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Impact of economic growth and electricity consumption on CO2 emissions in BRICS countries: A panel data analysis

Shibalal Meher

Nabakrushna Choudhury Centre for Development Studies, Bhubaneswar
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Abstract

This paper examines the impact of economic growth and electricity consumption in BRICS countries using panel data over the period 1990 to 2014. The variables pass through the integration test, cross-dependency test, cointegration test and Granger causality test. The analysis was conducted using Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) approaches. The results clearly suggests for a long run relationship of economic growth and electricity consumption with carbon emissions. There is unidirectional causality running from GDP and electricity consumption to carbon emissions. It is found that carbon emissions increase more than proportionately with the increase in electricity consumption. Our findings do not support the expected Kuznets effect on carbon emissions in BRICS countries. There is declining trend of carbon emissions at the early stage of development, which begins to rise after the turning point, thereby passing through a phase of increasing carbon emissions. It is suggested that the BRICS countries, which have emerged as the growing economies of the world, should make concerted efforts to develop a carbon reducing policy so as to achieve a sustainable economic growth.

Keywords: Economic growth, electricity consumption, carbon emissions, Environmental Kuznets Curve, BRICS, FMOLS, DOLS.

[1] Professor of Development Studies, Nabakrushna Choudhury Centre for Development Studies, Bhubaneswar.
E-mail: smeher62@rediffmail.com

1. Introduction

The world is facing increasing threat of global warming and climate change due to the rising greenhouse gas[2](GHG) emissions as a result of human activity. The Intergovernmental Panel on Climate Change (IPCC, 2014) maintains that the key factors that lead to increased GHG emissions are, among others, the increasing economic activity and energy usage. This has been the major ongoing concern for both the developed and developing countries. While carbon dioxide (CO2) is the biggest contributor to the problem, there is global effort to reduce carbon emissions through different forums. While both the developed and developing countries are responsible for the increase in CO2 emissions, the developing countries are mostly blamed for the exhaustive use of energy and other resources for their attempt to increase economic growth.

As the debate surrounds anthropogenic carbon emissions and climate change typifies sustainable development dilemma, the global climate effort put forward by the Paris Agreement advocates urgent attention towards carbon mitigation and adaptation strategies (Adeneye *et al.*, 2021). The increase in carbon emissions is the result of increasing economic activities, where electricity plays a crucial role, which is produced mostly by fossil fuel combustion. While economic development is crucial for the emerging economies, it is noteworthy to assess the impact of economic growth and energy consumption (electricity consumption) on carbon emissions.

The link among energy consumption, carbon emissions and economic growth has received considerable attention by both policy makers and researchers, as the achievement of sustainable economic growth has gradually become a major global concern (Antonakakis*et al*., 2017). The interest in this field has been increased by a number of scholars in recent years. The existing studies in this field can be classified into the following three groups. The first group consists of studies that investigate the causal links between energy consumption and economic growth (see, among others, Kraft and Kraft, 1978; Chiou-Wei *et al*., 2008; Chontanawat *et al*., 2008; Huang *et al*., 2008; Akinlo, 2009; Apergis and Payne, 2009b; Ghosh, 2009; Payne, 2010; Ozturk, 2010; Eggoh *et al*., 2011; Joyeux and Ripple, 2011; Al-Mulali and Sab, 2012; Chu and Chang, 2012; Dagher and Yacoubian, 2012; Shahbaz and

[2]Greenhouse gases are gases in the Earth's atmosphere that produce the greenhouse effect. Changes in the concentration of certain greenhouse gases, from human activity (such as burning fossil fuels), increase the risk of global climate change.

Lean, 2012; Abbas and Choudhury, 2013; Bozoklu and Yilanci, 2013; Dergiades et al., 2013;Yıldırım *et al*., 2014, Heidari *et al*., 2015; Saidi and Hammami, 2015; Sbia *et al*., 2017). This group of studies focuses on the total energy consumption and a particular country or a group of countries, although some studies disentangle the energy usage by energy source. These studies show no conclusive relationship between economic growth and energy consumption, but provide four alternative hypotheses, viz. growth hypothesis, conservation hypothesis, feedback hypothesis and neutrality hypothesis[3].

The second group of studies concentrates its attention on the relationship between economic growth and emissions (e.g. Grossman and Krueger, 1991; Dinda, 2004; Stern, 2004; Chang, 2010; Ghosh, 2010; Kijima *et al*., 2010; Menyah and Wolde-Rufael, 2010a; Ozturk and Acaravci, 2010; Govindaraju and Tang, 2013; Al- Mulali *et al*., 2015; Furuoka, 2015; Gao and Zhang, 2014;Yang and Zhao, 2014; Arvin et al., 2015; Gozgor *et al*., 2018; Bekun et al., 2019; Beyene and Kotosz, 2019; Mahembe *et al*., 2019; Adedoyin *et al*., 2020). These studies are fuelled by the Environmental KuznetsCurve (EKC) hypothesis[4].Findings of these studies are once again inconclusive and country or region specific, as in the case of the energy-growth relationship.

