests	(+) Energy consumption	Energy consumption ↔ CO_2 emissions	Inverted U-shaped
Karanfil & Li (2010)	1970–2005	Time Series, Panel	China and India	Panel causality tests	(+) Coal consumption	Coal consumption → CO_2 emissions	Inverted U-shaped
Odhiambo (2010)	1971–2007	Time Series, Panel	Kenya, Tanzania, and Uganda	Johansen cointegration and causality tests	(+) Energy consumption	Energy consumption ↔ CO_2 emissions	-
Sadorsky (2010)	1990–2006	Panel	Emerging economies	Fixed-effects model	Financial development (-)	-	-

Sinha & Sinha (2010)	1971–2006 Panel	SAARC countries	Cointegration	Economic growth (+), Energy consumption (+)	-	Inverted U-Shaped
Toda & Yamamoto (2010)	1980–2006 Time Series	China	Cointegration	Energy consumption (+), Economic growth (-)	-	Inverted U-Shaped
Wang et al. (2010)	1971–2006 Time series	Tanzania	ARDL	Energy consumption (+)	-	-
Wolde-Rufael (2010)	1980–2007 Panel	BRIC countries	Multivariate Granger causality	Energy consumption (+), FDI (+), GDP (+)	Energy consumption ↔ CO_2 emissions, FDI ↔ CO_2 emissions, GDP↔ CO_2 emissions	Inverted U-Shaped
Pao & Tsai (2011)	1953–2006 Time Series	China	Cointegration analysis	Economic growth (-), energy consumption (+), financial development (-)	-	Inverted U-Shaped
Jalil & Feridun (2011)	1980–2009 Time series	Tunisia	ARDL	Financial development (+), urbanization (+), industrialization (+)	-	-
Shahbaz & Lean (2012)	1995–2009 Panel	China	Panel data model	Energy intensity (-), enterprise size (+), foreign direct investment (-)	-	-
Zhang et al., (2012)	1971–2010 Time series	China	ARDL	Economic growth (+), energy consumption (+)	Economic growth ↔ CO_2 emissions, energy consumption ↔ CO_2	Not inverted U-Shaped
Rahman & Mamun (2013)	1995–2010 Panel	China	Fixed-effects model	Regional productivity (+), energy consumption (+)	-	-
Sun et al., (2013)	1990–2010 Panel	MIST countries	Panel cointegration	Financial development (+)	-	-
Zafar & Ahmad (2013)	2006–2010 Panel	China	Spatial Durbin model	Foreign direct investment (-), economic development (+)	-	-
Cai et al., (2014)	1995–2010 Panel	China	Fixed-effects model	Economic growth (+), energy consumption (+)	-	-
Wang et al., (2014)	1980–2011 Time Series	China, India	ARDL	(+) economic growth, (+) coal consumption	Economic growth ↔ CO_2 emissions, coal consumption ↔ CO_2 emissions	Inverted U-Shaped
Khan & Abbas (2014)	1997–2012 Time series	China	Decomposition	(+) industrial structure, (−) energy intensity, (−) fuel mix	-	-
Liu et al., (2015)	1973–2010 Time series	India	STIRPAT model	(+) energy intensity, (+) technology intensity	-	Not inverted U-Shaped
Chakraborty et al., (2015)	1980–2011 Panel	Central America	NPSVAR	(−) fossil fuel prices, (+) renewable energy output	Fossil fuel price → CO_2 emission, renewable energy output → CO_2 emissions	Not inverted U-Shaped

Apergis & Payne (2016)	1980–2013	Time Series	Pakistan	ARDL	(+) urbanization, (+) energy consumption, +human development	Urbanization → CO_2 emissions, energy consumption → CO_2 emissions, human development → CO_2 emissions	Inverted U-Shaped
Ali & Akbar (2016)	1980–2011	Time Series	Pakistan	ARDL	(+) GDP per capita, (−) trade openness, (+) population growth	GDP per capita → CO_2 emissions, trade openness → CO_2 emissions, population growth → CO_2 emissions	Inverted U-Shaped
Nasir & Ur Rehman (2016)	1990–2013	Panel	OECD countries	GMM	(+) Renewable energy consumption	-	Not inverted U-Shaped
Çetin & Ertürk (2016)	1971–2014	Time Series	Malaysia	ARDL	Urbanization (+), Affluence (+), Trade openness (+)	-	Inverted U-shaped
Shahbaz et al., (2017)	1971–2014	Time Series	Pakistan	Granger causality, ARDL	Energy consumption (+), Economic growth (+)	Energy consumption ↔ CO_2 emissions, Economic growth ↔ CO_2 emissions	Inverted U-shaped
Abbas et al., (2017)	1980–2015	Panel	South Asian	Panel cointegration, FMOL	Economic growth (+), Energy consumption (+)	-	Inverted U-shaped
Ali and Akbar (2018)	1980–2014	Panel	Asian populous countries	Fixed-effects model, dynamic panel model	Population density (-), Economic growth (-), Energy use (+), Exports (-)	-	-
Das and Paul (2018)	1960–2013	Time Series	Taiwan	Nonlinear ARDL approach	Economic growth (+), Energy consumption (+)	Economic growth ↔ CO_2 emissions, Energy consumption ↔ CO_2 emissions	Inverted U-shaped
Chen and Li (2018)	1965–2014	Time Series	South Africa	Cointegration test	Energy consumption (+)	-	-
Chang and Lee (2018)	2000–2015	Panel	Developing countries	Fixed-effects model	Regional GDP per capita (-), Fossil fuel consumption (+), Population density (+), Urbanization (+), Road density (+)	-	-
Zhang et al., (2019)	1980–2014	Time Series	Pakistan	STIRPAT model	Urbanization (+), Population (+)	-	-
Hassan and Yousaf (2019)	1995–2014	Time Series	China	Regression	FDI (-)	-	Inverted U-shaped
Hu et al., (2019)	1990–2014	Panel	35 Countries	Fixed-effects model	Renewable energy consumption (-), Non-renewable energy consumption (+)	-	Inverted U-shaped
Sadorsky (2019)	1995–2015	Time Series	China	LMDI decomposition model	GDP (+), Energy intensity (-), Structure effect, (-), Energy intensity effect (+)	-	-

