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Article

Impact of economic growth, renewable energy consumption and energy intensity on CO_2 emissions in BRIC countries: An application of CS-ARDL

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Abstract: Global CO_2 emissions pose a serious threat of climate change for high-growth countries, requiring increased efforts to preserve the environment and meet growing economic needs through the use of renewable energies. This research significantly enhances the current literature by filling a void and differentiating between short-term and long-term impacts across economic growth, renewable energy consumption, energy intensity, and CO_2 emissions in BRIC countries from 2002 to 2019. In contrast to approaches that analyze global effects, this study's focus on short and long-term effects offers a more dependable insight into energy and environmental research. The empirical results confirmed that the effect of economic growth on CO_2 emissions is positive both in the short and long term. Moreover, the effect of energy consumption is negative in the short term and positive in the long term. The effect of energy intensity is positive in the short term and negative in the long term. Accordingly, policy recommendations must be adopted to ensure that these economies respond to the notion of sustainable development and the relationship with the environment. BRIC countries must strengthen their industries in the long term in favor of the use of renewable energies by introducing innovation and technology. These economies face the challenge of a transition to renewable energy sources by creating a new energy and industrial sector environment that is more environmentally friendly atmosphere.

Keywords: renewable energy consumption; CO_2 emissions; energy intensity; economic growth; CS-ARDL

1. Introduction

The increase in global production and distribution of energy has a significant influence on the development of contemporary economies, in particular, on the progression of many national and international companies (Jeuland et al., 2021). Energy constitutes an essential element in industrial operations and in the transport sectors (Singh et al., 2021; Wu et al., 2021). However, this dependence has been heavily criticized because of its harmful effects on the environment and humanity.

Currently, the increasing level of CO_2 emissions is creating an unfavorable global climate marked by destabilization (Jian et al., 2019). This prompted various countries to sign agreements such as the Paris Agreement (2015) and the Kyoto Protocol (2005). These countries have obtained recommendations to reduce and minimize CO_2 emissions. Hall et al. (2013) claim that more than 190 countries have signed these agreements. However, despite the commitments and reforms adopted, CO_2 emissions have further increased due to high energy consumption.

Many industrial revolutions have historically relied on non-renewable resources. However, their negative effects on the environment have recently been the subject of numerous studies (Yasmeen et al., 2022). The excessive dependence of the contemporary economy on non-renewable energy sources has given rise to various harmful consequences on environmental degradation.

The universe in its movement is based on energy in all its forms and patterns. The vast majority of global energy comes from non-renewable resources such as fossil fuels, oil and gaz. Urbanization and wars are challenges for a healthy global environment. As a result, the diversification of renewable energy sources has expanded business opportunities, thereby promoting the level of economic growth (Pena et al., 2022). Renewable energies can be like a land relief plan. The past years have been marked by a rapid and important increase in the consumption of renewable energies, clean and non-polluting energy. It is environmentally friendly. In 2023, the International Energy Agency announced that the BRIC countries accounted for 23% of the global Gross Domestic Product (GDP) and 42% of the world's population. The rapid and significant evolution of economic growth, revewable energy consumption, and energy intensity in BRIC countries (Brazil, Russia, India, and China) raises questions about their environmental impact, particularly regarding CO_2 emissions. **Figure 1** shows the evolution of renewable energy consumption in BRIC countries (2015–2021).