Finally, the third group of studies combines the aforementioned tworelationships and thus uses a unified framework to identify the links among energy consumption, carbon emissions and economic growth (e.g. Soytas *et al*., 2007; Ang, 2008; Apergis and Payne, 2009a; Halicioglu, 2009; Soytas and Sari, 2009; Zhang and Cheng, 2009; Menyah and Wolde-Rufael, 2010b;Chang, 2010; Pao and Tsai, 2011; Niu et al, 2011; Wang *et al*., 2012a,b; Al Mamun *et al*., 2014; Asif *et al*., 2015; Heidari *et al*., 2015; Wang and Yang, 2015; Magazzino, 2016; Antonakakis *et al*., 2017;Ito, 2017; Nguyen and Wongsurawat, 2017; Cai *et al*., 2018; Dar and Asif 2018; Phong et al., 2018; Phuong and Tuyen, 2018). Despite the fact that it is a relatively new area of study, a wealth of literature has emerged, given its

[3] The growth hypothesis is supported when there is evidence of unidirectional causality running from energy consumption to economic growth. In conservation hypothesis, there is causality from economic growth to energy consumption. The feedback hypothesis presents a bidirectional causality between energy consumption and economic growth. The neutrality hypothesis suggests no causality between energy consumption and economic growth.

[4] The Environmental Kuznets Curve (EKC) hypothesis postulates an inverted-U-shaped relationship between economic growth and environmental degradation. That is, the environmental quality deteriorates at the early stages of economic development /growth and subsequently improves at the later stages (Dinda, 2004).

importance to policy makers. Table 1 presents some recent studies relating to energy consumption, carbon emissions and economic growth.

It is found that there are diverse results relating to the relationship between economic growth, energy consumption and carbon emission. The diverse results are due to the use of different models, time periods and countries. Even within the same group of countries different results are found. Further, not much studies are devoted to the major emerging economies like BRICS, which are the largest contributor of greenhouse gases.

2. BRICS: An overview

BRICS is an important grouping of countries (Brazil, Russia, India, China and South Africa) bringing together the major emerging economies from the world. It comprises 42 per cent of the world population, having 23 per cent of the world GDP and over 16 per cent share in the world trade. The BRICS countries alone contribute 42 per cent of the carbon emissions (Table 2).They are already among the top emitters of greenhouse gases in the world largely due to their consumption of fossil fuels. China and India are the first and third largest greenhouse emitters in the world and Russia, Brazil and South Africa are not far behind. The emergence of BRICS as not only major economies, but major greenhouse emitters over last two decades, has made them central to global climate discussions (Downie and Williams, 2018). After quit of US from the Paris agreement, BRICS leaders were quick to reaffirm their support for the Paris agreement calling upon the international community to jointly work towards the implementation of the Paris agreement on climate change. Since they have emerged as the growing economy in the world and started playing leading role in the ‘global growth story’, it is realistic to anticipate that they can continue to act as an engine of global growth and take active part in carbon reduction despite being the largest emitters of greenhouse gases. In the following, we present a brief discussion of the trends and growth of per capita carbon emissions, electricity consumption and Gross Domestic Product (GDP) of the BRICS countries during the period 1990 to 2014.

The trends in per capita carbon emissions, electricity consumption and Gross Domestic Product (GDP) of the BRICS countries are presented in Figures 1 to 3. In Figure 1, the levels of per capita carbon emissions are plotted for the emerging economies of BRICS for the time 1990 to 2014. While there is increasing trend in per capita carbon emissions for all the

BRICS countries over time, Russia is the largest per capita carbon emitting country throughout the period, followed by South Africa. The per capita carbon emissions of China is rising speedily after the 1990s and remained over Brazil and India throughout. India's per capita carbon emissions is lowest among the BRICS countries during the period. Figure 2 depicts the per capita electricity consumption, which is an important component of energy consumption in BRICS countries. The level of Russia's per capita electricity consumption remained highest throughout the period followed by South Africa. China showed rapid upward trend in per capita electricity consumption and crossed Brazil in 2007. India's per capita electricity consumption though showed increasing trend, remained lowest among the BRICS countries. Figure 3 depicts the trends in the level of per capita GDP. The level of per GDP is largest in Brazil, followed by Russia. South Africa's GDP remains higher than that of China and India. At the same time, China's per capita GDP has shown a significant upward trend, which has increased in an increasing trend. On the other hand, India's per capita GDP remained lowest throughout. To summarise, Russia has the highest level of carbon emissions and electricity consumption, while Brazil has the highest level of per capita GDP during the period 1990 to 2014. On the other hand, India has not only lowest level of per capita GDP, but also has lowest per capita carbon emissions and electricity consumption among the BRICS countries. At the same time, China shows significant upward trends in the three indicators.

The varying growth of per capita carbon emissions, electricity consumption and GDP among BRICS countries can be seen from Table 3.China and India have higher annual growth not only in per capita GDP but also in per capita carbon emissions and electricity consumption compared to other BRICS countries. Between China and India the growths are much higher in China than in India. Russia and South Africa having higher level of per capita carbon emissions and energy consumption, show significantly lower growth in carbon emissions and electricity consumption compared to other BRICS countries. While there is decline in the annual growth of carbon emissions in Russia, it is only 1.16 per cent in South Africa. Similarly the growth of per capita electricity consumption in these two countries is less than two per cent per annum as compared to 22.74 per cent in China and 10.15 per cent in India. The growth in per capita GDP of Brazil, Russia and South Africa remains much lower than China and India. To summarise, China and India, which had low level of per capita carbon emissions, energy consumption and GDP, show higher annual growth compared to other

BRICS countries over the period 1990 to 2014. At the same time, Russia, Brazil and South Africa with high level of per capita carbon emissions, energy consumption and GDP show very lower growth.