Bao et al., (2019)	2005–2016	Panel	China	Developing countries	Agricultural output (+), Agricultural labor force (-), Agricultural machinery (+), Urbanization rate (-)	-	Inverted U-shaped
Li et al., (2020)	1980–2016	Panel	Asian economies	Panel cointegration and causality tests	Industrialization (+), Urbanization (+), Trade openness (-), Renewable energy consumption (-)	Industrialization → CO_2 emissions, urbanization → CO_2 emissions, trade openness ← CO_2 emissions, renewable energy consumption ← CO_2 emissions	Inverted U-shaped
Raza et al., (2020)	1995–2017	Panel	ASEAN-5 countries	FMOLS and Granger causality tests	Natural gas consumption (-), Trade openness (-)	Natural gas consumption ← environmental pollutants, trade openness ← environmental pollutants	-
Shahbaz & Farhani (2020)	1990–2013	Panel	African Countries	ARDL, FMOLS, DOLS	Economic growth (+), Renewable electricity consumption (-), Non-renewable electricity consumption (+)	-	Not inverted U-Shaped
Tiba & Frikha (2020)	1995–2018	Panel	East Asian Countries	GMM, FMOLS, DOLS	Economic growth (+), Energy consumption (+)	-	Inverted U-shaped
Fan et al., (2020)	2003–2016	Panel	Developing countries	Spatial panel data analysis	Financial development (-), Trade openness (-)	-	Not inverted U-Shaped
Zheng et al., (2020)	2006–2017	Panel	China Provinces	Panel data approach	Economic growth (+), Urbanization (+), Energy consumption (+)	-	-
Zhang et al., (2021)	2000–2017	Panel	ASEAN countries	Panel data analysis	Renewable energy consumption (-)	-	-
Almutairi et al., (2021)	1990–2016	Panel	Top CO2 emitting countries	Panel data analysis	Natural gas consumption (+)	-	-
Hasanov & Bulut (2021)	2006–2017	Panel	China Provinces	Spatiotemporal analysis	Economic growth (+), Energy consumption (+), Foreign direct investment (-)	-	-
Li et al., (2021)	2005–2017	Panel	Developing countries	Panel smooth transition regression	Environmental regulation (-)	-	-
Sun et al., (2021)	1990–2017	Panel	Next-11 countries	Panel data analysis	Financial development (+), Economic growth (+), Energy consumption (+)	-	Not Inverted U-Shaped
Ullah et al., (2021)	-	Literature review	-	-	Carbon pricing policies (-)	-	Inverted U-shaped
Wang et al., (2021)	-	Literature review	-	-	Energy consumption (+), economic growth (+)	-	Inverted U-shaped

Xie et al., (2021)	1995–2017 Time Series	China	ARDL, Granger causality test	Financial development (+), technological innovation (-)	Financial development ↔ CO_2 emissions, technological innovation ↔ CO_2 emissions	-
Zhang & Yao (2021)	2008–2019 Panel	Turkey Provinces	Pooled OLS, fixed-effects model	Energy consumption (+)	-	-
Acar et al., (2022)	1990–2018 Panel	-	Panel regression, GMM	Renewable energy (-)	-	-
Almansoori & Ferreira (2022)	1980–2018 Time Series	Ghana	FMOLS, Granger causality	Agricultural productivity (-)	CO_2 emissions ← Agricultural productivity	-
Asante-Boateng et al., (2022)	1971–2017 Time Series	Mexico	Panel data regression	Trade (-), technological innovations (-)	-	-
Barroso et al., (2022)	1990–2018 Panel	OECD countries	Panel/quantile regression	Renewable energy (-)	-	-
Bölük & Mert (2022)	2005–2018 Panel	China Provinces	Spatial Durbin model	Industrial structure (-)	-	-
Chen et al., (2022)	1990–2018 Time Series	Indonesia	ARDL, asymmetric causality test	Biomass consumption (+)	CO_2 emissions ← Biomass consumption	-
Elnar & Sukmana (2022)	1996–2017 Time Series	Portugal	Spatial autoregressive model	Electricity generation from fossil fuels (+)	-	-
Faria & Alves (2022)	1990–2017 Panel	OECD countries	Dynamic panel model	Renewable energy consumption (-)	Renewable energy consumption ↔ CO_2 emissions	-
Hassani et al., (2022)	2007–2016 Panel	65 countries	GMM	Trade (-)	-	-
He & Wei (2022)	2006–2017 Panel	China Provinces	Fixed-effects model	Renewable energy consumption (-), Technological innovation (-)	-	Inverted U-shaped
Huang et al., (2022)	1975–2019 Time Series	Bangladesh	ARDL model	Renewable energy use (-), GDP per capita (+)	Renewable energy use → CO_2 emissions, GDP per capita → CO_2 emissions	-

Note. The above table uses different symbols, The above symbols such as (+, -) mean that the (+) positive, or (-) negative impact on dependent variables. While (↔) is used for bidirectional causality, (→) is used to explain unidirectional, and (←) is used for reverse causality.