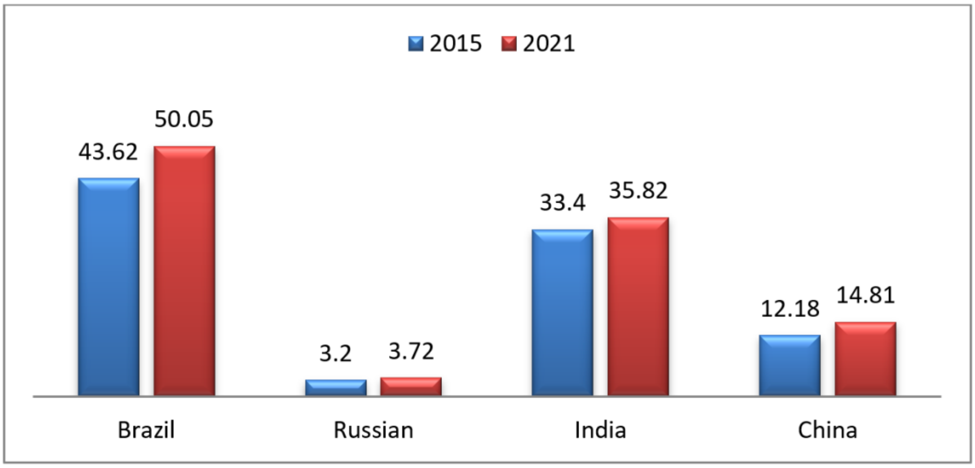

Figure 1. Evolution of Renewable energy consumption in BRIC countries.
Source: World Bank 2024.

However, as these nations achieve financial stability by relying primarily on non-renewable energy sources, this creates a trade-off where environmental security is jeopardized, resulting in a marginal cost. This study makes a significant contribution to existing literature by addressing a gap, distinguishing between short-term and long-term effects among economic growth, renewable energy consumption, energy intensity, and CO_2 emissions in BRIC countries from 2002 to 2019. In contrast to methods that examine overall effects, the distinction between short-term and long-term effects in this study provides a more reliable answer to research on energy and the environment. This study empower companies, organizations, and governments across BRIC countries to formulate more effective environmental policies aimed at ensuring long-term sustainability. However, the novelty of this study lies in testing and comparing the effect of economic growth, renewable energy consumption, and energy intensity on CO_2 emissions in BRIC countries, while distinguishing between short-term and long-term effects and emphasizing the following question: Does the short-term effect of these three variables converge with the long-term effect, using an empirical CS-ARDL approach (Cross-Section Autoregressive Distributed Lag) as an extension of the ARDL (Autoregressive Distributed Lag) model since it allows us to study a group of countries and it allows us to solve the problems of cross section dependence.

2. Literature review

The relationship between economic growth and environmental quality indicators can be explained by the Environmental Kuznets Curve (EKC). This relationship requires certain compatibility between economic growth and environmental protection.

From this curve, we can identify three effects linking economic growth to the quality of the environment. An improvement in economic growth following the increase in national consumption and production generates an increase in the level of pollution emitted; this is called the scale effect. The composition effect or the effect of the structural transformation of production on the environment. For example, without any improvement in the technology coefficient, the passage from an agriculture-based economy to a predominantly industrial economy has resulted in an increase in pollution intensity. The technique effect captures the implementation of environmental policy by improving pollution control efforts through the increase in wealth created.

Economic growth affects CO_2 emissions through the channel of energy consumption. Arvin et al. (2015) studied the effect of transport intensity, urbanization and economic growth on CO2 emissions in G-20 countries. The results show that the increase in transport intensity stimulates the economic growth of developing countries. While the intensity of transport has no effect on the economic growth of developed countries in the short term. This can be explained by the low intensity of transport, especially in the air transport sector, which should improve.

Mehmood (2022) studied the effect of renewable energy and governance on the CO_2 emission of South Asian countries of India, Pakistan, Sri Lanka, and Bangladesh. These countries are experiencing rapid economic growth and today are in dire need of energy. An increase in the consumption of renewable energy by 1% causes a drop in CO_2 emissions by more than 13%. In addition, an improvement in the level of governance of 1% generates a decrease of 7.7%.