From the above discussion, it is clear that the emerging economies of BRICS countries not only vary in economic growth but also their energy consumption and the resultant carbon emissions vary considerably. However, they are converging overtime. Since the BRICS countries are the growing economies of the world and are emerging as the global leaders, they can contribute for the sustainable global development. It is therefore pertinent to study the impact of economic growth and electricity consumption on carbon emissions in BRICS countries, which can be useful for planning sustainable global development.

3. Data and Methods

The data used in this study are annual observations covering the period from 1990 to 2014 obtained from World Development Indicators updated on 26.04.2021. The variables under study are: per capita carbon dioxide emissions defined in metric tons (CO2), per capita GDP at 2010 constant US$ measuring economic growth (GDP), and per capita electric power consumption in kWh (EPC). These data are collected for all the BRICS countries. The selection of the period is based on the constraint of data availability for all the BRICS countries during the period. While data for Russia are not available prior to 1990, data after 2014 are not available for all the variables.

In order to study the long term relationship between the variables in a panel data analysis, the first step is to test whether the variables contain unit roots. For this we have adopted four different unit root tests, viz. Levin-Lin-Chu (LLC) test (Levin *et al*., 2002), Im, Pesaran and Shin (IPS) test (Im *et al*., 2003), Fisher types tests using the ADF test and the PP test. While LLC and IPS assume homogenous unit root, ADF and PP-Fisher assume heterogeneous unit root (Baltagi, 2013). These tests are simply multiple-series unit root tests that have been applied to panel data structures. The null hypothesis of these panel unit root tests states that panel series has a unit root (non-stationary).

If the variables are found to be integrated of order one, then the next step in our analysis is to test for cointegration. In our analysis we employ the most popular cointegration tests like

Pedroni (1999) and Kao (1999) tests. The Petroni and Kao tests are based on Engle-Granger (1987) two-step (residual-based) cointegration tests. The tests are implemented on the residuals obtained from the following regression:

$$\ln CO2_{i,t} = \alpha_i + \beta_{1i} \ln EPC_{i,t} + \beta_{2i} \ln GDP_{i,t} + \beta_{3i} \ln GDP^2_{i,t} + \varepsilon_{i,t} \qquad (1)$$

where $i = 1,\ldots,N$ and $t = 1,\ldots,T$, T is the number of observation over time , N is the number of countries in the panel, and $\varepsilon_{i,t}$ is the estimated residuals indicating deviations from the long run relationship.It is assumed that the slope coefficients and the member specific intercepts can vary across each cross-section. To compute the relevant panel cointegration test statistics, the cointegration regression in equation (1) is estimated by OLS, for each cross-section. The panel and group statistics are estimated using the residuals from the cointegration regression equation (1).

To test for the null hypothesis of no cointegration against the cointegration in the panel, Pedroni (1999) developed seven cointegration statistics. These are Panel v-Statistic, Panel rho-Statistic, Panel PP-Statistic, Panel ADF-Statistic, Group rho-Statistic, Group PP-Statistic, and Group ADF-Statistic. The first four statistics are known as panel cointegration statistics and are based on the within approach, while the last three statistics are group panel cointegration statistics and are based on the between approach. In the presence of a cointegrating relationship, the residuals are expected to be stationary. The panel v-Statistic is a one sided test where large positive values reject the null of no cointegration. For the remaining statistics, large negative values reject the null hypothesis of no cointegration. Besides the Pedroni test we use Kao (1999) test, which is based on the Engle-Granger two-step procedure, and imposes homogeneity on the members in the panel. The null hypothesis of no cointegration is tested using an ADF-type test. While Kao test specifies cross-section specific intercepts and homogenous coefficients, Pedroni tests allow for heterogeneous intercepts and trend coefficients across cross-sections (Othman and Masih, 2015).

Pedroni’s heterogeneous panel cointegration test and the Kao cointegration test are only able to indicate whether or not the variables are cointegrated and if a long-run relationship exists between them. Since they do not indicate the direction of causality, we conduct Granger causality tests on the relationship between variables. The following models are used to test the Granger panel causality.