3. The Model

The harmful impacts of environmental change are an increasing concern for the global community. CO2 emissions are a significant contributing factor to this issue and their prevalence is causing significant damage to the planet's climate. It is well recognized that energy production and consumption are vital components of socio-economic growth, but it is equally important to ensure that they are sustainable and do not come at the cost of environmental damage. The BRICS nations—Brazil, Russia, India, China, and South Africa—have recognized the critical importance of addressing environmental change and have pledged to decrease greenhouse gas (GHG) emissions by 2020. The Kyoto Protocol, a legally binding international agreement, has been instrumental in uniting countries to combat climate change collectively. These countries are part of a larger global community that recognizes the effect of GHG emissions on environmental change and the need for urgent action. Climate change can lead to changes in precipitation patterns, which can have adverse effects on agriculture (IPCC, 2014). Moreover, climate change can exacerbate water scarcity and reduce water availability for various sectors, including energy production and agriculture (Kundzewicz et al., 2008). The authors of Ali and Audi (2016); Audi and Ali (2017); Audi and Ali (2018); Audi, Ali, and Kassem (2020); Ali, Audi, and Roussel (2021); Ali, Audi, Bibi, and Roussel (2021); and Ali, Audi, Senturk, and Roussel (2022) have incorporated political, social, and economic globalization as determinants of CO2 emissions, with already tested indicators, i.e., energy production from coal and economic growth. The pollution haven hypothesis explains that economic globalization facilitates the relocation of pollution-intensive industries to developing economies with relaxed environmental regulations, thereby increasing emissions (Copeland & Taylor, 2004). Meanwhile, the EKC hypothesis posits that as political and social globalization strengthens governance, social norms, and environmental policies, emissions initially rise with economic growth but eventually decline at higher income levels due to sustainable development measures (Grossman & Krueger, 1995). The mathematical model becomes as follows:

$$CO_{2it} = f(C_{it}, Y_{it}, Y^2_{it}, Eg_{it}, Pg_{it}, Sg_{it}) \tag{1}$$

i = selected cross-section (Brazil, Russia, India, China, South Africa);
t = time period (1991 to 2022).
The linear estimated regression model is written as follows:

$$LCO_{2it} = \alpha + \beta_1 LC_{it} + \beta_2 LY_{it}, + \beta_3 LEg_{it} + \beta_4 LPg_{it} + \beta_5 LSg_{it} + U_{it} \tag{2}$$

To check the responsiveness of the dependent variable with respect to each explanatory variable, we have transformed all of the variables in the natural logarithm.
To check the existence of the EKC hypothesis, the nonlinear model can be written as follows:

$$LCO_{2it} = \alpha + \beta_1 LC_{it} + \beta_2 LY_{it} + \beta_3 LY^2_{it} + \beta_4 LEg_{it} + \beta_5 LPg_{it} + \beta_6 LSg_{it} + U_{it} \tag{3}$$

where LCO_2 is the natural log of CO_2 emissions per capita, LC is the natural log of energy production from coal, LY is the natural log of GDP per capita in current US dollars, LY2 is the natural log of GDP per capita squared, LEg is the natural log of the economic globalization index, LPg is the natural log of the political globalization index, and LSg is the natural log of the social globalization index. The hypothesis is that CO_2 emissions are positively impacted by energy production, represented by a $\beta 1 > 0$. The connection between economic growth and CO_2 emissions is theorized to follow an inverted U-shaped pattern, with $\beta 2 > 0$ and $\beta 3 < 0$. Finally, the impact of disaggregate globalization is expected to be negative ($\beta 4$, $\beta 5$, $\beta 6 < 0$) if economies are converging to developed countries, but positive ($\beta 4$, $\beta 5$, $\beta 6 > 0$) if there is a divergence. Several studies have identified varied relationships between CO_2 emissions and different aspects of globalization. Wang et al. (2021) found that economic globalization positively influences CO2 emissions, whereas political globalization has a negative effect. Ouyang, Li, and Du (2020) observed that social globalization increases CO2 emissions in developing countries but decreases them in developed nations. Lei, Liu, Hafeez, and Sohail (2021) reported that coal-based energy production significantly contributes to CO2 emissions. These diverse findings highlight a research gap in understanding the impact of disaggregated globalization on CO2 emissions, particularly in the context of BRICS nations, where such studies are scarce in the existing literature.
Table 2 provides the definitions of all the selected variables and Table 3 gives summary statistics of all variables. The missing values of variables are intended through the process of extrapolation. The methods of extrapolation (used for forecasting future trends based on past patterns) are based on two major steps. In the first step, we calculate the linear slope ratio of the two time periods series, y and x. Here y represents the current value of time, y_1 and y_2 represent the last years and vice versa for x. We can solve the slope = m using the equation $m = (y_2 — y_1)/(x_2 — x_1)$. In the second step, we re-count a line equation. ($y = y_1 + m (x — x_1)$). After that, we can extract the value of the next successive year value

for y and x in the equations above suggested by (Shahid et al. 2024) All the selected variables have reasonable descriptive statistics to make further empirical analyses.

Table 2. Variable and data sources.

Variables	Definition	Sources
CO_2	CO_2 emissions (metric tons per capita)	World Development Indicators
C	Energy production from coal sources (% of total)	-
Y	GDP per capita (Current US dollars)	-
Y2	GDP per capita squares term	-
Eg	Economic globalization Index	KOF Swiss Economic Institute
Pg	Political globalization Index	-
Sg	Social globalization Index	-

Table 3. Descriptive statistics results.