Abban et al. (2022) studied coevolution between renewable energy, economic growth and CO_2 emissions from 9 major oil-producing countries in Africa during the period 2000–2019 using wavelet coherence analysis. The results show that renewable energies have a negative effect on CO_2 emissions (countercyclical effect), while economic growth, trade openness and globalization have a positive impact with CO_2 emissions (cyclical impact). Dilanchiev et al. (2024) studied the effect of FDI, renewable energy and migrant remittances on environmental quality in the main remittance recipient countries, during the period from 2000 to 2021. The results show that the effect of FDI is negative on CO_2 emissions. On the other hand, the impact of renewable energies is negative. The contribution of migrant transfers is not neglected. Nuta et al. (2023) developed a comparative study between emerging countries in Europe and Asia of the effect of urbanization, financial development, economic growth, renewable energy consumption and structure industrial analysis on environmental degradation during the period 1995 and 2019, using the feasible generalized least squares (FGLS) method. The results show that for the case of two regions, economic growth has a positive and significant effect on CO_2 emissions. Countries in these regions are moving from lower-emissions-intensive goods to higher-emissions-intensive economic products. Renewable energy sources are therefore essential to combat pollution in both regions. The increase in renewable energy consumption significantly reduces CO_2 emissions in these two regions. However, Zhu et al. (2021) find that the integration of innovation and technology, the use of renewable resources and the phasing out of old technology industries reduce CO_2 emissions. Muhammad et al. (2022) indicate that secondary industries in developed countries promote environmental protection better than in developing countries through the use of high technologies. Similar studies (Han et al., 2021; Zhao et al., 2022) stated that modernization especially industrial modernization plays a major role in improving the climate environment.

To study the interactions between economic growth, renewable energy consumption, energy intensity and CO_2 emissions, various empirical methodologies have been adopted. For example, Alama et al. (2016) studied the effect of energy consumption, income and population growth on CO_2 emissions. They used a sample consisting of four countries namely, India, Indonesia, China and Brazil during a period from 1970 to 2012. The authors used the ARDL model to study the short-term and long-term effects. The results show a significant increase in CO_2 emissions which is due to the increase in energy consumption.

Besides, Riti et al. (2017) examined the interplay between CO_2 emissions, economic growth and energy consumption by considering the economy of China. To do this, various empirical methodologies were used, their results show contradictory effects compared to previous work.

In the other hand, Le and Ozturk (2020) considered a sample of 47 emerging market and developing economies. They tried to analyze the impact of financial development, globalization, globalization and institutional quality on CO_2 emissions. Many estimators have been used such as CCEMG, AMG and DCCE. Empirical results indicated that energy consumption promotes increased CO_2 emissions.

This work is the subject of an empirical modeling of the short-term and long-term effects of economic growth, renewable energy consumption and energy intensity on CO_2 emissions. We use the CS-ARDL model. This article is structured as follows: A third section provides data and methodologies. The results of the estimates and interpretations were presented in section 4. The last section provides conclusions and policy implications.

3. Data and methodologies

The objective of this work is to study the interaction between economic growth, renewable energy consumption, energy intensity and CO_2 emissions in BRIC countries. The variables used are taken from the WDI. The data frequency is annual and the study period extends from 2002 until 2019. CO_2 emissions are considered as dependent variables. GDP, REC and EI indicate the independent variables. **Table 1** describes the variables, specifying the units and the sources. The log is used for all variables in order to obtain efficient empirical results (Mehmood, 2022).

Table 1. Variables description and sources.

Abreviation	Indicator name	Unit	Source
CO_2	carbon emissions	kt	WDI
GDP	per capita GDP	current US$	WDI
REC	renewable energy consumption	% of total final energy consumption	WDI
EI	energy intensity	level of primary energy (MJ/$2017 PPP GDP)	WDI

The model to be estimated is specified as follows:

$$lnCO2_t = \alpha_0 + \alpha_1 lnGDP_t + \alpha_2 lnREC_t + \alpha_3 lnEI_t + \varepsilon_t \quad (1)$$

where $lnCO_2$ is carbon emissions (kt), lnGDP is per capita GDP ((current US$), lnREC represents renewable energy consumption (% of total final energy consumption), and lnEI is energy intensity (level of primary energy (MJ/$2017 PPP GDP)).