$$\ln CO2_{it} = \alpha_{1i} + \sum_{k=1}^{K} \beta_{1i,k} \ln CO2_{i,t-k} + \sum_{k=1}^{K} \gamma_{1ik} \ln EPC_{i,t-k} + \sum_{k=1}^{K} \delta_{1ik} \ln GDP_{i,t-k} + \sum_{k=1}^{K} \sigma_{1ik} \ln GDP^2_{i,t-k} + \varepsilon_{1i,t} \quad (2)$$

$$\ln EPC_{it} = \alpha_{2i} + \sum_{k=1}^{K} \beta_{2ik} \ln EPC_{i,t-k} + \sum_{k=1}^{K} \gamma_{2ik} \ln CO2_{i,t-k} + \sum_{k=1}^{K} \delta_{2ik} \ln GDP_{i,t-k} + \sum_{k=1}^{K} \sigma_{2ik} \ln GDP^2_{i,t-k} + \varepsilon_{2i,t} \quad (3)$$

$$\ln GDP_{it} = \alpha_{3i} + \sum_{k=1}^{K} \beta_{3ik} \ln GDP_{i,t-k} + \sum_{k=1}^{K} \gamma_{3ik} \ln CO2_{i,t-k} + \sum_{k=1}^{K} \delta_{3ik} \ln EPC_{i,t-k} + \sigma_{3ik} \ln GDP^2_{i,t-k} + \varepsilon_{3i,t} \quad (4)$$

$$\ln GDP^2_{it} = \alpha_{4i} + \sum_{k=1}^{K} \beta_{4ik} \ln GDP^2_{i,t-k} + \sum_{k=1}^{K} \gamma_{4ik} \ln CO2_{i,t-k} + \sum_{k=1}^{K} \delta_{4ik} \ln EPC_{i,t-k} + \sigma_{4ik} \ln GDP_{i,t-k} + \varepsilon_{4i,t} \quad (5)$$

where *i* refers to country, *t* to the time period (t=1,…,T) and *k* to the lag. The long-run equilibrium coefficients can be estimated by using single equation estimators such as the fully modified OLS procedures (FMOLS) developed by Pedroni (2000), the dynamic OLS (DOLS) estimator from Mark and Sul (2003), the pooled mean group estimator (PMG) proposed by Pesaran *et al*. (1999) or by using system estimators as panel VARs estimated with Generalized Method of Moments (GMM) or Quasi Maximum Likelihood (QML). In our study, we use both FMOLS and DOLS estimators to estimate the long run coefficients.These techniques aim to estimate the long run equilibrium relationship among the variables identified in prior cointegration tests (Othman and Masih, 2015). The FMOLS procedure accommodates the heterogeneity that is typically present, both in the transitional serial correlation dynamics and in the long run cointegrating relationships (Papiez, 2013). However, it is less robust if the data have significant outliers and also have problems in cases where the residuals have large negative moving average components, which is a fairly common occurrence in macro time series data (Harris and Sollis, 2003). On the other hand, the DOLS estimator corrects standard OLS for bias induced by endogeneity and serial correlation on the leads and lags of the first-differenced regressors from all equations to control for potential endogeneities (Ageliki et al., 2013).Wagner and Hlouskova (2010) verify that the DOLS estimator outperforms all other studied estimators, both single equation estimators and system estimators, even for large samples. However, the DOLS method has the disadvantage of reducing the number of degrees of freedom, which leads to less reliable estimates. For cointegrating equation estimations, DOLS and FMOLS aim to estimate the model presented in equation (1).

4. Empirical Findings

Panel Unit Root Tests

Before running for the panel unit tests, we verified the presence of cross-dependency in our panel dataset. To detect the cross-dependency we applied the most frequently used tests, viz. Breusch-Pagan LM, Pesaran scaled LM, bias-corrected scaled LM and Pesaran CD. The results of the tests are presented in Table 4. The results clearly showed the strong presence of cross-dependency, indicating that panel unit root tests should provide more reliable inference.

We have applied LLC, IPS, and Fisher type tests using ADF and PP to test the integration of the variables. The results are presented in Table 5. The results show that all the variables, i.e. lnCO2, lnEPC, lnGDP and $lnGDP^2$, are non-stationary at levels and stationary at first difference, except in case of lnCO2 which is stationary at level in ADF-Fisher test. This shows that the variables are integrated of order one, which can be suitable for the cointegration test.

Cointegration Test

After we found the integration of variables of order one, we proceed for the test of cointegration of the variables. We applied both the Pedroni and Kao tests of panel cointegration. The results are presented in Table 6. The null hypothesis of all tests assume no cointegration between variables. It is observed that the majority of Pedroni's tests suggest rejecting the null hypothesis of no cointegration. Out of the 11 tests, seven tests reject the null hypothesis of no cointegration. Similarly, the Kao cointegration test suggests rejecting null hypothesis of no cointegration. Therefore, both Pedrini and Kao tests suggest presence of cointegration among the variables.

Pairwise Granger panel causality test

Though the variables are cointegrated, it is necessary to find out the direction of causality of the variables. To test the causality of the variables we have used pairwise Granger panel causality test using stacked test (common coefficients). The result of the Granger causality is presented in Table 7. It is found that there is unidirectional causality that runs from energy consumption to carbon emissions, GDP per capita to carbon emissions, and squared GDP to carbon emissions. This indicates that electricity power consumption and GDP are the factors influencing carbon emissions in BRICS countries. We have therefore estimated single regression equation with lnCO2 as dependent variable and lnEPC, lnGDP and $lnGDP^2$ as independent variables to study the impact of these variables on carbon emissions.