Variables	LCO_2	LC	LY	Leg	LPg	LSg
M	1.369	3.394	7.932	3.721	4.441	3.983
SD	0.943	1.342	1.077	0.369	0.148	0.274
Mdn	1.395	4.226	8.128	3.793	4.476	4.056
Max	3.194	4.561	9.678	4.531	4.531	4.311
Min	0.432	0.659	5.707	2.628	3.25	3.202
Skew	−0.144	−0.933	−0.522	−1.324	−4.91	−0.981
Kurt	1.613	1.293	2.223	1.866	30.15	2.361
Observations	160	160	160	160	160	160

4. Econometric Methodologies

Using the econometric methodology has become an integral part of applied economics and other management sciences. In this study, various unit root tests, e.g., the Levin, Lin, and Chu (LLC) (Levin, Lin, & Chu, 2002), Im, Pesaran, and Shin (IPS) (Im, Pesaran, & Shin, 2003), Breitung (2002), Maddala, and Wu (1999) tests have been employed to assess the stationarity of the variables. A variety of methods have been used to evaluate the influence of regressors on the regressed, including ordinary least squares (OLS), fixed effects (FE), fully modified OLS (FMOLS), and dynamic OLS (DOLS). OLS and FE models have provided valuable insights into the association between CO2 emissions and selected explanatory variables, whereas fully modified OLS and dynamic OLS models have been used to investigate the long-run cointegration coefficients for the in-depth investigation of coefficient stability. Coefficient stability is a measure of how much a test score varies due to factors like the time and occasion of the test. It can also refer to the stability of a regression coefficient. These coefficients are residual-based or error corrections for heterogeneous data sets. Additionally, to overcome the limitations of traditional regression methodology, a panel quantile regression model has been applied. This model is suitable for detecting crucial relationships that might be missed by traditional regression due to its focus on mean effects. Binder and Coad (2011) discuss the limitations of the traditional regression methodology and highlight the benefits of using panel quantile regression to analyze the relationship between CO2 emissions and explanatory variables. Koenker and Bassett (1978) developed a model of panel quantile regression, in which the coefficients represent the partial derivative of the dependent variable's conditional quantile concerning certain regressors. These coefficients reflect the marginal change in the dependent variable at the q-th conditional quantile, which results from a marginal change in a certain regressor (Yasar, Nelson, & Rejesus, 2006). In this study, coefficients are estimated at nine quantiles of CO_2 emissions using models q10, q20, q30, q40, q50, q60, q70, q80, and q90. Models q10 and q20 assess the impact of each dimension of globalization on low CO2 emitters, while the 50th percentile model (q50) examines the impact on medium CO_2 emitters, and the 90th percentile model (q90) focuses on high CO_2 emitters. The generalized approach of median regression analysis can also be applied to other quantiles, as shown below:

$$Q_{yi}\ (\tau|x_i) = x^T{}_{i\ \beta\tau} \tag{4}$$

A panel quantile regression analysis shows how independent variables affect different parts of the dependent variable's distribution (not just the mean), while simultaneously controlling for overlooked individual characteristics by leveraging the panel data. This regression also allows the researchers to identify the problem of heterogeneous effects across different quantiles. Applying quantile regression is particularly advantageous when heavy distributions are present in the data.

However, unobserved heterogeneity within a country may not be accounted for using this technique. To address this limitation, panel quantile fixed effects were utilized in the current study to examine both conditional and unobserved individual heterogeneity. Previous studies, such as those by Lamarche (2010), Galvao (2011), and Koenker (2004), have applied quantile regression to panel data in the context of econometric theory. The fixed-effect panel quantile regression model used in this study can be expressed as follows:

$$Q_{yi}\,(\tau_k|\alpha_i x_{it}) = \alpha_i + x'_{it}\,(\tau_k) \tag{5}$$

When applying panel quantile regression with fixed effects, the incidental parameters problem may arise. This problem occurs when the number of fixed effects are relatively large compared to the number of observations for each cross-section, potentially leading to inconsistency as the number of individuals approaches infinity (Lancaster, 2000; Neyman & Scott, 1948). Fixed effects are employed to eliminate unobserved effects, but the linearity of expectations may not be appropriate for conditional quantiles (Canay, 2011). To address this issue, Koenker (2004) introduced a methodology that accounts for unobservable fixed effects by estimating them simultaneously with the effects of covariates across different quantiles. A penalty term is used in this approach to minimize computational difficulties during parameter estimation, which can be calculated as follows:

$$\min_{(\alpha,\beta)} \sum_{k=1}^{K} \sum_{t=1}^{T} \sum_{i=1}^{N} \mathrm{Wi}\ \ \mathrm{P\tau k}\,(y_{it} - \alpha_t - x^{T}_{it}\,\beta(\tau_k)) + \lambda \sum_{i}^{N} |\alpha t| \tag{6}$$

The equation above represents the fixed-effect panel quantile regression, where i indicates the countries (N), T denotes the number of observations per country, k represents the quantile index, and x refers to the matrix of explanatory variables. The quantile loss function is denoted by Ptk, while the weight given to the kth quantile to regulate the fixed effect estimation is represented by Wk. This research adopts equally weighted quantiles, where Wk = 1/K, as recommended by Alexander, Harding, and Lamarche (2011). The tuning parameter λ is utilized to enhance the estimation of β and reduce individual effects to zero. As λ approaches zero, the penalty term disappears, and the usual fixed effect estimator is obtained. Conversely, as λ tends to infinity, the model estimate is achieved without individual effects. For this study, λ is set to 1 (Damette & Delacote, 2012). The quantile function for τ of the variables under investigation can be specified as follows:

$$LCO_{yi}\,(\tau|\alpha_i,\xi_t,x_{it}) = \alpha_i + \xi_t + \beta_{i\tau}LC_{it} + \beta_{2\tau}LY_{it} + \beta_{3\tau}LY^2_{it} + \beta_{4\tau}LEg_{it} + \beta_{5\tau}LPg_{it} + \beta_{6\tau}LSg_{it} + U_{it} \tag{7}$$

All the indicators have been explained above, except U, which represents the white noise error term.