To estimate the short-term and long-term effects via the CS-ARDL approach, it is important to test the cross section dependence, the slope heterogeneity test to checks the similarities among the data and the second generation stationarity tests, namely the CIPS and the CADF in the presence of cross section dependency. However, in the absence of CSD, the first generation tests (IPS, LLC, PP and ADF (Madalla and WU, 1999)) are used.

3.1. Cross-sectional dependence test (CD)

Before using the second generation unit root tests on Panel data, it is necessary to check the evidence of CSD and slope heterogenity in the data. In this study, we apply the CD test advanced by Pesaran (2004). This statistic depends on the correlations between the residuals of each line of the model. The CD occurs due to the same socio-economic structures.

The CS equation is written as follows:

$$\text{CSD} = \sqrt{\frac{2T}{N(N-1)N}\left(\sum_{i=1}^{N-1}\sum_{K=i+1}^{N}\widehat{corr\iota, t}\right.} \quad (2)$$

where T shows cross sections and N is showing time. $\widehat{corr\iota, t}$ represents the correlation residual estimate.

3.2. Slope homogeneity (SH) test

To verify the slope homogeneity, Pesaran and Yamagata (2008) test is employed. This test checks the similarities among the data. The equation of slope homogeniety (SH) is specify as follow:

$$\Delta_{\widetilde{SH}} = N^{1/2}2K^{1/2}\left(\frac{1}{N}s^{\sim} - \text{k}\right) \quad (3)$$

$$\Delta_{\widetilde{ASH}} = N^{1/2}\left(\frac{2K(T-k-1)^{-1/2}}{T+1}\left(\frac{1}{N}s^{\sim} - \text{k}\right)\right) \quad (4)$$

where: $\Delta_{\widetilde{\text{SH}}}$ and $\Delta_{\widetilde{\text{ASH}}}$ is delta tilde and adjusted delta tilde. If the two statistics are significant at 1%, we adopt the heterogeneity of panel structure.

3.3. Stationarity test

If cross section dependence (CSD) and SH are verified, we can use the second generation of unit root tests. CIPS is employed to identify the level of integration. In the next step, we apply the Westerlund and Edgerton (2007) cointegration test.

3.4. CS-ARDL approach

In the context of this work, we use the CS-ARDL method to know the values of the coefficients. Çoban and Topcu (2013) as well as Yao et al. (2019) claim that this method cares for heterogeneity through the estimation of common correlated effects (CCE). Equation (5) is written as follows:

$$G_{i,t} = \sum_{I=0}^{P_x} \theta_{I,i}\, X_{i,t-1} + \sum_{I=0}^{P_w} \alpha_{I,i}\, W_{i,t-I} + \varepsilon_{i,t} \quad (5)$$

Equation (5) is relative to the ARDL model and can be modified using the cross sections (Equation (6)). This is made to get rid of inappropriate illations about CD (Chudik and Pesaran, 2015).

$$G_{i,t} = \sum_{I=0}^{a_x} \theta_{I,i}\, G_{i,t-I} + \sum_{I=0}^{a_w} \alpha_{I,i}\, W_{i,t-I} + \sum_{I=0}^{a_z} \beta_i{}',\, \mathrm{I}\bar{Z}_{t-I} + \varepsilon_{i,t} \quad (6)$$

The averages of all variables are as under:

$$\bar{Z}_{t-I} = \bar{W}_{i,t-I}\; \bar{G}_{i,t-I}$$

a_x, a_w and a_z indicates the lags of predictors. $G_{i,t}$ represent the dependant variable such as CO_2 emissions and $W_{i,t}$ holds the independent predictor. Z shows average of CD to conquer the overrun possessions (Liddle, 2013). The CS-ARDL model estimates short and long term values. Thus, the long term values and the MG estimator are described in Equation (7):

$$\hat{\vartheta}_{MG} = \frac{1}{N} \sum_{i=1}^{N} \hat{\vartheta}_i \quad (7)$$