Long run equilibrium

We have estimated the long run equilibrium relationship of the single regression equation with lnCO2 as dependent variable and lnEPC, lnGDP and $lnGDP^2$ as independent variables as we observe the unidirectional relationship. We have estimated the long run coefficients using FMOLS and DOLS estimators. Both pooled and grouped mean of the long run coefficients are estimated using FMOLS and DOLS. It is observed from Table 8that both per capita electricity consumption and per capita GDP influence per capita carbon emissions significantly in all the models. The coefficients are elastic, indicating that there is more than proportionate change in per capita carbon emissions with the change in per capita electric power consumption and GDP. The coefficients of lnEPC are found to be positive in all the cases indicating that with the increase in per capita electricity consumption there is increase in per capita carbon emissions. This is plausible as the BRICS countries generate electricity mostly by using fossil fuel. At the same time, the estimated coefficients of lnGDP are noticed to be negative and that $lnGDP^2$ has a positive sign. This shows that economic growth does not have the expected Kuznets effect on carbon emissions in BRICS countries. At the early stage of economic growth, carbon emissions cannot be avoided, but when reaching a higher level, however, circumstances would gradually be improved as the level of development and welfare improves. The result is however in contradiction to the expected one and thereby cannot find an inverted U-shaped threshold point. This indicates that in the early stage, there is declining trendof carbon emissions, but it immediately begins to rise after the turning point,showing a U-shaped curve instead of inverted U-shaped curve of Kuznets hypothesis.

The above findings are also observed with the individual BRICS countries (Table 9).In all the five BRICS countries electricity consumption has positive influence on carbon emissions, indicating that with the increase in electricity consumption there is increase in the carbon emissions. There is evidence of increase in carbon emissions more than proportionately to the increase in electricity consumption, with the exception of India. Our findings of different countries also do not support the expected Kuznets effect on carbon emissions. While the estimated coefficients of lnGDP are negative, the coefficients of $lnGDP^2$are positive. This is in contradiction to the inverted U-shaped curve of Kuznets hypothesis. Hence, in these countries, there is declining trend of carbon emissions at the early stage of development, but begins to rise after the turning point.

5. Conclusions

In this paper the impact of economic growth and electricity consumption on carbon emissions in BRICS countries has been examined by using panel data over the period 1990 to 2014. The integration of the variables is verified by using LLC, IPS and Fishers ADF and PP tests. The long run relationship of the variables are tested by using Pedroni and Kao cointegration test. The causality of the variables are verified by using Granger causality test. The long run coefficients are estimated by using FMOLS and DOLS estimators. It is found that the variables are integrated of order one. All the variables are cointegrated indicating their long run relationship. There is unidirectional causality running from GDP and electricity consumption to carbon emissions. The single equation estimation reveals that carbon emissions is significantly influenced by economic growth and electricity consumption in BRICS countries. With the increase in electricity consumption the carbon emissions increases more than proportionately. The economic growth does not have the expected Kuznets effect on carbon emissions in BRICS countries. In the early stage, there is declining trend, but it immediately begins to rise after the turning point. Hence, the BRICS countries are passing through a phase of increasing carbon emissions. As the BRICS countries are the largest emitters of carbon dioxide, which is the major source of greenhouse gases, they need to reduce carbon emissions through coordinated efforts. Even though they have shown concern towards carbon mitigation in different summits, this needs to be transformedinto action. Since BRICS countries are emerging as the global leaders, they can show the path for a sustainable economic growth.

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Figure 1: Trends in per capita carbon emissions in BRICS countries (metric tons)

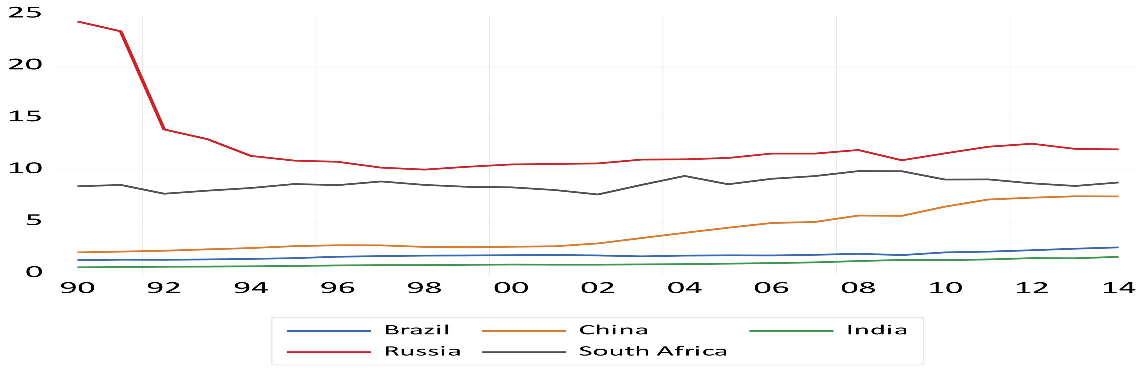

Figure 2: Trends in per capita electricity consumptionin BRICS countries (kWh)