5. Results and Discussion

5.1. Results of Panel Unit Root Test

This section presents the estimated results of this study. In this study, we have used E-Views 11 for estimation purposes. Before estimating the panel quantile regression models, stationarity tests were performed on the variables using various unit root tests, including LLC (Levin, Lin, & Chu, 2002), IPS (Im, Pesaran, & Shin, 2003), Breitung (2002), and Maddala and Wu (1999) tests, because each test has different strengths and weaknesses depending on the characteristics of data, and whether a set of time series data from multiple cross-sectional units (a panel) was used. Additionally, due to differences in the incidence of trends, potential structural breaks, and the noise level, choosing the right test helps to provide better results for data problems. Most of the variables in this study are parametric and nonparametric. This is the reason we use a different set of unit root tests; in doing so, we ensure the accurate identification of whether a time series contains a unit root and needs to be transformed before further analysis. These tests are used to determine if the variables are stationary. The findings show that most unit root tests reject the null hypothesis of the presence of a unit root, implying that the variables attain stationarity. The null hypothesis, on the other hand, cannot be rejected at all levels but is rejected at their first differences. Consequently, it is concluded that using first differences is more appropriate for ensuring stationarity. The results of these tests are presented in Table 4.

Table 4. Results of panel unit root.

	At Levels				
	LLC	**IPS**	**Breitung**	**Fisher ADF**	**Fisher PP**
LCO_2	−1.529	−0.103	0.681	−0.495	−0.387
LC	3.0720	1.584	1.811	1.480	1.310
LY	−0.335	2.141	−0.191	2.196	2.599
Leg	−3.388 ***	−2.501 ***	−2.831 ***	−2.553 ***	−2.086 ***

LPg	−0.671	−0.370	−2.712 ***	−2.281 ***	−3.057 ***
LSg	−0.202	2.898	0.526	3.450 ***	2.066 ***
			First Difference		
LCO_2	−7.382 ***	−6.622 ***	−2.404 ***	−6.512 ***	−6.561 ***
LC	−2.531 ***	−5.635 ***	−4.469 ***	−8.362 ***	−8.368 ***
LY	−4.913 ***	−4.004 ***	−4.086 ***	−5.634 ***	−5.614 ***
Leg	−5.609 ***	−8.242 ***	−3.822 ***	−6.981 ***	−6.949 ***
LPg	−4.436 ***	−6.301 ***	−2.645 ***	−5.309 ***	−4.571 ***
LSg	−2.890 ***	−7.939 ***	−2.326 ***	−6.665 ***	−8.927 ***

Note: "LLC, IPS, Breitung, represent the panel unit root tests of Levin et al. (2002), Im et al. (2003), Breitung (2002). Fisher-ADF and Fisher-PP panel unit root tests, represent the Maddala and Wu (1999) respectively". *** Statistically significant at 1% level.

5.2. Estimated Outcomes

In this article, several regression methods, including ordinary least squares, fixed effects, fully modified ordinary least squares, and dynamic ordinary least squares, were employed to examine the influence of explanatory variables on the dependent variable. The estimated results for each method have been summarized in Table 5. Additionally, the outcomes of the panel quantile regression are presented in Table 6.

The results depicted in Table 6 indicate that energy production from coal has a significant and positive impact on CO_2 emissions for BRICS nations. The coefficients for ordinary least squares, fixed effects, fully modified ordinary least squares, and dynamic ordinary least squares are 0.304 and 0.3103, 0.1243 and 0.3413, 0.2873 and 0.471, and 0.31819 and 0.3103, respectively. Based on the coefficients (Table 5), a 1 percent increase in energy production from coal leads to a 12 to 47 percent rise in CO_2 emissions, depending on the estimation method used. The primary reason for the positive relationship between energy production from coal and CO_2 emissions in BRICS nations is the high demand for energy for households and commercial usage. These results are not surprising, given that BRICS is composed of emerging markets with limited resources for alternative energy production. Moreover, alternative energy production resources require time, technology, and fixed costs. These findings are consistent with previous studies (Shahbaz, 2013; Sahoo & Sahoo, 2022; Pata, 2018; Khan, Teng, & Khan, 2019; Wang & Li, 2024) that established a positive relationship between energy production from coal and CO2 emissions.

According to the estimated results of the quantile regression presented in Table 6, this study finds that energy production from coal has a positive and significant impact on CO_2 emissions across all nine quantiles, with the impact ranging from 2 to 35 percent. The results suggest that there is no significant difference in the parameter estimates across the first five quantiles, while there is a significant difference from the medium quantile to the highest quantile. This provides crucial evidence that the positive impact of energy production from coal is present across the entire conditional distribution of CO_2 emissions, consistent with prior research [9,149]. This study further reveals that the smaller positive effect of energy production from coal at the higher tail of the distribution indicates a positive CO_2 emissions effect. The positive shift of all the quantiles implies that energy production from coal has a higher-order stochastic distribution that dominates the CO_2 emissions distribution. However, the lower positive shift at the higher quantiles suggests that CO_2 emissions from energy production by coal are negatively skewed. This indicates that reducing energy production from coal in Brazil, Russia, India, China, and South Africa could help decrease CO_2 emissions caused by energy production from coal.