$$\hat{\vartheta}_{CS-ARDL,i} = \frac{\sum_{I=1}^{P_w} \alpha_{I,i}{}^{Px}}{1-\sum I=0}\, \theta_{I,i} \quad (8)$$

$$\Delta G_{i,t} = \delta_i (G_{i,t-1} - \vartheta_i W_{i,t}) - \sum_{I=0}^{a_{x-1}} \theta_{I,i}\, \Delta_I G_{i,t-I} + \sum_{I=0}^{a_{w-1}} \alpha_{I,i}\, \Delta_I W_{i,t-I} + \sum_{I=0}^{a_z} \beta_i{}',\; \mathrm{I}\bar{Z}_{t-I} + \varepsilon_{i,t} \quad (9)$$

where: $\Delta_I = t - (t - 1)$.

4. Empirical results

Table 2 provides descriptive statistics of the variables studied. The mean of each variable falls within the interval [1.8236, 14.3407]. The variables have excess kurtosis more than zero and therefore exhibit leptokurtic distribution. We note that the standard deviation varies between 0.3597 and 1.0850 justifying the significant variation in risk. The skewness parameter is negative except for $lnCO_2$. This result indicates the evidence of asymmetric effect.

In order to avoid the problem of data co-integration bias, the cross section (CD) test is performed. The results are reported in **Table 3**. We note the significant rejection of the null hypothesis of the absence of DC for all the variables studied, namely CO_2, GDP, REC and EI at the 1% significance level. This indicates CD evidence in the dataset.

Table 2. Descriptive statistics.

Statistics	$lnCO_2$	lnGDP	lnREC	lnEI
Mean	14.3407	8.3458	2.8348	1.8236
Median	14.3011	8.6550	3.3871	1.8301
Maximum	16.1864	9.6787	3.8901	2.4069
Minimum	12.6469	6.1502	1.1568	1.3190
std-dev	1.0850	0.9757	1.0447	0.3597
Skewness	0.1536	−0.5110	−0.6212	−0.0143
Kurtosis	2.1044	1.9945	1.7849	1.5542

Table 3. Cross-sectional dependency results.

$lnCO_2$		lnGDP		lnREC		lnEI	
CD-test	*P*-value	CD-test	*P*-value	CD-test	*P*-value	CD-test	*P*-value
8.86*	0.000	11.55*	0.000	4.77*	0.000	3.51*	0.000

Note: * denote the significance at 1%.

In the presence of cross section dependency, second generation unit root tests are performed. In this work, we focus on the CIPS test. According to the results reported in **Table 4**, it is assumed that the variables are stationary in level and in difference with the exception of the dependent variable (CO_2) which is stationary in difference (I(1)). Thus the scope of the ARDL model is validated.

Table 4. CIPS unit root test results.

Variables	Unit root test (CIPS)	
	I(0)	I(1)
lnCO2	−2.067	−2.478*
lnGDP	−2.466*	−3.827*
lnREC	−2.862*	−2.856*
lnEI	−2.949*	−3.310*

Note: * denote the significance at 1%.

The results of the SH test (Pesaran and Yamagata, 2008) are reported in **Table 5**. This test assumes the homogeneous slope values. The results justify that the Delta tilde and Delta tilde adjusted parameters are significant at a threshold of 1%.

Table 5. Results of slope heterogeneity.

	Dependant variable: $lnCO_2$	
Statistics	Value	prob
Delta tilde	8.862*	0.000
Delta tilde Adjusted	10.428*	0.000

Note: * denote the significance at 1%.

To check whether the variables are cointegrated or not over long periods, we perform the cointegration test of Westerlund (2007). The results are presented in **Table 6**. By observing the *p*-values, we admit that the two parameters Ga and Pa allow the significant rejection of the null hypothesis of absence of cointegration. These different results demonstrate the existence of a cointegration relationship between the variables in the long term.

Table 6. Westerlund (2007) panel cointegration test.