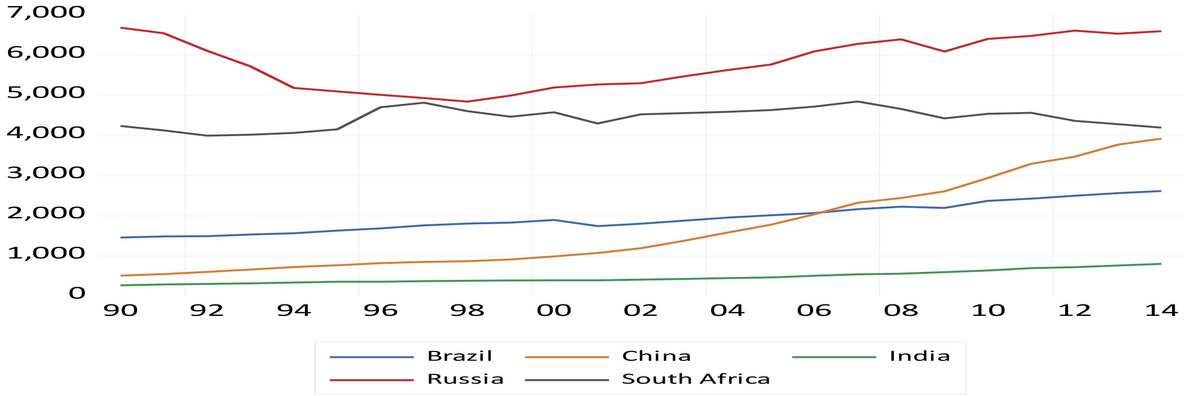

Figure 3: Trends in per capita GDPin BRICS countries (constant 2010 US$)

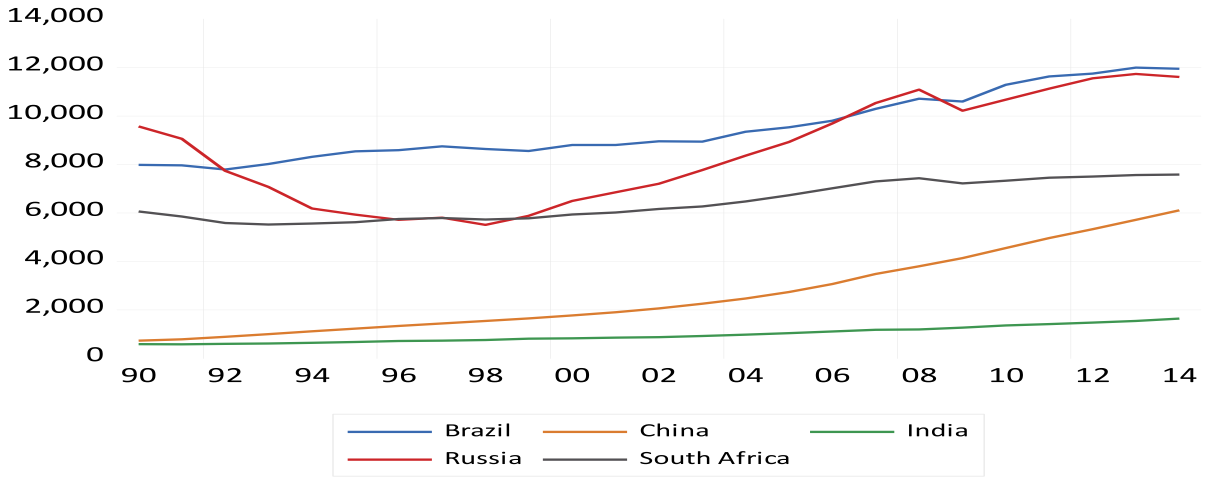

Table 1: Empirical studies on the relationship between economic growth, energy consumption and CO2 emissions

Authors	Countries	Period	Data	Methodology	Main findings
Apergis *et al*. (2010)	19 Developed and developing countries	1984-2007	Real GDP, nuclear and renewable energy consumption and CO2 emissions	Panel cointegration and error correction model	NUC ⇒CO2, REC CO2, REC ⇔GDP, NUC ⇔GDP.
Chang (2010)	China	1981-2006	Oil, coal, natural gas, electricity consumption, CO2 emissions and real GDP	Vector error correction model	GDP⇒CO2 , OIL and COAL, ELEC ⇒GDP and CO2.
Ozturk and Acaravci (2010)	Turkey	1968-2005	GDP per capita, CO2 emissions per capita total energy consumption per capita and employment ratio	ARDL coitegration and Granger causality test	No evidence of EKC. CO2 and EC does not cause GDP
Pao and Tsai (2010)	BRICS	1971-2005	GDP per capita, CO2 per capita and total energy consumption per capita	Panel cointegration and VECM	Short-run: EC ⇔CO2, EC and CO2 ⇒GDP Long-run: EC ⇔GDP, CO2 ⇒EC and GDP.
Alam *et al*. (2012)	Bangladesh	1972-2006	GDP per capita, energy consumptions per capita, electricity consumption per capita and CO2 emissions per capita	ARDL and VECM	Short-run: EC ⇒GDP, ELEC GDP, EC ⇒CO2, CO2 ⇒G Long-run: EC ⇒G, ELEC ⇔G, EC ⇔CO2, CO2 ⇒G.