Economic development and CO_2 emissions in BRICS countries are positively and significantly correlated, according to the estimated data shown in Table 5. In particular, CO_2 emissions are positively impacted by the linear term of income per capita, but CO_2 emissions are significantly impacted negatively by the square of income per capita. These findings suggest the presence of an inverted U-shaped relationship between income per capita and CO2 emissions, which is consistent with prior research (Shahbaz, Khraief, Uddin, & Ozturk, 2014; Zhang, Wang, & Wang, 2017; Ganda, 2019; Rahman, Murad, Ahmad, & Wang, 2020; Minlah & Zhang, 2021; Mahmood, Furqan, Hassan, & Rej, 2023; Sharma & Das, 2024). The estimates of ordinary least squares, fixed effects, fully modified ordinary least squares, and dynamic ordinary least squares for both linear and nonlinear terms are presented in Table 5. The coefficients for a 1% increase in income per capita range from 18% to 61% for CO_2 emissions, depending on the estimation technique used. Conversely, a 1% increase in the square of income per capita reduces CO_2 emissions by 9% to 56%, depending on the estimation technique. The study's results (Table 6) support the existence of the environmental Kuznets curve by showing that economic growth has a positive and significant impact on CO_2 emissions from the lowest to the highest quantile, but at the highest quantile, this relationship becomes negative and significant. Additionally, the results show that at the lowest quantile, the linear term of income per capita has a positive and substantial influence on CO_2 emissions; at the highest quantile, however, this connection becomes negative and significant. Conversely, at the lowest quantile, the square of per capita income has a negative and significant effect on CO_2 emissions; however, at the sixth, seventh, and eighth quantiles, this connection is positive and significant, and at the highest quantile, it becomes negative and significant. These findings suggest that a 1 percent increase in economic growth leads to a more than 21 percent increase in CO_2 emissions at the lowest quantile with a positive effect, and this effect diminishes at higher quantiles, supporting the rebound effect in economic growth. This result is in line with the phases theory of economic development (Rostow, 1959), which postulates that, beyond a certain point, there is a negative correlation between economic growth and unfavorable environmental circumstances. The results further corroborate the presence of the EKC hypothesis in the case of BRICS countries by confirming the inverted U-shaped link between economic development and CO2 emissions. These findings are consistent with earlier research (Pao & Tsai, 2011; Kiliç & Balan, 2018; Marc, 2024) that found a positive correlation between CO2 emissions and economic growth.

Based on the results presented in Table 5, it can be concluded that economic globalization has a significant and positive impact on CO_2 emissions in BRICS countries. Economic globalization is a broad term that covers the movement of goods, services, capital, labor, and information and technology across borders. The growth of international institutions like the IMF and the World Bank has played a crucial role in promoting economic globalization [159]. Improved telecommunication levels, greater trade openness, and more efficient long-distance transport have resulted from the increasing trend toward economic globalization. While these activities have attracted foreign investors and led to economic and business growth, they have also contributed to a deterioration in the quality of the environment (Shahbaz, Tiwari, & Nasir, 2013). The past literature has reported a negative relationship between the quality of the environment and economic and business activities (Bokpin, 2017; Hou, 2019; Habibullah & Kamal, 2024). The results obtained using different estimation techniques, such as panel OLS, fixed effects, FMOLS, and DOLS, are presented in Table 5. A single percent rise in economic globalization is linked to a 1 percent to 28 percent rise in CO2 emissions, depending on the estimation technique used. However, the panel ordinary least squares method indicates a positive but insignificant relationship between economic globalization and CO2 emissions. These findings are in line with the previous literature (You & Lu, 2018; Kalaycı & Hayaloğlu, 2019; Yang et al., 2021; Jamel & Zhang, 2024), which estimates a positive relation between economic globalization and CO2 emissions.

The estimated outcomes of quantile regression (Table 6) show that economic globalization is impacting CO_2 emissions positively and significantly from the lowest quantiles to the 7th quantile. However, economic globalization has an adverse and significant impact on CO_2 emissions in the 8th and 9th quantiles. The estimated outputs indicate that there is a significant variation in the parameter estimates from the lower to higher quantiles. This approves that economic globalization creates positive impacts across the medium conditional distribution of gasses emissions. The higher economic globalization at the higher tail of the distribution exhibits a negative CO_2 emissions effect. The positive shift until the 7th quantile means that economic globalization has a higher-order stochastic distribution which dominated the CO_2 emissions distribution. The negative shift at the higher quantiles means that CO_2 emissions by economic globalization are negatively skewed. This means that CO_2 emissions by economic globalization can be diminished by raising economic globalization in Brazil, Russia, India, China, and South Africa. These outcomes are in line with the past literature, which suggests that economic globalization has a positive impact on CO2 emissions (Costantini & Monni, 2008; Choi, Ang, & Zhou, 2010; Dreher, 2006). The emergence of international institutions such as the International Monetary Fund (IMF) and the World Bank has expanded overall globalization, including economic globalization (Wu et al., 2022; Ahmad & Shah, 2024). The rising economic globalization has improved the level of telecommunication, the efficiency of long-distance transport, and trade openness (Shahbaz, 2013). However, rising economic activities also diminish the quality of the environment (Nordhaus, 2007; Newell & Mulvaney, 2013). Our estimates using OLS, fixed effect, FMOLS, and DOLS methods support the positive relationship between economic globalization and CO2 emissions, with slopes ranging from 0.067 to 0.2827 (Wang, Zhou, Zhou, & Wang, 2010; Zenios, 2024). Therefore, it is meaningful to note that the adverse relationship between economic globalization and CO2 emissions at the higher quantiles suggests that after the threshold level, economic globalization can no longer have a positive effect on CO2 emissions. This outcome supports the inverted U-shaped relationship between economic growth and CO2 emissions, which is consistent with the EKC theory (Frankel & Rose, 2010; Hassen & Ram, 2014; Ahmed & Alvi, 2024).