Statistics	value	*Z*-value	robust *P*-value
Gt	−2.120	1.500	0.710
Ga	−7.560*	2.217	0.010
Pt	−6.463	−1.015	0.140
Pa	−13.805*	−0.481	0.000

Note: * denote the significance at 1%.

Table 7 shows the empirical results of the CS-ARDL technique in BRIC countries. The effect of economic growth on CO_2 emissions is positive both in the short and long term. A percent point of economic growth increases carbon emissions (CO_2) by 12% and 14% respectively in the short and long term. This result is consistent with (Le and Ozturk, 2020; Abban et al., 2022). These countries are characterized by strong economic growth. Economic growth stimulates pollution. The creation of wealth and the enhancement of fragile material living conditions, as well as the preservation of species diversity and natural energy resources. This economic revolution engenders new technologies, faster production techniques, lifestyle changes, improved living standards, exhaust the factors of production (because of the use of non-renewable resources and adverse effects on the environment.

Table 7. CS-ARDL results: long- and short-term estimation.

	Coefficient	Std error	significance level
Short term			
ΔlnGDP	0.1219**	0.0600	0.042
ΔlnREC	−0.4434*	0.1591	0.005
ΔlnEI	0.5168*	0.1107	0.000
Long term			
lnGDP	0.1425**	0.0653	0.029
lnREC	0.5803*	0.1455	0.000
lnEI	−0.4890*	0.1816	0.007
ECM	−0.9362*		0.000

Note: * and ** denotes the significance at 1% and 5%.

The effect of energy consumption is negative in the short term and positive in the long term. A percent point of renewable energy consumption decreases carbon emissions (CO_2) by 44% in the short term. This result is confirmed by Mehmood (2022). The consumption of renewable energies is more ecological. Renewable energy sources such as solar, wind, hydroelectric, and biomass produce energy without burning fossil fuels. By using these renewable sources instead of coal, oil, and natural gas, which emit CO_2 when burned, the overall carbon footprint of energy production is reduced. But in the long term, a percent point of renewable energy consumption increases carbone emissions by more than 58%. This result is justified with Riti et al. (2017). In the long term, the energy and industrial sectors are sectors that pose a threat to the environment. The renewable energy sector is not developed in the long term. The relatively high cost of the facilities remains a handicap to be available to all. The expansion of renewable energy usage fosters innovation and investment in clean energy technologies. Progress in these technologies results in enhanced efficiency, reduced expenses, and wider adoption, hastening the shift away from carbon-heavy fossil fuels. Nonetheless, it's crucial to acknowledge that certain phases of production, manufacturing, transportation, and installation of renewable energy technologies may still involve CO_2 emissions due to the use of fossil fuels in industrial processes.

The effect of energy intensity is positive in the short term and negative in the long term. A percent point of energy intensity increases carbon emissions (CO_2) by 51% in the short term. Energy intensity deteriorates environmental efficiency. Reducing energy intensity can also smooth the path toward adopting cleaner energy sources. As industries improve their energy efficiency, they may find it more appealing to invest in renewable energy technologies, known for their lower carbon emissions compared to fossil fuels. Governments implement policies aimed at curbing energy intensity, like energy efficiency regulations or incentives for renewable energy adoption. Such measures can spur investments in technologies and methods that cut CO_2 emissions, thus fostering a beneficial environmental impact. In the long term, a percent point of energy intensity decreases carbon emissions (CO_2) by 48%. This result is contradictory to Arvin et al. (2015). This result justifies that the BRIC countries build in the long term a new energies sectors friend of the environment which requires costly reforms. Industries characterized by high energy intensity typically heavily depend on energy-intensive operations like manufacturing, refining, and chemical production. Such processes often entail the combustion of fossil fuels or other energy-intensive activities, leading to the release of CO_2 as a byproduct. As a result, elevated energy intensity within industrial sectors translates to increased CO_2 emissions stemming from these activities.