Jayanthakumaran *et al*. (2012)	China, India	1971-2007	GDP per capita, CO2 emissions per capita and total energy consumption per capita	ARDL bounds test approach	Evidence in favour of EKC, GDP and EC $\Rightarrow$CO2
Govindaraju and Tang (2013)	China, India	1965-2009	GDP per capita, CO2 emissions per capita and coal consumption per capita	Cointegration test VECM	China: GDP$\Leftrightarrow$COALC, COALC $\Leftrightarrow$CO2 , GDP$\Rightarrow$CO2 India: GDP$\Leftrightarrow$CO2 , COALC $\Leftrightarrow$CO2 , GDP$\Rightarrow$COALC
Ozcan (2013)	12 Middle East countries	1990-2008	Real GDP per capita, CO2 emissions per capita and total energy consumption	Panel cointegration FMOLS and Panel VECM	Evidence in favour of EKC (5 out of 12 countries) GDP$\Rightarrow$EC, EC $\Rightarrow$CO2.
Saboori and Sulaiman (2013)	5 ASEAN countries	1971-2009	Real GDP per capita, CO2 emissions and total energy consumption	ARDL bounds test approach to cointegration and VECM	Mixed results depending on the country
Shahbaz *et al*. (2013)	Indonesia	1975-2011*	Real GDP per capita, CO2 emissions per capita, total energy consumption per capita, financial development and trade openness per capita	ARDL bounds test approach to cointegration and VECM	GDP$\Rightarrow$CO2 , EC $\Leftrightarrow$CO2
Cowan *et al*. (2014)	BRICS	1990-2010	Electricity consumption, carbon dioxide emissions and real GDP	Panel Granger causality	Mixed results depending on the country.
Farhani *et al*. (2014)	Tunisia	1971-2008	Real GDP per capita, CO2	ARDL bounds test	GDP and EC $\Rightarrow$CO2,

			emissions per capita, total energy consumption per capita and trade openness	approach to cointegration and VECM	CO2 and GDP⇒EC.
Salahuddin and Gow (2014)	GCC	1980-2012	CO2 emissions, total energy consumptions, GDP	Panel Granger causality	EC ⇔CO2, GDP⇒EC,
Heidari et al. (2015)	5 ASEAN countries		GDP per capita, CO2 emissions and energy consumption	Panel smooth transition regression (PSTR)	GDP⇒CO2, EC ⇒CO2
Zakarya et al. (2015)	BRICS	1990-2012	CO2 emissions, primary energy consumption, FDI net inflow, GDP per capita	Pedroni cointegration, Granger causality,Fully Modified OLS and Dynamic OLS	CO2⇒ GDP, EC, FDI
Magazzino (2016)	Italy	1970-2006	Real GDP per capita, CO2 emissions and energy consumption	Toda and Yamamoto, Granger non-causality	EC ⇔CO2, GDP⇔CO2
Antonakakis *et al*. (2017)	106 countries	1971-2011	Real GDP, CO2 emissions and energy consumption	Panel Vector Auto Regression and Impulse Response function	GDP⇔EC
Cai *et al*. (2018)	G-7 countries		Real GDP per capita, CO2 emissions and energy consumption	ARDL Bounds Test	Mixed results depending on the country.
Munir *et al*. (2020)	5ASEAN countries	1980-2016	GDP, CO2 emissions and energy consumption	Panel Granger non-causality	Mixed results depending on the country.
Odugbesan and	MINT countries	1993-2017	GDP per capita, energy	ARDL Bounds test	Mixed results

Rjoub (2020)			consumption, CO_2, urbanisation		depending on the country.
Osobajo *et al*. (2020)	70 countries	1994-2013	CO_2 emissions, energy consumption and GDP growth	Pooled OLS, fixed effects, Granger causality, Pedroni and Kao cointegration	GDP growth $\Leftrightarrow CO_2$, EC $\Rightarrow CO_2$
Rahman *et al*. (2020)	BCIM-EC member countries	1972-2018	CO_2 emissions, GDP per capita, energy use and trade openness	ARDL approach, Dumitrescu and Hurlin panel non-causality test	GDP $\Rightarrow CO_2$, $GDP^2 \Rightarrow CO_2$
Nosheen *et al*. (2021)	Asian economies	1995-2017	GDP, CO_2 emissions and energy consumption	LM bootstrap cointegration, FMOLS, DOLS	EC $\Rightarrow CO_2$

Table 2: Carbon emissions of BRICS countries (2018)

Countries	Carbon emissions (Mt)	Share (%)
Brazil	457	1.25
China	10,065	27.52
India	2,654	7.26
Russia	1,711	4.68
South Africa	468	1.28
BRICS total	15,355	41.98
Global total	36,573	100.00

Source: Author's calculation

Table 3: Annual Growth of per capita carbon emissions, electricity consumption and GDP in BRICS countries (%)

Country	CO2	EPC	GDP
Brazil	4.95	5.68	4.23
China	14.29	22.74	22.74
India	8.14	10.15	10.92
Russia	-2.50	1.62	5.93
South Africa	1.16	0.69	3.51
CV (%)	109.61	84.13	84.13

Source: Author's calculation

Table 4: Cross-section dependence tests

Test	lnCO2	lnEPC	lnGDP	$lnGDP^2$
Breusch-Pagan LM	93.07837*	101.6734*	199.7770*	202.3303*
Pesaran scaled LM	18.57689*	20.49880*	42.43543*	43.00637*
Bias-corrected scaled LM	18.47272*	20.39464*	42.33126*	42.90220*
Pesaran CD	5.025022*	8.374784*	14.03875*	14.13878*