The results (Table 5) indicate that political globalization has a significant adverse impact on CO_2 emissions in the case of BRICS nations. Political globalization refers to the extension of the world political system and its establishments across countries, regions, and continents. Political integration can lead to deeper regional cooperation, such as trade blocks, and create mechanisms to deal with trade barriers designed to protect participating countries (Frankel & Rose, 2002). Political globalization empowers world institutions, i.e., the World Bank, IMF, WTO, and UNO to review political and governance issues of member nations and guide them accordingly. Rising global warming has raised the concerns of these global institutions to monitor the political, governance, and business activities of member nations to control CO2 emissions

(Mirrlees, 2013). Our estimates using panel OSL, fixed effects, FMOLS, and DOLS methods show an adverse and significant relationship between political globalization and CO_2 emissions, with coefficients of −0.2971 and −0.2976, −0.235 and −0.2467, −0.261 and −0.261, and −0.8435 and −0.224, respectively. According to the coefficients in Table 4, a 1% increase in political globalization is associated with a 22% to 84% decrease in CO_2 emissions, depending on the estimation technique used. However, the panel ordinary least squares method shows an adverse and insignificant relation between political globalization and CO_2 emissions.

The estimated outcomes of quantile regression (Table 6) show that political globalization has an adverse and significant effect on CO2 emissions from the lowest quantiles to the 6th quantile. However, political globalization has a positive and rising effect on CO2 emissions from the 7th quantile to the higher quantiles (Banister, 2011; Balsalobre-Lorente, Driha, & Sinha, 2021). The results indicate that there is a significant difference in the parameter estimates from the lowest quantile to the highest quantile. The results show that the negative political globalization effect is present across the conditional distribution of CO2 emissions. However, higher political globalization at the higher tail of the distribution exhibits a positive CO2 emissions effect (Dreher, 2006). The negative shift until the 6th quantile means that political globalization has the lowest order stochastic distribution, which dominated the CO2 emissions distribution. The positive shift at the higher quantiles means that CO2 emissions by political globalization are positively skewed. This means that CO2 emissions by political globalization can be reduced by raising political globalization in Brazil, Russia, India, China, and South Africa (You & Lu, 2018; Kalaycı & Hayaloğlu, 2019; Yang et al., 2021; Costantini & Monni, 2008; Choi, Ang, & Zhou, 2010).

The outcomes (as reported in Table 5) show that social globalization has a significant adverse impact on CO2 emissions in BRICS nations. Social globalization refers to the cross-border movement and convergence of cultures, habits, media, and lifestyles (Nordhaus, 2007). This type of globalization may contribute to CO2 emissions by increasing urbanization and the demand for travel and transportation (Hassen & Ram, 2014; Frankel & Rose, 2002). Our estimates from panel OLS, fixed effects, and DOLS methods show a positive and significant link between CO_2 emissions and social globalization. Specifically, a 1 percent increase in social globalization leads to a 19 percent to 62 percent increase in CO_2 emissions. However, the results of the FMOLS method show an insignificant relation between CO_2 emissions and social globalization.

The estimated outcomes of the quantile regression (Table 6) show that social globalization has an adverse and significant impact on CO2 emissions across all nine quantiles and ranges from 6 to 162 percent (Frankel & Rose, 2002; Mirrlees, 2013). The findings indicate that the parameter estimates vary across all the first seven quantiles but there is no significant difference in parameter estimates from the eighth quantile to higher quantiles (Nordhaus, 2007). This supports the idea that the negative social globalization effect has existed across the entire conditional distribution of CO2 emissions. The smaller social globalization at the higher tail of the distribution exhibits a negative CO2 emissions effect (Frankel & Rose, 2002). The negative movement of the quantiles represents that social globalization has a higher order stochastic distribution, which dominated the CO2 emissions distribution (Mirrlees, 2013). The higher negative shift means that CO2 emissions by social globalization are negatively skewed (Frankel & Rose, 2002). This means that the CO2 emissions by social globalization can be diminished by raising social globalization in Brazil, Russia, India, China, and South Africa (Hassen & Ram, 2014; Frankel & Rose, 2002; Mirrlees, 2013).

Table 5. Panel results for BRICS countries LCO_2 dependent variables.

Variables	Panel OLS		Fixed Effect		FMOLS		DOLS	
LC	0.304 ***	0.3103 ***	0.1243 **	0.3413 ***	0.2873 ***	0.471 ***	0.31819 ***	0.3103 ***
LY	0.496 ***	0.6145 ***	0.2375 ***	0.18451 ***	0.183 ***	0.2106 ***	0.5648 ***	0.2147 ***
LY^2		−0.1034 **		−0.095 ***		−0.109 ***		−0.564 ***
LEg	0.2827	0.2245 **	0.0670	0.1617 ***	0.232 **	0.191 ***	0.2207 **	0.103 ***
LPg	−0.2971	−0.2976	−0.235 ***	−0.2467 ***	−0.261 ***	−0.261 ***	−0.8435	−0.224 **
LSg	0.6181 **	0.6181 **	0.5674 ***	−0.0401	−0.221	0.3801	0.1910 ***	0.3800 ***
Obser	160	160	160	160	160	160	160	160

- Fixed effect proposed by correlated random effect Hausman test statistics
- DOLS developed by Stock and Watson (1993) and FMOLS are used to check the long-run co-integration results of estimated coefficients. Both tests are residual-based or error-correction, testing for homogeneous or heterogeneous co-integration of the variables.
- ***, ** represents 1% and 5% levels of significance.