5. Conclusion and policy implication

This study examines the impact of economic growth, renewable energy consumption and energy intensity on carbon (CO_2) emissions in BRIC countries from 2002 until 2019 using the CS-ARDL approach. The advantage of this approach is to distinguish between short and long term effects.

This results show that the effect of economic growth, is positive on the CO_2 emissions of the BRIC countries in both the short and long term. These economies are characterized by a significant economic revolution to fight against poverty. The BRIC countries are in an economic race with the rest of the world, which requires a lot of energy. A percent point of economic growth increases carbon emissions (CO_2) by 12% and 14% respectively in the short and long term. The effect of energy intensity on CO_2 emissions is positive in the short term and negative in the long term. This relationship justifies the validation of the environmental Kuznets curve.

Renewable energy consumption is an effective solution for environmental improvement. A percent point of renewable energy consumption decreases carbon emissions (CO_2) by 44% in the short term. But unfortunately, the environmental policies adopted are no longer effective in the long term. In the long term, the results exceeded all expectations. A percent point of renewable energy consumption increases carbone emissions by more than 58%. These countries must then put in place strong and strict environmental policies in matters of non-waste of natural resources by developing sources and the sector of renewable energies by effective techniques in order to improve the climatic quality.

Indeed, the adoption of renewable energies like solar, wind, hydropower, and biomass plays a crucial role in reducing CO_2 emissions. Unlike fossil fuels such as coal, oil, and natural gas, which emit CO_2 when burned for energy production, renewable energies operate without emitting CO_2 directly. However, it's important to acknowledge that certain phases of production, manufacturing, and installation of renewable energy technologies may contribute to CO_2 emissions. For instance, the manufacturing process of solar panels or wind turbines may rely on fossil fuels in industrial processes, and transportation and installation of these technologies can also lead to CO_2 emissions. Nonetheless, the CO_2 emissions associated with these stages are generally much lower compared to those produced by the continuous use of fossil fuels for electricity generation. The incorporation of developed technology, knowledge and patents into businesses and the means of transport and the way of life in general requires an increase in the level of education and public expenditure. These projects require serious will on the part of governments and people because they can take a long time to achieve and to be accessible to all. It is essential to take measures in terms of law, tax and convention incentives and to facilitate administrative procedures that will lead to the introduction of cleaner and more environmentally friendly enterprises when production increases. It is noted the importance of photovoltaic energy as clean and renewable energy is becoming more and more important in the energy market and which become stored in batteries.

The research findings have highlighted several policy implications. The BRIC countries possess significant potential for advancing renewable energy sources like solar, wind, hydroelectric, and biomass energy. Investing in these sectors can yield multiple benefits, including the creation of new job opportunities, fostering technological innovation, and mitigating CO_2 emissions by substituting fossil fuels with cleaner alternatives. Furthermore, modernizing infrastructure to enhance energy efficiency and curb CO_2 emissions is imperative. This may entail investments in various areas such as public transportation, eco-friendly buildings, smart electrical grids, and waste management systems. Implementing environmental policies like carbon taxes, emission quotas, and subsidies for clean energy can incentivize CO_2 emission reduction and facilitate the transition to a low-carbon economy. Prioritizing research and development in clean technologies is essential for reducing CO_2 emissions while bolstering economic competitiveness. This effort could involve advancements in carbon capture and storage technologies, electric vehicles, energy efficiency solutions, and other innovative approaches. Collaboration among BRIC countries, alongside cooperation with other nations, international organizations, and private sector entities, is crucial for sharing best practices, technologies, and financial resources aimed at effectively reducing global CO_2 emissions in an equitable manner. By adopting these measures, BRIC countries can not only contribute to combating climate change by reducing CO_2 emissions but also stimulate sustainable and innovative sectors, thereby fostering long-term economic growth.

This work remains subject to major criticisms both theoretically and empirically. Theoretically, the model does not take into account sectoral variations. Empirically, we can use other more sophisticated empirical approaches which lead to more intuitive and more efficient results.

Conflict of interest: The author declares no conflict of interest.

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