Note: Null hypothesis: No cross-section dependence (correlation)
Level of significance: *$p < 0.01$
Source: Author's calculation

Table 5: Panel Unit Root Test

Variables	Method	Level		First Difference	
		Statistic	Prob.	Statistic	Prob.
LnCO2	Levin, Lin & Chu t	-0.94192	0.1731	-6.88788*	0.0000
	Im, Pesaran and Shin W-stat	-1.49873	0.0670	-5.59981*	0.0000
	ADF - Fisher Chi-square	38.5954*	0.0000	50.6329*	0.0000
	PP - Fisher Chi-square	15.9300	0.1017	57.0233*	0.0000
LnEPC	Levin, Lin & Chu t	0.81963	0.7938	-2.82672*	0.0024
	Im, Pesaran and Shin W-stat	2.36577	0.9910	-2.77619*	0.0028
	ADF - Fisher Chi-square	4.54731	0.9193	25.2521*	0.0049
	PP - Fisher Chi-square	3.04449	0.9804	42.9858*	0.0000
LnGDP	Levin, Lin & Chu t	-0.62961	0.2645	-3.21954*	0.0006
	Im, Pesaran and Shin W-stat	2.90821	0.9982	-3.80253*	0.0001
	ADF - Fisher Chi-square	2.25601	0.9940	33.1883*	0.0003
	PP - Fisher Chi-square	0.99376	0.9998	41.1165*	0.0000
$LnGDP^2$	Levin, Lin & Chu t	0.42268	0.6637	-3.17258*	0.0008
	Im, Pesaran and Shin W-stat	3.55531	0.9998	-3.50277*	0.0002
	ADF - Fisher Chi-square	1.38174	0.9993	30.7912*	0.0006
	PP - Fisher Chi-square	0.53209	1.0000	38.6038*	0.0000

Note: * denotessignificant at 1% level of significance.
Source: Author's calculation

Table 6: Cointegration tests for BRICS countries

Methods		Test	Statistics	Prob.	Weighted statistics	Prob.
Pedroni	Within dimension	v	0.613823	0.2697	-0.509903	0.6949
		rho	-0.618394	0.2682	-0.394441	0.3466
		PP	-3.000959*	0.0013	-1.877985**	0.0302
		ADF	-3.077341*	0.0010	-2.042209**	0.0206
	Between dimension	rho	0.623927	0.7337		
		PP	-1.688033**	0.0457		
		ADF	-1.648205**	0.0497		
Kao		ADF	-6.344965*	0.0000		

Note: * and ** denote the rejection of null hypothesis of no cointegration at 1%&5% levelsofsignificance respectively.
Source: Author's calculation

Table 7:Pairwise Granger Causality Tests `

Null Hypothesis:	Obs	F-Statistic	Prob.
LnEPC does not Granger Cause LnCO2	115	11.5815*	3.E-05
LnCO2 does not Granger Cause LnEPC		1.01333	0.3664
LnGDP does not Granger Cause LnCO2	115	6.75380*	0.0017
LnCO2 does not Granger Cause LnGDP		0.04011	0.9607
$LnGDP^2$ does not Granger Cause LnCO2	115	6.77609*	0.0017
LnCO2 does not Granger Cause $LnGDP^2$		0.05822	0.9435

Note: * denotes the rejection of null hypothesis of no cointegration at 1% level of significance.
Source: Author's calculation

Table 8: Estimation of long run coefficients (Panel analysis)

	FMOLS		DOLS	
	Pooled	Grouped	Pooled	Grouped
LnEPC	1.603609*	1.823454*	1.503862*	1.743941*
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
LnGDP	-1.914644*	-2.546638*	-1.832993*	-2.242794*
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
$LnGDP^2$	0.071910*	0.117913*	0.073070*	0.092636*
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Adjusted R-squared	0.979985	0.697082	0.996083	0.492630

Note: * denotessignificant at 1% level of significance
CO2 is the dependent variable
Source: Author's calculation

Table 9: Estimation of long run coefficients (Individual Countries)

Country	FMOLS			DOLS		
	LnEPC	LnGDP	$LnGDP^2$	LnEPC	LnGDP	$LnGDP^2$
Brazil	1.444630*	-1.575679*	0.049156**	1.159338*	-1.569080*	0.074929*
	(0.0021)	(0.0000)	(0.0314)	(0.0056)	(0.0000)	(0.0072)
China	1.277186*	-1.429893*	0.051907*	3.209670*	-2.622191*	-0.020835
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.2536)
India	0.682084*	-1.331738*	0.106532*	0.596263**	-1.237869*	0.105690*
	(0.0005)	(0.0000)	(0.0000)	(0.0377)	(0.0014)	(0.0064)
Russia	5.216111*	-7.639183*	0.321745*	2.587556*	-3.632193**	0.156999*
	(0.0000)	(0.0000)	(0.0000)	(0.0077)	(0.0120)	(0.0092)
South Africa	0.497261**	-0.756699	0.060223**	1.166876**	-2.152637**	0.146398*
	(0.0251)	(0.0562)	(0.0110)	(0.0103)	(0.0109)	(0.0044)

Note: * &** denote significant at 1%& 5% levels of significance respectively.
CO2 is the dependent variable
Source: Author's calculation