Table 6. Panel quantile regression analysis.

Variables Quantiles									
	10th	**20th**	**30th**	**40th**	**50th**	**60th**	**70th**	**80th**	**90th**
LC	0.329 ***	0.340 ***	0.346 ***	0.347 ***	0.334 ***	0.223 ***	0.207 ***	0.231 ***	0.018
	[9.845]	[15.050]	[11.258]	[10.018]	[7.999]	[2.468]	[2.488]	[2.863]	[0.066]
LY	0.2147 ***	0.1736 **	0.0052 **	0.1291 ***	0.620 *	0.0156 **	0.2302 **	−0.0134	−0.2511
	[2.744]	[1.721]	[1.822]	[2.532]	[1.323]	[1.532]	[1.502]	[−1.193]	[−1.192]
LY^2	−0.0436 *	−0.037 *	−0.0246	−0.065	−0.1182 *	0.0191 *	0.0121 **	0.0413	−0.029 *
	[−1.451]	[−1.632]	[−1.231]	[−1.219]	[−1.549]	[1.454]	[1.573]	[1.143]	[1.232]
Leg	1.119 **	1.0674 **	1.4514 **	1.2597 **	0.6222 *	1.1486	1.1463 **	−0.0678 *	−0.106 *
	[1.843]	[2.009]	[2.143]	[1.8764]	[1.135]	[1.323]	[1.517]	[−0.228]	[−0.132]
LPg	−1.335 ***	−1.193 ***	−1.062 ***	−0.930 ***	−0.0465 **	−0.037 *	0.9952	0.21681	1.489 *
	[−7.41]	[−6.812]	[−4.649]	[−3.74]	[−1.541]	[−1.434]	[0.955]	[0.759]	[1.2011]
LSg	−0.067 **	−1.568 ***	−1.800 ***	−1.628 ***	−0.998 *	−1.558	−1.368	−0.091	−0.2707
	[−1.561]	[−2.819]	[−2.401]	[−2.123]	[−1.291]	[−1.407]	[−1.367]	[−0.162]	[−0.615]
C	0.2628 ***	0.634 **	0.453	0.023 ***	1.637	0.30703	−0.468	−1.962	0.622
	[2.314]	[0.823]	[1.433]	[1.563]	[0.2073]	[1.042]	[−0.043]	[−0.205]	[−0.695]

[] represents the t-statistics values of the estimated coefficients; ***, **, and * show the level of significance at 1% , 5% and 10%, respectively.

6. Concluding Remarks

This article has explored the impact of energy production from coal, economic growth, and political, social, and economic globalization on CO_2 emissions in BRICS nations from 1991 to 2022. This article has used various estimation methods, i.e., OLS, fixed effects model, FMOLS, DOLS, and panel quantile regression methods to obtain empirical findings. The outcomes indicate that energy production from coal and the level of growth is boosting CO_2 emissions in BRICS nations. The results show that the linear form of per capita income raises CO_2 emissions, whereas nonlinear per capita income lowers CO_2 emissions among the selected sample. This implies an inverted U-shaped link between per capita income and CO_2 emissions and the presence of EKC in BRICS. The findings reveal that energy production from coal raises the amount of CO_2 emissions across all quantiles, while economic growth raises CO_2 emissions at lower quantiles and a negative impact at higher quantiles; this also indicates the existence of an EKC in BRICS nations. Policymakers need to prioritize the development of other sources of energy production to reduce dependency on coal and promote economic growth and environmental sustainability. Economic globalization is raising CO_2 emissions, whereas political globalization is lowering it, and social globalization does not play any significant role in determining the level of CO_2 emissions. The outcomes indicate that economic globalization differs across the distribution of CO_2 emissions, with a positive effect in the lower to medium quantiles and a negative effect in the higher quantiles. These findings show that a threshold exists beyond which economic globalization can no longer raise CO_2 emissions; these results support the environmental Kuznets curve theory. Therefore, this study suggests that efforts should be made to limit CO_2 emissions by economic globalization in the higher quantiles. Political globalization hurts CO_2 emissions, indicating that deeper regional cooperation and the empowerment of global institutions can lead to a reduction in CO_2 emissions. This reveals that global institutions, i.e., the World Bank, IMF, and UNO help in monitoring the political, governance, and business activities of member nations to decrease CO_2 emissions. The results highlight a complex relationship between globalization and emissions and provide evidence that the influence of globalization on CO_2 emissions varies across the distribution of quantiles. The findings have important policy implications, suggesting that efforts should be made to balance economic growth and environmental protection by adopting effective measures to limit CO_2 emissions from disaggregate globalization while promoting deeper regional cooperation and empowering global institutions to control CO_2 emissions.

7. Limitations and Future Directions

Our study has several limitations and by delimiting them, future studies can be conducted.

- Our study focuses on aggregate CO_2 emissions, without disaggregating the effects across different industrial sectors. A sector-specific approach could provide deeper insights into the role of globalization in influencing emissions in manufacturing, transportation, and energy industries separately.

- We primarily analyzed CO_2 emissions, but other greenhouse gases (GHGs), such as methane and nitrous oxide, also contribute significantly to climate change. Future research could expand the scope to examine a broader range of environmental pollutants.
- Although our study covers a substantial period (1991–2022), data limitations prevent us from incorporating real-time policy changes and technological advancements. Future studies could employ real-time data analysis and machine learning techniques to predict environmental trends more accurately.
- While we analyzed coal-based energy production, we did not explicitly examine the role of renewable energy transitions. Future research could investigate how renewable energy policies interact with globalization to impact emissions.

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